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INTERPRETATION OF THE STATISTICS OF OCCURENCE OF ALOUETTE I EARTH ECHOES

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INTERPRETATION OF THE STATISTICS OF OCCURRENCE OF ALOUETTE I EARTH ECHOES

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Abstract—The strength of Earth echoes on Alouette I ionograms, tabulated in Alouette I booklets (ALOSYN), is used to produce contours of the percentage occurrence of Earth echoes on polar projection maps of the Earth. These maps can be used to show the relative noise level over much of the ocean area of the Earth. In general, a very low percentage occurrence of Earth echoes corresponds to regions of high radio noise level due to thunderstorm activity and to h.f. radio wave interference. An unusually low percentage occurrence of Earth echoes is observed over Greenland suggesting that the radio waves are absorbed in the thick ice sheet. An extremely high percentage occurrence of Earth echoes near the north magnetic dip pole can be explained by the collimating or focussing effect of field-aligned ionization irregularities in the ionosphere. There is some indication that sea is a better reflector of radio waves than land.

INTRODUCTION

The Alouette I satellite is in a circular polar orbit at a height of about 1000 km. It contains a sweep frequency h.f. ionospheric topside sounder, with sweep period of about 18 sec. Satellite transmissions below the upper frequency limit of 11·5 Mc/s and above f_0F2 (i.e. above the maximum frequency of the ordinary wave reflected from the ionosphere at vertical incidence) can penetrate the ionosphere, be reflected at the Earth's surface and subsequently can be received at the satellite. The resulting traces on the ionogram have been called "Earth echoes". Both ordinary and extraordinary wave Earth echoes are observed on the Alouette ionograms (see Fig. 1). The strength of the Earth echoes on the ionograms is represented in the Alouette I data booklets (1965) by the classifications 1, 2 and 3; 1 denotes strong, well-defined echoes (Fig. 1a), 2 denotes weak and intermittent echoes (Fig. 1b) and 3 denotes that no Earth echoes were observed on the ionogram (Fig. 1c). In this paper, maps are presented which show the percentage of ionograms with Earth echoes for periods near the September equinox, 1962 and the June solstice, 1963.

The presence or absence of Earth echoes on the Alouette I ionograms is governed by the following factors:

(1) directivity of the sounder transmissions
(2) radio noise level at the satellite
(3) reflectivity of the Earth's surface.

The directivity of the sounder transmissions is determined by the orientation of the antenna radiation pattern and by anisotropy in the plasma. The satellite spin period was about 43 sec in October, 1962 and 57 sec in July, 1963. Due to the spin, when the high frequency dipole is perpendicular to the surface of the earth, nulls in the pattern of the antenna might be directed downward periodically over a series of ionograms. On these occasions the possible number of ionograms with Earth echoes would be reduced by less than one half. However, by a statistical study using a large number of ionograms recorded on different occasions for a given area, the effect of orientation should be minimized. Anisotropy in the plasma can be caused by magnetic field-aligned ionization irregularities.

At low and mid magnetic latitudes the energy associated with Earth echoes propagates vertically, that is at a considerable angle to the direction of the magnetic field, and would probably not be seriously affected by the irregularities. At high latitudes the energy associated with Earth echoes propagates approximately along the magnetic field direction and can become trapped by the irregularities, thus causing a beaming or focussing of the radio energy in the direction of the magnetic field. This focussing could have considerable effect on the strength of Earth echoes at high latitudes.

The radio noise level at the satellite will be a combination of naturally generated noise, due mainly to lightning storms and to cosmic noise, and man-made noise or interference due to ground based h.f. transmissions at frequencies above f_0F2. The combination of natural and man-made noise will be referred to as "total noise". The level of total noise at the satellite can affect the reception of Earth echoes by decreasing their signal to noise ratio, by activating the receiver AGC or by causing intermodulation (Hartz, 1963) in the satellite receiver. These three possibilities cannot be entirely separated, but all can produce the same result: an absence of Earth echoes on the ionograms when the total noise level is high.

Information may be obtained on the total noise level at 1000 km if factors (1) and (3) above can be separated from (2) and conclusions may be drawn about the reflectivity of the Earth's surface if factors (1) and (2) above can be separated from (3). It has been seen above that in a statistical study (1) should not be a problem at low and mid latitudes; thus at these latitudes only factors (2) and (3) need be separated.

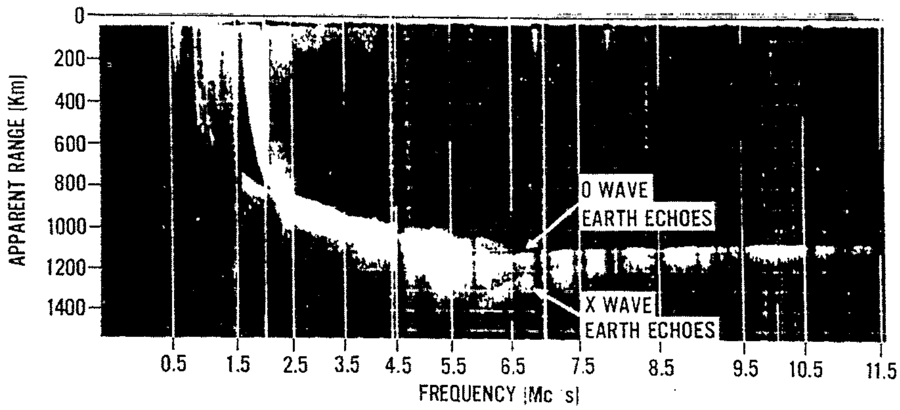
OBSERVATIONAL RESULTS

To produce maps which show the percentage of ionograms with Earth echoes, the Earth's surface was divided into zones of 10° of longitude and 10° of latitude. (Data extend up to 80·5°N latitude and hence the upper latitude zones include data from 70°N to 80·5°N latitude.) For each of these zones the percentage of ionograms showing Earth echoes of classifications 1 and 2 was calculated, and the calculated percentages are presented in Table 1 (fall equinox) and Table 2 (summer solstice). The number of ionograms used to calculate a particular percentage is given in brackets. If there were four ionograms or less in a particular zone, no percentage was calculated for that zone. The percentages in Tables 1 and 2 are used to draw percentage contours on the polar projection maps of Figs. 2 and 3 respectively. From the percentages (and utilizing the number of ionograms used to calculate the percentage to give subjective weight to the percentages) 10, 30, 50, 70 and 90 per cent contours were drawn on the maps.

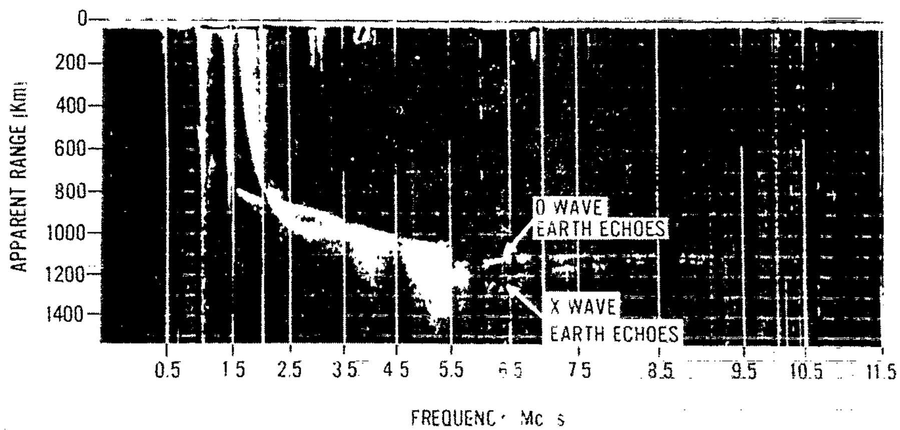
In the equatorial region values of f_0F2 can often be near or exceed the maximum frequency of the ionogram (11·5 Mc/s). Ionograms for which no ground echoes are observed because the f_0F2 is near or greater than the maximum frequency of the ionogram are tabulated in the ALOSYN booklets (1965) as classification 3. Since ground echoes might exist at frequencies greater than 11·5 Mc/s all the data with f_0F2 equal to or greater than 10·5 Mc/s were excluded.

Data for the period of September 29, to October 10, 1962 were used for Fig. 2. In Fig. 3 data for July 1 to July 10, 1963 were used for North and South America. However, in order to obtain sufficient data, records from July 1 to July 25, 1963 were used for the North Atlantic and European region (i.e., east of 50°W longitude and south of 70°N latitude as indicated by the dashed line in Fig. 3a), and data from June 17 to June 20 and July 1 to July 25, 1963 were used for the Australian region (Fig. 3b). Thus data from June 17 to July 25, 1963 are included in Fig. 3.

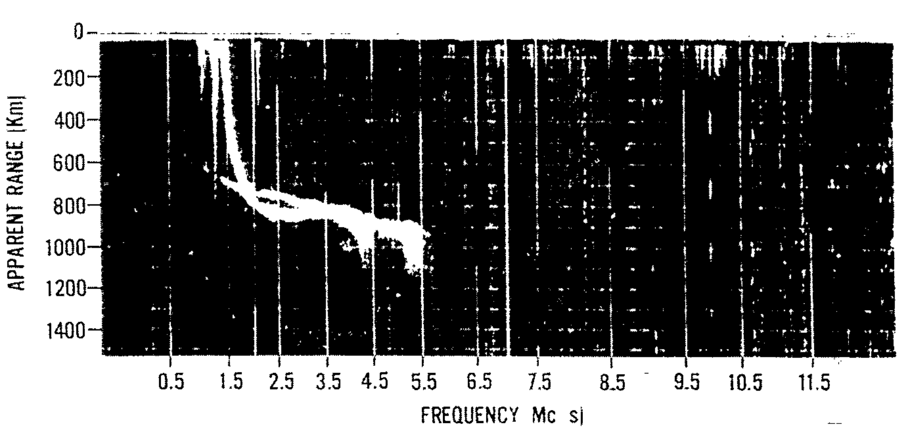
FIG. 1. IONOGRAMS RECORDED AT THE RESOLUTE BAY TELEMETRY STATION ILLUSTRATING THE THREE CLASSIFICATIONS OF EARTH ECHOES.



(a) Classification 1—July 2, 1963, 1226/37 GMT, 63.7°W long., 72.3°N lat., satellite height 1038 km.



(b) Classification 2—July 1, 1963, 0813/53 GMT, 53.9°W long., 80.5°N lat., satellite height 1035 km.



(c) Classification 3—July 2, 1963, 0514/40 GMT, ⁻⁻.1 W long., 69.4°N lat., satellite height 1029 km.

TABLE 1a. NORTH HEMISPHERE
Percentage of Earth echoes and number of ionograms (Fig. 2a)

	75°N	65°N	55°N	45°N	35°N	25°N	15°N	5°N
35°E	50(10)	0(5)						
25°E	40(10)	0(12)				0(6)		
15°E	18(22)	0(25)	9(22)	0(10)				
5°E	18(40)	3(39)	0(17)	0(14)	4(24)			
5°W	20(54)	23(44)	70(10)	10(20)	18(11)	17(18)		
15°W	23(56)	17(46)	41(29)	54(26)	36(22)	29(14)		
25°W	23(61)	17(52)	43(14)	47(15)				
35°W	2(61)	24(17)	52(27)	58(19)	50(5)			
45°W	21(39)	14(36)	27(30)	53(19)	53(17)			
55°W	49(65)	47(38)	30(40)	45(44)	26(27)	83(18)		0(7)
65°W	90(52)	41(34)	19(57)	12(34)	26(43)	21(39)	19(37)	20(46)
75°W	85(53)	63(24)	21(29)	8(25)	15(34)	11(36)	6(35)	3(40)
85°W	95(56)	78(36)	52(23)	24(49)	7(55)	25(53)	13(32)	8(59)
95°W	98(59)	77(52)	26(34)	41(46)	46(41)	65(23)	8(13)	12(35)
105°W	97(59)	84(49)	52(62)	60(52)	25(32)	33(15)		
115°W	96(70)	88(48)	45(20)	28(43)	100(10)	100(7)		
125°W	96(74)	49(53)	47(30)					
135°W	92(72)	73(44)	63(49)					
145°W	95(76)	51(47)	90(41)	86(7)				
155°W	92(76)	65(48)	85(34)					
165°W	92(63)	70(46)	88(26)	100(9)				
175°W	87(60)	56(34)	79(24)	90(10)				
175°E	85(48)	46(26)	60(5)					
165°E	67(15)							
125°E						17(6)	0(8)	0(9)

TABLE 1b. SOUTH HEMISPHERE
Percentage of Earth echoes and number of ionograms (Fig. 2b)

	75°S	65°S	55°S	45°S	35°S	25°S	15°S	5°S
25°W	0(5)							
35°W	36(11)	75(8)						
45°W	60(15)	60(10)	90(10)	29(7)				
55°W	92(24)	75(20)	85(26)	92(25)	55(29)	46(30)	0(17)	0(9)
65°W	14(14)	74(46)	94(32)	67(51)	37(63)	22(63)	2(50)	0(32)
75°W		65(17)	77(48)	56(50)	62(37)	42(33)	0(12)	0(16)
85°W		93(15)	82(17)	56(9)	79(24)	52(31)	30(30)	5(40)
95°W							0(6)	30(20)
155°E				53(15)	67(12)	62(13)		
145°E				83(12)	80(25)	68(22)	91(11)	
135°E				82(17)	70(23)	76(58)	42(19)	
125°E				89(27)	88(32)	68(28)	50(14)	

DISCUSSION

Two maps corresponding to different seasons were produced, rather than one, to determine whether certain observed features would be repeated on the two maps. The local time periods at latitudes below 70° were chosen to be similar for the two maps to eliminate local time effects; differences occurring between the maps may thus result from seasonal effects. It is found that, in general, the features of the maps agree; there are however some differences. The percentages of Earth echoes at latitudes greater than 60° in the south hemisphere and in the north hemisphere (east of Greenland) are lower in Fig. 2 than in Fig. 3. This probably indicates a higher noise level in the polar regions in October, 1962

TABLE 2a. NORTH HEMISPHERE
Percentage of Earth echoes and number of ionograms (Fig. 3a)

	75°N	65°N	55°N	45°N	35°N	25°N	15°N	5°N
55°E	57(7)							
45°E	60(15)							
35°E	64(14)	0(12)						
25°E	74(19)	0(29)	0(19)	0(8)	22(18)			
15°E	69(47)	3(34)	0(40)	3(30)	18(67)			
5°E	64(66)	7(54)	1(83)	2(49)	2(55)			
5°W	84(69)	32(57)	10(79)	8(76)	5(66)	25(8)		
15°W	91(78)	30(70)	56(25)	6(17)				
25°W	71(80)	55(73)	37(43)	71(49)	85(52)	67(21)		
35°W	30(94)	50(84)	44(103)	53(87)	71(45)	85(46)		
45°W	38(110)	49(93)	59(128)	49(43)	48(58)	76(17)		
55°W	71(112)	76(62)	48(63)	54(63)	70(56)			
65°W	91(117)	74(58)	61(41)	7(45)	41(41)	39(28)	33(21)	21(47)
75°W	95(117)	81(68)	21(57)	3(37)	0(6)	0(9)	0(13)	26(46)
85°W	93(114)	73(37)	33(51)	51(43)	19(47)	35(37)	24(58)	49(56)
95°W	96(91)	75(65)	56(50)	38(52)	29(38)	36(14)		
105°W	96(91)	71(73)	39(51)	38(48)	24(37)	52(21)		
115°W	97(104)	71(62)	37(70)	28(65)	59(17)	100(10)		
125°W	95(92)	69(68)	42(53)	20(5)				
135°W	93(108)	49(70)	60(57)					
145°W	84(104)	60(72)	78(71)	100(6)				
155°W	86(120)	51(77)	72(68)	70(10)				
165°W	80(108)	60(81)	73(66)	100(14)				
175°W	65(74)	47(73)	76(29)					
175°E	57(28)	26(34)						

TABLE 2b. SOUTH HEMISPHERE
Percentage of Earth echoes and number of ionograms (Fig. 3b)

	75°S	65°S	55°S	45°S	35°S	25°S	15°S	5°S
35°W			100(26)	100(40)				
45°W	100(19)	98(40)	98(40)	100(27)	92(13)			
55°W	95(19)	92(51)	100(38)	81(26)	48(21)	47(15)	33(18)	31(16)
65°W		92(49)	96(56)	88(43)	60(30)	42(58)	43(68)	36(61)
75°W		96(26)	85(48)	64(50)	70(61)	78(60)	28(43)	13(46)
85°W					77(13)	61(40)	58(45)	68(60)
155°E				100(8)	72(18)	72(18)	55(20)	
145°E				92(37)	88(60)	88(60)	77(47)	
135°E				95(37)	91(46)	91(46)	85(53)	
125°E				95(42)	91(56)	75(40)	47(34)	

than in July, 1963; the reason for this is not known. The percentages of Earth echoes at the equator are lower in Fig. 2 than in Fig. 3; this can be explained by thunderstorm activity (World Meteorological Organization, 1956). In September and October (Fig. 2), thunderstorm activity, and hence radio noise, is considerably higher near the equator in South America than it is in June and July (Fig. 3). In July there is an intense high in thunderstorm activity centered in Florida; this probably contributes to the extremely low percentages of Earth echoes observed in this region in July (Fig. 3).

Along the coast of Europe and the east coast of North America, percentage occurrence of ionograms with Earth echoes is quite low. This is very likely due to the high man-made noise level in these regions. The intense low along the east coast of North America in July is probably caused by a combination of thunderstorm activity and man-made noise.

Figures 2 and 3 have been compared with maps of "expected values of atmospheric radio noise" published in C.C.I.R. documents (1964). The gross features of Figs. 2 and 3, such as the low percentage occurrence of Earth echoes near the equator roughly coincide with the high noise regions on the CCIR maps. The CCIR maps do not depict detail; the maps are based mainly on data from sixteen stations throughout the world. There are only three stations in North America all located near 40°N latitude, one in Europe, and one located in Greenland for the whole Arctic region. The CCIR maps are intended to show only naturally generated noise, whereas the contours given here are affected by the presence of both natural and man-made noise. Because of the difference in the effective reflection coefficient of radio waves from the ocean and from various types of terrain, Figs. 2 and 3 cannot be used directly as total noise maps. However data obtained entirely over the ocean, where the reflectivity might be assumed to be constant, provide an indication of the relative amounts of total noise.

In the CCIR maps the noise level, for a given longitude, has in general a maximum near the equator and decreases with increasing latitude. From the data presented in Figs. 2 and 3 no definite conclusions concerning a latitude dependence of the noise level can be obtained.

In Figs. 2 and 3 the tendency is for the low percentage contours to be located overland, and the high percentage contours to be located over the sea. With the exception of one point in mid-Australia (Fig. 3), all the percentages on the maps greater than 90 per cent correspond to sea or coast regions. This observed location of the contours might be explained on the basis of radio noise since regions of higher noise level would be expected to exist over land than over sea. However the sharp rise in percentage occurrence of Earth echoes (see 35°N and 25°N at 115°W in Tables 1 and 2) along the Pacific coast of North America indicates that the low percentage contours over land is not due entirely to radio noise but possibly results from land being a poorer reflector of h.f. radio waves than sea.

One high percentage region is of particular interest; this is the region centered on the North magnetic dip pole (no data available for South magnetic dip pole). The percentage occurrence of Earth echoes falls off considerably to the west of this region. Radio noise would also be expected to fall off to the west of this region since it is further from populated areas. This indicates that lack of noise is not a likely explanation of the high percentage occurrence of Earth echoes near the dip pole. The Earth echoes return from vertically below the satellite in the vicinity of the dip pole and hence these echoes would propagate parallel (or very nearly parallel) to the Earth's magnetic field. The decreased spatial attenuation associated with propagation along field-aligned ionization irregularities (Muldrew. 1963) probably accounts for the high percentage occurrence of Earth echoes in the region.

A region of extremely low percentage occurrence of Earth echoes occurs over Greenland. In Fig. 2a, between 40°W and 50°W and between 70°N and 80·5°N, only one out of a total of sixty-one ionograms contained Earth echoes. In Fig. 3a, (see also Table 2a) Earth echoes were observed on 30 per cent of the ionograms (94) recorded between 30°W and 40°W and 70°N and 80·5°N whereas near the east and west coasts of Greenland, Earth echoes were observed on 91 per cent of the ionograms. Large increases in the percentage occurrence of Earth echoes occur within distances of a few hundred kilometers both on the east and west coasts of Greenland. Since the satellite is at a height of 1000 km the noise level would not be expected to change significantly in a distance of a few hundred kilometers. It is thus highly probable that the low percentage occurrence of Earth echoes over

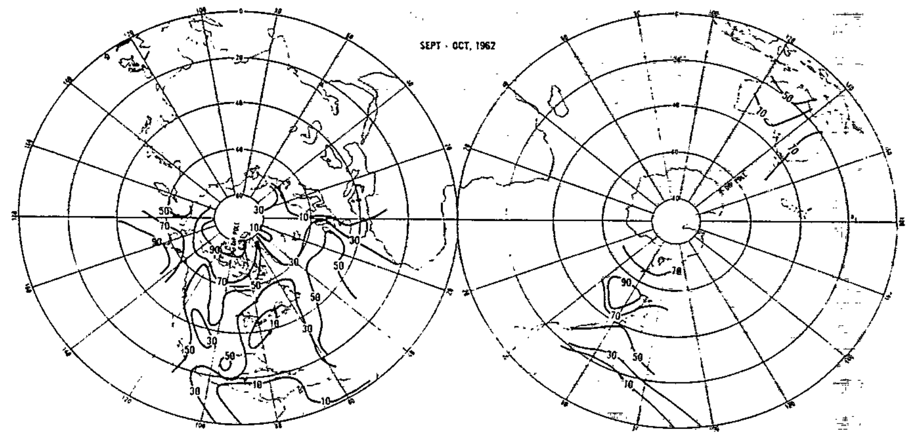


FIG. 2a. FIG. 2b.

FIG. 2. CONTOUR MAP OF PERCENTAGE OCCURRENCE OF EARTH ECHOES OBSERVED ON ALOUETTE I IONOGRAMS FROM DATA RECORDED BETWEEN SEPT. 29 AND OCT. 10, 1962.

(a) North Hemisphere
(b) South Hemisphere

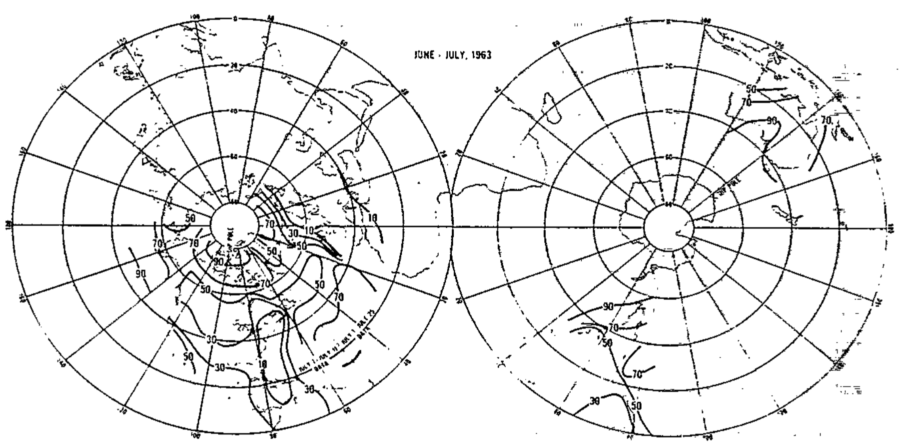


FIG. 3a. FIG. 3b.

FIG. 3. CONTOUR MAP OF PERCENTAGE OCCURRENCE OF EARTH ECHOES OBSERVED ON ALOUETTE I IONOGRAMS.

(a) North Hemisphere. Data west of 50°W and all data above 70°N recorded between July 1 and July 10, 1963. Data east of 50°W and south of 70°N recorded between July 1 and July 25, 1963.

(b) South Hemisphere. South America data recorded between July 1 and July 10, 1963. Australia data recorded between June 17 and June 20, 1963 and between July 1 and July 25, 1963.

Greenland is due to low reflectivity. Piggot and Barclay (1961), and Piggot (1961) using a vertical incidence sounder at Halley Bay, Antarctica found a ground reflection loss of 2 db and inferred from this that reflection actually occurred at the interface between the sea and the iceshelf rather than at the upper interface between the iceshelf and the air. At Halley Bay the iceshelf is about 150 m thick and over Greenland the ice is about 3 km thick. Thus the Alouette signals apparently penetrate the ice without significant reflection and because of the large thickness of ice the radio energy is probably almost entirely absorbed in its passage through the ice.

Over Australia the percentage occurrence of Earth echoes is quite high, relative to other land masses, indicating that this continent may be a good reflector of radio waves. This could be due to the desert conditions in the interior of the continent but strong Earth echoes might also be expected due to the lack of ground based interference, since the population is sparse in this region. Chai *et al.* (1965) calculated reflection coefficients of the Earth's surface from the Earth echoes near 9 Mc/s on twelve Alouette ionograms of which ten were recorded over Australia and two over sea. The general conclusion of their analysis was that the sea is a better reflector of radio waves than desert or forest. Because of the many unknown factors involved in their analysis such as equipment calibration, interference, size of the surface area involved, ionospheric effects and antenna position it is felt that a qualitative statistical approach such as taken here is more appropriate.

CONCLUSIONS

1. Contour maps of the type presented here could be produced from Alouette I data (1965) for various seasons, local times and sunspot numbers. Assuming h.f. reflectivity from the ocean surface is independent of location on the Earth, these maps could be used as a measure of the total noise level at a height of 1000 km at low and mid latitudes. If the noise level is high or low over a large area of the Earth at 1000 km, it would be expected to be high or low at ground level over this area. Regions in which exceptionally low occurrence of Earth echoes occur (e.g., Europe and the Atlantic seaboard in Figs. 2 and 3) indicate, independent of Earth reflectivity, regions of high total noise and hence these maps could be useful in determining the optimum location of h.f. communication receivers.

2. High percentages of Earth echoes are observed to occur at high northern dip latitudes. At high dip latitudes Earth reflected h.f. radio waves will propagate along or very nearly along the direction of the Earth's magnetic field. This high percentage of Earth echoes is probably due to the focussing into a beam of the h.f. radio waves transmitted through the ionosphere by means of ionization irregularities aligned along the Earth's magnetic field. This focussing or collimating effect along the Earth's magnetic field would likely exist during spread-*F* conditions. It is expected that this is of interest to radio astronomers using h.f.

3. The thick layer of ice covering Greenland is a good absorber of h.f. radio waves.

4. From Alouette I data there are some indications that the sea is a better reflector of h.f. radio waves than the land.

REFERENCES

Alouette I Ionospheric Data (ALOSYN) 1965. Defence Research Telecommunications Establishment, Ottawa, Canada.

Chai, R. C., Fung, A. K. and Moore, R. K. 1965. *J. Res. Natn. Bur. Stand.* **69D**, 641–649.

Hartz, T. R. 1963. Defence Research Telecommunications Establishment, Ottawa, Report No. 1123, October.

International Radio Consultative Committee (C.C.I.R.), (1964) *Documents of the Xth Plenary Assembly*, Report 322. International Telecommunications Union, Geneva.
MULDREW, D. B. 1963. *J. geophys. Res.* **68**, 5355–5370.
PIGGOTT, W. R. and BARCLAY, L. W. 1961. *J. atmos. terr. Phys.* **20**, 298–299.
PIGGOTT, W. R. 1961. *Proc. IRE* **49**, May.
World Meteorological Organization, World distribution of thunder storm days, (1956) Part 2, WMO/OMM-No. 21, TP. 21. Geneva, Switzerland.

Резюме—Сила земных эхо на ионограммах АЛУЭТТ I, табулированная в книжках АЛУЭТТ I (АЛОСИН), применяется для воспроизводства контуров процентного содержания явления земного эхо на полярных проекционных картах Земли. Этими картами можно пользоваться для указания относительного уровня шума над почти что всей площадью, занимаемой океанами Земли. Вообще говоря, лишь весьма небольшой процент явлений земных шумов соответствует областям с высоким уровнем радиошума, из-за активности гроз и помех высокочастотных радиоволн. Необычайно низкий процент явлений земных эхо наблюдается над Гренландией, повидимому по причине поглощения радиоволн толстым ледниковым покровом. Исключительно высокий процент явлениий земного эхо вблизи северного магнитного полюса, должно быть объясняется эффектом коллимации или же фокусировки выравненных полем неоднородностей ионизации в ионосфере. Есть некоторые основания предполагать, что радиошумы лучше отражаются морем, нежели сушей.

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