OVERVIEW OF NATO/AC 243/PANEL 3 ACTIVITIES CONCERNING RADIOWAVE PROPAGATION IN COASTAL ENVIRONMENTS

(Tour d'horizon des activités de l'OTAN/AC243/Com.3 concernant la propagation radioélectrique en zone côtière)

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Résumé Les campagnes de mesure conduites en collaboration internationale au voisinage de Lorient en 1989, Toulon en 1990 et Lorient en 1993 ont permis l'acquisition de nombreuses données simultanées de propagation à des fréquences de 3 à 94 GHz et de caractérisation du milieu. Les deux premières campagnes, sur des trajets transhorizon, ont donné lieu à une exploitation statistique des amplitudes reçues avec recherche de corrélation aux modèles de propagation dans la couche limite océanique. La dernière, sur un trajet plus court, est axée sur la caractérisation des distorsions de front d'onde créées par les effets de réflexion et de réfraction.

I - INTRODUCTION

The performances of most systems operating at RF and millimeter waves can be seriously affected by propagation effects. That is the reason why NATO established the Research Study Group No.8 (RSG8) within Panel 3 (physics and electronics) of Defense Research Group (AC 243), with its Propagation Subgroup (PSG) responsible for the propagation aspects. Comparison of mm and other wavelengths was to be considered. In maritime and coastal environments, the use of such wavelengths for various military applications like anti-ship seekers, fire control radars, ship to ship communications or Electronic Support Measurements (ESM) led to the setting up of specific measurement campaigns; the last three are reported hereafter.

The first two experiments used facilities close to Lorient, on the Atlantic coast, and Toulon, on the Mediterranean coast of France, with the purpose of documenting the refractive effects for medium range over the horizon paths **[11]**. These experiments, which are referred to as Lorient 89 and Toulon 90 campaigns, are described in this paper, and some typical results are presented.

The latest cooperative work of RSG8/PSG took place recently (fall 1993) near Lorient, on a line-of-sight 10 km path over seawater. This experiment, referred to as Lorient 93 campaign, was devoted to the analysis of phase-front distortions due to multipath along with refractive effects, and to the assessment of performances for naval systems like short range tracking radars. Analysis of the data, either on a statistical base or as specific case studies, is being performed presently, but some early typical results will be given in this paper after a detailed description of the experiment. Further reports about the last Lorient experiment will be available from the recently established RSG21 of Panel 3, in charge of assessing propagation and signatures effects on naval systems.

The nations (and institutions) contributing to those common activities of RSG8/PSG were France (CELAR and CERT-ONERA), Canada (DREV), Germany (FGAN-FHP), the Netherlands (FEL-TNO) and USA (NRL and NCCOSC-RDTE Div.).

II - STATE OF THE ART KNOWLEDGE OF REFRACTIVE EFFECTS

1. Refractivity in the Marine Boundary Layer (MBL)

Refraction effects are related to the gradients of the refractive index, n, especially in the vertical direction, but sometimes also in the horizontal direction. n and its usual forms N and M are easily calculated for an air parcel if the pressure, temperature, and vapor pressure are known.

Over the ocean, air adjacent to the surface is saturated with water vapor, and the relative humidity is nearly 100 %. Within a few meters above the surface, the air rapidly dries out and reaches an ambient value that depends on the meteorological conditions.

This rapid decrease of the air moisture creates a strong negative M gradient, which decreases in magnitude with increasing height. The few meters where the M gradient is negative are referred to as the evaporation duct, and the height where the M gradient is zero, is defined as the evaporation duct height, which has been shown to be a good measure of the strength of the evaporation duct **[1]**, **[2]**.

The evaporation duct is a nearly permanent propagation phenomenon over the ocean that can strongly affect the performances of EM sensors operating close to the sea surface. Directions of cm and mm wavelength propagation within 1° of horizontal are concerned with the evaporation duct effects which lead principally to a modification of the position and shape of the interference lobes due to multipath propagation in the line-of-sight region. Also the steep refractivity gradients encountered in the evaporation duct can cause ducting with detection ranges well beyond the radio horizon, accompanied by holes in the upper radar coverage. Thus, the use of sophisticated EM sensors close to the sea surface requires good characterisation of the propagation medium and accurate propagation models for the evaluation of coverage.

2. Modelling of the vertical refractive index profile

Several atmospheric models allows one to describe the vertical structure of the air in the Marine Boundary Layer (MBL) from a limited set of standard meteorological parameters. They all are based on the physics of the turbulent transport processes at the sea surface. The variation of the influential atmospheric parameters is described by a logarithmic formulation but with an air stability dependent correction. The various existing models differ in the formulation of this correction factor and in the method to calculate the main profile parameters (stability length, roughness lengths, etc).

So far, for the analysis of the experimental data, two MBL models have been used by the members of RSG8/PSG :

- the PAULUS model **[3]** based on an earlier model developed by JESKE **[4]** which uses an empirical stability correction function ;

- a second MBL model, developped at CELAR, referred to as the BULK - CELAR model, which relies on new advances in the understanding of turbulent transport processes to estimate the stability correction function **[5]**.

The major limitation appears to be in adequate meteorological measurements. For example, in stable cases (i.e., $T_{air} > T_{sea}$), small changes in the air-sea temperature difference can result in significant differences in the calculated evaporation

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duct height and then can change the predicted radar detection range by many kilometers. The proximity of the coast can cause particular phenomenon to appear such as the stable cases [6]. Thus, the performances of both MBL models had to be assessed by measurements.

3. Modelling of radiowave propagation

Once the vertical modified refractivity profile has been determined, it is possible to model EM propagation by solving the wave equation either through a modal analysis [7] or through a technique known as the Parabolic Equation (PE) [8]. Propagation models based on a modal analysis are difficult to use, especially in case of range varying refractivity profiles. In coastal regions such horizontally non homogeneous conditions can be encountered if dry and warm air coming from land slides over a moist and cooler air mass at the sea surface.

In contrast, PE solvers can handle range varying atmospheric conditions and also accomodate sea surface roughness although it is much more time consuming to compute the results then.

For the analysis of the data, members of the RSG8/PSG used PE models above all.

III - DESCRIPTION OF THE EXPERIMENTS

1. LORIENT 89 and TOULON 90 campaigns

a) Description of the sites

Since refractive effects, which both campaigns were devoted to, are known to be driven by meteorological conditions, opposite conditions were selected for the two experiments : LORIENT 89 took place in fall and winter on the North Atlantic coast, and TOULON 90 in summer on the Mediterranean coast in conditions close to those over warmer seas. Figures 1 and 2 show the geographical locations of both campaigns. The propagation path, indicated by a straight line, lied in the vicinity of the coast so that propagation conditions sometimes varied significantly along the path, especialy when low wind speed or advection movements prevailed. On the other hand, when the wind was blowing relatively strongly at a right angle to the propagation path, the conditions were thought to be homogeneous. Finally, both geographical locations are representative for coastal conditions.

In both experiments, the geometry of the path was representative of over the horizon propagation conditions, with changes of the antenna heights due to the tide in case of LORIENT 89 (tidal effects are negligible in the Mediterranean). During TOULON 90 campaign, the over-the-horizon links were completed by some LOS measurements at 36 GHz (see Figure 2).

b) RF equipments

The propagation measurements were performed using seven propagation sets operating at 3.0, 5.6, 10.5, 16.0, 35.0, 36.0 and 94.0 GHz. In addition, Germany (FGAN) performed measurements with a 95 GHz monopulse radar. During both experiments, the radiolinks were operated continously during several months, allowing analysis of the data on a statistical (long-term) base.

c) Meteorological sensors

Various meteorological sensors were used during the two campaigns :

- two meteorological stations were set up, one at each end of the path, to supply the standard meteorological parameters needed by MBL models (ie : T_{air}, pressure, relative humidity and wind speed) except the sea temperature (they also included some other parameters).

- a meteorological buoy was moored near the middle point of the path. It measured the same set of meteorological parameters as the weather stations, along with the sea temperature and the wind direction, the latter being important for horizontal homogeneity considerations.

- data on sea surface temperature were acquired, as given by the infrared radiometer on the transiting satellite NOAA11.

In addition, some specific meteorological sensors were used during the TOULON campaign like a digital thermometer and a psychrometer to check the reliability of the other measurements. Finally, direct measurement of the air refractivity was performed using a refractometer.

Table 1 gives the differences between reference data (those delivered by the psychrometer) and the data collected by the weather stations. Significant discrepancies are noticed in the humidity measurements, which prove the difficulty to get reliable data on humidity.

2. LORIENT 93 campaign

a) Description of the site

Measurements were made over a line-of-sight 10 km path between ILE DE GROIX and GAVRES, on the Atlantic coast (see Figure 1 for a description of the geographical location of the experimental site). Again some coastal influence can be expected, especially when the wind was blowing from the North, or from the North West.

b) Description of the RF equipments

The purpose of this latest experiment differed from that of LORIENT 89 and TOULON 90 campaigns. In fact, the previous experimental work of PSG focussed on amplitude effects and LORIENT 93 was devoted to the analysis of the distortions of the phase-front, due essentially to multipath which can be accompanied by ducting. Thus, RF equipments used during LORIENT 93 are specific sensors dedicated to angle-of-arrival (AOA) assessment, like arrays or monopulse radars. In addition, the previously used 36 GHz RF link was used for propagation path loss assessment.

Table 2 gives a brief description of the various RF equipments used almost continuously during the four weeks of LORIENT 93 campaign. During the campaign, observations of refraction effects in the IR and the visible were also performed, which could be interesting for comparison between radiowaves and IR (refractive effects are not the same in both cases). A GPS receiving set was also provided for the analysis of propagation effects on its signal at grazing angles.

REFERENCE	TEMPERATURE	HUMIDITY	PRESSURE
SIMOUN STATION	+ 1.4° C (average)	between + 3 and + 15 %	- 3 HPa (average)
NATO STATION	+ 1° C (average)	between - 2 and + 25 %	+ 5 HPa (average)
BUOY	between - 0.6 and - 1.5° C	between - 2 and 23 %	$\lvert\delta P\rvert < 1$ HPa

Table 1: Difference between reference data (psychrometer) and data collected by the weather stations

SYSTEMS	PROVIDED BY
LOLETTA: 8 + 1 elements receive array at 10.5 GHz and transmitter; 2 elements interferometer at 16 GHz and transmitter ; IR camera and recorder	FEL-TNO (NL)
Monopulse receiver at 35 GHz and transmitter Monopulse receiver at 94 GHz and transmitter	FGAN (GE)
4 elements receive array at 35GHz and transmitter GPS receiver for grazing angle analysis	CERT-ONERA (FR)
Line-of-sight system at 36 GHz	CELAR (FR)

Table 2: Radiofrequency equipments

c) Description of the meteorological sensors (cf. Table 3)

The two weather stations and the meteorological buoy, used in the previous campaigns, were used again durinf LORIENT 93. But additional sensors have been used during this latest campaign : among them, an upper-air measurement system consisting of radiosondes launched by balloons filled with helium along with the transmitting/receiving and storage package has to be noticed. In fact, after the analysis of the data measured during LORIENT 89 and TOULON 90, the inclusion of a more detailed upper air structure in prediction models was recommended.

One has to notice also the use of another buoy, during LORIENT 93, dedicated to the measurement of the instataneous wave height; since phase front distorsions are strongly related to multipath effects, knowledge of the sea state is in fact of great importance.

Evaporation duct height statistics

Concerning LORIENT 89, histograms of evaporation duct height calculated by BULK-CELAR and PAULUS methods are presented in Figure 3. They differ radically from predictions derived from the Engineer' s Refractive Effects Prediction System (EREPS) Surface Duct Summary (SDS) computer program. In the latter the distribution of evaporation duct height is derived from 15 years of surface meteorological observations made by ships at sea for 10 degrees-by-10-degrees areas of the world known as Marsden Squares (MS). Using BULK - CELAR, the mean duct height is 6.1 m, while it is 8.2 m according to the SDS. The atypical form of the measured distributions is due to the unusually fine weather encountered during the test period and the short timescale of the trial that is not representative of conditions met in an "average" year.

EQUIPMENTS	PROVIDED BY
. NATO weather station with rain gauge and computer storage . Refractive index "profiler" : 3 altitudes measurement system	FEL-TNO (NL)
. Pulsonic weather station . Riding buoy . Spectropluviometer	CELAR (FR)
. Upper-air measurement system : radiosondes launched by balloons filled with helium	NCCOSC(US) DREV(CA)

Table 3: Meteorological equipments

IV - SOME TYPICAL RESULTS

1. LORIENT 89 and TOULON 90 campaigns

a) Meteorological data

Occurence frequency of events

Table 4 gives the occurrence frequency of nine criteria related to air stability, refractivity gradients, horizontal homogeneity and presence of hydrometeors.

Analysis of stability

Based on the statistics of the air-sea temperature difference, conditions (in terms of stability) were different during the two campaigns : LORIENT 89 showed a majority of stable cases ($T_{air} < T_{sea}$ for 75 % of the time), while during the three months measurement of TOULON 90 about 40 % of the time stable conditions were observed. The vicinity of the land can be the reason why such high percentage of stable cases are observed, when conditions are often unstable in open sea regions.

Occurrence of surface-based duct

Later analysis of all the meteorological and radio data enables us to make an estimate of the periods when a surface-based duct could be prevailed. These periods represent 3 % of the total time of the experiment for LORIENT 89, and 14 % for TOULON 90. These percentages agree quite well with the known statistics [9]. However, the need of specific equipment for a more detailed description of upper-air structure has also been demonstrated during both experiments.

Subrefraction

In general, subrefraction is likely to occur under very stable atmospheric conditions associated with high humidity and often low visibility. This was the case during the LORIENT 89 campaign and situations where dM/dz was greater than 118 M units/km represent 25 % of the total time, and where it was greater than 157 M units/km 12 % of the time. During TOULON 90 campaign, subrefraction was much more frequent and dM/dz was greater than 118 M units/km only 0.4 % of the time.

CRITERION	LORIENT CAMPAIGN Occurrence frequency of events (in % of the total dura- tion of the experiments)	TOULON CAMPAIGN Occurrence frequency of events (in % of the total dura- tion of the experiments)
estimated surface-based ducts	3	14
measured subrefraction (path loss greater than diffraction loss)	25 at 3 GHz 13 at 10.5 GHz 11.5 at 36 GHz	8 at 3 GHz 0.4 at 10.5 GHz 0.15 at 36 GHz
dN/dz>118 N/km (calculated by bulk-CELAR model)	25	0.4
dN/dz>157 N/km (calculated by bulk-CELAR model)	12	0.04
neutral conditions (|ASTD|<0.5°)	13	33
unstable conditions (ASTD<0)	24	60
very unstable conditions (ASTD<-2° C)	4	6
homogeneous situation	29	9
rain or fog situation	30	0.8

Table 4: Occurrence frequency of events for the two campaigns

campaign and situations where dM/dz was greater than 118 M units/km represent 25 % of the total time, and where it was greater than 157 M units/km 12 % of the time. During TOULON 90 campaign, subrefraction was much more frequent and dM/dz was greater than 118 M units/km only 0.4 % of the time.

Presence of horizontal homogeneity

Essentially because of the proximity of the shore, the propagation conditions sometimes vary significantly along the link. An "homogeneous situation" criterion was therefore considered based principally on the wind speed and the wind direction. According to it, the percentage of time where the situation is homogeneous is very low, as given in Table 4. This means that most of the time the conditions were nonhomogeneous along the path, which is typical of coastal regions.

b) Radio propagation data

Cumulative probability

Concerning the LORIENT 89 campaign, a study of enhancement factors (measured path loss relative to diffraction loss) shows that 50 % of the time, the enhancement at 3 GHz was more than 5 dB, and 10, 10 and 6 dB at 5.6, 35.0 and 94.0 GHz respectively. Enhancements larger than 10 dB are observed 19 %, 48 %, 70 %, 70 %, 50 % and 21 % of the time at 3.0, 5.6, 10.5, 16.0, 35.0 and 94.0 GHz respectively. An explanation for the distinct behaviour at the different frequencies can be given with the PC-PEM predictions (using PE method) of Figure 5. Maximum enhancement factors of 18-20 dB and 16-18 dB for 10.5 and 16.0 GHz respectively indicates the presence of duct heights of about 6m. At the higher frequencies (35 and 94 GHz) the maximum overall enhancement at such duct heights is smaller and the signal fluctuation as a function of the duct height and tide becomes significant. Indeed, the analysis of the 36 GHz data reveals that the path loss varied by more than 40 dB, while the maximum received signal reached the free space level.

Moreover, when ducting effects are observed at the lower frequencies, large fluctuations in the 94 GHz signal level are observed around the level obtained without ducting. It appears that turbulence in the low troposphere diminishes the duct effects at this frequency.

Concerning TOULON 90 campaign, the cumulative distribution of enhancement factor was analysed for all frequencies. For lower frequencies, the enhancement ranges between 0 and 40 dB, with more than 10 dB enhancement measured during 58 %, 75 %, 93 %, 95 %, 97 % and 18 % of the time, respectively. This suggests large duct heights, which indeed have been observed.

Once again, an inspection of the received signal strength versus time shows a very strongly fluctuating signal at 94 GHz, most of the time. Also at 35 GHz there are fluctuations but much less.

Finally, a comparison of the data related to the French 36 GHz link with those related to the German 35 GHz link shows directly the influence of the 1 m higher position of the 36 GHz receiver. Obviously, the path loss measured by the latter are less on average than those for the 35 GHz link.

Comparison of predictions and measurements

Long-term predictions

MLAYER (based on a modal approach) has been used with a neutral evaporation-duct profile (which is log-linear) weighted by the annual evaporation duct height-percent-occurrence distribution to give the accumulated frequency distributions of absorption-free path loss, which are then compared to the measured distributions. Figure 6 shows the results at 16 and 94 GHz, for the LORIENT 89 campaign. The comparisons between predictions and measurements are excellent up to and including 16 GHz. Thus, a system designer could use such long-term theoretical predictions to assess possible interference effects on existing systems, for example.

At 35 and 94 GHz, the predictions generally underestimate the path loss by 5 to 7 dB. However, the shape of the predicted and measured curve are similar, which may indicate that gaseous absorption is underestimated in models. Other possible explanations for the differences at the highest frequencies may be :

- surface roughness effects, which are likely to increase the predicted path loss ;
- horizontal homogeneity of the meteorology along the path affecting absorption ;
- the shape of the evaporation duct M profile near the surface which has a stronger effect as the frequency increases ;
- more probably a combination of all these factors.

Generally speaking, the conclusions are the same for the TOULON 90 campaign. Good long-term predictions up to 16 GHz, and poorer results for the millimeter waves. However, for the 3 and 5.6 GHz cases, the predictions generally overestimate the measured path loss, particularly near free-space levels. This might be attributed to the presence of elevated layers. So, once again the need of a detailed description of upper air structure is recommanded.

Short-term predictions

For every 10 minutes, the path loss predictions were calculated using the meteorological data of the buoy, the PAULUS model and PC-PEM.

In the case of LORIENT 89, the calculated overall rms deviations are 6.3, 6.8, 6.5, 6.6, 7.5 and 6 dB respectively for the frequencies in ascending order. Then, we can conclude that the short-term predictions are not as good as long-term predictions.

In the case of TOULON 90, the short-term predictions are even poorer, since the calculated overall rms deviations are respectively 11.8, 11.2, 8.8, 9.1, 7.6 and 10.4 dB. Larger differences were observed at the lower frequencies (3.0 and 5.6 GHz). The presence of other types of ducts (elevated layers) than the evaporation duct is thought to be the cause.Indications are that there was surface duct during about 26 % of the time.

Generally speaking, it can be concluded that, when calculating the refractivity profile based upon a single point measurements, good predictions are possible if we consider long-term statistics. For short-term analysis, the refractivity profile should be measured at several ranges.

Another way to proceed, when data at various frequencies are available, consists in deducing the duct height from path loss measured at a frequency and then predicting path loss at the other frequencies using this duct height. In the context of the LORIENT campaign, the use of the 3 GHz data to estimate the duct height reduced discrepancies significantly. But this was not the case for the TOULON 90 campaign : other atmospheric structures than the evaporation duct were likely to prevail.

It is obvious that in general short-term predictions are not as accurate as the long term predictions. However, it must be noted that the measurements ranged only over a part of the year and that the geographical location of both sites may have caused specific land-induced effects.

Spectral analysis

The fine structure of the refractivity of the atmosphere varies both temporally and spatially, causing amplitude fluctuations referred to as scintillations. However, over-the-horizon propagation of millimeter waves at low altitude above the sea is also closely linked to the conditions of the sea surface (i.e., the sea state).

Main conclusions about power spectra of scintillations are:

- the general shape of the fading spectra at 35 GHz on a over-the-horizon path and at 36 GHz on a line-of-sight path is essentially the same for the higher frequency spectra range (f>1Hz) ;
- the reflection from the sea does not seem to affect the fading densities at higher spectral frequencies (f>1 Hz) ;
- the power spectra are pronounced at the low-frequency end and power spectra densities are consistently higher at shorter wavelength ;
- at all measured frequencies (10.5 GHz, 35.0 GHz, 36.0 GHz and 94.0 GHz) the spectra follow the $f^{-8/3}$ power law showing excellent agreement with the theoretical model given by Tatarski **[10]** ;
-the power spectra of signal fading in the lower frequency range (F<1Hz) are closely linked to the conditions of the sea surface. When the sea is calm, the shape of the power spectrum shows a more or less marked spectral density peak in the lower frequency range (around 0.1 Hz). Due to signal reflection against the sea surface, these frequency peaks can be associated with the periodicity of the swell. When the sea is rough, the peaks are smoothed out (except at 10.5 GHz) because the reflections from the sea surface at shorter wavelength are more random.

2. LORIENT 93 campaign

Either on a long-term statistical base or related to case studies, the analysis of LORIENT 93 data concentrates on AOA determinations in order to assess the phase-front distortions effects due to multipath and ducting essentially, and also to the atmospheric turbulence in the case of the millimeter waves.

Overall data analysis has not yet been completed, statistical results are not yet available, and so we present here only a case study corresponding to 28 September, a day of smooth sea conditions. Figure 7 gives the path loss and AOA measured by the Ku-band interferometer provided by TNO.

Obviously both the path loss and the AOA highly depend on the tide height, which indicates that multipath is the dominant mechanism with regard to phase-front distortions and also to path loss. Also a strong correlation between AOA and path loss is noticed, which confirms the main role played by multipath effects. In contrast, there is no evidence of a strong correlation between the measured duct height and either the AOA or the path loss. The calculation of the interference pattern (due to multipath) at 5 h 00 UT and 17 h 00 UT shows that the X-band array was situated in a null (destructive interferences) at these times. Figure 7 shows that the measured AOA is completely erroneous, at these moments Thus, difficulties encountered by tracking systems operating at low altitude above the sea surface due to reflection are well illustrated here.

V - CONCLUSION

This paper has emphasized the availability of radiowave propagation and meteorological data provided by extensive experimental cooperative work conducted by RSG8/PSG. This material has allowed an assessment of refractive and multipath effects on systems operating in a maritime environment, near the coast, either in centimeter or in millimeter wavelengths.

Main conclusions that can be derived from 3 main campaigns are :

- with regard to predictions, obtaining meteorological profiles is more critical than using them in propagation models ;
- for cm-wave systems, use of existing models provides sufficient prediction performance for global sensors performance study, while short term data is not as accurate but can be operationally useful ;
- at mm-waves, poorer prediction performances were obtained even for global sensor performance study. It is thought to be due to the increasing sensitivity of the refractive profiles and duct height on the path loss computation as the frequency increases and also to the insufficient characterization of sea-state effects.

Also the work performed by RSG8/PSG allows one to analyse the implications on military systems:

-multipath and refractivity gradients permanently affect the operations of cm- and mm-wave naval sensor against low-flying targets ;
-for naval radar systems, ducting leads to over-the-horizon detection of low-flying targets. However, for short and medium ranges the probability of detection may be degraded at ranges depending on the geometry of the path ;
-refractive effects can modify the target acquisition range of missile seekers and affect the ship's ECM effectiveness ;
-under ducting conditions active systems can be detected at longer ranges (OTH) by Electronic Warfare Support Systems (ESM) ;
-better performance of radar or communication systems should be obtained through frequency agility or diversity, antenna height diversity and applying advanced processing array antennas and adaptative signal processing.

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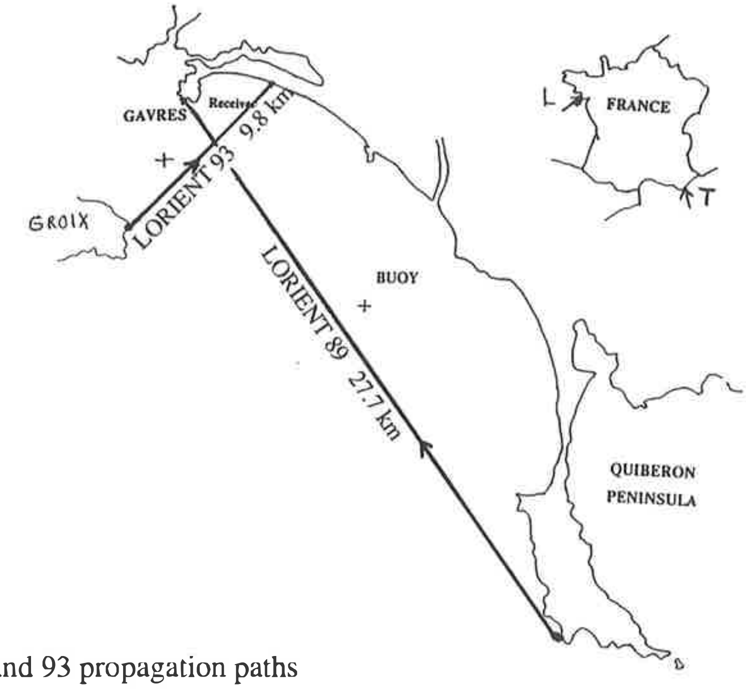

Figure 1 : Lorient 89 and 93 propagation paths

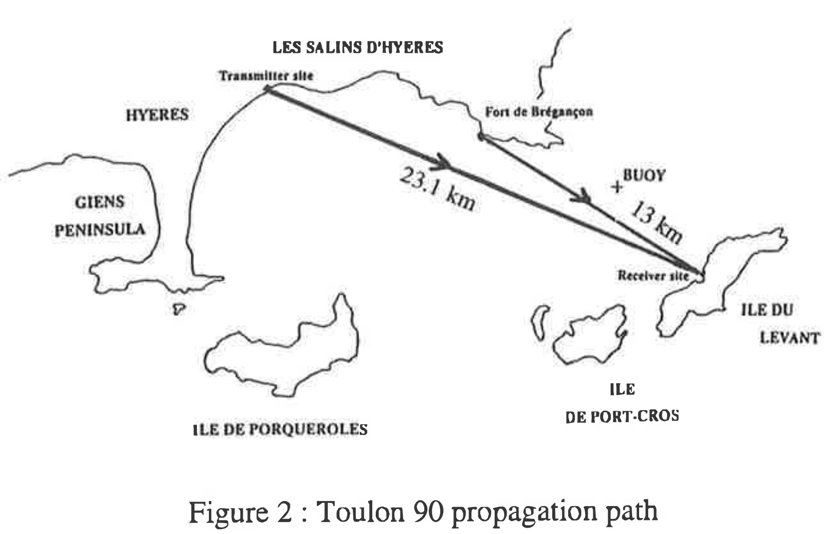

Figure 2 : Toulon 90 propagation path

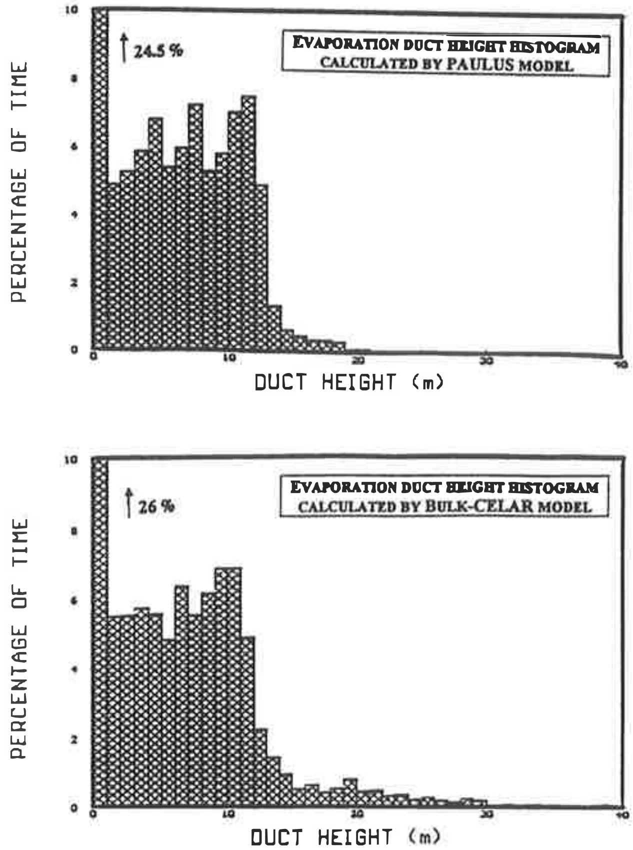

Figure 3 : Duct-height histograms for Lorient 89 ; different MBL modelling

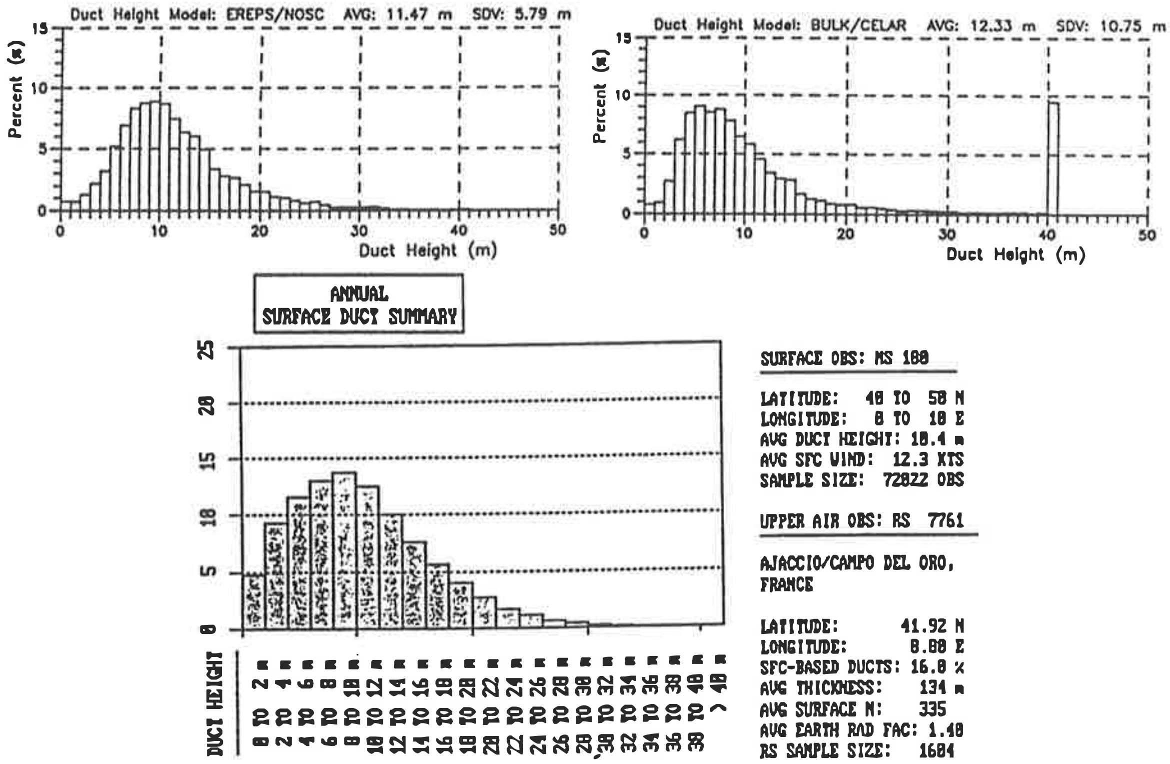

Figure 4 : Duct-height histograms for Toulon 90 and long term data base

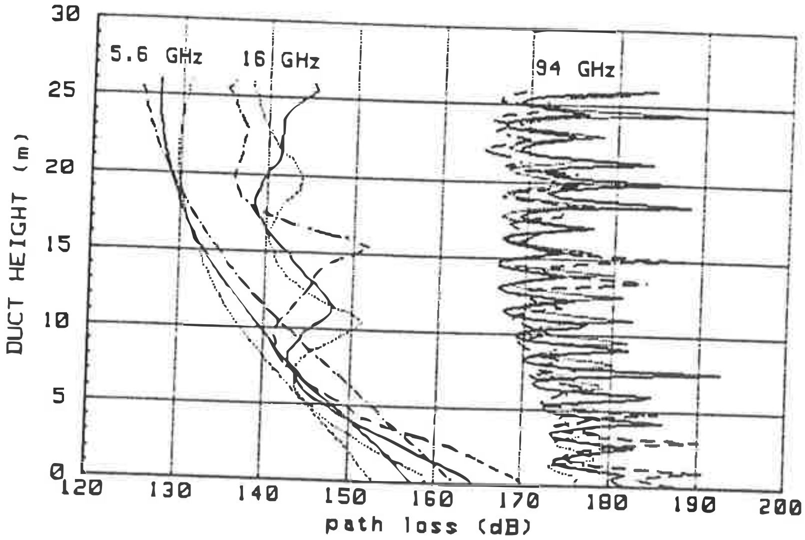

Figure 5 : Path loss dependence with receiver height and tidal effects
(PC-PEM calculations)

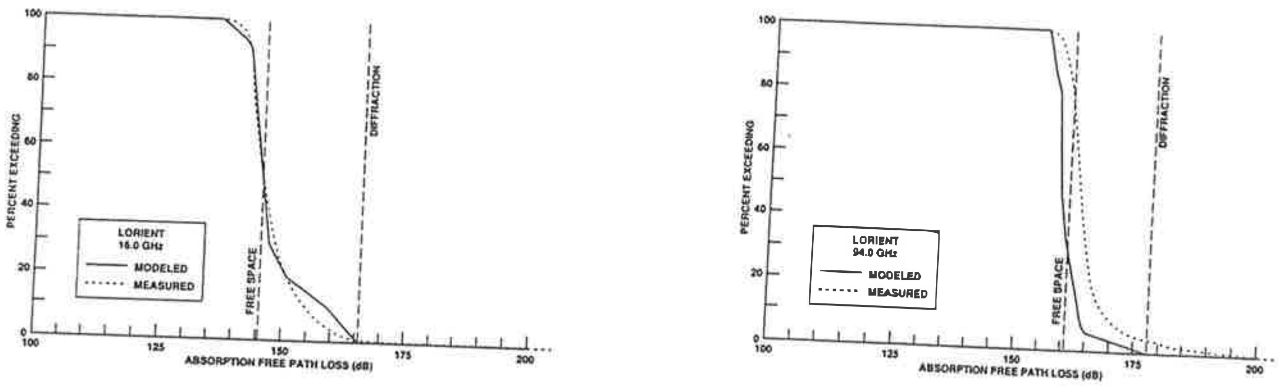

Figure 6 : Comparison, at 16 and 94 GHz, of observed path loss
with predicted values

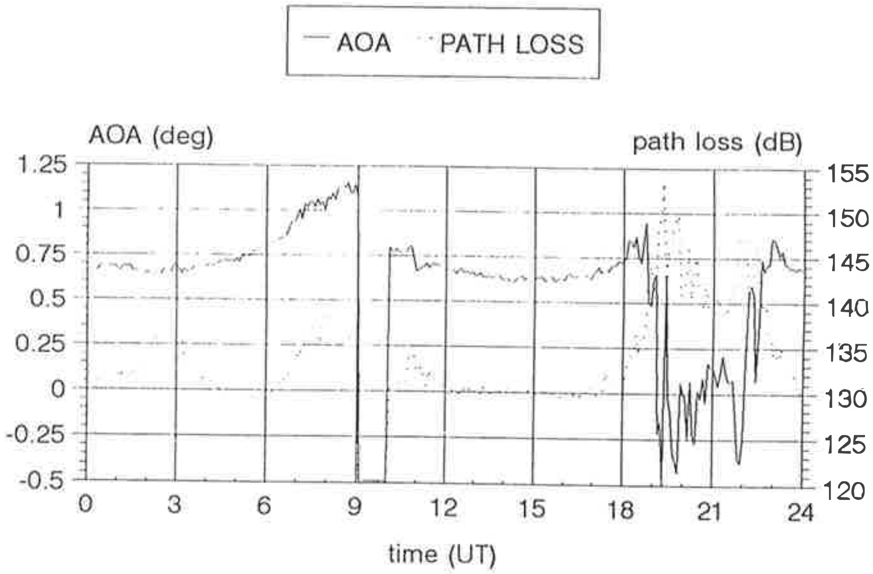

Figure 7 : Lorient 93: Measured path loss and angle of arrival at 16 GHz for september 28 th. : tidal effect with smooth sea