Low-Altitude Point-Target EXperiment (LAPTEX): Analysis of horizon target detection

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SUMMARY

During the Low-Altitude Point-Target EXperiment (LAPTEX), conducted in Summer 1996 in Crete (Greece), tracking of low-level targets up to horizon ranges were performed in the IR to assess near-sea surface effects on IR surveillance system performance. This paper presents the analysis of two measurement sessions which are deemed representative of conditions in mid-latitude inner-sea littoral environments. During one session, atmospheric refraction permits beyond-the-horizon tracking, while during the other session, refraction is responsible for producing mirages and reducing slightly the maximum detection range. Received signal versus range is compared with model calculations using MODTRAN, the IR Boundary Layer Effects Model (IRBLEM) and the Thermal Range model for Point target detection (TRP). For the selected conditions, in which aerosol extinction does not play a major role, models are shown to provide an appreciably accurate description of transmission and received signal-to-noise ratio versus range.

1. INTRODUCTION

In July 96, the NATO AC/243 Panel 4 Research Study Group 5 conducted a measurement campaign, the Low-Altitude Point-Target EXperiment (LAPTEX), in the Mediterranean Sea with sensors and equipment installed on the island of Crete, in Greece. The objective was to assess performance of IR surveillance systems in mid-latitude inner-sea littoral environment and to collect data for supporting on-going development of models aimed at:

i - describing environmental effects on near-sea surface electro-optical detection;
ii - predicting performance of IRST systems;
iii - characterizing sea and sky background near the horizon, and
iv - describing ship signature.

Low-flying aircraft detection and identification experiments were also conducted. During the 3 week campaign, Canada, Denmark, Germany, Italy, the Netherlands, the United Kingdom and the United States performed measurements while Greece provided logistic and technical support along with ships and aircrafts. A description of the experiment is given in Ref. 1.

To fulfill objectives i. and ii., ship-mounted IR targets were tracked using on-shore sensors during ship outbound and inbound runs. The analysis presented in this paper focuses on two specific sessions, for which observations are compared with model calculations. TNO-FEL in the Netherlands [2] and FfO in Germany [3] have already reported on some of their respective observations.

This paper combines measurements of Canada, Germany and the Netherlands teams together with revised model calculations, incorporating near-sea surface effects with a close look at refraction effects. For the analysis we use two propagation models, MODTRAN developed by Phillips Laboratory in the US and the IR Boundary Layer Effects Model (IRBLEM) which is currently under development at DREV, and one system model, the Thermal Range model for Point target detection (TRP), developed in Germany. The experimental setup and equipment are briefly presented in section 2.0, section 3.0 gives details on the atmospheric conditions during the selected sessions, section 4.0 presents models used for the analysis and section 5.0 presents and discusses observations made during the two sessions together with model calculations. Finally, section 6.0 summarizes lessons learned and draws conlusions.

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2. EXPERIMENTAL SETUP

LAPTEX was conducted at the NATO Forces Accuracy Check Site (FORACS) near Chania and Souda Bay in Crete (Greece). For the near-sea surface target tracking sessions, IR targets provided by TNO-FEL were mounted on the Greek Research vessel Strabon (A 476). Targets were mounted 13.6 m above the water surface using a tower installed on the ship; one target heading forward and the other one heading backward, so to perform target tracking during both out- and in-bound ship runs. During a session, the Strabon sailed away up to a certain range beyond the horizon and then returned, following a 60 degree North trajectory, as shown in Fig. 1.

2.1 Sensors

TNO-FEL and FfO performed measurements in the 3-5 and 8-12 micron IR windows. However, data analysis in this paper is limited to the 3-5 band only, since long range tracking (R > 15 km) was not possible in the 8-12 with the sensors used due to the high absolute humidity in this maritime region [2]. TNO-FEL and FfO sensors were located about 100 m apart along the coast line, 20.4 and 19.7 m above the sea surface, respectively. Note that the latter are relevant heights for IR surveillance systems on a ship. Simultaneously, DREV performed high-resolution imaging in the visible to capture the fine refraction-induced phenomena using cameras located 10 and 20 m above the sea surface. Specifications of sensors used by the three nations are summarized in Table 1.

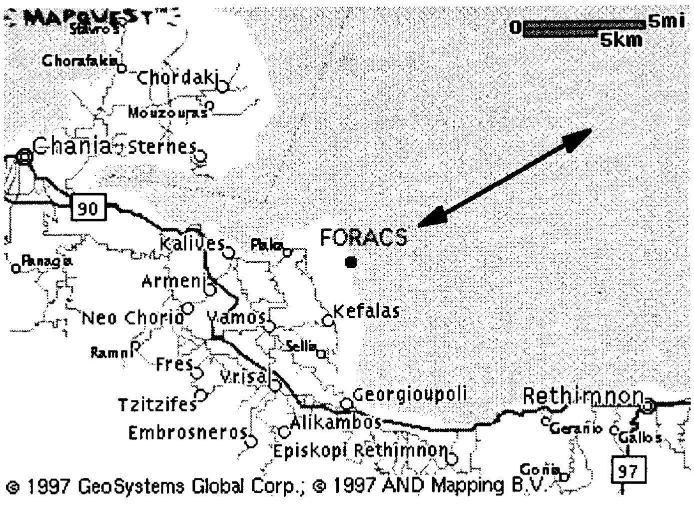

Fig. 1 LAPTEX at FORACS (Crete); the double-head arrow shows Strabon trajectory

Table 1 - Sensors

	MODEL	Band (microns)	IFOV (mrad)	NEI (10^{-14} W/cm^2)	Height (m)
TNO-FEL	Cincinnati-IRC160	3.7-4.6	0.1	1.0	20.4
FfO	Cincinnati-IRRIS 256-LN	3.0-5.0	0.1	1.4	19.7
DREV	Sony AVC-D5 (2)	> 0.8	0.01	-	20.3 & 10.4

2.2 Meteorological measurements

Extensive meteorological measurements were performed at sea and on land. A wave-rider buoy and a buoy made at TNO-FEL were moored 1.1 km from FORACS. They together provide the basic parameters needed for model computations: pressure, air and sea temperature, humidity, wind speed and direction, and wave height. The wave rider buoy also gives wave spectra and direction, which can be useful to investigate the impact of sea roughness on calculations, and to conduct sea background studies. Furthermore, standard meteorological measurements were performed continuously on the Strabon by both TNO-FEL and DREV during tracking sessions.

Moreover, onboard Strabon were collected data on aerosol extinction, using two different techniques: (1) using a Particle Measurement Systems (PMS) put in place and operated by TNO-FEL, which gives the distribution of the particle size from which the extinction coefficient can be derived through Mie scattering calculation; (2) using a Particle Volume Monitor (PVM) or exctinctionmeter, which gives a signal proportional to the forward scattering coefficient at 3.8 microns.

3. CASE STUDY

In this paper we analyze 2 experimental sessions conducted on the 16 and 22 July respectively. Continuous meteorological recording at various locations and redundancy of measurements are suitable to reliably characterize the prevailing conditions. From a global analysis of meteorological data considering all sources of information, we came up with the sets of data shown in Table 2 to describe the conditions that prevailed on the 16 and 22 July at LAPTEX. These sets mostly correspond to the buoy data, as in many instances ship meteorological measurements are suspected to be contaminated by ship structure and motion; in particular, for most runs, the measured wind speed and humidity appear to be highly correlated with the ship speed.

Table 2 - Meteorological data for the 16 and 22 July

	16 July 96 **9-12 hrs*** **super-refraction**	**22 July 96** **19-22 hrs*** **sub-refraction**
Air temperature (C)	27.4	24.2
ASTD (C)	+ 2.0	- 0.5
Humidity (% / g/m3)	57 / 14.3	64 / 14.1
Wind speed (m/sec)	4.5	3.0
Wind direction (dg North)	320 - 340	300 - 325
24-hr avg. wspd (m/sec)	5.1	4.1
Wave height (m)	0.3	0.7
Visible range** (km)	> GOS + 6	GOS - 1
Meas. Extc. coef. (km-1)	0.020	0.019
NAM Extc. coef. (km-1)	0.018	0.010

* *Local time*

** *GOS: geometrical optical sight (km)*

The two selected runs were conducted under good weather conditions, with very good visibility and moderate wind. The absolute humidity was relatively high, as expected in this maritime mid-latitude area. The North-West wind, which blew perpendicular to the ship trajectory, brought in a mixture of sea and land air. These coastal conditions are thought to be typical in this area in Summer. They are definitely representative of conditions that prevailed during the 3 week campaign, except for 3 or 4 days when the sea got very rough and prevented ship tracking sessions.

What differentiates the conditions is the air-sea temperature difference (ASTD), leading to different kinds of refraction conditions. On 16 July, super-refraction prevailed near the surface, permitting beyond-the-horizon detection. On 22 July, sub-refraction prevailed, which is known to limit the maximum inter-vision range (MIVR) between target and sensor, compared with the geometrical optical sight (range limitation imposed by earth curvature in the absence of refraction effect) [4]. These refraction effects on detection range were confirmed by observations in the visible. Table 2 gives the maximum detection range observed by Canada in the visible using a camera 10 m above the sea surface and a target onboard ship 7 m above the surface. The ASTDs for the 16 and 22 July were common values at LAPTEX, and at the same time among the maximum and minimum values recorded. The 16 and 22 July were selected to consider the cases where refraction effects were among the strongest observed.

The last two rows of Table 2 give, in the 3-5 band, the measured aerosol extinction coefficients onboard Strabon and the calculated values using NAM (in MODTRAN), respectively. For the NAM calculations, an air mass parameter (AMP) of 3 was chosen as it was found to lead to calculated visibilities greater than 50 km, which was judged in agreement with observed visibilities. Greater values of AMP would give visibilities which are less than likely, considering observations made in the visible. For the 16 and 22 July sessions, the average PMS and PVM extinction coefficients agree very well. Note that for 16 July, very good agreement is obtained between calculation and measurement while, for 22 July, the calculation is about half the measured value.

4. MODELS

To support the analysis of the 16 and 22 July observations, calculations were performed using 3 computational models, two propagation models and one system detection model: The MODerate resolution TRANsmission (MODTRAN v3.5), the IR Boundary Layer Effect Model (IRBLEM v2.7.5) and the Thermal Range model for Point target detection (TRP). MODTRAN [5] is a widely used radiative tranfer model which was developed by Phillips Laboratory as a successor to LOWTRAN 7. Details on MODTRAN are given in several dedicated papers included as part of these Proceedings.

IRBLEM is a propagation software package which is being developed in the framework of a joint Canada-Netherlands program with the aim of complementing MODTRAN for dealing with near-sea surface propagation effects [6]. The model combines effects of molecular absorption, aerosol extinction and refraction, taking into account the rapid change of refractivity and aerosol content with respect to the elevation near the sea surface. In IRBLEM, vertical profiles of refractivity, C_n^2 (turbulence) and aerosol extinction coefficient are calculated and fed into a ray-tracing module, together with molecular transmittance obtained using MODTRAN, to compute what is hereafter called *effective transmittance*. The effective transmittance is the product of the molecular transmittance, the aerosol transmittance and the refractance, the latter being a refraction-dependent gain factor expressed in transmittance units. This new quantity was introduced several years ago [7]. The analysis presented in this paper shows some experimental validation of refractance calculation. IRBLEM is made modular. It is composed of modules that can be readily substituted. In the following analysis of LAPTEX data, computation of aerosol extinction was substituted by measurements made onboard Strabon.

The Thermal Range model for Point target detection (TRP), developed in Germany, has been designed to perform a complete IR system detection calculation [8]. Thus, as opposed to MODTRAN and IRBLEM, which are propagation models exclusively, TRP is a system model from which system performance can be assessed. TRP performs target-background contrast radiance computation, takes into account atmospheric transmission along with turbulence-induced blurring, and finally, it contains a sensor model which takes into account the sensor optics, detector sensitivity and size, and platform jitters. For the TRP calculations shown in this paper, sensor and target were assumed to be fully stabilized. Furthermore, IRBLEM is used to provide the effective transmittance and C_n^2; the latter is required to estimate blurring effect on detectability.

5. OBSERVATIONS AND CALCULATIONS FOR THE SELECTED CASES

5.1 - 16 July

Figure 2 shows TNO-FEL measurements for 16 July together with MODTRAN and IRBLEM* calculations for 16 July, wherein the TNO-FEL average received signal is converted to effective in-band transmittance. Outbound and inbound run data are shown. The average signal is calculated considering 50 frames and the range is given by a GPS system onboard. The star (*) in IRBLEM* means that, in IRBLEM, measurement of aerosol extinction is used instead of any prediction. For the TNO-FEL sensor, the geometric optical sight of the IR source is 29.3 km. As predicted under positive ASTD conditions, tracking is performed beyond the horizon, up to 32 km. At this range, the received signal was strong enough to keep tracking much further away. Unfortunately, the ship stopped at 32 km and returned in accordance to the plan.

From close range to 20 km, MODTRAN and IRBLEM* calculations are very close to each other. At these ranges, the refraction effect on transmission is negligible (i.e. refractance=1) and, since in IRBLEM the molecular absorption is given by MODTRAN, the difference between the two calculations turns out to be dependent upon the aerosol extinction only. As mentioned above, for 16 July the NAM prediction of aerosol extinction is very close to the measurement.

From 20 km and further, one notices that IRBLEM* transmittance decreases slightly more rapidly than MODTRAN transmittance, leading to a better agreement with observations. This is due to refractance, unaccounted for in MODTRAN, which decreases with range under positive ASTD conditions. For this run, transmission is dominated by molecular transmittance, and near the horizon, refractance gets as significant as the aerosol transmittance. According to IRBLEM*, at 30 km, the molecular transmittance is 0.14, aerosol transmittance is 0.55 and refractance is 0.54.

Figure 3 shows the FfO measurements with the SNR calculations obtained from the TRP-IRBLEM* combination. For selected ranges, 3 seconds of signal were analyzed. Each dot in the Figure shows the result for one camera frame. For the German setup, the geometric optical sight is 28.8 km. The calculated BEST and WORST case curves correspond respectively to the optimistic and pessimistic situations where the target peak received signal always falls in the middle of a detector (optimistic) or always falls between detectors (pessimistic), taking into account turbulence-induced blurring. In particular, at 30 km, TRP-IRBLEM* calculations show that, because of turbulence, only 66 % of the available energy hits the detector even in the BEST case, whereas some 34 % of target energy reaches a detector in the WORST scenario.

5.2 - 22 July

Figure 4 shows signal received with the TNO-FEL IRC160 system during the outbound run of 22 July, converted again to transmittance, together with MODTRAN calculation. The solid line marked with squares shows the average received signal, and the x's and *'s denote the average-plus-standard deviation and average-minus-standard deviation, respectively. This allows one to appreciate the level of signal fluctuations along the path. It is noteworthy that MODTRAN calculation, which includes NAM calculation, gives a relatively good description of the signal variation with range. This is obtained even though the calculated aerosol extinction coefficient differs significantly from the measured one (as shown in Table 2), as the aerosol contribution remains small compared with molecular absorption.

Figure 5 shows the same graphic, except that a modified IRBLEM*, hereafter refered to as IRBLEM**, is used instead of MODTRAN for the calculations. The Monin-Obukhov theory used to describe the vertical refractivity profile ceases to apply when the stability length, L (which is an indicator of the level of atmospheric stability), is too low. To obtain a reliable result, one shall ensure, as a rule of thumb, that L is greater or equal to the sensor height. This was not the case for the 22 July run because of the prevailing low wind speed. It was then decided to present calculations considering the closest conditions where the theory applies. IRBLEM** calculation means that IRBLEM* is used considering a slightly increased wind speed (to 4 m/sec) so to have the stability length just greater than sensor height. It is noteworthy that, in the case of 16 July, L was sufficiently high for the model to apply.

Note that with IRBLEM**, the increase of signal just before target loss is pretty well described. This steep increase of signal is due to a refraction-induced mirage. The calculated maximum inter-vision range (MIVR), 28 km, is however slightly less than observed, 28.4 km. Let us recall that in this case the geometric optical sight is 29.3 km. The calculated transmittance variation with range agrees very well with the measurement trend, except near 20 km where significantly more signal is received. The cause of this signal increase has yet to be investigated.

Figure 6 shows the FfO SNR measurements and TRP calculations for the 22 July. In this case, the predicted turbulence is much less than for 16 July; calculations show that more than 90% of the available energy falls on the detector in the BEST case (defined above). Near MIVR, one observes a tremendously large SNR variation; large variation of signal was also observed from TNO-FEL measurements. Because of the ship motion, due to the waves, for one frame the target may be beyond the horizon, while for subsequent frames the target signal is magnified due to the presence of a mirage. For the German sensor, the geometric optical sight is 28.8 km, the observed MIVR is about 27.5 km and the predicted MIVR is 27.8 km.

In summary, for the 22 July, molecular absorption is the principal source of attenuation along the path. Refraction is responsible for abruptly limiting detection range about 1 km less than the geometric optical sight but, nonetheless, the mirage increases detectability at MIVR.

6. LESSONS LEARNED AND CONCLUSIONS

Experiments were conducted by the NATO Research Study Group 5 in the Mediterranean Sea in Summer 1996 to assess performance of IR systems under typical mid-latitude littoral inner-sea conditions. In this paper, we presented analysis of tracking of low-level targets in the 3-5 micron band, with targets getting near and crossing the horizon.

For most of the 3 week campaign, the visibility was good and the wind was moderate and blew along the coast. Under these conditions, IR transmission versus range was shown to be dominated by molecular absorption, because of the characteristically high absolute humidity in this region. When the air-sea temperature difference (ASTD) is negative, refraction is likely to be the second factor of importance (so it was on 22 July). Under this condition, the maximum detection range is reduced vis-à-vis the geometric optical sight but the signal intensity is significantly increased at detection range due to mirage formation. Since occurrence of large negative ASTD leading to significant range limitation is improbable in this region, especially in Summer, because of mirage, refraction can be said to globally produce a positive effect on detection. Furthermore, positive ASTD (16 July) makes possible detection beyond-the-horizon, even for small ASTDs. Under these conditions, however, refraction losses, described by refractance in the calculations, reduces transmittance - and thereby detectability - at horizon ranges and further. Tracking beyond the horizon in the IR was achieved more than once at LAPTEX. For the cases considered in our analysis, aerosol extinction did not play a critical role, being of the order of refractance under positive ASTD conditions. Aerosol extinction becomes more significant when the sea gets rough.

In our analysis, MODTRAN calculation globally gave a relatively good description of the transmittance variation versus range. NAM calculation of aerosol extinction was shown to be less than satisfactory, producing however no major impact on total transmittance because of the limited significance of this factor in the selected cases. For the selected cases, very good description of the received signal variation with range is obtained when using IRBLEM with measured aerosol extinction. This leads us to conclude that MODTRAN calculation of molecular transmittance (used in IRBLEM) and the IRBLEM description of refraction effects are valid and of appreciable accuracy. The main source of inaccuracy in the propagation models would then reside in the estimation of aerosol extinction. Finally, the TRP model developed in Germany proves valid and efficient for carrying out system study in marine conditions when combined with IRBLEM calculations to account for near-sea surface atmospheric effects.

7. REFERENCES

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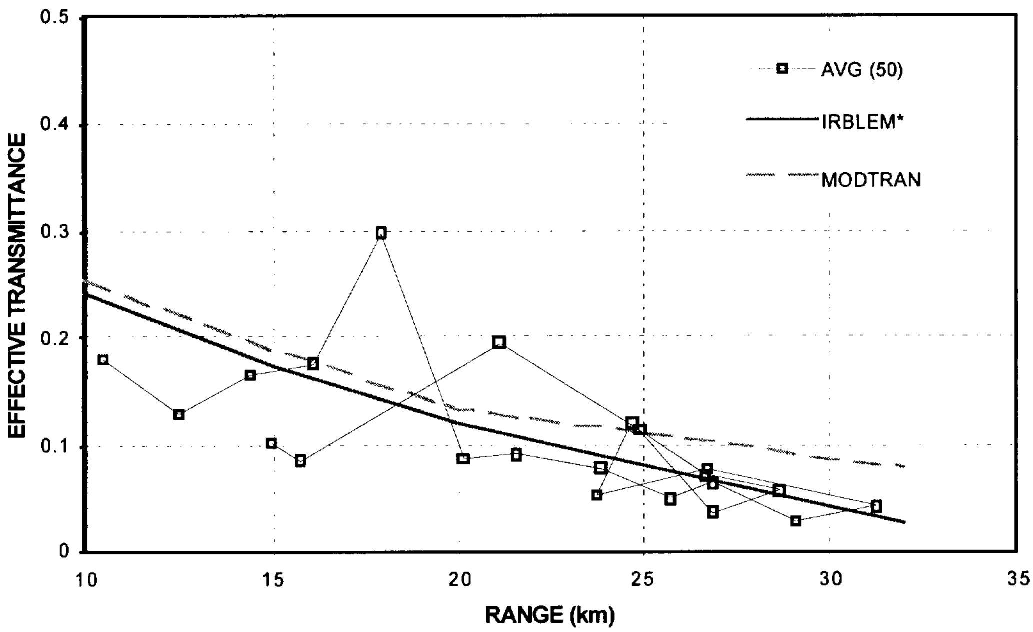

Fig. 2 TNO-FEL measurements in the 3-5 band for 16 July with IRBLEM* and MODTRAN calculation

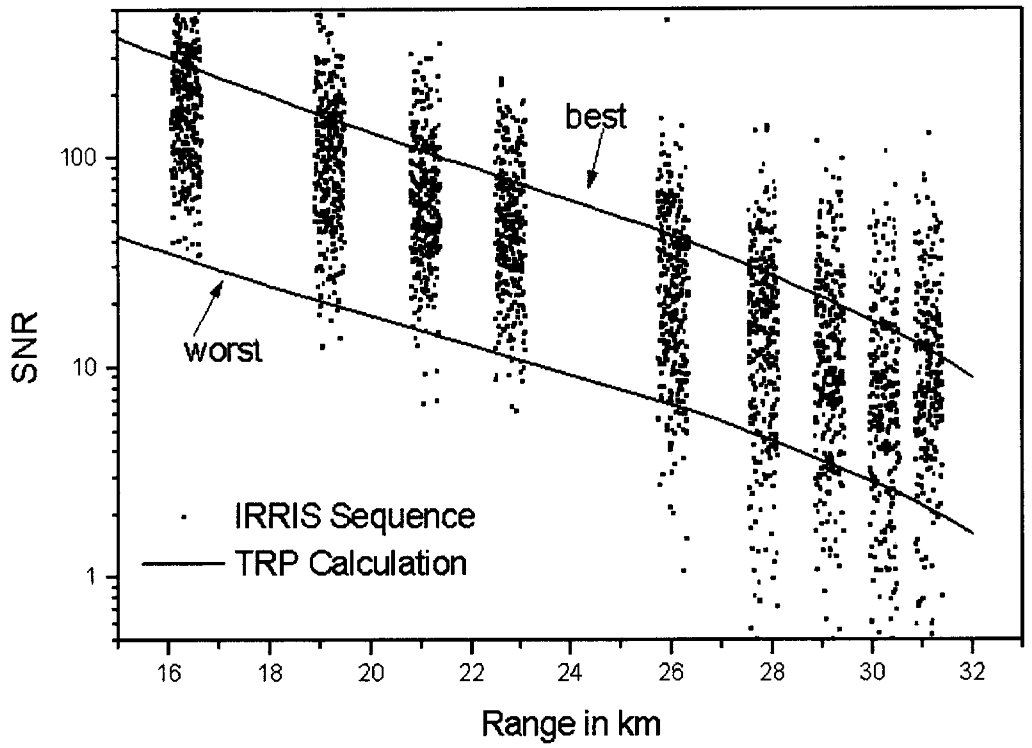

Fig. 3 FfO measurements in the 3-5 band for 16 July with TRP-IRBLEM* calculation

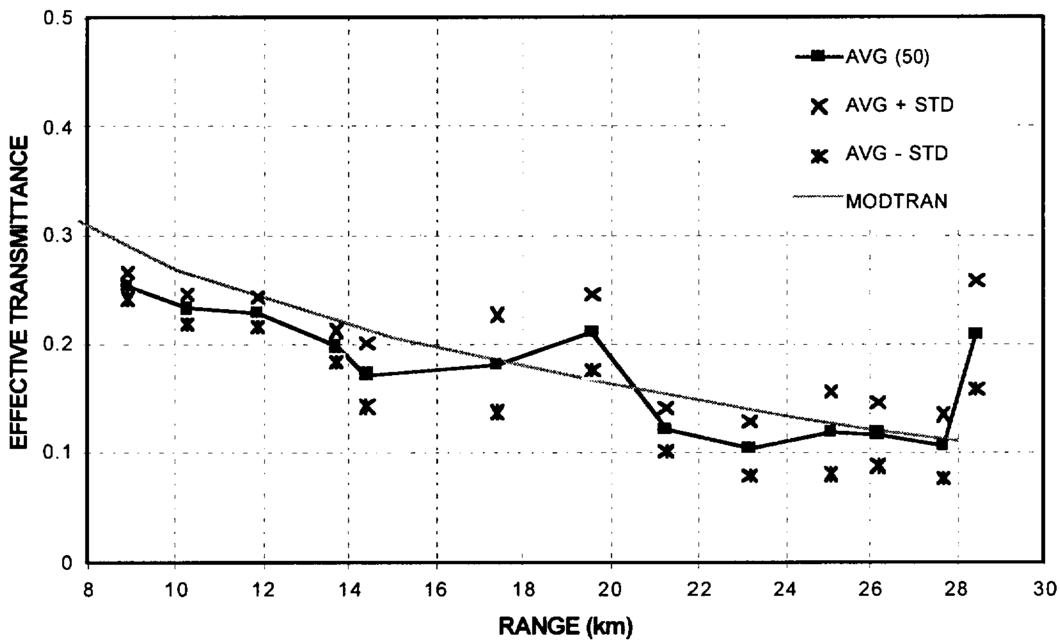

Fig. 4 TNO-FEL measurements in the 3-5 band for 22 July with MODTRAN calculation

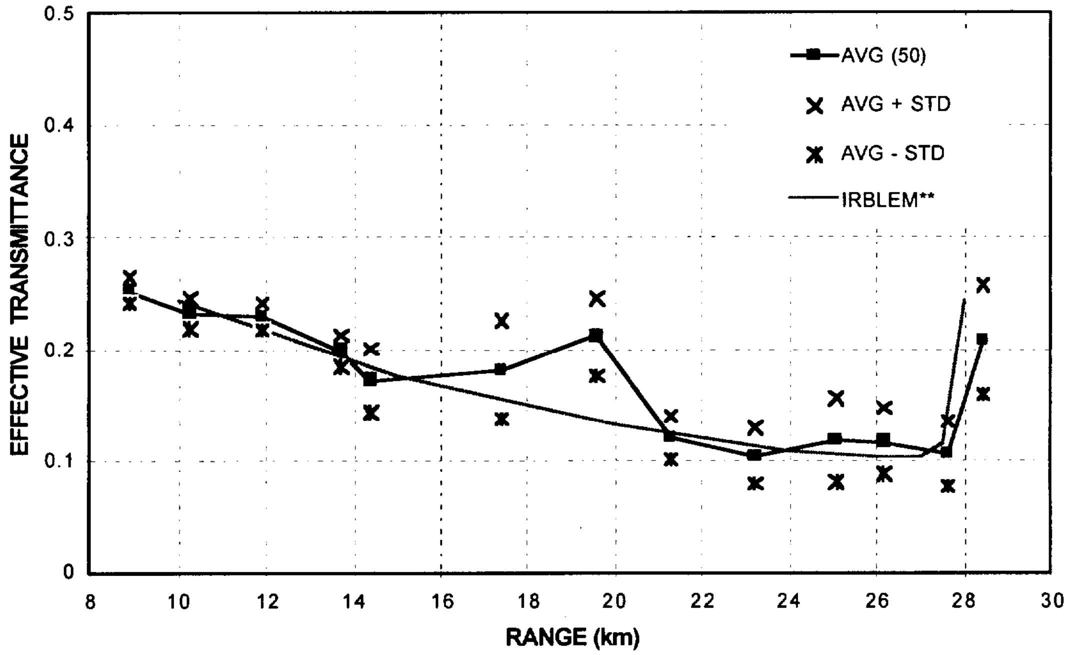

Fig. 5 TNO-FEL measurements in the 3-5 band for 22 July with IRBLEM** calculation

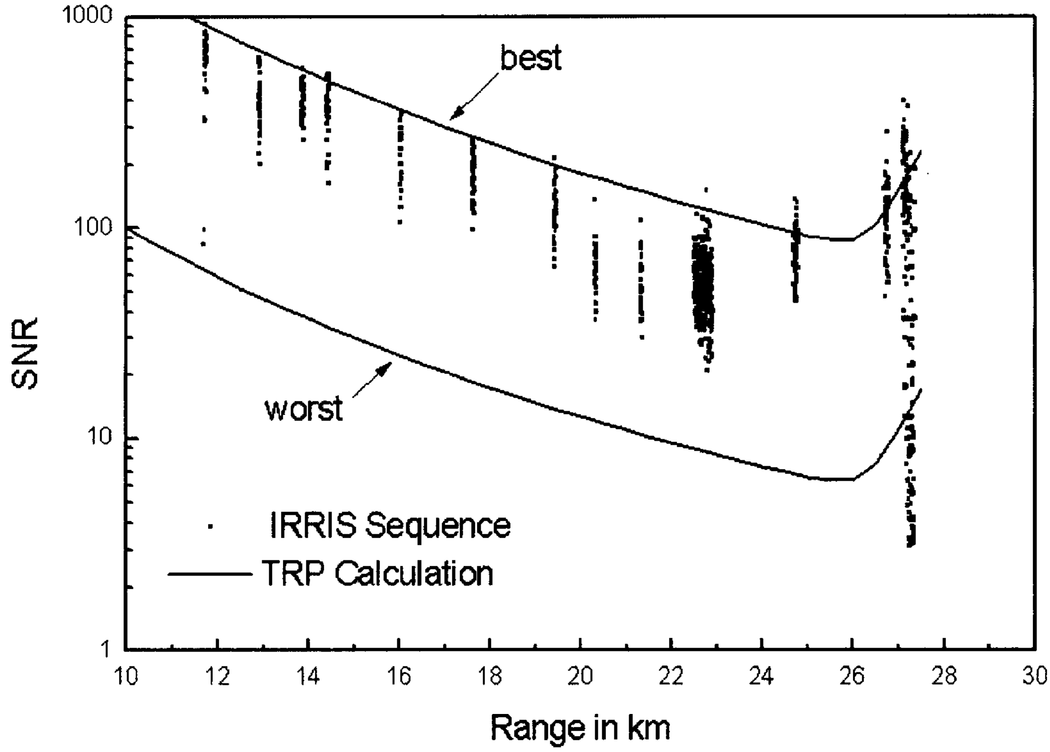

Fig. 6 FfO measurements in the 3-5 band for 22 July with TRP-IRBLEM** calculation