The Feature of Sea Clutter and Its Reason Under Different Evaporation Duct

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Abstract- **The paper begins to study with a view to the character of the sea clutter below different evaporation duct. Frist, the paper simulated and analyzed the atmospheric refraction environment on Dartmouth Canada in 1993. Then, two data files with different strength duct are used to analyze sea clutter strength feature. Moreover, the mechanism of sea clutter is discussed through the ray tracing, the gazing angles and the propagation loss. The main results and contributions are as following: (1) There are evaporation duct phenomena in the Dartmouth experiments; (2) The sea clutter strength in the stronger duct is larger than that in the weaker duct; (3) The character of power spectrum. In the weaker duct, there is a larger value in certain frequency, and the aim's character is very distinctive. Then, in the stronger duct, power spectrum is uniformity, and the aim's character is illegibility. (4) To discuss the cause of formation from the character of electromagnetic wave propagation, relative to the weaker duct, the paper found that the electromagnetic wave ray propagates farther, the gazing angles are bigger, and the propagation loss is smaller. All of these are the reasons why sea clutter becomes stronger.**

Keywords- The Sea Clutter; Atmospheric Duct; Ray Tracing; Gazing Angles; Propagation Loss

I. INTRODUCTION

Sea clutter can disturb a working radar, so the research of sea clutter becomes hotter and hotter. Furthermore, the relation between sea clutter and evaporation duct performed through evaporation duct theory has been developed. For example, the study of RFC (Refractivity From Clutter) was developed and perfect in overseas. In recent years, there are some explorations about sea clutter in our country [1, 2]. But we are short of the study of the relation between sea clutter and evaporation duct, so it brings many difficulties about the RFC. Above all, the paper analyses sea clutter strength feature under different evaporation ducts, and discusses the mechanism of formation from electromagnetic wave propagating.

II. MODELING OF EVAPORATION DUCTS

A. The Introduction of Data

The paper uses the IPIX Radar's experiment data on Dartmouth Canada in 1993 [3]. We can obtain 14 data files from the Internet, and each file has 14 ranges return signals. There are two polarizations, HH and VV (Lpol). The data have much surrounding data, besides sea clutter actual measurement data, including wind arrow, wind velocity, temperature, relative humidity, the wave period and the high of wave, etc, which are very valuable.

Many papers have used the data, but we cannot calculate the atmospheric refraction environments of Dartmouth, for the experiment has not measured sea surface temperature, and so there are no papers that study the data through the atmospheric refraction environments. Evaporation duct is a common phenomenon, so it must exit on Dartmouth, and the experiment must be influenced by it, and sea clutter strength is not the same as the feature in the standard atmosphere. This is the main question that the paper should solve.

B. Analyzing Surrounding Data and Calculation of Evaporation Duct

In order to conclude evaporation duct, the paper obtained sea surface temperature through interpolating NCEP/NCAR data [4], then concluded evaporation duct height by PJ mode [5], the results are listed in Table 1. We can see that duct height extension is from 3.5 to 10.3 m, and the average height is 4.2 m.

C. Selecting of Actual Measurement Data

The actual measurement data must conform to several conditions:

- The evaporation duct heights have large disparity;
- The radar's parameters are equal;
- Wind arrows and velocities are tantamount;
- The sea surface situations are alike.

Table 1 shows surrounding data and evaporation duct heights of the two files. From Table 1, it is clear that in the 26th and the 30th, the difference of evaporation duct height is 3.5 m, wind arrows and wind velocities are similar, the difference of significant wave height is only 0.14 m, so sea space situations can be considered as analogous. And wave directions and the radar's parameters are the same according to the information of Internet [3], so these two data files conform to conditions and can be further researched. In the 30th, the evaporation duct height is 10.3 m, the dissimilar of atmosphere amendable refracted rate ΔM is 20.32. In the 26th, evaporation duct height is 6.8 m by comparison, the difference of atmosphere amendable refracted rate ΔM is 18.27, so the 30th can be regarded as the stronger duct, and the 26th is the weaker duct.

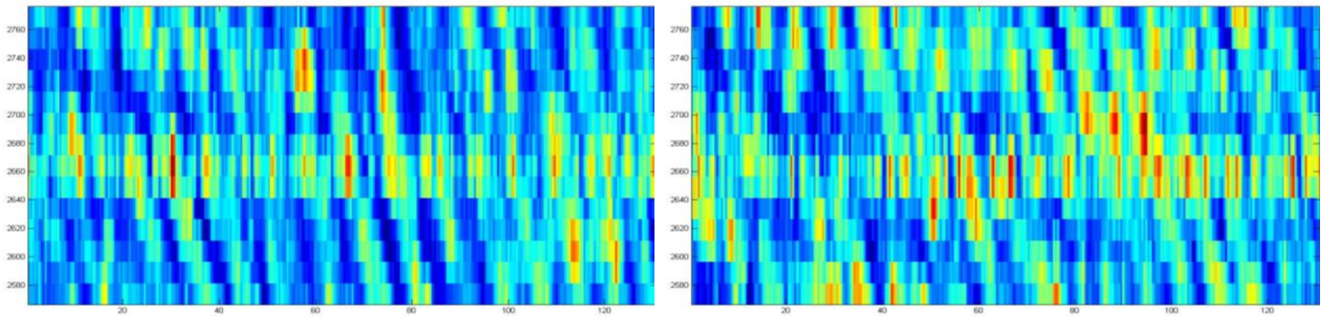
III. THE SEA CLUTTER FEATURE UNDER DIFFERENT EVAPORATION DUCTS

A. Sea Clutter Strength Feature

Sea clutter amplitude can show the strength of radar echoes. And these can be obtained by analysis the 26th and the 30th data. Fig. 1 shows the 26th and the 30th radar return signals value. Through Fig. 1, the radar echoes of the 26th are weaker than that of the 30th. Because two sea space situations are simple, the diversity of radar echoes is only caused by the disparity of evaporation ducts. The average value calculated through calculating the two data's 14 ranges return signals (Table 2) of the 30th is larger than that of the 26th.

TABLE 1 THE ATMOSPHERIC REFRACTION ENVIRONMENTS OF THE SEA CLUTTER EXPERIMENT AT DARTMOUTH [6]

Data	Wind Arrow °	Wind Velocity m/s	Temperature ℃	Humidity %	Sea Space Temperature ℃	Max Height m	significant wave height m	Evaporation Duct Height m
17	301	2.8	7.3	81	5.8	3.10	2.10	4.3
18	303	2.8	7.4	80	5.8	3.08	2.08	4.5
19	308	3.3	7.7	79	4.8	3.05	2.05	4.6
25	206	2.5	4.4	55	4.8	1.55	1.01	7.0
26	211	2.5	4.2	57	4.8	1.56	1.03	6.8
30	210	5.3	8.8	61	7.6	1.25	0.89	10.3
31	206	4.2	7.7	67	7.4	1.28	0.89	8.0
40	208	2.5	6.4	87	6.8	1.34	0.91	3.5
54	308	5.6	3.2	60	4.8	0.97	0.66	8.3
280	216	3.1	8.7	89	8.7	2.40	1.44	3.8
283	NaN	0	8.5	93	8.3	2.11	1.30	xxx
310	313	9.2	4.0	86	3.5	1.38	0.90	3.7
311	313	9.2	4.0	85	3.5	1.38	0.90	3.7
320	317	7.5	4.3	81	2.8	1.34	0.91	5.2



(a) (b)

Fig. 1 The 26th and the 30th radar return signals value (a: the 26th, b: the 30th;.x axis: sampling points, y axis: distance; the tending to red area: stronger return signals, the tending to blue area: weaker return signals)

TABLE 2 THE 26TH AND THE 30TH AVERAGE VALUE

The 26th		The 30th	
HH	*VV*	*HH*	*VV*
0.8102	0.9564	0.8978	1.0657

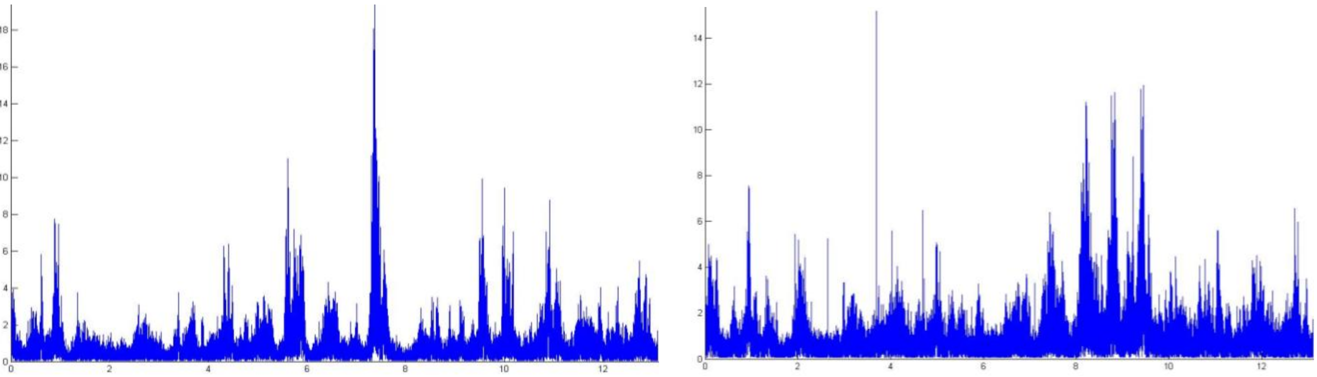
B. The Time Series of Amplitude and Histogram Plot

Then, we study the time series of the sea clutter amplitude, and the examples are the range 10 data. Just like Fig. 2, sea clutter ups and downs is bigger in the 26th, but the average sea clutter amplitude value of the 26th is less than that of the 30th. Through analyzing histogram plot (Fig. 3), in the 26th, the frequency nearby "0" is higher, so the sea clutter amplitude distribution spike is obvious. On the contrary, the frequency deviate from "0" is higher in the 30th, which shows the sea clutter amplitude distribution tail is long, besides range 10, other histogram plots have the analogous feature.

C. The Sea Clutter Power Spectrum Feature Under Different Evaporation Ducts

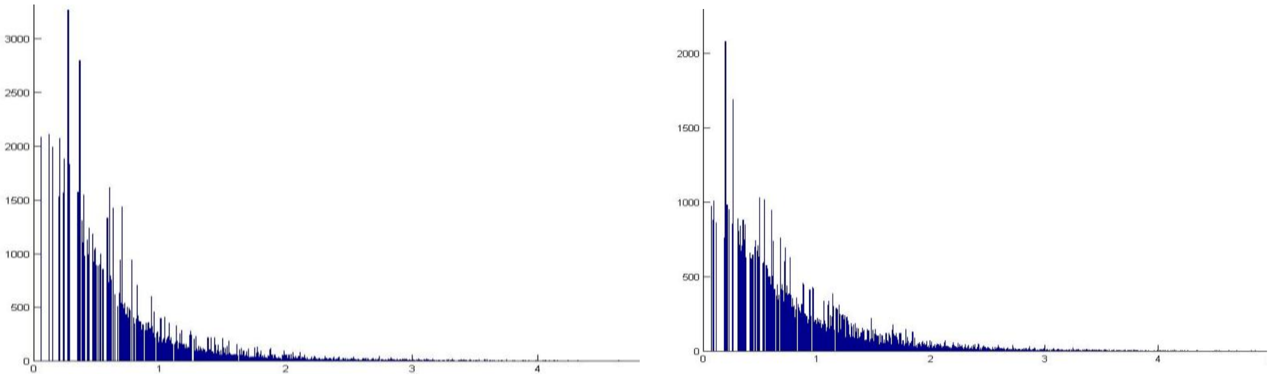
The periodogram is used to estimate the power spectrum under different polarization modes based on two sets of full range data and calculate the average power spectrum (Table 3). The power spectrum under VV polarization at range 10 is analyzed, which can show that the distribution of sea clutter power spectrum is matching a Gauss-type more than cubic or exponential, and that under HH polarization is similar. Fig. 4 shows sea clutter power spectrum of the 26th and 30th range 10 under VV polarization. It can be seen from the figure, power spectral values of the 26th are higher than 300 Hz, while the 30th is symmetrical at all spectrum frequency components. We can see that the sea clutter characteristics of the 30th are more significant for its plenty frequency components and more close to Gauss-type distribution.

Besides Range 10, the power spectrum of the range which contains return signals has the better stringency. Take range 10 as an example (Fig. 4, only the power spectrum under VV polarization, HH polarization is similar). It can be seen from Fig. 4 that the amplitude of power spectrum of the 26th is distinctly ups and downs near 150Hz for the existence of return signals.



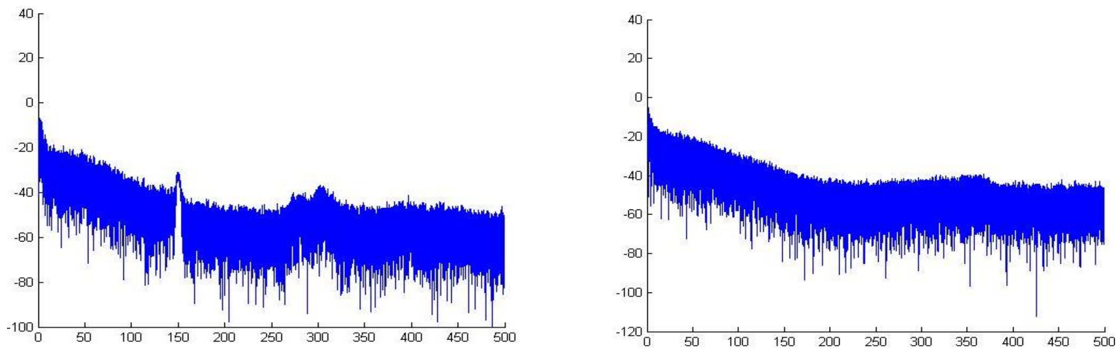
(a) (b)

Fig. 2 Time series of the sea clutter amplitude of the 26th and the 30th range 10 data (x axis: Time, y axis: Amplitude; a: the 26th, b: the 30th)



(a) (b)

Fig. 3 The sea clutter histogram plots of the 26th and the 30th range 10 data (x axis: Amplitude, y axis: Frequency; a: the 26th, b: the 30th)



(a) (b)

Fig. 4 Sea clutter power spectrum of the 26th and 30th range 10 under VV polarization (a: the 26th,b: the 30th,x-axis is frequency, y-axis is amplitude of power spectrum)

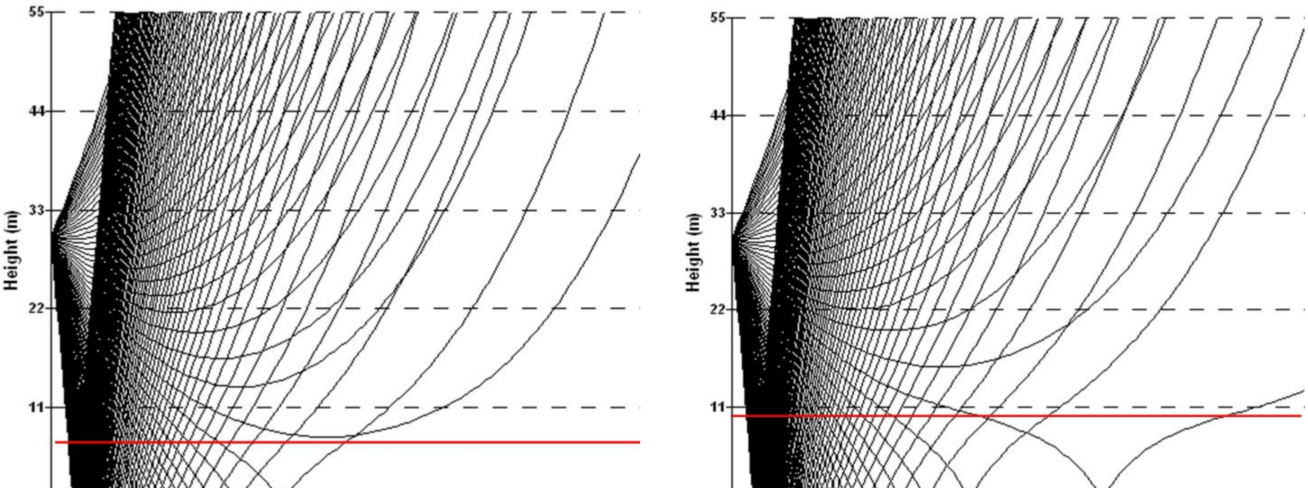
TABLE 3 AVERAGE OF POWER SPECTRUM OF GROUP 26 AND 30

Range	26	30
1	-44.524	-44.064
2	-44.793	-43.376
3	-45.543	-42.612
4	-44.962	-43.301
5	-44.461	-43.553
6	-48.398	-47.035
7	-49.809	-47.344
8	-48.005	-43.710
9	-45.078	-43.373
10	-44.418	-42.536
11	-45.333	-43.131
12	-45.313	-43.805
13	-45.088	-43.875
14	-45.270	-44.021
Average	-45.785	-43.9811

In contrast, the 30th is gently ups and downs near 300 Hz without the similar characters of the 26th. In fact the 30th contains the target spectrum, but cannot be seen from the figure. This indicates that the frequency characteristic of sea clutter obscures the power spectral characteristics of the target return signals due to strong sea clutter of the 30th.

In addition, the value of the power spectrum amplitude is directly ratio to the sea clutter strength, and the difference can be analyzed by calculating the average. The power spectrum of the actual value is very close to 0, a direct comparison is not convenient, so the value is dealing with taking the natural logarithm, and then magnifying 10 times. The value of the 26th and 30th of range 10 is -44.418 and -42.536, while the average is -45.785 and -43.9811, and the last one is bigger.

Above all, the average power spectrum of sea clutter is larger under stronger atmospheric duct, and target frequency is weaker. Of course, the characteristics of sea clutter spectrum is a complex phenomenon, related with a variety of factors, in order to get a more general conclusions, and it also needs more data analysis. However, the feature that large amplitude of sea clutter under strong atmospheric duct can indicate strong return signals energy is of universal significance [7].



(a) (b)

Fig. 5 The ray tracing distribution of the 26th and the 30th (Red solid lines show the high of evaporation duct, the 26th is 6.8 m; the 30th is 10.3 m)

IV. THE CAUSE OF SEA CLTTER STRENGTH FEATURE UNDER DIFFERENT EVAPORATION DUCT

The situation of electromagnetic wave propagating can be reflected by sea clutter strength feature in the atmosphere, according to the paper [8], the radar echoes include not only the echo signals inside measuring area but also beyond measuring area, so the radar can receive stranger return signals for electro-magnetic wave propagates farther than the measuring area distance, it would lead to stronger sea clutter, and then the amplitude value is larger. So the character of electromagnetic wave propagating in the atmosphere can interpret the reason of sea clutter strength feature under different evaporation ducts. In a word, the character of electromagnetic wave propagating in the atmosphere includes ray tracing and propagation loss.

A. The Ray Tracing Feature in the Experiment at Dartmouth

The radar used in the experiment is located at a height of 30 meters above mean sea level, and the max evaporation duct height is 10.3 m, so the radar height is higher than evaporation duct. It is not easy for electromagnetic wave to produce the atmospheric duct propagation, but there are still disparities between evaporation duct and standard atmosphere. The master performance is that electromagnetic wave ray tracing is winding, and the propagating distance is influenced. Fig. 5 shows the ray tracing distribution of the 26th and the 30th. We can see ray tracing feature of the 26th and the 30th. The concentrated ray region represents strong electromagnetic area, and the thin ray region represents weak. The farthest distance ray reaches is specific to the limited distance R_{lim} .

Ray tracing is clear bending because of evaporation duct, and the limited distance R_{lim} is larger than normal. Furthermore, in the 26th, the limited distance R_{lim} is farther than 2775 m, that the scope of experiment has explored, it is close to the 30th. In this way, the radar may receive radar echoes beyond the extent of 14 ranges (2775 m), and sea clutter is mixed return signals. In the 30th, R_{lim} is larger than that in the 26th for its stronger evaporation duct, so electromagnetic wave can reach farther sea distance, and radar can receive stronger echo signals energy. Of course, whether electromagnetic wave can receive the farthest region such as Fig. 4 showed, depends on electromagnetic wave propagation loss, that is to say, whether electromagnetic wave energy is enough to become echo signals in so far area.

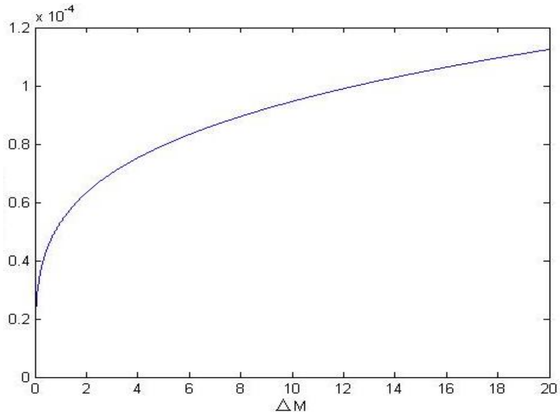


Fig. 6 The curve between limit grazing angle $\psi_{\lim}$ and ΔM (x-axis is limit grazing angle y-axis is ΔM)

B. Grazing Angle Characteristic in Dartmouth Experiment

Grazing angle is the sensitive factors of backscattering coefficient σ^0, and the presence of atmospheric duct makes electromagnetic wave propagation trajectory bending, resulting in the change of the grazing angle. The limit grazing angles of the 26th and 30th data can be calculated from formula, ΔM is defined as the difference of modified refractivity between duct bottom (surface for evaporation duct) and duct top, and then the limit grazing angle of the 26th is $\psi_{\lim}$ =0.0062997°, the 30th $\psi_{\lim}$ =0.0064693°is bigger than the 26th.

Because the grazing angle is equal to or greater than the limit grazing angle, it also shows that the grazing angle of the 30th as whole is bigger than the 26th. The relation of grazing angle and atmospheric duct can be indicated by curve. The curves (Fig. 6) of limit grazing angles $\psi_{\lim}$ and $\triangle M$ are shown by formula, and the limit grazing angle increased significantly with $\triangle M$.

From the relation of grazing angle and the scattering coefficient, it is shown that the greater the grazing angle, the greater the backscattering coefficient, and the stronger the sea clutter. This also proves that the sea clutter is stronger of the 30th than the 26th.

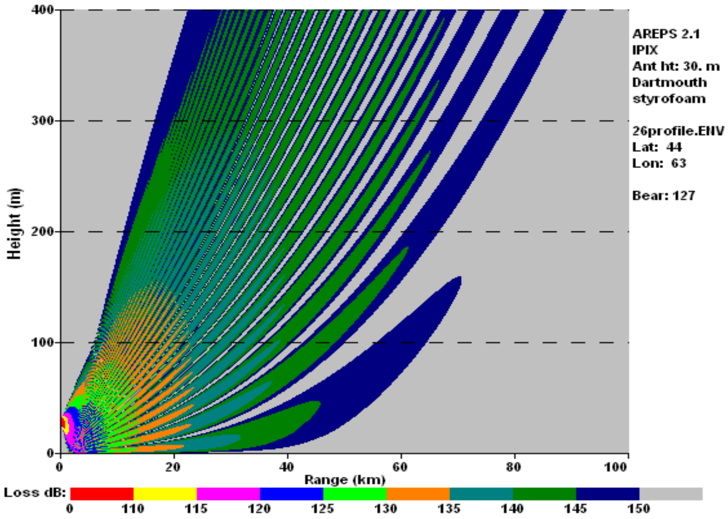
Of course, since the assumption is that there is no energy loss in the electromagnetic wave propagation, but in fact, the electromagnetic waves propagation in the atmosphere is attenuated with distance, whether the IPIX radar can receive to exceed sea clutter echoes is dependent on the electromagnetic wave propagation loss. The cause of the sea clutter characteristics is explained with the electromagnetic energy propagation loss under atmospheric duct as follows:

C. The Feature of Propagation Loss in the Experiment at Dartmouth

Electromagnetic wave's propagation loss in the 26th and the 30th has been modeled through operating AREPS [8] (Advanced Refractive Effect Prediction System), and the result is shown at Fig. 7. It shows the character of propagation loss in the 26th and the 30th. It is clear that electromagnetic wave energy is enough to become echo signals at the region ray can reach in both 26th and 30th, so two data include the echo signals exceeding 2775 m. Evaporation duct can influence electromagnetic wave and let it become "advanced distortion", the extent of "advanced distortion" depends on the evaporation duct height, electromagnetic wave becomes trap tracing if "distortion" arrives at critical status. In the 30th, the phenomenon is more obvious, which explains that propagation loss in the 30th is shorter than that in the 26th, and electromagnetic wave energy in the 30th is stronger than that in the 26th. So the sea clutter echoes amplitude in the 30th are bigger than that in the 26th, just as III obtain conclusion.

Fig. 8 shows the electromagnetic wave propagation loss changes with distance at 5 m, the x-axis is the distance on the ground, the y-axis is the propagation loss value; the area close to the origin is the radar blind. The distance is 27.2 km under standard atmospheric conditions, 39.1 km when duct height is 6.8 m of the 26th, and 60.8 km when duct height is 10.3 m of the 30th. It is shown that electromagnetic waves distance increases with duct height, also the propagation loss decreases with the duct height.

The attenuation factor A which decrypts the electromagnetic wave propagation loss, refers to the radar's transmit power and receive power ratio. The smaller the loss and value of factor A, the bigger the received power and the stronger the radar echoes. It is also proved that the sea clutter return signals are stronger when the electromagnetic energy is bigger overstep range in the 26th and 30th of Canadian Dartmouth experiment. The echo energy of the 30th is stronger than the 26th for its strong electromagnetic energy.



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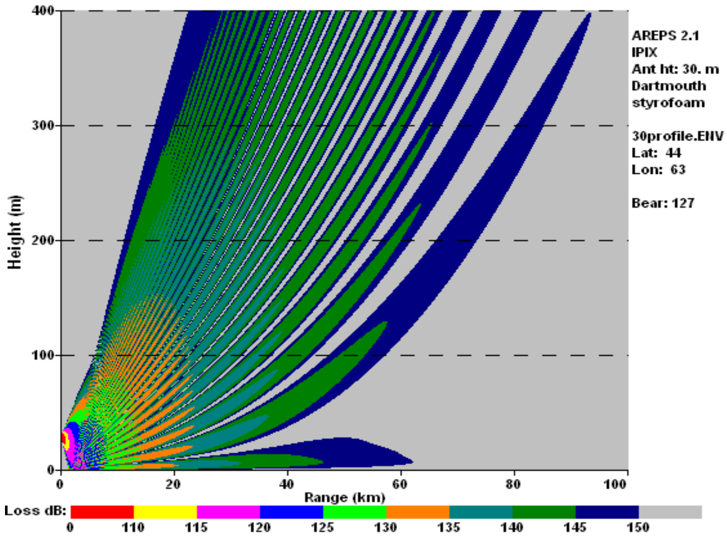
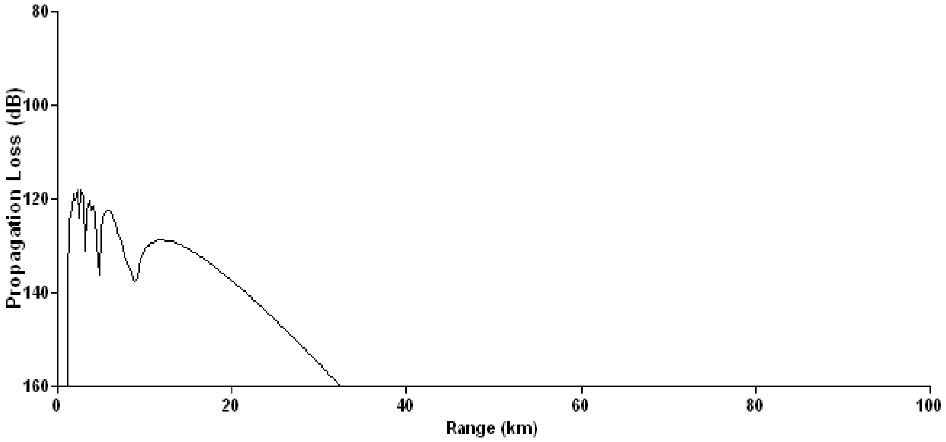


(b)

Fig. 7 The character of propagation loss in the experiment *at Dartmouth in the 26th and the 30th* (x axis is rang (km), y axis is height (m), color code is one way propagation loss PL (dB) a: the 26th, evaporation duct height is 6.8m; b: the 30th, evaporation duct height is 10.3 m)



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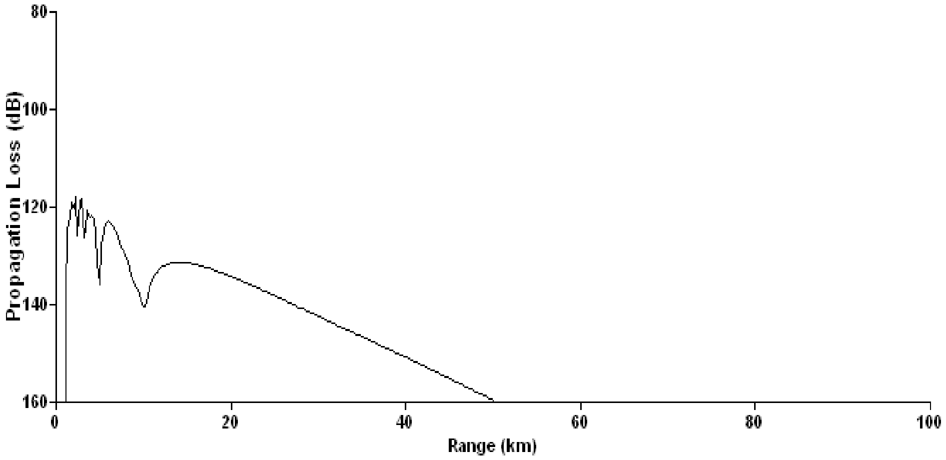

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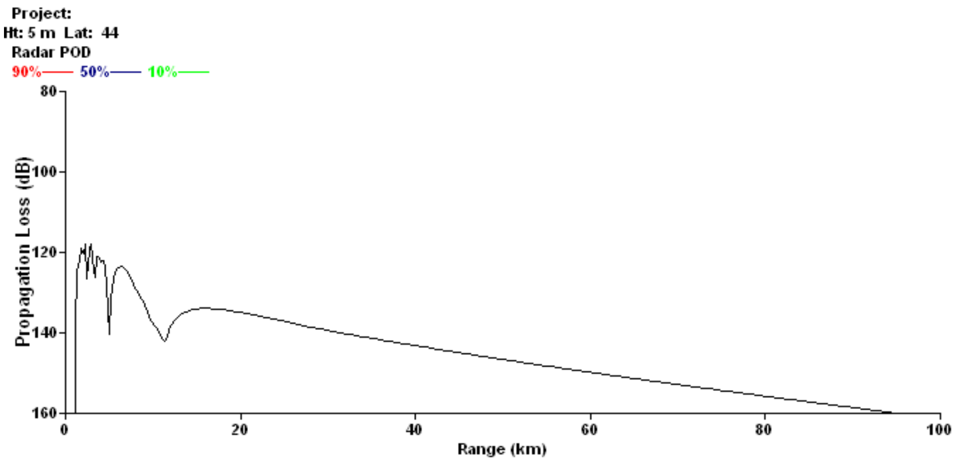

(c)

Fig. 8 The electromagnetic wave propagation loss changes with distance at 5 m (A: standard atmospheric; b: duct equal to 6.8 m of the 26th; c: duct equal to 10.3 m of the 30th)

V. DISCUSSIONS AND CONCLUSIONS

The paper lists the following discussions and conclusions:

1) There are evaporation duct phenomena in the environment of sea clutter experiment at Dartmouth, evaporation duct height is from 3.5 to 10.3 m, the phenomena affect sea clutter experiment.

2) The sea clutter strength feature: Sea clutter amplitude is stronger in the stronger evaporation duct (the 30th) than that in the weaker evaporation duct (the 26th); Through analyzing histogram plot, the sea clutter amplitude distribution tail is long in

the stronger evaporation duct, on the contrary, the sea clutter amplitude distribution spike is obvious.

3) The sea clutter power spectrum feature: Power spectral values of the weaker evaporation duct are higher than 300 Hz, while the stronger is symmetrical at all spectrum frequency components; the sea clutter characteristics of the stronger is more significant for its plenty frequency components and well-distribution. And then, the value of the stronger evaporation duct is relatively bigger.

4) The reason of sea clutter strength feature: The reason of sea clutter strength feature is studied by analyzing the character of electromagnetic wave propagating in the atmosphere. The results list: IPIX Radar's electromagnetic wave can reach farther area place than the scope of 14 ranges, so the radar can get radar echoes beyond the space of 14 ranges (2775 m), and sea clutter turns into mixed return signals. The farther region electromagnetic wave can reach, the stronger sea clutter radar echoes become, and sea clutter strength is larger too. In the stronger evaporation duct (the 30th), ray tracing is farther, the gazing angle is bigger and propagation loss is smaller, so the IPIX Radar can receive stronger radar echoes energy exceeding 2775 m, and sea clutter in the stronger evaporation duct is stronger than that in the weaker evaporation duct (the 26th). All in all, sea clutter strength of the 30th is bigger than that of the 26th.

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