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The Research and Experiment of the Modified Terrain Parabolic Equation Model Based on the Amended Atmosphere Attenuation Algorithm

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Abstract: Terrain Parabolic Equation Model (TPEM) is widely used in the numerical simulation of electromagnetic wave propagation. But the algorithm and theory of atmosphere attenuation in TPEM is not consistent with the real fact, this disadvantage induces the calculation error directly. According to this disadvantage, this paper uses the amended algorithm of the attenuation ratio to modify the TPEM based on the relation between the degressive water vapor density and the vertical altitude. With the contrast test of electromagnetic wave propagation and radar detection, the numerical simulation results of the TPEM and modified TPEM are contrasted, analyzed and validated, and the contrast conclusion shows the validity and veracity of the modified TPEM.

Keywords: Atmosphere Attenuation Ratio; Water Vapor Density; Modified TPEM; Contrast Test

1. Introduction

The atmospheric attenuation has important effect on the electromagnetic wave propagation, especially for the high frequency and frequency by absorption lines, the attenuation can not be ignored [1]. At present, the effective method to simulate the electromagnetic wave propagation among the troposphere is the terrain parabolic equation model (TPEM) [2]; it not only includes various propagation mechanisms, but also considers the radiation system, atmosphere environment and terrain characters. At the same time, for the atmosphere attenuation along the propagation rout, the TPEM calculates the absorption attenuation of the water vapour and oxygen, uses the simplified attenuation algorithm of CCIR (1900)[3].

This simplified attenuation algorithm can give the propagation loss of atmosphere attenuation quickly, but not accurately because of the atmosphere nonuniformity in vertical distribution. Actually, the atmosphere attenuation in low altitude is more greater than it in the upper air, and the attenuation of the water vapour and oxygen still relate to water vapour density, relative humidity, air pressure and temperature, etc[4]. So the atmosphere attenuation algorithm and theory application of TPEM have follow shortages.

(1)The TPEM only considers the atmospheric nonuniformity in the calculation of refractive index, but not in the calculation of atmosphere attenuation, it is inconsistent in the abstract.

(2)The atmosphere attenuation ratio is degressive with the vertical altitude actually, but the TPEM considers it as settled ratio, this does not match the case and can bring the calculation error.

(3)TPEM uses the settled attenuation accumulation to stand for the whole attenuation characters in the propagation space, which ignores the height difference between the transmitter and target and can not be applied in the attenuation calculation of slant route.

In this paper, the relation between water vapour density and vertical altitude is induced to calculate the degressive attenuation ratio, and the atmospheric attenuation of different height and range can be accumulate by this degressive attenuation ratio. Through this amended algorithm of atmospheric attenuation, the TPEM can be modified and avoid the shortages mentioned above. And the veracity this modified TPEM can

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be validated by the contrast test of electromagnetic wave propagation and radar detection in 2007.

2. The amended algorithm of atmospheric attenuation in TPEM

Based on the reference [5], in the real atmosphere environment above sea surface, water vapor density ρ varies with the vertical altitude as the follow expression approximatively.

$$\rho = \rho_o \exp(-h/2) \quad (1)$$

ρ_o is the water vapor density on the sea surface which unit is g/m^3, and h is the vertical altitude.

According to the water vapor equation [4] $\rho = e/R_a T$, R_a is the specific air constant, T is the air temperature, and e is the water vapor pressure. The water vapor pressure e can be gotten by the observation data of relative humidity r_h and air pressure p through the simple expression $e = r_h \times p/(62.2 + 37.8 \times r_h)$.

Here, for the route attenuation of water vapor, the attenuation ratio can not be considered as constant, but the expression 1 is introduced into the attenuation ratio of water vapor of ITU（2005）, and gets the expression of r_w.

$$r_w = \left\{ \frac{3.98\eta_1 \exp[2.23(1-r_t)]}{(f-22.235)^2 + 9.42\eta_1^2} g(f,22) + \frac{11.96\eta_1 \exp[0.7(1-r_t)]}{(f-183.31)^2 + 11.41\eta_1^2} + \frac{0.08\eta_1 \exp[6.44(1-r_t)]}{(f-321.226)^2 + 6.29\eta_1^2} + \frac{3.66\eta_1 \exp[1.6(1-r_t)]}{(f-325.153) + 9.22\eta_1^2} + \frac{25.37\eta_1 \exp[1.09(1-r_t)]}{(f-380)^2} + \frac{17.4\eta_1 \exp[1.46(1-r_t)]}{(f-448)^2} + \frac{844.6\eta_1 \exp[0.17(1-r_t)]}{(f-557)^2} g(f,557) + \frac{290\eta_1 \exp[0.41(1-r_t)]}{(f-752)^2} g(f,557) + \frac{8.3328\times 10^4 \eta_2 \exp[0.99(1-r_t)]}{(f-1780)^2} g(f,1780) \right\} \quad (2)$$

$$g(f,f_i) = 1 + \left(\frac{f-f_i}{f+f_i} \right)^2 \quad (3)$$

η_1 and η_2 are the parameters vary with water vapor density ρ, and their expressions are as follow.

$$\eta_1 = 0.955 r_p r_t^{0.68} + 0.006\rho$$

$$\eta_2 = 0.735 r_p r_t^{0.5} + 0.0353 r_t^4 \rho$$

$$r_p = P/1013;$$

$$r_t = 288/(273+T);$$

According to the expression 1, parameters of η_1 and η_2, we can get the degressive expression of water vapor attenuation ratio r_w. At the same time, refer to the attenuation expression of dry air in ITU（2005）, the attenuation ratio γ_0 (dB/km) can be calculated as:

$$\gamma_0 = \left[\frac{7.2 r_t^{2.8}}{f^2 + 0.34 r_p^2 r_t^{1.6}} + \frac{0.62\xi_3}{(54-f)^{1.16\xi_1} + 0.83\xi_2} \right] f^2 r_p^2 \times 10^{-3} \quad (f \le 54GHz) \quad (4)$$

The parameters ξ_1, ξ_2, ξ_3 are expressed as:

$$\xi_1 = \varphi(r_p, r_t, 0.0717, -1.8132, 0.0156, -1.6515);$$

$$\xi_2 = \varphi(r_p, r_t, 0.5146, -4.6368, -0.1921, -5.7416);$$

$$\xi_3 = \varphi(r_p, r_t, 0.3414, -6.5851, 0.2130, -8.5854);$$

$$\varphi(r_p, r_t, a, b, c, d) = r_p^a r_t^b \exp[c(1-r_p) + d(1-r_t)] \quad (5)$$

Then, the route attenuation of electromagnetic wave propagation L_{abs} will be calculated by the attenuation ratios of r_o, r_w and the propagation range d.

$$L_{abs} = (\gamma_o + \gamma_w)d \quad (6)$$

Use the expression 6, the attenuation calculation of modified TPEM is consistent with them of TPEM in the form, and reach the aim of considering the atmosphere nonuniformity in attenuation ratio and accumulating the attenuation loss in the propagation routes. In theory, the results of modified TPEM are more exact, and this also can be validated by the following test.

3. Numerical simulation and test contrast

Radar detection is actually the electromagnetic wave propagation, so the simulation results of modified TPEM can be validated by the detection range. Here, a contrast test in 2007 of electromagnetic wave propagation and radar detection is selected, and the typical data of 22th May is used here to validate the numerical simulation results of TPEM and modified TPEM.

3.1 Test description

The test location is in 119° 48′ 15 E and 26° 24′ 10 N, and 598m heights above sea level. The main parameters of test equipment are showed in table 1. The atmosphere data comes from the synoptic chart of Fujian observatory and the sounding data of GTS1.

The environment of 22th May is fog all-day, and atmosphere attenuation badly effects the electromagnetic wave propagation. The fig1（a）is the synoptic chart of 700bp at the clock of 20:00, it shows the wind is south-western, 2m/s and air temperature is 9.4℃in 3100m heights. The fig 2 (b) shows the modified atmosphere refractive index and the trapped layers calculated by the recording data of sounding balloon at the clock of 19:00[6]. The recording data also show that the temperature of observation station is 25.8℃, air pressure is 997.5bp, relative humidity is 81%, and the water vapour density is 33.4 g/m^3 which are calculated by the water vapor equation.

Table 1: The main parameters of the test equipment

Frequency	Polarization	Impulse accumulation	Antenna type
C-band	VV	correlative accumulation	Parabolic

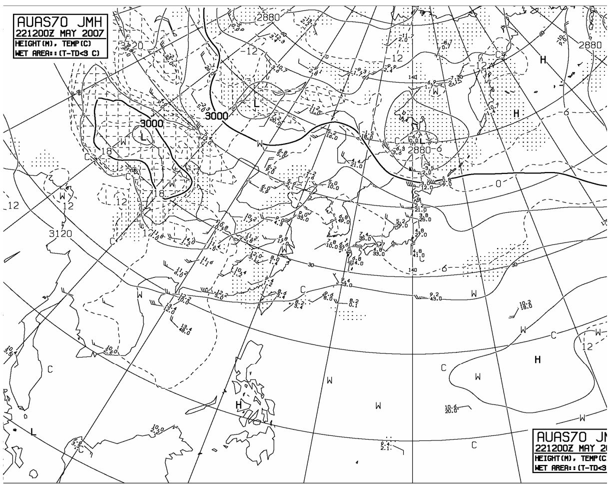

Fig 1(a): Synoptic chart of 20 o'clock in 22 May

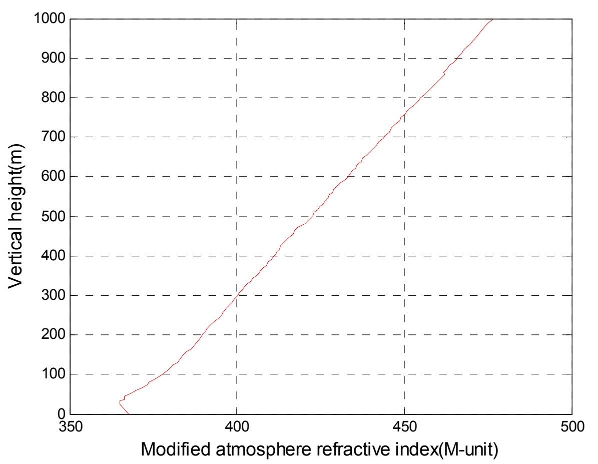

Fig 1(b): The profile of modified atmosphere refractive index

3.2 Numerical simulation and test contrast

According to the test equipments and atmosphere environments, the numerical results of detection at the clock of 19:21on 22th May can be simulated by the TPEM and modified TPEM as fig 2 and fig 3, the detailed algorithm and radar evaluation method can refer to [7]. The fig 2(a) and fig 3(a) show the propagation loss of atmosphere attenuation in the TPEM and modified TPEM, and fig 2(b) and fig 3(b) show the detection of targets based on the TPEM and modified TPEM.

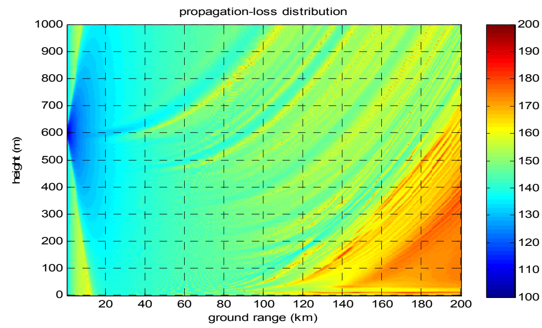

Fig 2(a): Propagation loss numerical simulation of TPEM

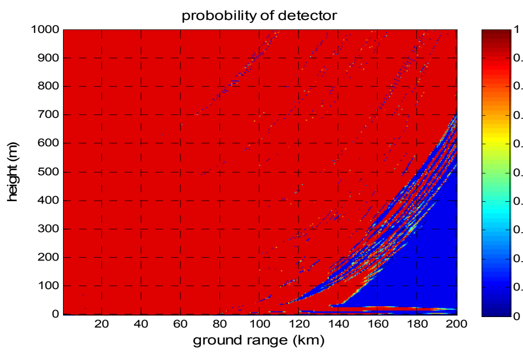

Fig 2(a): Radar detection numerical simulation of TPEM

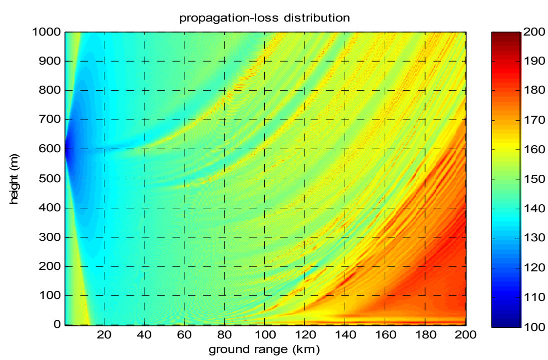

Fig 3(a): Propagation loss numerical simulation of modified TPEM

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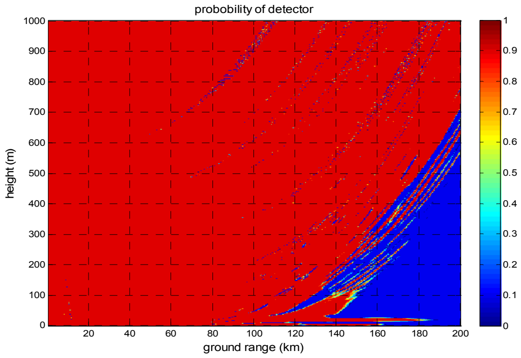

Fig 3(a): Radar detection numerical simulation of modified TPEM

At the same time, the recording data of targets detection are showed in table2 at the clock of 19:21on 22th May.

Tabel2: The recording data of target detection

Time	Target number	Detection range（nm）	Azimuth（deg）
05/22/1921	01	94.8	163
05/22/1921	02	94.8	146

Contrast fig 2(a) and fig 3(a), the propagation loss simulation of TPEM and modified TPEM are approximately same in the close quarters (about 40km), but with the increase of propagation range, the discrepancy from atmosphere attenuation becomes distinct especially in altitudinal contrast, and the calculation results of modified TPEM is several dB greater than them of TPEM. This conclusion consists with the theoretic analysis. At the same time, contrast the target detection fig 2(b) and fig 3(b) with the table 2, the simulation conclusion of modified TPEM is more close to the test recording data, and the advantage and validity of modified TPEM are obvious. In addition, the reasons of discrepancy between the simulation results and test observation mostly sum up as follow.

①In the test, the atmosphere environment data of observation station are used to stand for the atmosphere environment of the whole propagation space, the atmosphere nonuniformity is ignored.

②Although the stability of atmosphere environment in definite area, but use the data of sounding-balloon at the clock of 19:21 stand for the environment at the clock of 19:00 still can bring calculation error.

③Among the detection, the target characters is not clear, and the target height is estimated by its reflected area, so the numerical simulation results of targets detection are not consist with the recording data.

④The radar system has some heat noise and system error in the working load and the TPEM still has other factors which are not considered and can affect the propagation loss.

Anyway, the numerical simulation results and test recording data can testify the validity of TPEM and modified TPEM in the definite propagation range.

4. Conclusion

To avoid calculation error of the atmosphere attenuation and application shortage of TPEM in the numerical simulation of electromagnetic wave propagation, this paper introduces the degression expression of water vapor desity with vertical altitude into the calculation expression of atmosphere attenuation ratio, and get the modified TPEM. A test of electromagnetic wave propagation and radar detection validate the simulation results of the modified TPEM. The work of this paper make the algorithm and theory of atmosphere attenuation in the TPEM become unification. More details of the atmosphere attenuation of electromagnetic wave propagation and the method of numerical simulation should be investigated by following work.

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