Assessment of Evaporation Duct Propagation Simulation

Iurii Levadnyi, *Victor Ivanov*, and *Vyacheslav Shalyapin*
Institute of Radiophysics and Electronics NAS of Ukraine, Department of Remote Sensing of the Earth.
12, Proskura str., Kharkov, 61085, Ukraine,
yulev@ire.kharkov.ua

Abstract

The evaporation duct strongly influence microwave radars and communication systems. For evaluation of their performance in such environment combination of split-step parabolic equation and Monin-Obukhov similarity theory are usual approach. There are several variants of semiempirical functions used in the similarity theory which leads to different models for evaporation duct height estimation. Five models were analyzed in this paper and evaporation duct height derived from them were compared with "effective" duct height obtained minimizing the difference between measured propagation factor and split-step parabolic equation calculation for varying evaporation duct height by least-square method. The best result in average was showed by ECMWF model and for other models "effective" evaporation duct heights was lower then obtained from bulk measurements. It means that combination of these models and split-step parabolic equation method leads to overestimation of propagation factor values.

1 Introduction

The propagation of microwaves in the troposphere is affected by spatial distribution of refractivity. Sufficient gradient of humidity near sea surface leads to a vertically decreasing index of refraction, which causes formation of evaporation duct in a first tenth meters. The coverage of microwave radars and communication systems strongly affected by this waveguide. Correct prediction of electromagnetic wave propagation in real environment should be made in order to optimize their performance. The combination of split-step parabolic equation method for radiowave propagation simulation and Monin-Obukhov similarity theory for vertical refractivity distribution evaluation are often used for this purpose. The similarity theory used several variants of empirical functions and roughness parameter what led to different models for evaporation duct height (EDH) estimation. Five models were analyzed in this paper and their combination with split-step parabolic equation were compared with our experimental data to evaluate their performance for microwave propagation assessment.

2 Split-step parabolic equation method

The parabolic equation is paraxial approximation to the Helmholz wave equation. The most efficient method for numerical solution of the parabolic equation is split-step Fourier transform method. It can easily handle refractive index inhomogeneities and appropriate boundary conditions. The wave fields begins at the antenna and marches out in range. The solution at range step $x + \Delta x$ is given by [1]

$$u(x + \Delta x, z) = e^{-jk_0(n^2-1)\frac{\Delta x}{2}} \cdot F^{-1}\left[e^{jp^2\frac{\Delta x}{2k_0}} F[u(x, z)]\right], \tag{1}$$

where n is the index of refraction, k_0 is the free space wavenumber, Δx is the incremental range step over which the solution is propagated, p is the spatial wavenumber written as $k_0 sin\theta$, where θ is the propagation angle from horizont, F and F^{-1} forward and backward Fourier transforms. The type of Fourier transform is defined by boundary conditions. For Dirichlet boundary conditions sine transform and for Newman boundary conditions cosine transform is used respectively. The mixed Fourier transform is used for imperfectly conducting surface [1]. Since the algorithm models two-dimensional, forward propagation, effects such as lateral diffraction and backscattering have been neglected. Influence of rough sea surface on radiowave propagation are accounted by means of Milller-Brown-Vegh model [2].

978-1-4244-6051-9/11/$26.00 ©2011 IEEE

3 Evaporation Duct Refractivity from Bulk Meteorological Measurements

The modified refractivity profile $M(z)$ can be calculated using profiles of pressure $P(z)$, absolute temperature $T(z)$ and water vapor pressure $e(z)$:

$$M(z) = (n(z) - 1) \cdot 10^6 + \frac{z}{R_e} = 77.6 \frac{P(z)}{T(z)} + 373 \cdot 10^3 \frac{e(z)}{T^2(z)} + \frac{z}{R_e}, \tag{2}$$

where R_e is Earth radius. Pressure is calculated on the barometric equation. The Monin-Obukhov theory is used to calculate vertical profiles of air temperature and humidity. Following this theory the vertical profiles of wind speed u, virtual potential temperature θ and humidity q are given by

$$u(z_u) - u(0) = \frac{u_*}{k} \left[\ln \frac{z}{z_{0u}} - \psi_u(\zeta) \right], \tag{3}$$

$$\theta(z_\theta) - \theta(0) = \frac{\theta_*}{k} \left[\ln \frac{z}{z_{0\theta}} - \psi_h(\zeta) \right], \tag{4}$$

$$q(z_q) - q(0) = \frac{q_*}{k} \left[\ln \frac{z}{z_{0q}} - \psi_h(\zeta) \right]. \tag{5}$$

In this equations, u_*, θ_* and q_* are scales for wind speed, temperature and humidity respectively, z_{0u},$z_{0\theta}$ and z_{0q} are their roughness parameters. k is von Karman constant which has a value of about 0.4. The functions ψ are accounted for departures of the surface layer from the neutral stability conditions and they depend on dimensionless height $\zeta = z/L$, where L is Monin-Obukhov length, which is the characteristic length for dynamic turbulence in surface layer and defined as

$$L = \frac{u_*^2 \theta}{k g \theta_*}, \tag{6}$$

where g - gravitation acceleration. Several variants of the empirical ψ functions and roughness parameters were derived based on the different meteorological measurements during last years of developing this theory. Some prevailing models LKB(Liu-Katsaros-Businger) [3], RSHMU (Russian State Hydro-Meteorological University) [4], ECMWF (European Center for Medium range Weather Forecast) [5], COARE (Coupled Ocean-Atmosphere Response Experiment) [6] and P-J (Paulus-Jeske) [7] are discussed here.

4 Experimental Investigations

The experiments were conducted in tropical and subtropical regions of the Atlantic Ocean from May till July 1979. The radiowave propagation factor for 3.2 cm was obtained between two vessels moving towards each other and apart. The measurements were carried out for distances 10 – 300 km. Only in some cases, the distance was increased up to 500 km. The total error in determination of propagation factor didn't exceed 2–3 dB. The bulk measurements of air temperature, humidity, wind speed, and the sea surface temperature were carried out simultaneously. Radiosonde sensing of the upper troposphere was performed 4 times per day on both vessels and allow vertical profile of refractivity to be derived from their pressure, temperature and humidity measurements.

5 Analysis and Discussion

The experiment was conducted in open ocean where evaporation duct and the elevated duct could occur. Analysis of the radiosonde soundings showed low probability of elevated duct presence during the data collection. This result together with analysis of bulk measurements and previous investigations leads to that the evaporation duct is primary propagation mechanism for this region. The available data are 39 distance dependencies of propagation factors between 10 and 300 km. The most important part of the data is the overhorizon before the troposcatter region where evaporation duct plays dominant role. A range dependence of propagation factor there is close to linear decay which primary depends on evaporation duct height. Thus we could characterize this curve by specific attenuation or some "effective" evaporation duct height. The least square method which minimize the difference between simulation by split-step parabolic equation method and experimental values of propagation factor was used to find "effective" duct height. The range of evaporation duct height variation was chosen from 3 m to 16 m. Such range showed EDH calculation from bulk measurements by all models except P-J. For each distance dependence of propagation factor was also calculated evaporation duct height from bulk meteorological measurements. The comparison of EDH estimated by two method presented as scatter plot on Fig. 1 and results of regression analysis in the Table 1. Triangles, circles and stars correspond to different transmitter an receiver antennas heights: 4.5 m and 5.5 m, 12 m and 17 m, 12 m and 22.5 m. The solid line shows results of regression analysis and dashed line shows the best case when two methods gives equal results. All models except ECMWF overestimate EDH obtained from propagation measurements. It is mean that propagation factor values calculated by means of split step parabolic equation and these models for refractivity estimation are higher than the measured values. This result corresponds to previous investigations. The possible reasons for such difference are neglect of turbulent refractivity fluctuation and incomplete account for rough sea surface. ECMWF model in average shows results similar to the best case. The worst result was obtained for P-J model which overestimate values evaluated from propagation factor by 4 meters.

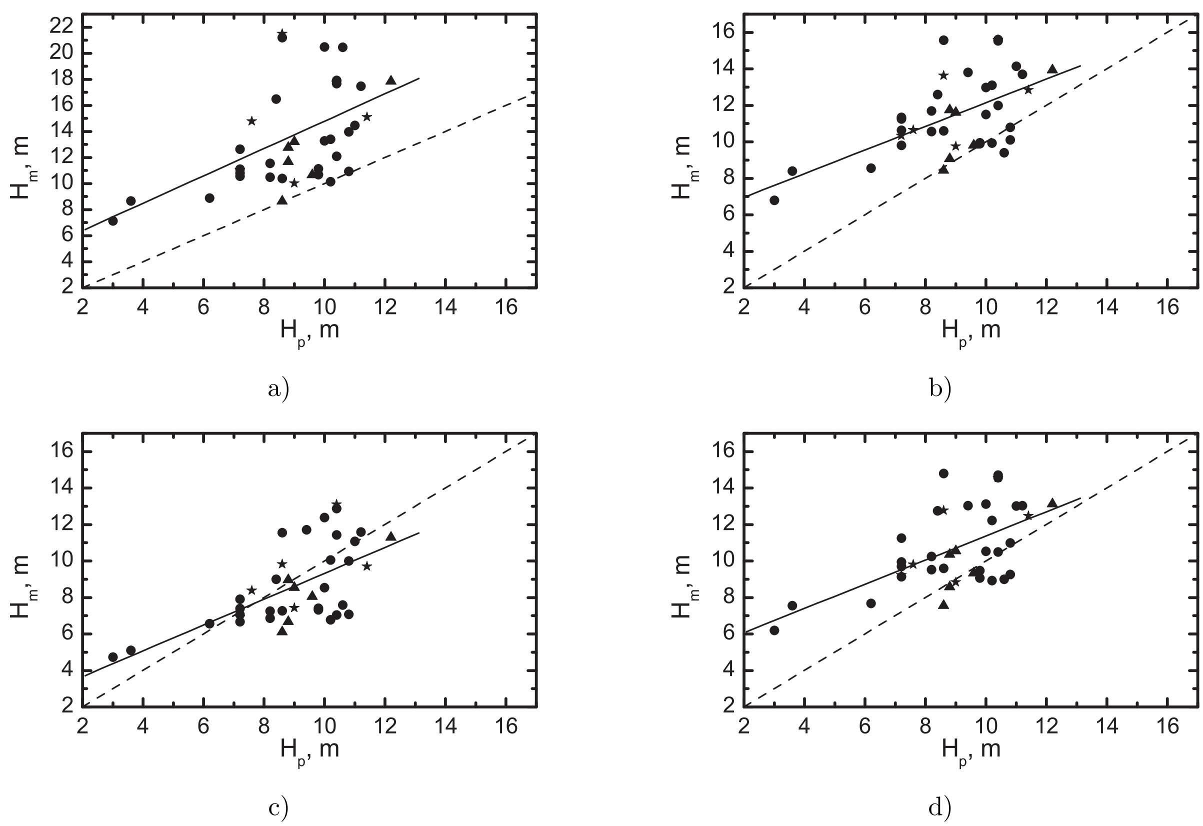

Figure 1: Evaporation duct height from bulk measurements vs. "effective" evaporation duct height for: a) PJ; b) RSHMU; c) ECMWF d) COARE

Table 1: Comparison of evaporation duct height estimation from bulk measurements and from propagation measurements

Model	a	b	Shift	Correlation	σ
LKB	5.10	0.67	2.16	0.57	2.94
RSHMU	5.66	0.65	2.51	0.57	2.69
ECMWF	2.24	0.71	-0.37	0.63	1.83
COARE	4.75	0.66	1.72	0.58	2.59
P-J	4.28	1.05	4.74	0.48	6.08

6 Conclusions

The comparison of simulation and experimental results at microwaves show that evaporation duct refractivity calculation from bulk meteorological measurements leads to overestimation of microwave propagation factor obtained by the split-step parabolic equation method over experimental values. This was already pointed in previous investigations. To improve the prediction agreement "effective" evaporation duct height could be used. It values differ in average from the one obtained from bulk meteorological measurements for the shift in Table 1. Just ECMWF model shouldn't be corrected accordingly for results from this data set.

7 References

1. M. Levy, *Parabolic equation methods for electromagnetic wave propagation*, London: The Institution of Electrical Engineering, 2000.

2. A. R. Miller, R. M. Brown, and E. Vegh, A new derivation for the rough surface reflection coefficient and for the distribution of sea wave elevations, *NRL Report 8744*, Naval Research Laboratory, Washington, D.C., 1983. 4 p.

3. W. T. Liu, K. B. Katsaros, and J. A. Businger, Bulk parameterization of air-sea exchanges of heat and water vapor including the molecular constraints at the interface, *J. Atmos. Sci.*, vol. 36, p. 1722–1735, 1979.

4. A. S. Gavrilov, Methods of calculating the structure of near-water atmospheric layer with reference to radio location over the ocean, in *Scattering and difraction of radar signals and their information content*, pp. 31-36, Leningrad: SZPI, 1984. [in Russian].

5. A. Woods, *Medium-Range Weather Prediction The European Approach*, Berlin: Springer-Verlag, 2005.

6. C. W. Fairall, E. F. Bradley, D. P. Rodgers, J. B. Edson, and G. S. Young, Bulk parametrization of air-sea fluxes for tropical ocean-global atmosphere coupled-ocean atmosphere response experiment, *J.Geophys.Res.*, vol. 101, no. C2, pp. 3742-3764, 1996.

7. R. A. Paulus, Practical application of an evaporation duct model, *Radio Science*, vol. 20, no. 4, pp. 887-896, 1985.