*IONOSPHERIC NETWORK ADVISORY GROUP (INAG)**

*INAG BULLETIN NO. 42***

An Atlas of Ionograms

A reference collection of ionograms from high latitude observatories

Compiled by A S Besprozvannaya and T I Shchuka

* Under the auspices of Commission G, working group G1 of the International Union of Radio Science (URSI).

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1. INTRODUCTION TO THE ATLAS

by A S Rodger, S M Broom and R W Smith

The Atlas of Ionograms compiled by A S Besprozvannaya and T I Shchuka of the Ionogram Reduction Group at the Geophysical Department of the Arctic and Antarctic Research Institute, Leningrad, USSR forms the entire INAG Bulletin. This Atlas should form a very valuable reference manual for those involved in ionogram interpretation and for scientists who used ionogram data in their research.

A few minor modifications to the original script have been made to make the scaling procedures more in accord with those recommended in the Handbooks of Ionogram Interpretation and Reduction and that used in the INAG Bulletins. A fuller discussion of the differences between the practices in the USSR and the standard INAG recommendations has been given in INAG 35 pp 3-6. Since most groups have not taken advantage of the simplications made at Washington (eg.,the combining of Es-r and Es-k) the examples have been modified to be consistent with the original practise.

There is an additional local rule regarding the scaling of range spread-F adopted in the USSR. Range spread-F is divided into two groups, unresolved range spread-F, Q, and resolved range spread-F,Q1,with trough-ridge traces being incorporated into the latter group. The differences in these patterns results from the size of the reflecting structures. Structures with small horizontal size give unresolved range spread-F, medium scale features give resolved range spread-F and large structures give trough-ridge sequences. The two main features which comprise a trough-ridge structure are very different whereas those which form medium and small scale structure are much more similar in shape (see UAG-23A, Fig. 2.15 and 2.22). However, in the text we have kept the USSR interpretation but request the views of other groups on whether range spread-F should be comprised of one, two or three types (i.e., all range spread-F one group; Q and Q1 as given in this Atlas or resolved range spread-F, unresolved range spread-F and trough-ridge sequences).

We have also added a few additional comments to clarify why specific scalings have been adopted, or to provide further explanation of the ionogram sequences.

Ionograms from several observatories are used in this Atlas. The table below lists these stations together with their geophysical location.

	Geographic		Geomagnetic		L-shell
	lat	long east	lat	long east	
DIXON	74	80	63	162	6.9
HEISS	81	58	71	156	14.1
MIRNY	-66	93	-77	148	20.8
MOSCOW	55	37	51	121	2.5
NARSSARSUAK	61	315	71	37	7.1
NORTH POLE-8	80	165	70	205	13
TIKSI	72	129	60	192	5.6
VOSTOK	-78	107	-89	94	72

One further, more conventional, INAG Bulletin should be produced before the URSI General Assembly in Florence. However, there is still a great shortage of station notes, ionogram sequences, articles of historical or scientific interest. Please send your contributions to the Secretary as soon as you can.

2. AN ATLAS OF IONOGRAMS

by A S Besprozvannaya and T I Shchuka

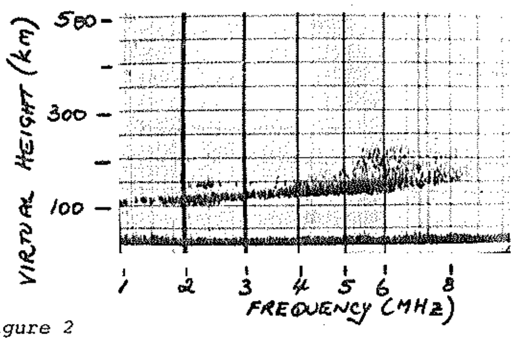
This Atlas has been prepared as a reference-book to be used for scaling and interpretation of high-latitude ionograms which reflect the specific polar ionosphere conditions. The Atlas has been compiled with the two objectives in mind: to help in the correct identification of the observed events and to facilitate making their scaling identical using the existing URSI rules and procedures.

The Atlas contains examples of ionograms corresponding to different station positions with respect to the main ionospheric trough and particle precipitation responsible for discrete and diffuse aurorae. The complexity in determining the parameters of high latitude sporadic ionization in the E region and their interpretation and reduction of spread traces in F region are dealt in greater detail.

The Atlas has been prepared in the Geophysical Department of the Arctic and Antarctic Research Institute, Leningrad, USSR, in accordance with the INAG recommendation to prepare reference material for training the operators of high-latitude ionospheric stations. The ionogram reduction has been carried out in accordance with the URSI Handbook with consideration of modifications and additions adopted at the Soviet National Workshops devoted to the ionogram interpretation and reduction.

The Atlas is primarily addressed to those concerned with the reduction of vertical sounding ionograms and to scientists who make use of ionospheric data in their research.

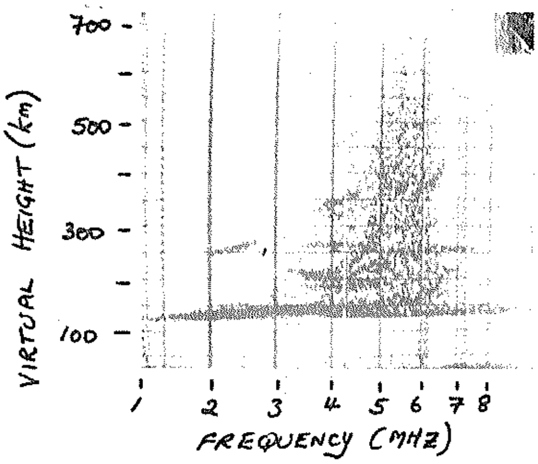
Figure 1 - An example of auroral Es (Es-a)



Dixon 1970 10 July 0300LT (105°E)

foE	foEs	fbEs	h'Es	Es type
A	076JA	076AA	105	a1

Figure 2

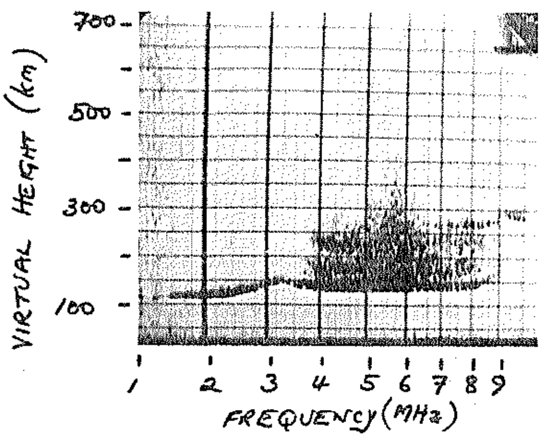


Dixon 1970 2 January 2015LT (105°E)

foEs	fbEs	h'Es	Es type
080JA	030-K	125	a2k2

Comment: This night-time ionogram shows a weak F-region trace with h'F at 200 km and foF2 at about 5.2 MHz. This is a relatively rare example of Es-a traces superposed on Es-k. Note the retardation on the second order Es-k trace and the low-frequency end of the F-trace.

Figure 3

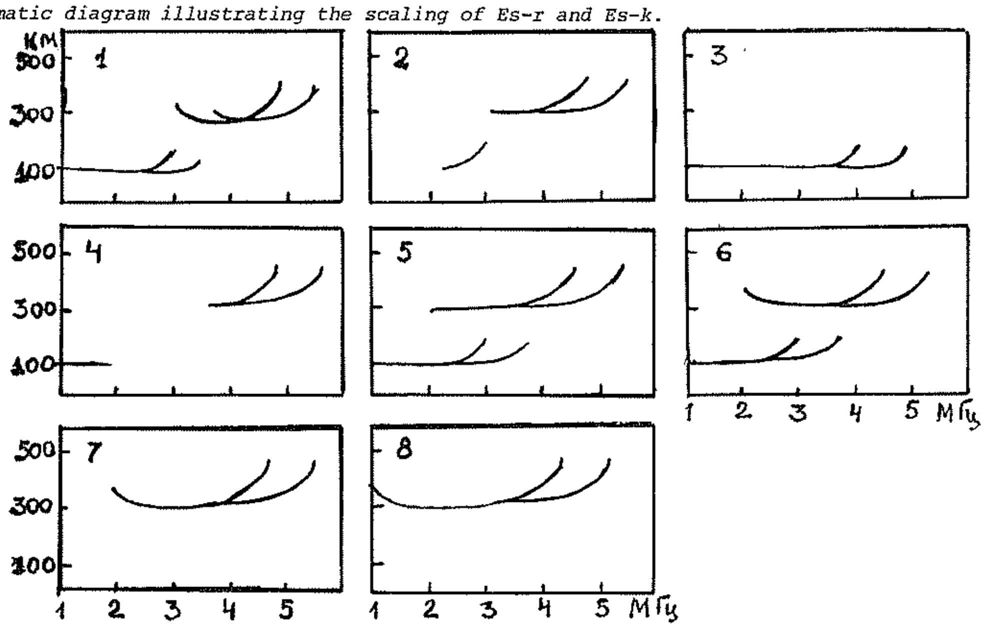


Dixon 1970 29 July 1715LT (105°E)

foE	foEs	fbEs	h'Es	Es type
350UA	082JA	082AA	130	a1

Comment: There is a small turn up at the high frequency end of the Es-a trace. In principle, this could be scaled as Es-r but Es-a was chosen as it provides a more accurate description of the entire Es trace, and indicates the considerable spreading present.

Figure 4 Schematic diagram illustrating the scaling of Es-r and Es-k.



	Tabulation			f plot symbol	
	foEs	fbEs	type Es	fbEs	type Es
1	030-K	030-K	k1	-o-	o
2	030-Y	030-Y	r1	-●-	●
3	040-K	040AK	k1	-●-	o
4	Y	Y	k1	Y	●
5	030	020	r1	-●-	o
6	030	020-K	r1	-o-	o
7	020EB	020EK	-	-	-
8	010EE	010EK	-	-	-

Comment: Each Es trace at 100 km is assumed to be a reflection from an Es layer.

Example 2: This pattern of traces is quite unusual. Although there is a turn up at the high-frequency end of the Es-trace, there is no corresponding turn down at the low frequency end of the F-trace which begins at foEs. This indicates that a significant tilt must be present in either the Es or F layers or indeed both. The descriptive letter Y on foEs and fbEs has been used to show the presence of this tilt. Under these circumstances, distinction between Es-k and Es-r is not possible (this illustrates one reason why combining k and r types was allowed at Washington). The choice of Es type should be made using the sequence of ionograms or the second order traces if there are any present.

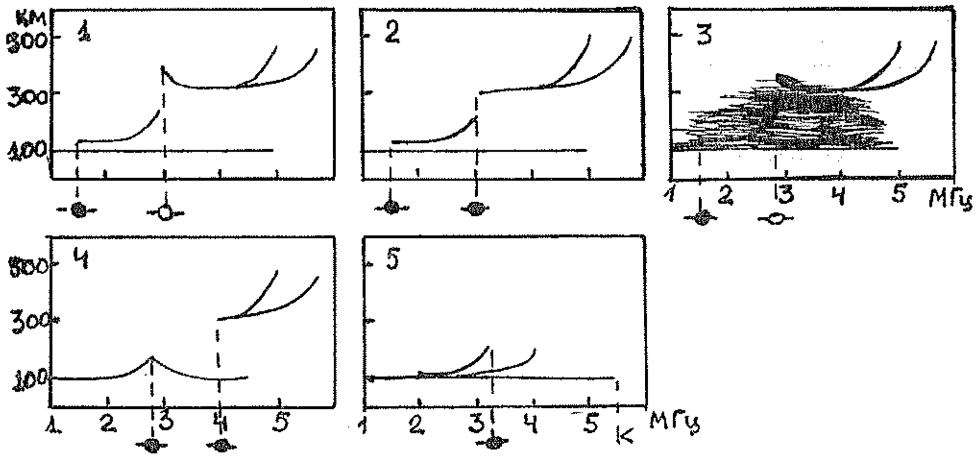
Example 3: This is another occasion when it is difficult to decide whether to scale as Es-r or Es-k. The presence of an x-mode trace often indicates Es-k is more likely. Second order traces can also be helpful. If this is seen up to a frequency close to foEs, then Es-k is scaled. However, if the second order extends over the lower frequency part of the first order trace only, then Es-r would be more appropriate. This interpretation is similar in approach to that for thin Es-layers which completely blanket (see figures 3.1 and 3.2 of UAG-23A).

Example 4: There is really insufficient evidence available to determine which type of Es is present without using the sequence of ionograms, but the example is intended to illustrate lacuna with the retardation near foEs cut off by the lacuna.

Examples 6-8: The use of the descriptive letter K with fbEs is a very effective way of inducting the effects of an Es-k layer which is not actually observed on the ionograms.

Figure 4a Schematic diagram illustrating the scaling of Es parameters when two Es layers are present.

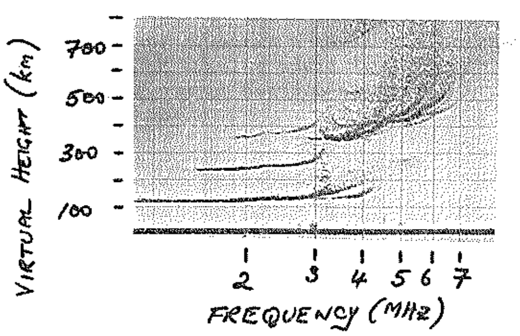
In each of these examples, two Es layers are present and one of them has group retardation at the high-frequency end. The layer with the highest value of foEs should be scaled and all Es parameters must be scaled from the same layer. Again the descriptive letters K on fbEs has been used to indicate the presence of an Es-k layer. Note, if the low Es is a weak trace, it should be ignored in accordance with the rules (see Handbook Chapter 2).



	foEs	fbEs	type Es
1	042JA	015-K	11k1
2	042JA	030--	11r1
3	042JA	015-K	a1k1
4	045--	040--	c1k1
5	047JA	020-K	11k1

Figures 5 - 8 These ionograms show similarities to the line diagrams provided in Figure 4 examples 1, 2 and 5, and to Figure 4a example 4 respectively.

Figure 5



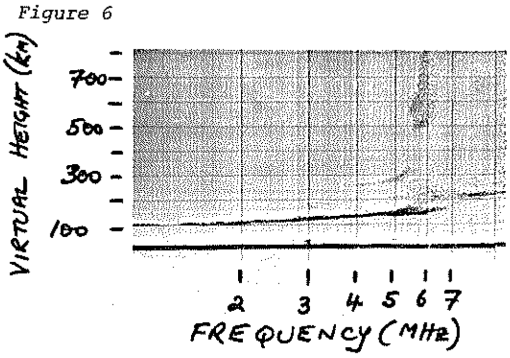
Tiksi 1958 7 September 2045LT (135°E)

foEs	fbEs	h'Es	Es type
030-K	030-K	115	k3s1

foF2	h'F	fxI	type F
048DF	350Q	070	FQ

Comment: There is an Es-s trace present extending above 3.0 MHz. This should not be used to determine Es parameters but only appears in the Es-types column

Figure 6



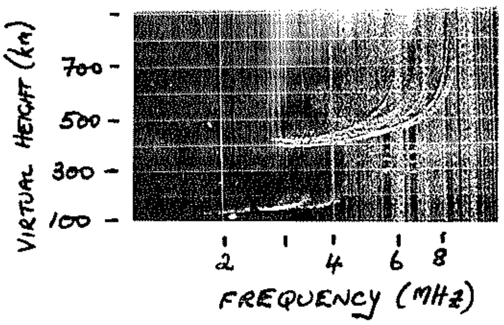
Tiksi 1958 3 September 2145LT (135°E)

foEs	foEs	h'Es	Es type
056	053	100	r2

foF2	h'F	fxI	type F
059UF	A	068OB	F

Comment: There is a weak Es-a trace above 6.0MHz and with a virtual height in excess of 200 km. It has been omitted from the scaling, as to include it would lead to a misrepresentation of the overhead ionosphere.

Figure 7



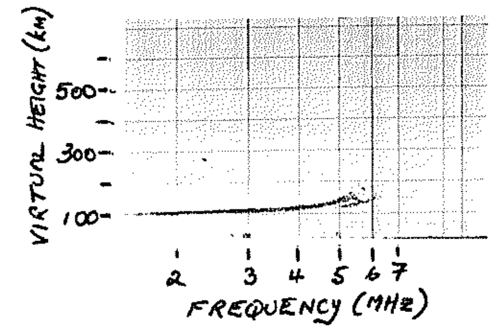
Narssarsuak 1958 3 January 1930LT (45°W)

foEs	fbEs	h'Es	Es type
034	027	110	r1

foF2	h'F	fxI	type F
060UF	400	085	F

Comment: The scaling of foF2 in this case is difficult. In the original manuscript foF2 was given as 060UF. However, the strongest F-region critical is at 8.0 MHz. The sequence of ionograms would probably resolve the problem.

Figure 8

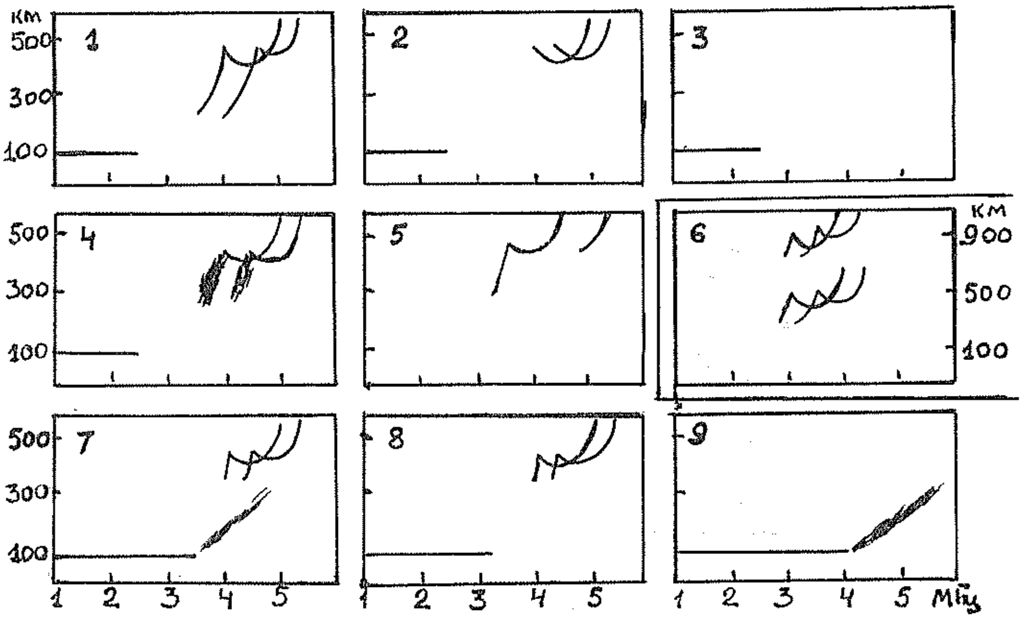


Tiksi 1958 30 June 0400LT (135°E)

foEs	fbEs	h'Es	Es type
054-K	054-K	100	k1

Comment: The weak Es-c trace is ignored under the weak trace rules. Note, the x-mode of the Es-c trace is not seen

Figure 9 Ionogram scaling for examples of lacuna



	fmin	foE	foEs	fbEs	foF2	foF1	h'F2	h'F	type Es
1	010EE	Y	030EG	030EG	050	400	400	250EY	-
2	010EE	Y	030EG	030EG	050	400EY	400	Y	-
3	010EE	Y	030EG	030EG	Y	Y	Y	Y	-
4	010EE	Y	030EG	030EG	050	400UF	400	Y	-
5	032	B	032EB	032EB	045	350	450	B	-
6	028-Y	Y	032EY	032EY	040	300	450	Y	-
7	010EE	A	035	Y	050	400	400	Y	11s1
8	010EE	A	Y	Y	050	400	400	Y	11
9	010EE	A	042-Y	042EY	Y	Y	Y	A	11s1

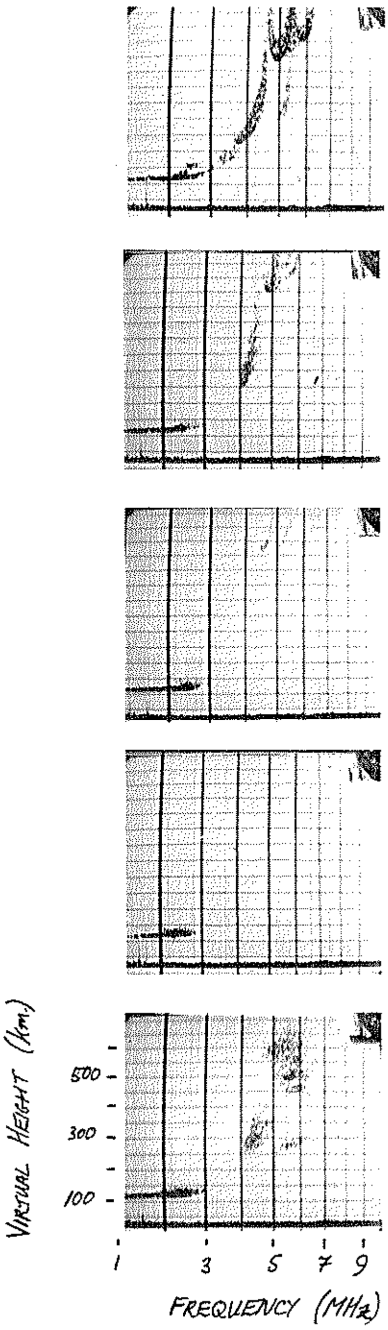
Comments

Examples 1-4. It is assumed that the traces at 100 km are normal E region reflections and foE is 3.0 MHz.

Examples 5-6. These examples are included to illustrate the differences between the absence of E and lower F region traces caused by high absorption (Example 5) and lacuna (Example 6). The key differences are that the x-mode F-region trace shows considerable absorption also with fmin Fx >>fmin Fo + fB/2 for example 5. In contrast, example 6 shows fmin fx = fmin Fo + fB/2. Also second order F region traces are observed in the latter case, hence lacuna is the most probable explanation for the missing traces.

Examples 7-9. It is assumed that the traces at 100 km are from Es layers for these cases. Analogous patterns can arise from a normal E trace e.g., UAG-23A Figure 2.19.

Figure 10 A sequence of ionograms from Dixon on 9 July 1970 showing the evolution of lacuna.



1530LT

fmin	foE	foEs	fbEs	h'Es	Es type
010EE	340UH	034EG	034EG	G	-
foF2	h'F2	h'F	foF1	fxI	type F
053	480	170-H	460	061-X	X

1545LT

fmin	foE	foEs	fbEs	h'Es	Es type
010EE	Y	033EG	033EG	G	-
foF2	h'F2	h'F	foF1	fxI	type F
051-F	550	250EY	460	063	F

1600LT

fmin	foE	foEs	fbEs	h'Es	Es type
010EE	Y	033EG	033EG	G	-
foF2	h'F2	h'F	foF1	fxI	type F
048	560UY	Y	Y	055-X	X

1630LT

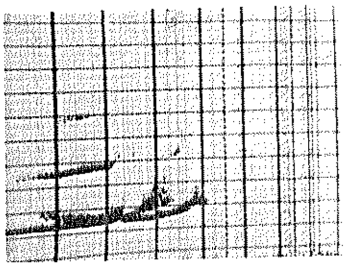
fmin	foE	foEs	fbEs	h'Es	Es type
010EE	Y	032EG	032EG	G	-
foF2	h'F2	h'F	foF1	fxI	type F
Y	Y	Y	Y	Y	-

1700LT

fmin	foE	foEs	fbEs	h'Es	Es type
010EE	Y	032EG	032EG	G	-
foF2	h'F2	h'F	foF1	fxI	type F
F	Q	250EY	460UY	065	FQ

Comment: The ionograms of 1545, 1600 and 1780 show partial lacuna, while the ionogram at 1630 shows total lacuna. At 1700, the descriptive letter Y has been used in preference to F with foF1 to illustrate that lacuna is the more important reason for the difficulty in scaling.

Figure 11 Examples of lacuna from Dixon on the 11 December 1970

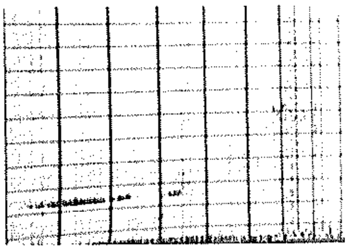


1530LT

foEs	fbEs	h'Es	Es type
040-K	040AA	100-Z	k1

foF2	h'F	fxI	type F
A	A	A	-

Comment: There is a slight indication that an Es-c layer may also be present. This has been ignored under the scaling on the weak and intermittent trace rule (UAG 23-A, p 29). A z-o-x triplet is present with very low absorption of the Z-trace. As Es type scaling is taken from the o-mode trace k1 is used.

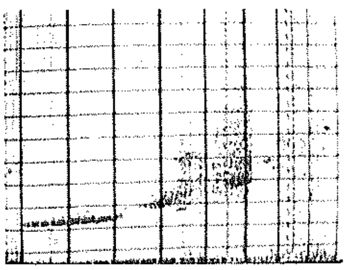


1545LT

foEs	fbEs	h'Es	Es type
Y	Y	110	k1

foF2	h'F	fxI	type F
A	A	A	-

Comment: There is insufficient evidence on this ionogram alone to be sure of the Es type. Es-k is used to maintain the continuity.

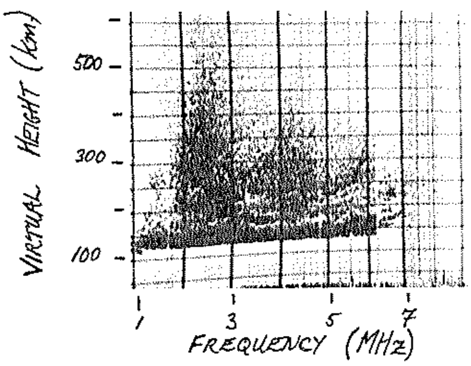


1600LT

foEs	fbEs	h'Es	Es type
060	034EK	145	a1k1

foF2	h'F	fxI	type F
A	A	A	-

Comment: Es-a is preferred as it indicates that very diffuse and spread traces are present.



1630LT

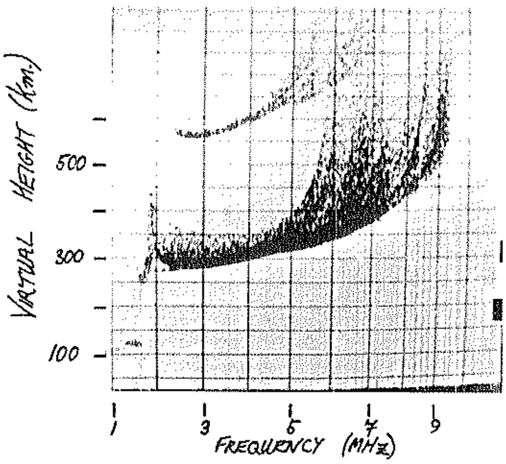
foEs	fbEs	h'Es	Es type
062JA	062AA	120	a1

foF2	h'F	fxI	type F
A	A	A	-

Comment: In each of these examples foF2 is expected to be below the top frequency of the blanketing Es layers. This sequence is typical of that observed in the auroral zone in the daytime during winter months under geomagnetically disturbed conditions.

Figures 12-14 These ionograms illustrate frequency, range and mixed spread-F (UAG 23A p58)

Figure 12



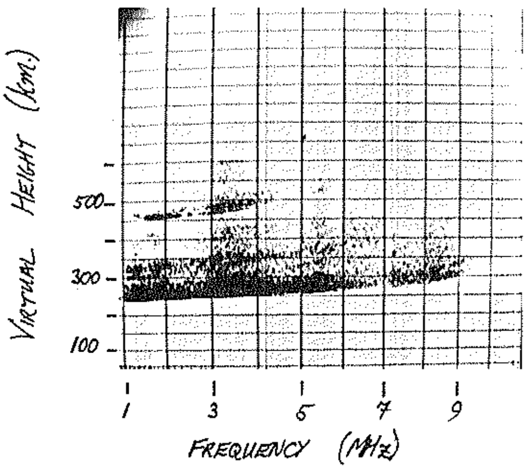
Mirny 1970 21 June 1215 (90°E)

foE	foEs	fbEs	h'Es	Es type
190	019EG	019EG	G	-

foF2	h'F	fxI	type F
058UF	275	092	F

Comment: At high geographic latitudes, normal E is often seen at heights near 200 km when the sun is below or close to the horizon at the earth's surface. Day to day sequence allows correct indentification of foE.

Example 13

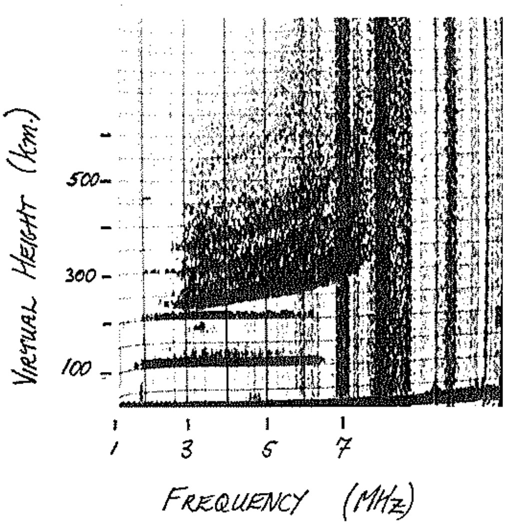


Vostok 1970 23 June 1400 (105°E)

foF2	h'F	fxI	type F
Q	250-Q	093	Q

Comment: An example of range spread-F. As the USSR uses Q1 for resolved range spread-F, QQ1 could be an acceptable spread-F scaling here to indicate that both unresolved and resolved range spread-F are present.

Example 14



Mirny 1970 28 January 2345 (90°E)

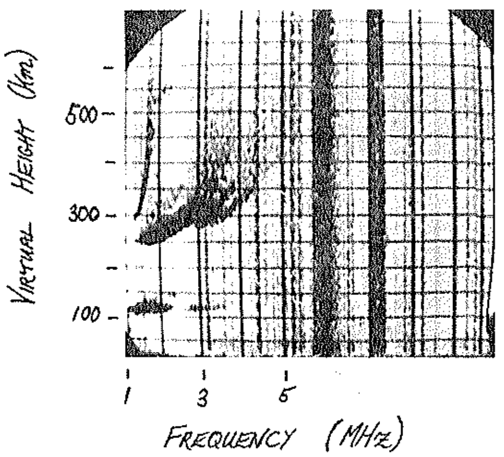
foEs	fbEs	h'Es	Es type
045JA	017	100	f3

foF2	h'F	fxI	type F
F	225-Q	070DS	FQ

Comment: Both range and frequency spread-F are present. This combination could be classified as spread-F type L (UAG-23A p58).

Figures 15-17. Further illustrations of spread-F typing including the polar spur (P).

Figure 15



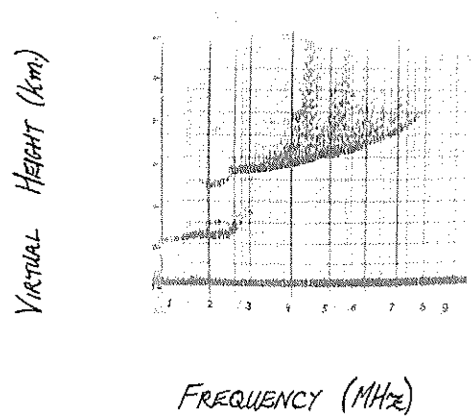
Norilsk 1967 14 December 0400 (90°E)

foEs	fbEs	h'Es	Es type
022	013	105	f1

foF2	h'F	fxI	type F
018	A	060	PX

Comment: This is part of trough-ridge sequence of ionograms. The sequence would help considerably in determining which of the two F layer is chosen as overhead. In this case, the lower frequency F-layer is scaled as the overhead layer.

Figure 16



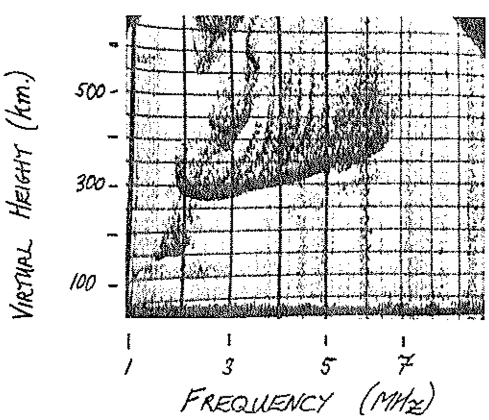
Dixon 1969 13 February 1710 (105°E)

foEs	fbEs	h'Es	Es type
027	025	110	r2

foF2	h'F	fxI	type F
044UF	320	080	PF

Comment: This example shows similarities to examples 2 and 5 on Figure 4.

Figure 17



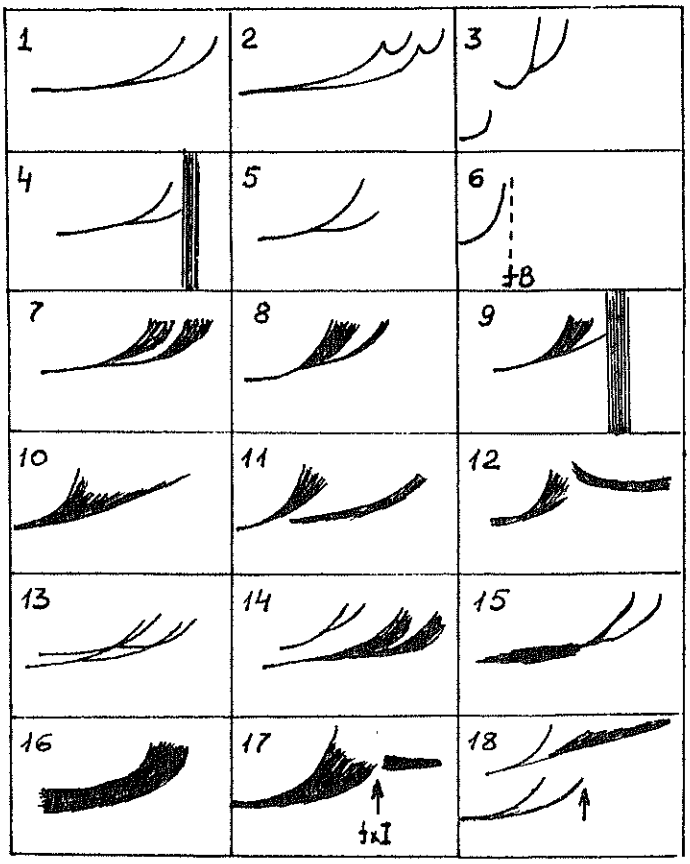
Dixon 1978 20 February 1705 (105°E)

foE	foEs	fbEs	h'Es
180UF	018EG	018EG	G

foF2	h'F	fxI	type F
039UF	270	070	Q1F

Comment: Q1 is used to indicate resolved range spread-F. See introduction for further discussion of the spread-F typing under these circumstances.

Figure 18 The scaling of fxI



	foF2	fxI	h'F	type F		foF2	fxI	h'F	type F
1	044	052-X	250	X	10	035-F	070	250	PF
2	044-H	052-X	250	X	11	035-F	070	250	PF
3	038EG	046-X	250	X	12	035-F	070	250	PF
4	044	052OS	250	X	13	044	053-X	250	XQ1
5	044	052OR	250	X	14	044-F	060	250	FQ1
6	010	017OB	250EE	X	15	044	052-X	250-Q	XQ
7	044-F	057	250	F	16	F	060	250-Q	FQ
8	044-F	056OR	250	F	17	044UF	060	250	F
9	044-F	056OS	250	F	18	044	052-X	250	X

Comment: It is stressed that the scaling of spread-F is indicated here in a separate column. Thus there are many differences from the scheme proposed in INAG Bulletin 33, pp 32-33 where the presence of spread-F was given in in the standard parameter tables. fB/2 = 0.8 MHz for these examples.

Example 3. Only an F1 layer present, F2 in G condition.

Example 11 and 14. In example 11, the oblique trace has a higher critical frequency than the overhead layer and is classified as a polar spur (P). In example 14, the oblique trace is at a frequency lower than foF2; thus the spread-F type is scaled as Q1 indicating resolved range spread-F.

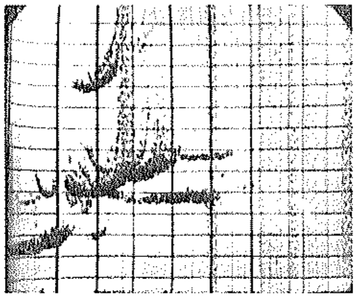
Example 17. The second trace at a higher frequency due to an oblique Es-a trace not a polar spur, which is why fxI is not scaled from the top frequency. The sequence of ionograms is normally of great benefit in resolving oblique Es-a from a polar spur trace (see Figure 19 for example).

Example 18. A backscatter trace from the earth's surface occurring only on second order traces. It is neglected for the purposes of scaling fxI.

Figure 19 An oblique Es-a trace causing difficulty in scaling fxI.

The example below from Heiss on 7 March 1977 illustrates the difficulty which can be experiened in determining fxI when oblique Es-a traces are present. The sequence of ionograms is very important under these circumstances. This sequence also shows the movement of the auroral oval with respect to the observatory.

The Handbook does not provide specific criteria for deciding when foEs should be scaled from Es-a layers. The height of the layer varies very rapidly with time and a criterion which can be adopted is to scale it when h'Es is less than h'F. In this sequence the criterion adopted for scaling Es-a is to measure it when h'Es is clearly less than 200 km. The main difficulty, well illustrated by the example, is that foEs nearly always increases with the obliquity of the Es-a, so there is an apparent conflict between picking foEs from the layer with the greatest value and the basic rule of scaling to measure the ionosphere nearest overhead. In this situation, the chairman would use the lowest Es-a trace for analysis.

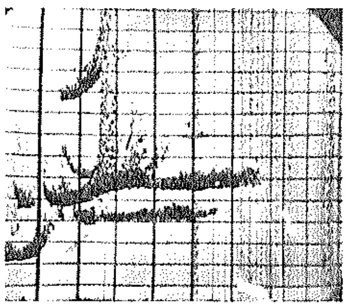


1230LT

foE	foEs	fbEs	h'Es	Es type
210	021EG	021EG	G	-

foF2	h'F	fxI	type F
038-F	245-H	051	F

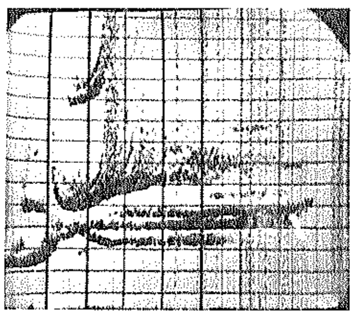
Comment: The second order F-trace has been used to determine foF2. In case of these examples on p13, there is a z-mode normal E region trace present. Its presence could be indicated with the h'E value.



1245LT

foE	foEs	fbEs	h'Es	Es type
205	020EG	020EG	G	-

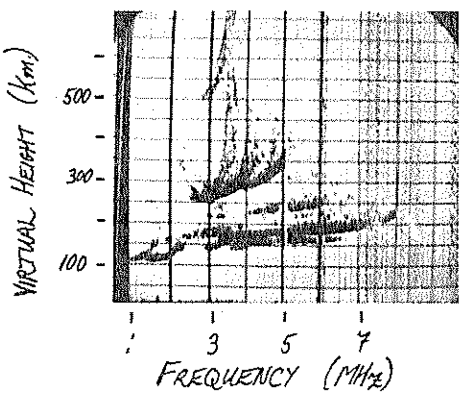
foF2	h'F	fxI	type F
037-F	240	053	F



1255LT

foE	foEs	fbEs	h'Es	Es type
205	082JA	020EG	160	a1

foF2	h'F	fxI	type F
036-F	240	060	F



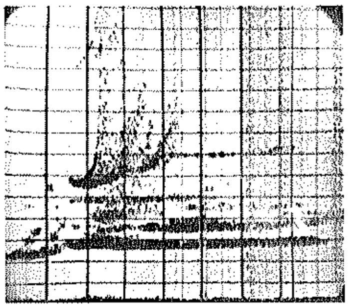
1300LT

foE	foEs	fbEs	h'Es	Es type
205	072JA	025	150	a1

foF2	h'F	fxI	type F
034-F	250	052	F

Comment: Despite the turn-up at the high-frequency end of the Es-trace, Es-a has been scaled to indicate the structure present.

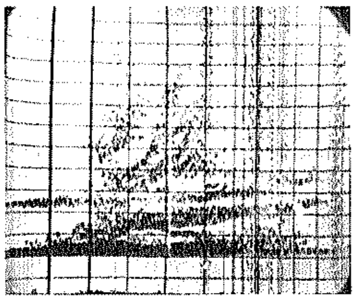
Figure 19 continued. Heiss 7 March 1977



1315LT

foE	foEs	fbEs	h'Es	Es type
200	084JA	025	130	al

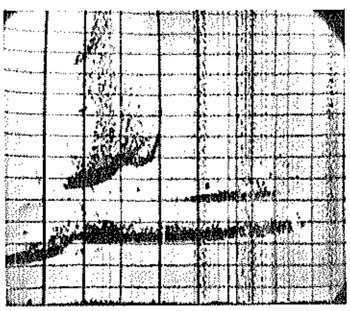
foF2	h'F	fxI	type F
032UF	270	055	F



1345LT

foE	foEs	fbEs	h'Es	Es type
A	092JA	030	100	al

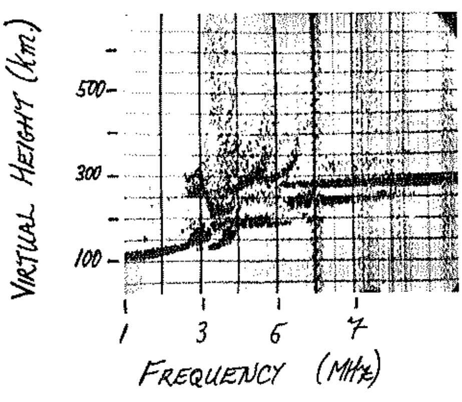
foF2	h'F	fxI	type F
F	F	063	PF



1355LT

foE	foEs	fbEs	h'Es	Es type
A	080JA	026	150	alrl

foF2	h'F	fxI	type F
034UF	280	050	PF



1400LT

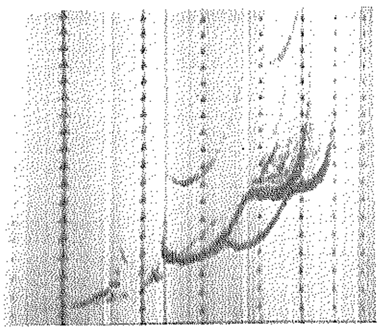
foE	foEs	fbEs	h'Es	Es type
A	032	027	100	rl

foF2	h'F	fxI	type F
F	F	056	PF

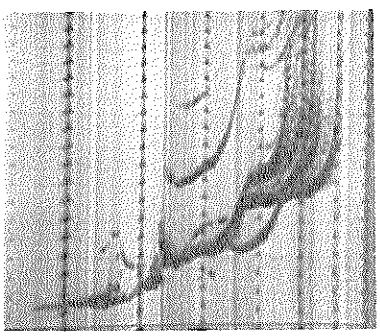
Comment: The oblique Es traces above 200 km have been neglected.

Figure 20 Three ionograms with different receiver gain settings.

The ionograms below from North Pole-8 on 19 August 1961 show the value of having three ionograms with different gain settings in close succession. In this case, the ionogram with minimum gain (1759LT) clearly shows which is the main F region trace, thus foF2 can be measured accurately. It is also interesting to note the effects of gain on other parameters also such as fmin, fm2, and the amount of spread-F present.



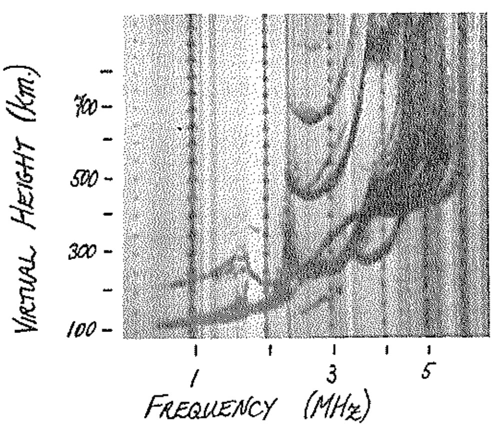
1759LT - LOW GAIN



1800LT - NORMAL GAIN

fmin	foE	foEs	fbEs	h'Es	Es type
007-Z	230-H	023EG	023EG	G	-

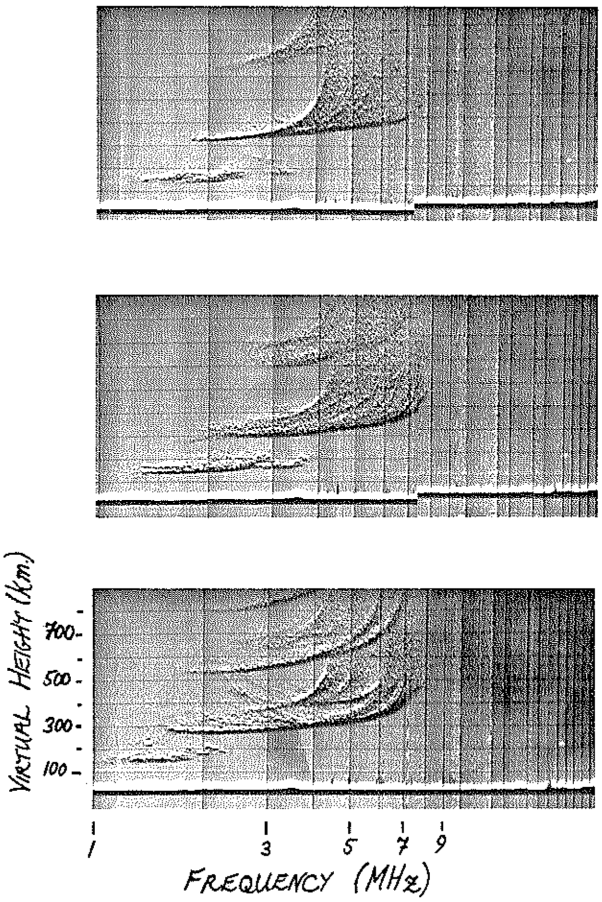
foF2	h'F2	h'F	foF1	fxI	type F
051-F	400-Q	230	390-L	060-X	Q1F



1801LT - HIGH GAIN

Figure 21 The determination of foF2 from the inner edge of a spread F trace.

The sequence below from Tiksi, recorded on 16 November 1958, illustrates sections 2.71 and 2.72 of the Handbook. Physically a ridge of ionisation has moved over the station and the scaling must take account of this. The scaling foF2 from the inner edge of the spread trace is appropriate at 1905 but not at 1930. Once again the sequence of ionograms and the second order traces provide valuable additional evidence for determining which layer is closer to overhead.



1905LT

foEs	fbEs	h'Es	Es type
026	017	115	r1
foF2	**h'F**	**fxI**	**type F**
042-F	310	080	F

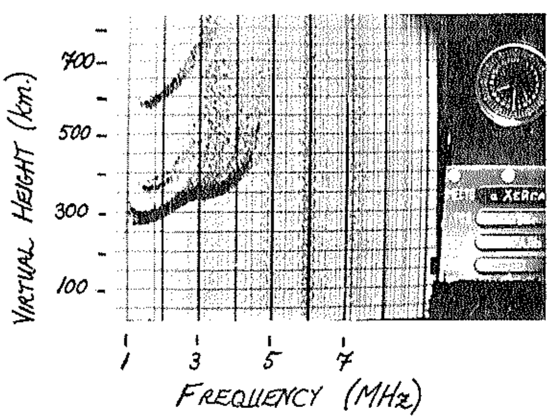
1915LT

foEs	fbEs	h'Es	Es type
027UF	017	115	r1
foF2	**h'F**	**fxI**	**type F**
F	300-Q	080	FQ

1930LT

foEs	fbEs	h'Es	Es type
023	016	120	r1
foF2	**h'F**	**fxI**	**type F**
062-F	265-Q	080	Q1F

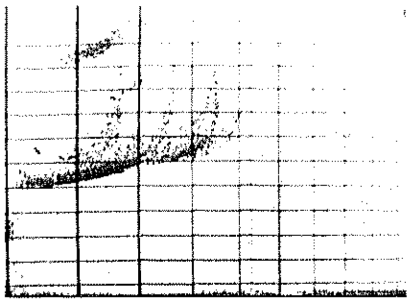
Figure 22 and 23 Further examples of foF2 determination under spread-F conditions.



Heiss 1958 20 February 1630LT (45°E)

foF2	h'F	fxI	type F
032UF	275	050	F

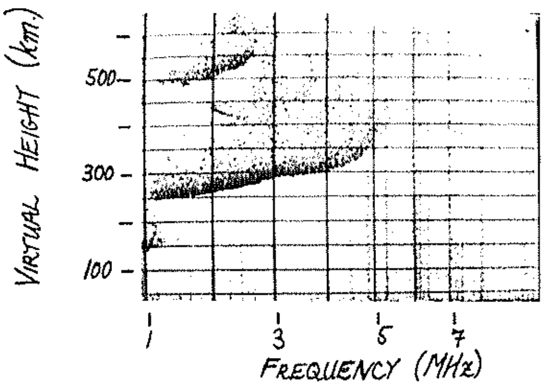
Figure 23 Dixon 28 November 1970



1759LT - LOW GAIN

foF2	h'F	fxI	type F
036	250	-	-

Comment: No entries have been made for fxI or type F. As these are gain sensitive parameters they must be scaled from the normal gain ionogram.



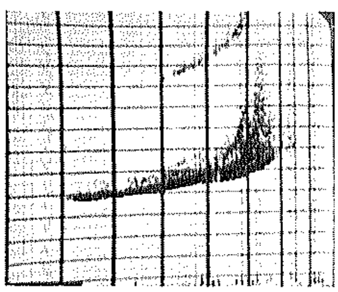
1800LT - NORMAL GAIN

foF2	h'F	fxI	type F
034DF	250	050	F

Comment: Conditions are changing very rapidly with time. The strong trace up to 3.2 MHz is overhead at both 1759 and 1800. It is possible to estimate foF2 by extrapolating from the break between the o-and x-mode traces using the shape of the layer at 1759. This gives foF2 at 3.6 MHz but is uncertain due to the large extrapolation. From the x-trace at 1800 a top limit for foF2 would be 044JF. The true value for foF2 probably lies between these limits but probably closer to 3.6 MHz. Thus foF2 could be scaled as 036DF.

Figure 24 Sequence illustrating large tilts.

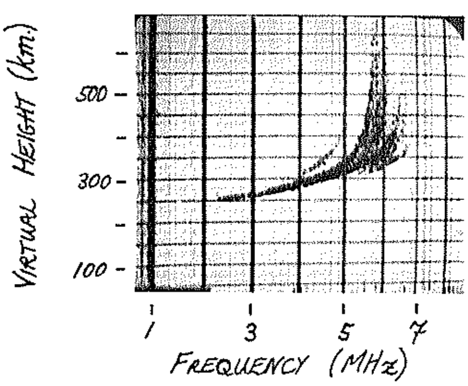
This sequence of ionograms from Dixon recorded on 2 February 1978 shows a trough of ionisation moving over the observatory.



1630LT

foEs	fbEs	h'Es	Es type
020EB	020EB	B	-

foF2	h'F	fxI	type F
063-F	240	076	F



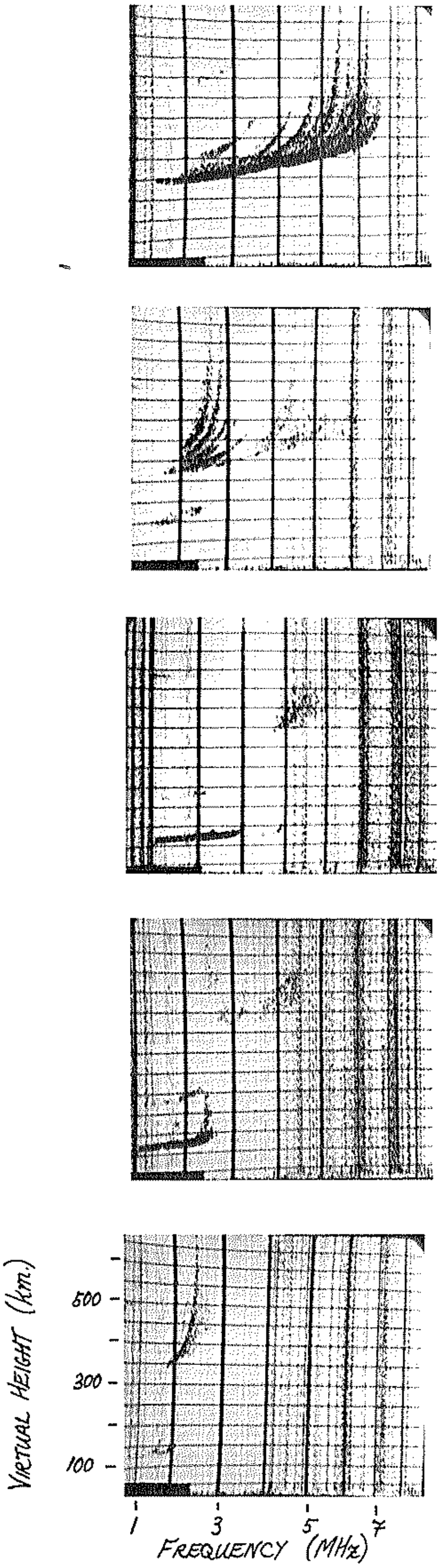
1700LT

foEs	fbEs	h'Es	Es type
022EB	022EB	B	-

foF2	h'F	fxI	type F
058-F	250	068	Q1F

Comment: z-mode F trace present. fzF2 is 5.0 MHz.

Figure 24 Dixon 28 November 1970



1715LT

foEs	fbEs	h'Es	type Es
014EB	014EB	B	-

foF2	h'F	fxI	type F
054UF	240	068	Q1F

Comment: foF2 in this case is rather difficult to determine uniquely but the quoted value appears most likely.

1745LT

foEs	fbEs	h'Es	type Es
023-R	017	150	r1

foF2	h'F	fxI	type F
028UF	270EA	060	PF

Comment: The original F layer with its critical frequency in excess of 4 MHz is now sufficiently oblique to be regarded as a polar spur trace. Hence the citing of P in the type F column.

1800LT

foEs	fbEs	h'Es	type Es
030-K	030AK	110	k2

foF2	h'F	fxI	type F
A	A	050	P

Comment: The sequence of ionograms shows that the overhead F layer at 1800 and 1815 LT is completely blanketed by the Es-layer. Thus replacement letters A have been used for foF2 and h'F. fxI is still determined from the polar spur trace which is unaffected by the Es.

1815LT

foEs	fbEs	h'Es	type Es
024-K	024AK	110	k2

foF2	h'F	fxI	type F
A	A	046	P

1830LT

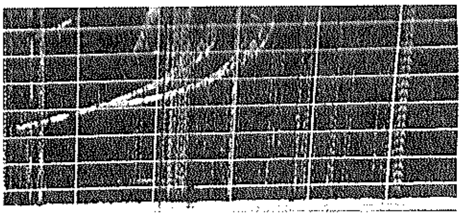
foEs	fbEs	h'Es	type Es
020	018	130	r1

foF2	h'F	fxI	type F
024	350EA	0320B	X

Comment: The polar spur trace has disappeared leaving only the o-mode F trace from the minimum of the trough.

Figure 25

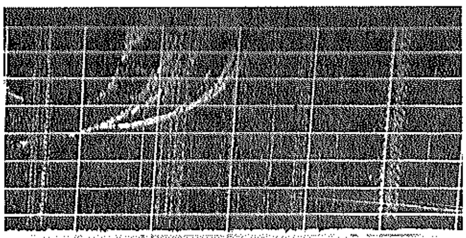
The sequence, from MOSCOW recorded on the 4-5 April 1978, illustrates the passage of the mid latitude electron density trough over a mid-latitude station during a geomagnetically active period. This sequence was originally called a replacement layer sequence and is further illustrated in UAG-50. Once again the main difficulty is in the identification of the overhead F layer.



2115LT

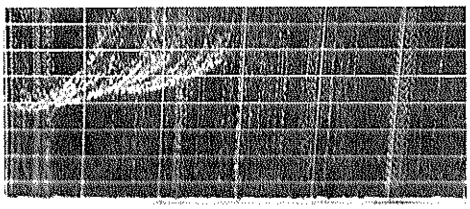
foF2	h'F	fxI	type F
034-V	315	044-X	Q1X

Comment: The additional critical frequency at 3.0 MHz shows that there is a very significant tilt present at the high-frequency end of the F layer trace. Hence the entry of Q1 in the type F column. The low-frequency end of the F-layer is nearly horizontal.



2145LT

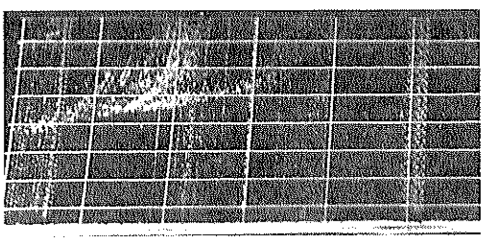
foF2	h'F	fxI	type F
032-V	360	041-X	Q1X



2215LT

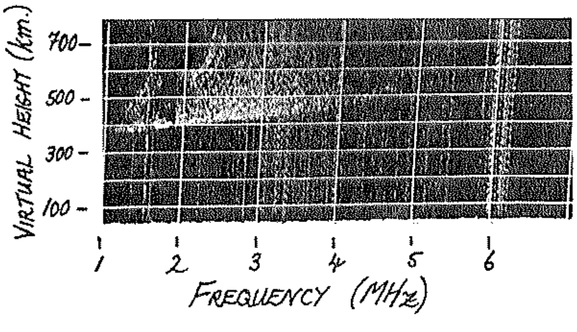
foF2	h'F	fxI	type F
023-F	370	038	PF

Comment: The very weak second order F trace above 700 km suggests that the F layer with the lowest critical frequency is closest to being overhead. This is confirmed by the typical oblique pattern near 2.3 MHz.



2245LT

foF2	h'F	fxI	type F
022UF	380	043	PF

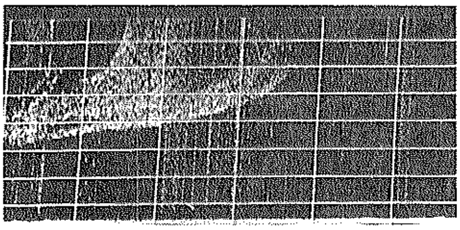


0000LT

foF2	h'F	fxI	type F
016	440EE	047	PX

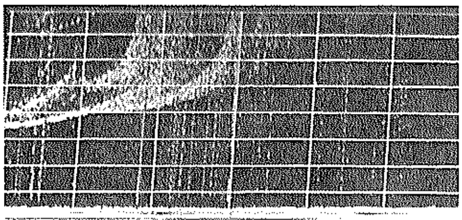
Comment: The combination PX in the type F column is used to indicate that fxI is scaled from a polar spur trace (P) but there is no significant frequency spread present on the overhead F layer (X).

Figure 25 continued *Moscow 4-5 April 1978*



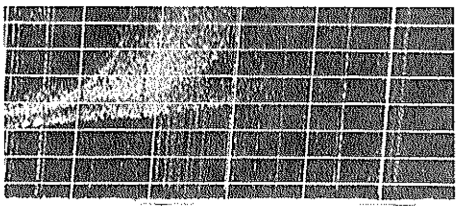
0115LT

foF2	h'F	fxI	type F
017	320-Q	047	PXQ



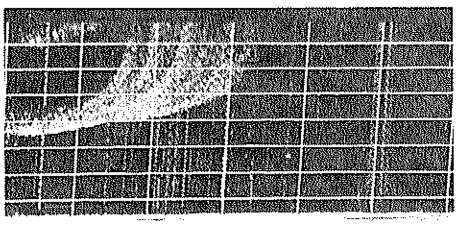
0130LT

foF2	h'F	fxI	type F
019	390	042	PX



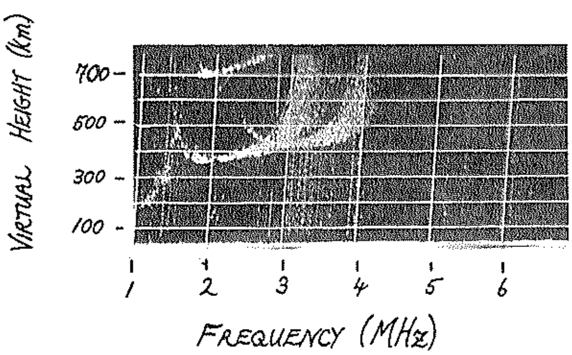
0200LT

foF2	h'F	fxI	type F
026UF	340	040	PF



0345LT

foF2	h'F	fxI	type F
027UF	340-Q	043	FQ

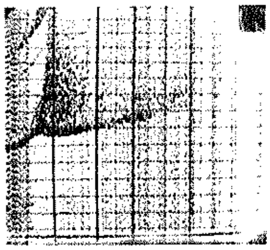


0430LT

foF2	h'F	fxI	type F
031-F	350	041	F

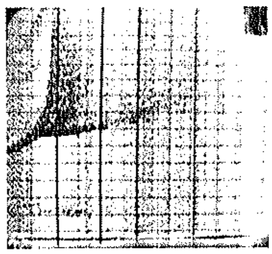
Figure 26 Dixon 4 January 1969

This sequence is taken from a geomagnetically quiet period. There is a polar spur trace present throughout the sequence in the frequency range 2-6 MHz but it remains at oblique incidence.



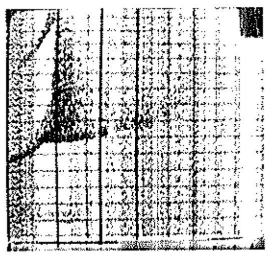
0530LT

foF2	h'F	fxI	type F
019-F	280-E	060	PF



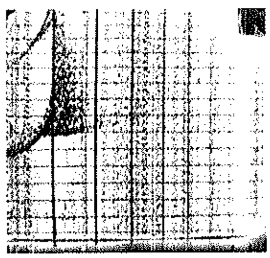
0545LT

foF2	h'F	fxI	type F
019-F	280-E	060	PF



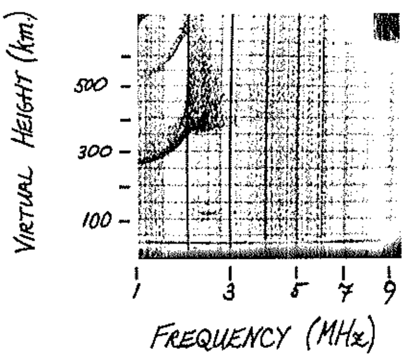
0600LT

foF2	h'F	fxI	type F
020-F	275-E	056	PF



0630LT

foF2	h'F	fxI	type F
020-F	270-E	040	PF



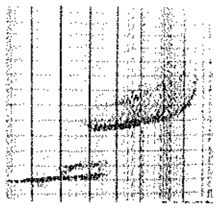
0645LT

foF2	h'F	fxI	type F
020-F	260-E	040	PF

Comment: The polar spur trace is rather weak above 2.9 MHz but can be more clearly seen on the original ionogram up to 4.0 MHz

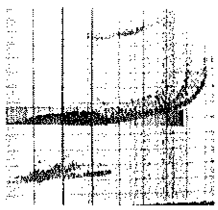
Figure 27 Dixon 24 January 1969

This sequence is taken from a period of moderate geomagnetic activity. The ionograms here should be contrasted with those in Figure 26, which was for quiet conditions. The main differences are that the ridge of ionisation observed obliquely in Figure 26 is now overhead. Also there is significantly more Es of the types associated with particle precipitation.



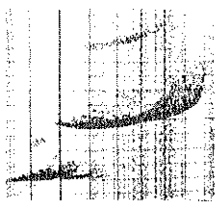
0530LT

foEs	fbEs	h'Es	Es type
036JA	036-K	100	f1r1
foF2	**h'F**	**fxI**	**type F**
078JS	265	086-X	FQ



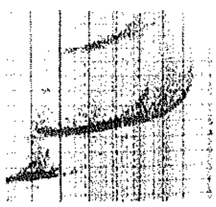
0545LT

foEs	fbEs	h'Es	Es type
034UC	034UC	100	r1
foF2	**h'F**	**fxI**	**type F**
082	275	090-X	XQ



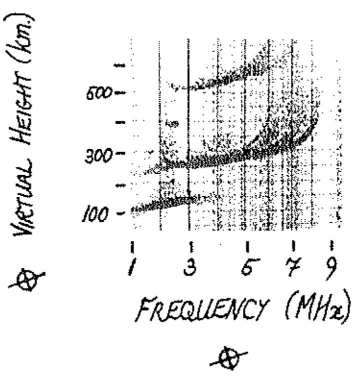
0605LT

foEs	fbEs	h'Es	Es type
036UK	024-K	100	r1k1
foF2	**h'F**	**fxI**	**type F**
074UF	270	090	F



0630LT

foEs	fbEs	h'Es	Es type
021UK	021-K	100	k1
foF2	**h'F**	**fxI**	**type F**
065UF	250	084	F

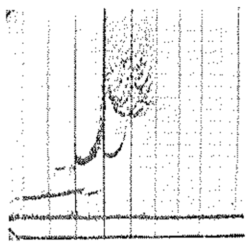


0645LT

foEs	fbEs	h'Es	Es type
025JA	020-K	105UA	r1k1
foF2	**h'F**	**fxI**	**type F**
062-F	250	083	F

Figure 28 Polar Cusp Precipitation

This sequence from Vostok, Antarctica recorded on 24 January 1970 (summer day) illustrates the effects which are normally observed on ionograms when the polar cusp (or cleft) precipitation is near the station. There is a very significant flux of precipitating particles in the cusp with low energies compared with those observed elsewhere in the auroral oval. These particles mainly stop at F-region heights usually near hmF1 at times within a few hours of magnetic noon.

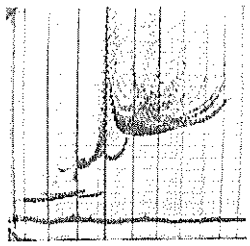


1745LT

fmin	foE	foEs	fbEs	h'Es	type Es
010	300UY	030EG	030EG	G	-

foF2	h'F2	h'F	foF1	fxI	type F
F	Q	255	400	060	FQ

Comment: The overlapping normal E and F traces near foE indicate there is a severe tilt present (see UAG 23A p 50). It is not possible to decide from these small reproductions whether it is this E or the F layer which is tilted, but UY has been used on foE on this occasion.

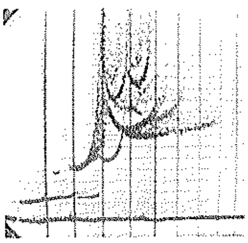


1750LT

fmin	foE	foEs	fbEs	h'Es	type Es
010	300-Y	030EG	030EG	G	-

foF2	h'F2	h'F	foF1	fxI	type F
F	390DQ	250	400-F	095	PFQ

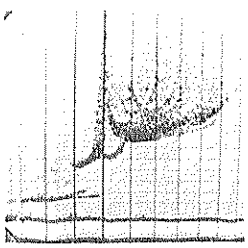
Comment: Note the presence of a z-mode F-trace near 2.5 MHz.



1800LT

fmin	foE	foEs	fbEs	h'Es	type Es
010	290UY	029EG	029EG	G	-

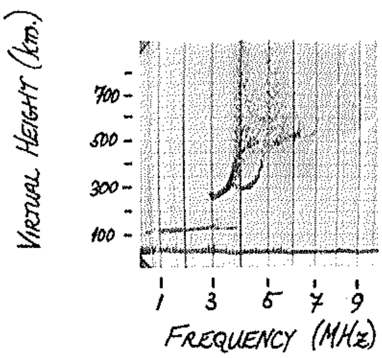
foF2	h'F2	h'F	foF1	fxI	type F
049UF	550	250	400-F	080	PFQ



1815LT

fmin	foE	foEs	fbEs	h'Es	type Es
010	280ZY	028EG	028EG	G	-

foF2	h'F2	h'F	foF1	fxI	type F
F	370-Q	255	390-F	094	PFQ



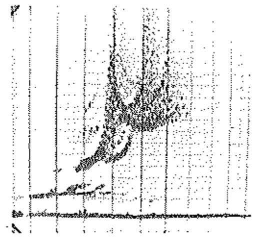
1830LT

fmin	foE	foEs	fbEs	h'Es	type Es
010	290EY	028EG	028EG	G	-

foF2	h'F2	h'F	foF1	fxI	type F
F	Q	250	390-F	070	FQ

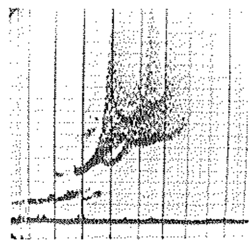
Figure 29 Station moving under the polar cusp during the summer.

When a station moves under the cusp in summer, the entire F-layer traces are very severely affected. The most readily identifiable feature is a rapid rise in the maximum plasma frequency of the F2 layer, with an associated fall of hmF2 to near hmF1. The cusp F-layer traces show considerable range and frequency spread-F. The sequence of ionograms below recorded at Vostok on 22 January 1970 show all these features as the station moves under the polar cusp. The ionogram at 1945LT is typical for overhead cusp precipitation.



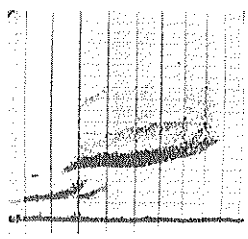
1905LT

fmin	foE	foEs	fbEs	h'Es	Es type
010	260UF	026EG	026EG	G	-
foF2	**h'F2**	**h'F**	**foF1**	**fxI**	**type F**
051DF	Q	220	390-F	070	PFQ



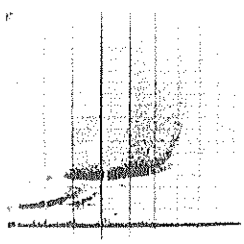
1915LT

fmin	foE	foEs	fbEs	h'Es	Es type
010	260UY	026EG	026EG	G	-
foF2	**h'F2**	**h'F**	**foF1**	**fxI**	**type F**
053DF	Q	225	400-F	070	PFQ



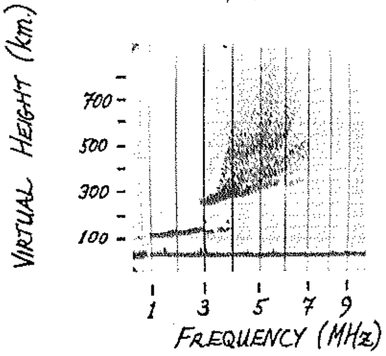
1945LT

fmin	foE	foEs	fbEs	h'Es	Es type
010	Y	026EG	026EG	G	-
foF2	**h'F2**	**h'F**	**foF1**	**fxI**	**type F**
Q	Q	240EY	Q	090	Q



2000LT

fmin	foE	foEs	fbEs	h'Es	Es type
010	Y	025EG	025EG	G	-
foF2	**h'F2**	**h'F**	**foF1**	**fxI**	**type F**
Q	Q	230-Q	Q	072	Q



2015LT

fmin	foE	foEs	fbEs	h'Es	Es type
010	Y	025EG	025EG	G	-
foF2	**h'F2**	**h'F**	**foF1**	**fxI**	**type F**
054UF	Q	250	400UF	0640B	PFQ

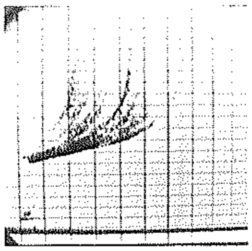
Figure 30 Station moving under the polar cusp in winter.

This sequence of ionograms, from Vostok on 27 June 1970, shows the station moving under the polar cusp under winter conditions. For this station in winter, there is no solar illumination of the E or F-layers at times when the polar cusp may be present. However, the similarity between the F-region traces at 2005LT in this example and 1945LT on Figure 29 recorded in summer is remarkable.

1905LT

foF2	*h'F*	*fxI*	*type F*
023UF	*E*	*043OB*	*F*

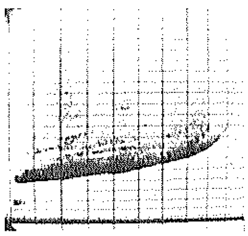
Comment: normal winter ionogram.



1930LT

foF2	*h'F*	*fxI*	*type F*
032UF	*350-Q*	*082*	*PFQ*

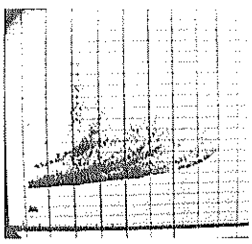
Comment: Cusp precipitation at oblique incidence.



2005LT

foF2	*h'F*	*fxI*	*type F*
Q	*230-Q*	*102*	*Q*

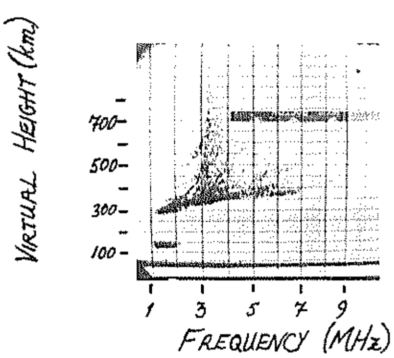
Comment: Cusp precipitation overhead.



2030LT

foF2	*h'F*	*fxI*	*type F*
032UF	*Q*	*090*	*PFQ*

Comment: The identification of foF2 at 3.2 MHz would be very doubtful using this ionogram alone. Additional information from unpublished ionograms must have been used to allow the determination of the value of foF2.



2055LT

foF2	*h'F*	*fxI*	*type F*
032UF	*280*	*090*	*PF*