ANOMALIES IN IONOSONDE RECORDS DUE TO TRAVELLING IONOSPHERIC DISTURBANCES

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Summary

Anomalies which frequently appear on ionosonde records of the F region during the passage of travelling disturbances are classified into four main types; and the diurnal and seasonal distribution of their occurrence is discussed.

It is suggested that the type of anomaly appearing on records depends on the ion density distribution at a height of about 200 km, which appears to be an upper bounding surface for the mode of travel of disturbances.

A particular study has been made of winter disturbances. These are found to be so frequent that they affect all ionosonde records obtained during this season. They travel distances of at least 3000 km with fronts possibly broader than 1000 km. Attempted correlation with geomagnetic storminess was unsuccessful.

Information is also presented on similar disturbances observed in North America.

I. Introduction

The existence of disturbances travelling horizontally in the ionosphere has been established by various workers. Munro (1950, 1953) has studied them extensively on a fixed frequency of 5·8 Mc/s, using a three-station triangulation to determine speed and direction. In order to observe disturbances of ion density at different heights in the ionosphere a programme of $h'f$ recording was initiated at these laboratories during 1951 using a fast sweep panoramic type recorder previously described (Heisler 1955).

This recorder has been in daily operation at Camden (150° 40′ E., 34° 03′ S.) near Sydney from 0900 to 1400 hr local standard time scanning a frequency range of 1–15 Mc/s in 15 sec, the records being made at 1 min intervals. Their study soon revealed the existence of anomalies which, because of their transient nature, are usually unobserved on records taken at intervals of 10 min or more. They appear most obviously at frequencies near the F_1 and F_2 penetration frequencies. Simultaneous observations on a three-station system for detecting ionospheric movements (Munro 1950) have established that these transient irregularities are always manifestations of travelling ionospheric disturbances (T.I.D.'s).

$h'f$ disturbances in general are much greater in amplitude than those studied by the more sensitive fixed frequency techniques and are often so large that penetration occurs on the corresponding fixed frequency record, thus making

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determination of speeds and directions impossible. On the other hand, disturbances observed on fixed frequency records are often too small to be resolved satisfactorily on ionosonde records. However, there are many disturbances which show up simultaneously on both types of record; these cases leave little doubt that the disturbances normally observed on these records differ only in magnitude.

This paper presents information on the diurnal and seasonal distribution of occurrence of ionosonde anomalies observed at Sydney during the years 1952 to 1955. (Corresponding statistical data for the smaller disturbances observed

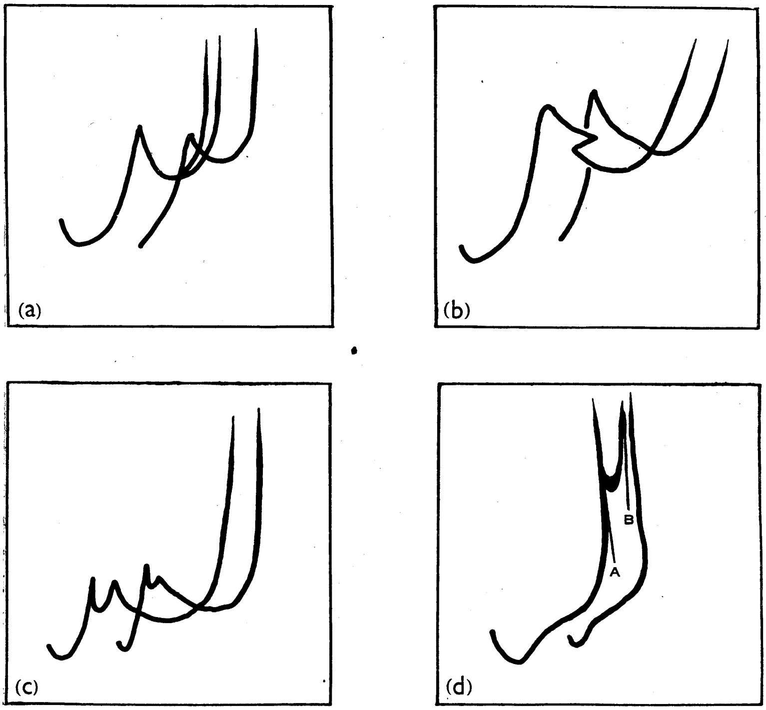

Fig. 1.—Types of anomalies on ionosonde records. (*a*) Type *A* anomaly, Camden, 1323 hr, October 25, 1954; (*b*) type *B* anomaly, Camden, 1032 hr, November 24, 1951; (*c*) type *C* anomaly, Camden, 1114 hr, September 25, 1953; (*d*) type *D* anomaly, Camden, 1001 hr, July 31, 1952.

on fixed frequency records are given in a paper by Munro (1958).) In some well-defined cases the amplitude too has been estimated. These show that the change in ion density during the passage of a disturbance is considerable. Analysis of records from all ionosonde stations in Australia indicated that the disturbances travel distances of at least 3000 km with fronts possibly broader than 1000 km.

Data obtained by G. H. Munro during a visit to America in June 1955 are also presented. These show that similar disturbances exist in the northern hemisphere travelling with directions and speeds different from the Australian counterparts.

II. Types of Anomalies

Ionosonde records taken at Camden during the years 1952–1955 have been examined and the anomalies observed have been grouped according to four main types. Figure 1 shows tracings of actual records in which these types are immediately evident, and they may be classified as follows:

(*a*) Type *A* or " split " type anomaly is marked by a distinct forking of the trace at F_2 penetration frequency. This is very similar to a " penetration frequency multiplet " in spread-*F* phenomena described by Singleton (1957).

(*b*) Type *B* or " *Z* " type anomaly has a fold in the F_2 trace forming a shape like the letter " Z ".

(*c*) Type *C* or " double peak " anomaly occurs in the F_1 trace as a cusp-shaped irregularity forming two distinct F_1 peaks.

(*d*) Type *D* or " cusp " anomaly appears as a cusp-shaped trace near F_2 penetration frequency.

Type *A* and *B* irregularities have already been explained by Munro (1953) as being due to complex reflections from curved isoionic surfaces in the ionosphere during the passage of a travelling disturbance. In these cases, only a reduction of ion density was evident, the ion density contours producing the complexities being curved concave upwards.

Types *C* and *D* are the cusp anomalies described by Munro and Heisler (1956). Type *C* occurs as a complexity in the F_1 layer, while type *D* occurs in the F_2 layer. Here a disturbance introduces an initial ion density reduction closely followed by an increase in ionization which produces closed contours or " islands " of higher ionization density. The cusp-shaped irregularities are due to non-vertical reflection of ionosonde transmissions from these islands.

III. Seasonal Distribution of Anomalies

In order to obtain an accurate representation of the seasonal distribution of anomalies, the total number of each type occurring during each month of the years 1952–1955 was divided by the total number of recording hours in that month to give a mean hourly rate of occurrence. Figure 2 shows the seasonal distribution and the total number of recording hours each month for the various types of irregularities. It is apparent that type *B* and *D* anomalies are typical summer and winter phenomena respectively, while type *C* is equinoxial. Type *A* appears to have a random distribution throughout the year.

IV. Disturbance Anomalies in Various Ion Density Distributions

The average seasonal ion density distributions at Camden on which these irregularities appear differ markedly from one another; these are shown in Figures 3, 4, and 5.

The type *D* anomaly occurs on the winter distribution shown in Figure 3, the lower trace on the diagram being the true height distribution of ion density determined by a method due to Kelso (1952). There is no definite F_1 layer and a true F_1 penetration does not occur. The height of maximum ion density is approximately 200 km.

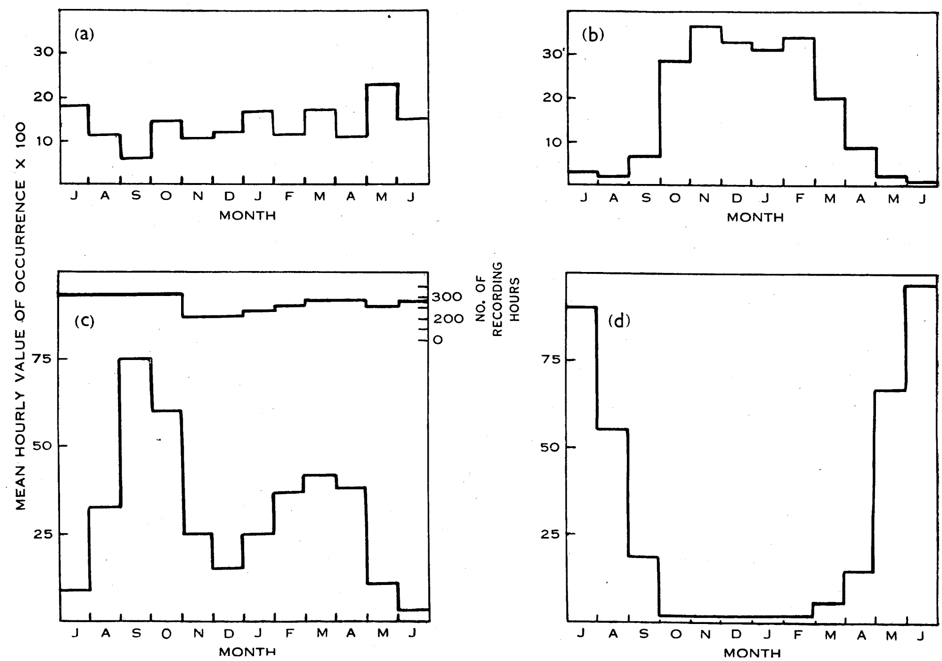

Fig. 2.—Mean hourly rate of occurrence of anomalies each month, July 1952–June 1955. (*a*) Type *A* anomaly; (*b*) type *B* anomaly; (*c*) type *C* anomaly; (*d*) type *D* anomaly.

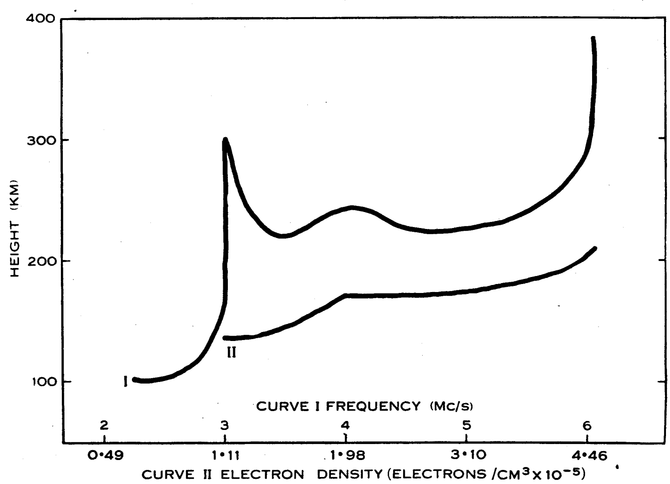

Fig. 3.—Typical ionosonde record (curve I) and true height distribution (curve II) before advent of a type *D* anomaly. Camden, 1015 hr, June 25, 1953.

Both virtual and true height equinoxial distributions appear in Figure 4. Here F_1 penetration occurs and a definite maximum value of F_1 electron density exists. Most of the F_2 layer is above 200 km in height with a maximum ion density at approximately 250 km. Type *C* anomalies appear in the F_1 trace of this distribution but are not seen at greater heights.

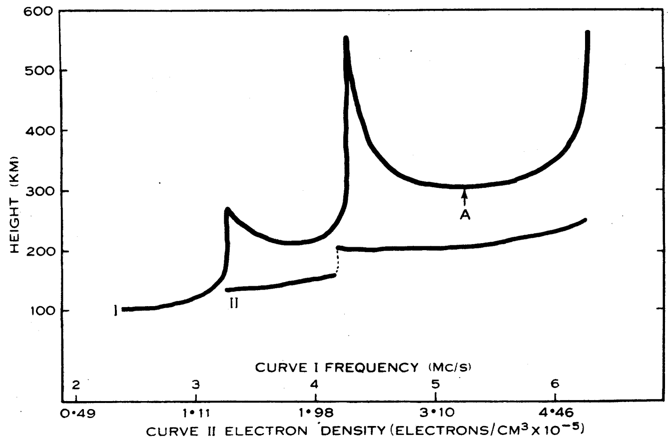

Fig. 4.—Typical ionosonde record (curve I) and true height distribution (curve II) before advent of a type *C* anomaly. Camden, 1148 hr, September 18, 1954.

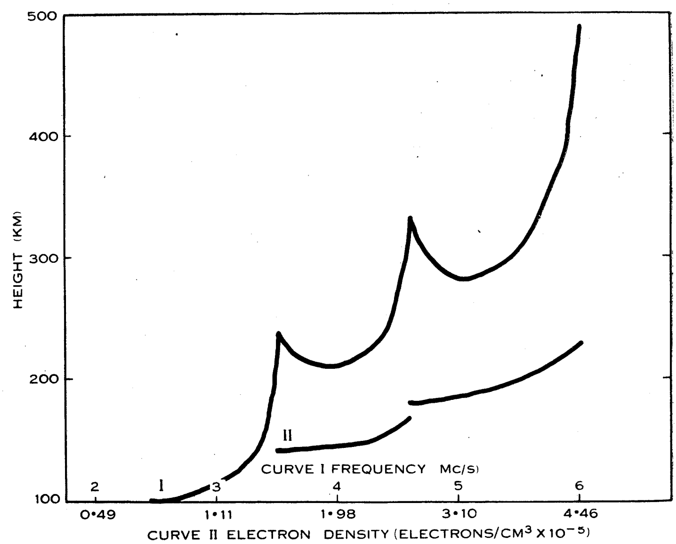

Fig. 5.—Typical ionosonde record (curve I) and true height distribution (curve II) before advent of a type *B* anomaly. Camden, 1216 hr, October 10, 1954.

Early in October the typical summer distribution develops as represented by Figure 5. This is associated with a sudden change in direction of travel of disturbances as described by Munro (1950). In this case the F_2 layer has a much greater semi-thickness than formerly, and its maximum again occurs at approximately 250 km. The type *B* anomalies which arise in this distribution rarely occur near the F_2 maximum, and they originate at an approximate height of 200 km on the F_2 trace.

There is a possibility therefore that all disturbances are contained by an upper boundary near 200 km and do not often occur above this height. The normal seasonal change in ionization height-distribution would therefore determine the type of irregularities observed. This would also explain why these are rarely seen on night records when the whole of the *F* region is well above 200 km. Further research is being undertaken at this laboratory to study this possibility.

Munro (1953) has indicated that complexities on ionosonde records due to travelling disturbance manifestations are more evident in a region where ion density changes slowly with height. This is obvious in Figure 1 where in all cases shown the complexity occurs on a steep portion of the *h'f* trace.

When a travelling disturbance affects regions where there is a rapid rate of change of ion density with height, as indicated at *A* in Figure 4, there may be no resulting complexity but only a small height change in the trace, probably too small to detect.

Figures 2 (*a*), 2 (*b*), 2 (*c*), and 2 (*d*) also illustrate the high frequency of occurrence of disturbances. For example, disturbances responsible for type *D* anomalies during June occur at the approximate rate of one per hour, and since their duration may be as long as 30 min, records are invariably abnormal during this month.

V. Diurnal Distribution of Anomalies

Figures 6 (*a*), 6 (*b*), 6 (*c*), and 6 (*d*) show the diurnal distribution of anomalies for the years 1952–1955. Type *A* irregularities have a broad maximum during the morning hours, while type *B* have a broad midday maximum. Type *C* anomalies show a marked increase after midday, but unfortunately in this case recording hours have been insufficient to show the time of maximum. Type *D* anomalies show a small broad maximum in the morning hours.

VI. Amplitude of Disturbances

The type *D* or cusp type anomaly is the most prominent of those discussed above. It is always readily recognizable on records, and during the winter, as already mentioned, it occurs frequently. For this reason it has been chosen as the most suitable type for study at this laboratory.

Figure 1 (*d*) shows this anomaly soon after its first appearance on a series of ionosonde records. The penetration frequency f_A at *A* represents the value N_A to which the ion density has fallen during the initial phase of the disturbance. As the disturbance progresses, the penetration frequency f_B of the cusp as measured at *B* increases, and its maximum value represents the maximum ion density N_B due to the disturbance.

$N_B - N_A$ is a measure of the total ion density change, and, if we assume that the disturbance is sinusoidal in form as suggested by Munro and Heisler (1956), then the percentage amplitude is given by

$$\{(N_B - N_A)/(N_B + N_A)\} \times 100 \text{ or } \{(f_B^2 - f_A^2)/(f_B^2 + f_A^2)\} \times 100.$$

Table 1 shows a number of amplitude values for various disturbances. Some of these amplitudes are quite large, representing as much as 36 per cent. total change in maximum ion density of the F_2 layer.

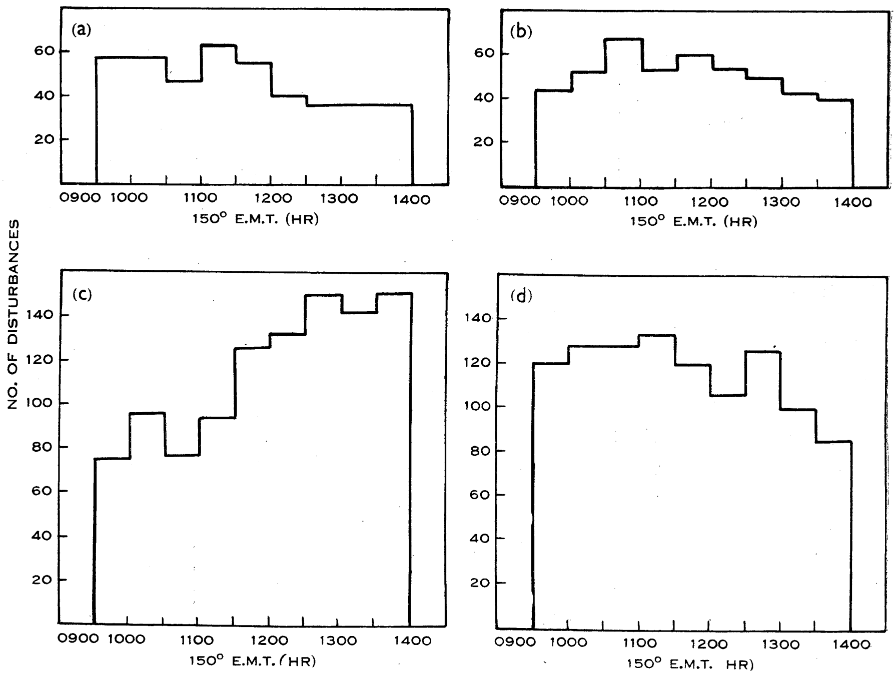

Fig. 6.—Diurnal distribution of anomalies, July 1952–June 1955. (*a*) Type *A*; (*b*) type *B*; (*c*) type *C*; (*d*) type *D*.

VII. Extent of Disturbances

Munro (1950) discusses a travelling disturbance of this type which occurred on July 5, 1948, appearing successively on records at Canberra (35° 18′ S., 149° E.), Sydney (33° 52′ S., 151° 11′ E.), and Brisbane (27° 30′ S., 153° E.). A method of triangulation described in the same paper showed the direction of travel and apparent horizontal speed of this disturbance to be 2° east of north and 10 km/min respectively. This, therefore, was an example of a disturbance travelling horizontally at least 900 km without any definite change in form or velocity.

The large amplitude of type *D* anomalies discussed above suggested that the extent of these disturbances may be even greater. Consequently, with the kind cooperation of the Ionospheric Prediction Service of the Department of the Interior and of the Bureau of Mineral Resources, Geology and Geophysics of the Department of National Development, a programme of continuous $h'f$ recordings was arranged for a fortnight during the month of July in 1954, 1955, and 1956. This programme operated at the following stations: Hobart (42° 53′ S., 147° 51′ E.), Canberra (35° 18′ S., 149° E.), Brisbane (27° 30′ S., 153° E.), Townsville (19° 10′ S., 146° 58′ E.), and Watheroo (30° 18′ S., 115° 56·6′ E.). By courtesy of the New Zealand Department of Scientific and Industrial Research a few records were also obtained from Christchurch (43° 30′ S., 172° 30′ E.).

TABLE 1

AMPLITUDES OF TYPE D DISTURBANCES AT CAMDEN

Date	Time	Minimum f^0F_2 (Mc/s)	Maximum Cusp Penetration Frequency (Mc/s)	Amplitude Ion Density Change (%)
6.vi.53	1044	4·7	5·5	15
10.vi.53	1045	4·9	5·4	10
12.vi.53	1145	5·25	5·75	9
15.vi.53	1123	5·25	5·75	9
16.vi.53	1123	5·1	5·75	12
	1315	5·7	6·5	13
17.vi.53	1241	4·6	5·2	12
19.vi.53	1200	5·0	6·0	18
22.vi.53	1133	5·4	6·0	10
27.vi.53	1228	5·4	6·1	12
28.vi.53	1227	5·4	6·25	14
	1309	5·6	6·25	11
3.vii.53	1108	4·6	5·5	18
	1130	5·3	6·0	12
10.vii.53	0942	4·9	5·25	7
	1132	5·6	6·25	11
16.vii.53	1251	5·0	5·5	9

From a comparison of Canberra, Sydney, and Brisbane records it immediately became obvious that disturbances seen at Canberra appeared at Sydney and Brisbane also, but at different times. Great circle distances and bearings were used to prepare a gnomonic chart of all Australian stations with Canberra as centre; and, assuming that the front of a disturbance was a great circle segment, or a straight line on the chart, it was possible by triangulation of Canberra, Sydney, and Brisbane to obtain directions and speeds of disturbances. Expected times of arrival at Townsville and times of appearance at Hobart were then determined for a large number of disturbances. Examples are shown in Table 2. The time quoted in parentheses is the estimated time of arrival in each case. It can be seen that estimated times and actual times of arrival of a disturbance correspond very closely, and this provides definite evidence of disturbances travelling from Hobart to Townsville, a distance of 3000 km. Moreover, the amplitude of a large disturbance occurring on July 18, 1955 is approximately

18 per cent. at Hobart, Sydney, and Townsville, which implies that for large disturbances at least there is little change in amplitude over the distance travelled.

The stations listed in the table lie approximately in a south-north line, which is the general direction of travel of disturbances in this hemisphere. Distortion of the distance scale on the gnomonic chart in the area considered is very small, and the scale is almost linear in the region bounded by longitudes

TABLE 2

TIME OF ARRIVAL OF DISTURBANCES AT STATIONS AND THEIR ESTIMATED SPEEDS AND DIRECTIONS

All times are 150° E.M.T.

Date	Hobart	Canberra	Sydney	Brisbane	Townsville	Speed (km/min)	Direction (°E. of N.)
14.vii.54 ..	1048 (1048)	1220	1247	1425	*	7·8	7
16.vii.54 ..	1006 (1006)	1152	1215	1346	1600 (1605)	8·4	23
19.vii.54 ..	1152 (1144)	1246	1303	1358	*	11·6	50
21.vii.54 ..	1018 (1024)	1202	1215	1342	1538 (1540)	8·2	350
16.vii.55 ..	† (0834)	1026	1044	1220	1426 (1426)	7·4	356
18.vii.55 ..	1056 (1056)	1242	1258	1424	1534 (1534)	9·0	10
21.vii.55 ..	0922 (0922)	1114	1135	1310	1502 (1502)	7·6	4
	1038 (1038)	1220	1234	1354	1540 (1540)	8·8	353
24.vii.55 ..	1025 (1025)	1124	1135	1234	1339 (1339)	12·4	2
	0917 (0917)	1128	1150	1344	1615 (1615)	5·8	358
25.vii.55 ..	0934 (0934)	1054	1114	1230	1310 (1310)	9·8	30
	1028 (1028)	1134	1155	1314	1342 (1342)	10·2	36

* No record available.

† Ten-minute records only available.

135° E. to 165° E. and latitudes 15° S. to 45° S. Outside this region the scale distortion becomes considerable, and an extension of the triangulation method analysis to include Watheroo and Christchurch is difficult, particularly when there is doubt as to the shape of the disturbance front.

However, the disturbance of July 19, 1954 which passes through Hobart and Brisbane and travels in a direction 50° east of north must have a broad front. On the gnomonic chart this distance is given by the projection of the Hobart-Brisbane line on the disturbance front drawn through Hobart and is approximately 700 km. This represents the minimum extent of the front, the actual frontal length being probably much greater. A similar disturbance of July 25, 1955, travelling 30° east of north and passing through Hobart and Townsville, has a front of at least 1000 km. In the cases considered disturbance fronts are approximately segments of a great circle.

There are indications that the front of some very large disturbances may be several thousand kilometres and it is intended to investigate this further by means of additional ionosondes placed in an east-west line.

Two disturbances occurring on July 24, 1955 provide an interesting example. These disturbances, travelling in approximately the same direction, almost due north, left Hobart at different times with markedly different speeds. Just before reaching Canberra they crossed over in space but maintained their separate identities to arrive later at Sydney, Brisbane, and Townsville. This means that, two disturbances existing simultaneously in the same medium were travelling at different speeds.

TABLE 3

TIME OF ARRIVAL OF DISTURBANCES AT STATIONS AND THEIR ESTIMATED SPEEDS AND DIRECTIONS

All times are 75° W.M.T.

Date	Ottawa	Morgantown	Derwood	Charlottes-ville	Speed (km/min)	Direction (°E. of N.)
18.i.51	(1012)	1012	1055	1047	5·2	117
	0730 (0742)	1033	1123	1142	2·7	160
	(0630)	1130	1215	1241	2·0	176
	1030	1313	1321	(1353)	4·5	184
28.i.51	0717 (0715)	0842	0913	0921	5·4	160
	(0616)	1127	1211	1233	2·0	180
	0800	1226	1313	(1325)	2·5	174

During a visit to America in June 1955 G. H. Munro found type *D* anomalies, similar to those discussed above, on northern hemisphere winter ionosonde records. With the kind permission of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington and the Canadian Defence Research Laboratories, records from Morgantown (37° 7′ N., 79° 9′ W.), Derwood (39° 1′ N., 77° 2′ W.), Charlottesville (38° 1′ N., 78° 5′ W.), and Ottawa (45° 20′ N., 75° 43′ W.) were analysed, and from three stations speed and direction of travel of disturbances were determined by triangulation methods. Expected time of arrival at the fourth station was then estimated and the results are presented in Table 3. The time quoted in parentheses is the estimated time of arrival of a disturbance. In some cases the estimated time and actual time of arrival correspond very closely. Here again the disturbances are large-scale phenomena, but directions and speeds of travel differ from those observed during the southern hemisphere winter at Sydney. They travel south instead of north, and more slowly.

VIII. Correlation with Magnetic Phenomena

Attempts have been made to correlate occurrence of type *D* anomalies with magnetic storm data. Comparisons were made between magnetograms and ionosonde records from Watheroo and no correlation was found between disturbed magnetic records and occurrence of travelling ionospheric disturbances. The extent of these disturbances and the fact that they originate well to the south of Hobart suggested a possible correlation between disturbed days and auroral effects. Here again no correlation was found. Magnetogram records from Macquarie Island (54° 30·2′ S., 158° 57′ E.) also showed no relationship to disturbed days.

IX. Conclusions

Ionosonde records taken at Sydney during the years 1952–1955 show transient anomalies that are the result of horizontally travelling disturbances in the ionosphere. These irregularities may be classified into four different types. One of these is random in occurrence, but the other three show definite maxima of occurrence during the winter, summer, and equinoxial periods respectively.

Study of typical true-height ion density distributions for these periods suggests the existence of a possible upper boundary to disturbances in the region of 200 km, and that the position and shape of the distribution with respect to this height determines the type of irregularity on ionosonde records. This study is being continued.

Amplitude of disturbances, in particular of those occurring during winter, is very large, and ion density changes of the order of 30 per cent. are not uncommon.

Disturbances have been shown to travel large distances with wide fronts. Many disturbances travel from Hobart to Townsville, a distance of 3000 km, with no apparent change in amplitude and have fronts of at least 1000 km. It is intended by the use of additional ionosondes to investigate further the shape and extent of disturbance fronts.

Occurrence of disturbances is quite frequent. Equinoxial and winter types occur approximately at the rate of one each hour. Summer disturbances occur at the average rate of one every two and a half hours; but many summer disturbances are probably not seen on records due to E_s blanketing, and it is possible that the frequency of occurrence is much higher than this. Since the duration of disturbances may be as long as 30 min, the ionosphere is almost continuously affected by them. During winter frequent increases in F_2 maximum occur because of disturbances which due to their large extent probably make maximum usable frequencies over any particular circuit higher than the predicted value.

X. Acknowledgments

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