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14. Abstract/Notes - *We present recent results on VLF long-distance propagation obtained on Itapetinga Radio Observatory, Atibaia, Brazil and at Antarctic Station Cmte. Ferraz, King George Island, Antarctic Peninsula.*

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RESULTS ON VLF LONG-DISTANCE PROPAGATION RECEIVED AT BRAZIL AND AT ANTARCTIC PENINSULA.

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We present some recent results on VLF long-distance propagation obtained on Itapetinga Radio Observatory, Atibaia, Brazil and at Brazilian Antarctic Station Cmte. Ferraz, King George Island, Antarctic Peninsula.

We can summarize them as:

a) Study of PCA events that occurred from September 1967 to November 1974 and their effects on phase records received from NWC (Australia)-Atibaia (Brazil) propagation path (Table 1) crossing the Antarctic continent (Figure 1). Nearly 50 PCA's from that period, of different intensities were studied and the most relevant ones (Table 2) were analysed in more detail. A good correlation between nighttime VLF signal phase advances and total proton flux content of energy 10 MeV $< E <$ 30 MeV measured by satellite (Explorer 34 and 41, NOAA 2 and 3 and ATS-1) was obtained for strong PCA events (WESTERLUND et al., 1969). Geomagnetic storms with sudden commencement, associated or not with proton precipitation, also produces well defined VLF signal phase advances (WILLIAMS and BOSTROM, 1967). Comparison of these results with those obtained in the northern hemisphere during PCA events (HAKURA et al., 1972) may provide relevant information on the behaviour of the ionosphere D-layer over the Antarctic region. Simultaneous analysis of VLF on non-polar propagation paths (MENDES et al., 1970) were also included for the major PCA discussed (Figure 2). Well defined phase deviations were detected showing the significant contribution of the South Atlantic Geomagnetic Anomaly to the ionization of the lower part of the ionospheric D-region (Figure 3, Table 3).

b) C-layer effect is observed on long distance VLF signal propagation at sunrise, when the solar illumination line (terminator) makes a small angle ($\alpha < 20^{0}$) with the propagation path (ABDU ét al., 1973; COMARMOND, 1977). The effect may be described as an additional phase advance, just after the sunrise normal phase advance, recovering in about 90 minutes (HARGREAVES, 1962). Analysis of different propagation paths shows that the magnitude of the observed effect presents a latitudinal (Figure 4) and solar cycle dependence (Figure 5). Data obtained for geomagnetic latitudes ranging 14^{0} N to 50^{0} S have shown that the C-layer effect seems to be more pronounced at higher latitudes. Finally, analysis of data at different phases of the solar cycle suggest that for the period of maximum activity the magnitude of the observed C-layer effect is reduced. These effects may be understood bearing in mind that cosmic radiation is the main responsible for the ionization of regions below the ionospheric D-layer. It is more intense at higher latitudes and also presents a variation with the solar cycle, being minimum when maximum solar activity occurs. In the analysis, different phenomena which could influence the C-layer effect were taken into account, such as SID's at sunrise, Forbush decrease, stratwarm and magnetic storms.

c) Preliminary results obtained by use of long distance VLF radio propagation signals, simultaneously received at the Brazilian Antarctic Station Cmte. Ferraz and at Itapetinga Radio Observatory, Atibaia, Brazil during the period from February 1986 to March 1987, when all transmissions were tracked in all frequencies of VLF range (COM and OMEGA). The observed effects are due to several ionization sources such as X-rays emitted during solar flares, cosmic radiation, energetic particles and meteor showers. During this period signals of frequency 13.6 kHz was continuously recorded for the propagation paths Argentina-Atibaia,SP and Argentina-Ferraz allowing the studies of seasonal variation in the lower ionosphere as well as the determination of the reflection height (Δ h) variation and the behaviour of the conductivity gradient ($\Delta \beta$), parameters necessary to the construction of diurnal and nocturnal D-region electron density models. In the prosecution of the study of phase and amplitude of VLF signals in the frequencies 10.2 kHz and 13.6 kHz for these propagation paths (Figure 6) it is possible to determine the electron flux (POTEMRA and ROSENBERG,1970) at altitudes ranging from 60 to 85 km. For the magnetic storm that occurred on February 1986 the following values of electron flux were obtained: $10 - 10^{4}$ electrons $cm^{-2}.s^{-1}.sterad^{-1}$ for the Antarctic region and $10^{2} - 10^{3}$ electrons $cm^{-2}.s^{-1}.sterad^{-1}$ for Argentina-São Paulo propagation path (Figure 7). Electron fluxes were calculated by fitting models β - H

(WAIT and SPIES, 1964) for each propagation path. In the first case it was found a night-time reference height of 83 km and a diurnal reference height of 65 km, with a nocturnal conductivity gradient $\beta_n = 0.8\ km^{-1}$ and diurnal $\beta_n = 0.3\ km^{-1}$. For the propagation path Argentina-Atibaia, SP, the corresponding reference height was 83 km and 67 km with $\beta_n = 0.5\ km^{-1}$ and $\beta_D = 0.3\ km^{-1}$ (Figure 8). The reception of these signals on different paths propagating in and outside the South Atlantic Geomagnetic Anomaly allows one to study the influence of this peculiar region on the analysed effects.

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CAPTIONS TO THE FIGURES

Fig. 1 - Gnomonic projection of all VLF propagation paths studied in this work. Dashed line represents the 0.3 G contour of constant magnetic field at an altitude of 100 km.

Fig. 2 - Representation of some diurnal phase deviations listed in Table 2.

Fig. 3 - Corresponding diurnal phase shifts on non-polar VLF propagation paths observed; (a) during the major events described in Section 3 and (b) during other PCA events or periods with high geomagnetic activity.

Fig. 4 - Phase variation ($\Delta\phi$) normalized to the propagation path distance (D) associated to C-layer effect and cut-off rigidity (Rg) as a function of geomagnetic latitude for seven different receiver sites of signals transmitted by Ω-Liberia in the frequency of 10.2 kHz (Point nº 1) and 13.6 kHz (remaining points).

Point 1. Liberia-Rio de Janeiro (Brazil).
Point 2. Liberia-Rio Grande (Brazil).
Point 3. Liberia - Polish Station of Arctowsky (Antarctic Peninsula).
Point 4. Liberia - Chilean Station of Pratt (Antarctic Peninsula).
Point 5. Liberia - Punta Arenas (Chile).
Point 6. Liberia - Brazilian Station Cmte. Ferraz (Antarctic Peninsula).

Fig. 5 - VLF signal phase variations associated to C-layer effects observed on 16.0 kHz GBR-Atibaia, SP propagation path, for the month of great intensity (January) together with solar sunspot number and neutron countings from the observatories of Kiel, Deep River and Climax.

Fig. 6 - Diurnal phase variation ($\Delta\phi$) of 10.2 and 13.6 KHz Ω-Argentina received at Ferraz Station (62° 05'S, 58° 24'W) (D= 2.2 Mm) and at Atibaia (23° 11'S, 46° 33'W) (D= 2.8 Mm). Also shown the correponding Ap index for the period. The arrows shows the SC for all receptions.

Fig. 7 - Calculated electron fluxes J (> 40 KeV) vs. phase advance (μs) for different energy ranges for each propagation path. Also shown the maximum phase deviation for Ω- Argentina (13.6 kHz) received at (a) Ferraz Station and (b) Atibaia.

Fig. 8 - Diurnal observed phase variation ($\Delta\phi$), normalized to the propagation path distance (D), as a function of frequency, for the Antarctic Peninsula and for Atibaia compared with WAIT and SPIES (1964) model and with a well behaved long-distance VLF propagation paths (REDER, 1981).

Table 1. Characteristics of monitored VLF transmitters.

Transmitter call sign	Location	Geographic Coordinates		Frequency (kHz)	Total distance (Mm)	Distance inside the SAGA (Mm)
NWC	North West Cape (Australia)	21°49'S	114°10'E	22.3 (15.5)	14.6	3.0
GBR	Rugby (U.K.)	52°22'N	1°11'W	16.0	9.5	3.0
NAA	Cutler, Maine (USA)	44°39'N	67°12'W	17.8	7.9	2.7
ALDRA	South of Bodø (Norway)	66°25'N	13° 9'E	12.3	11.3	2.8
Receiver site						
Umuarama Observatory S.Paulo (Brazil) (until August 1970)		22°48'S	45°30'W			
Itapetinga Radio Observatory S.Paulo (Brazil) (after August 1970)		23°11'S	46°33'W			

Table 2. *PCA effects and its association with optical flares, geomagnetic indices, proton flux and ionospheric D region lowering.*

PCA			FLARE DATA		Ap index	J (Ep > 10 MeV) particles/cm^2. s. sterad	ΔH 70 km D = 3.6 Mn	ΔH 60 km D = 6.6 Mn
Date	ΔΦ (μs)	Type	Observed UT	Importance				
13 Oct 67	7 (14 Oct)	D	not identified	.	13 (14 Oct)	-	4.3	2.4
2 Nov 67	6 (3 Oct)	D	2 Nov 0855	2B	23 (3 Nov)	-	3.7	2.1
15 Feb 68	13 (18 Feb)	D	not identified		35 (20 Feb)	-	8.1	4.5
28 Mar 68	8 (29 Mar)	D	not identified		27 (30 Mar)	-	5.0	2.8
31 Mar 68	12 (2 Apr)	D	not identified		27 (1 Apr)	-	7.5	4.2
* 4 Apr 68	7 (8 Apr)	D	not identified		36 (6 Anr)	-	3.9	1.2
* 9 Jun 68	32 (11 Jun)	A	9 Jun 0835	2B	103 (11 Jun)	354 (10 Jun)	24.0	11.1
* 9 Jul 68	15 (14 Jul)	A	9 Jul 1805	2B	35 (10 Jul)	54 (13 Jul)	8.5	3.6
26 Jul 68	7 (27 Jul)	D	not identified		15 (26 Jul)	-	4.3	2.4
29-31 Oct 68	21 (29 Oct)	A	20 Oct 1115	2B	122 (1 Nov)	1200 (31 Oct)	13.1	7.3
18 Nov 68	44 (18 Nov)	B	18 Nov 1026	1B	22 (18 Nov)	849 (18 Nov)	33.0	15.9
4 Dec 68	19 (6 Dec)	A	2 Dec 2027	3N	25 (5 Dec)	152 (6 Dec)	11.8	6.6
24 Jan 69	5 (24 Jan)	C	24 Jan 0707	2N	29 (25 Jan)	6 (24 Jan)	3.1	1.7
25 Feb 69	25 (25 Feb)	B	23 Feb 0500	1B	32 (27 Feb)	25 (25 Feb)	15.6	8.7
			24 Feb 2330	2B				
			25 Feb 0928	2B				
16 Mar 69	7 (17 Mar)	D	12 Mar 1744	1B	38 (17 Mar)	-	4.3	2.4
21-27 Mar 69	25 (23 Mar)	C	21 Mar 0142	2B	79 (24 Mar)	-5 (22 Mar)	15.6	8.7
29-31 Mar 69	30 (31 Mar)	C	30 Mar 0248	2B	24 (1 Apr)	66 (31 Mar)	18.7	10.4
5 Nov 70	11 (7 Nov)	B	5 Nov 0312	3B	58 (7 Nov)	42 (4 Nov)	6.8	3.8
23 Nov 70	8 (23 Nov)	D	not identified		30 (21 Nov)	1 (23 Nov)	5.0	2.8
24 Dec 70	13 (26 Dec)	C	not identified		14 (24 Dec)	5 (24 Dec)	8.1	4.5
8 Jun 72	12 (10 Jun)	C	8 Jun 1357	-F	14 (9 Jun)	10 (9 Jun)	7.5	4.2
16 Jun 72	23 (18 Jun)	C	not identified		126 (18 Jun)	21 (17 Jun)	14.3	8.0
19 Jun 72	28 (22 Jul)	C	not identified		33 (25 Jul)	25 (20 Jul)	17.4	9.7
4 Aug 72	58.5 (4 Aug)	A	2 Aug 0310	1B	132 (4 Aug)	68486 (4 Aug)	43.7	20.3
			2 Aug 1959	2B	182 (5 Aug)	13740 (8 Aug)		
			4 Aug 0619	3B				
			7 Aug 0348	1B				
			7 Aug 1505	3B				
3 Jul 74	33 (5 Jul)	B	3 Jul 0833	-B	130 (6 Jul)	300 (5 Jul)	20.6	11.5

A = Strong B = Medium C = Weak D = Very Weak * frequency 15.5 kHz

Table 3. PCA effects observed on non-polar VLF propagation paths crossing the SAGA.

Event	Transmitter	Δφ (μsec)	ΔH (70 km)	ΔH (60 km)
9/Jun/68	NAA	6.0	5.1	4.2
9/Jul/68	NAA	12.0	8.3	7.4
18/Nov/68	ALDRA	28.0	15.9	11.8
4/Dec/68	ALDRA	10.0	5.7	4.3
25/Feb/69	NAA	10.0	9.0	7.3
4/Aug/72	NAA	13.0	6.8	5.5
27/Jul/69	NAA	11.0	9.4	7.6
14/Mar/70	NAA	17.0	14.4	11.7
29/Mar/70	GBR	9.0	6.3	5.0
10/Jul/70	GBR	14.0	9.8	6.1
7/Nov/70	GBR	6.0	4.2	3.3

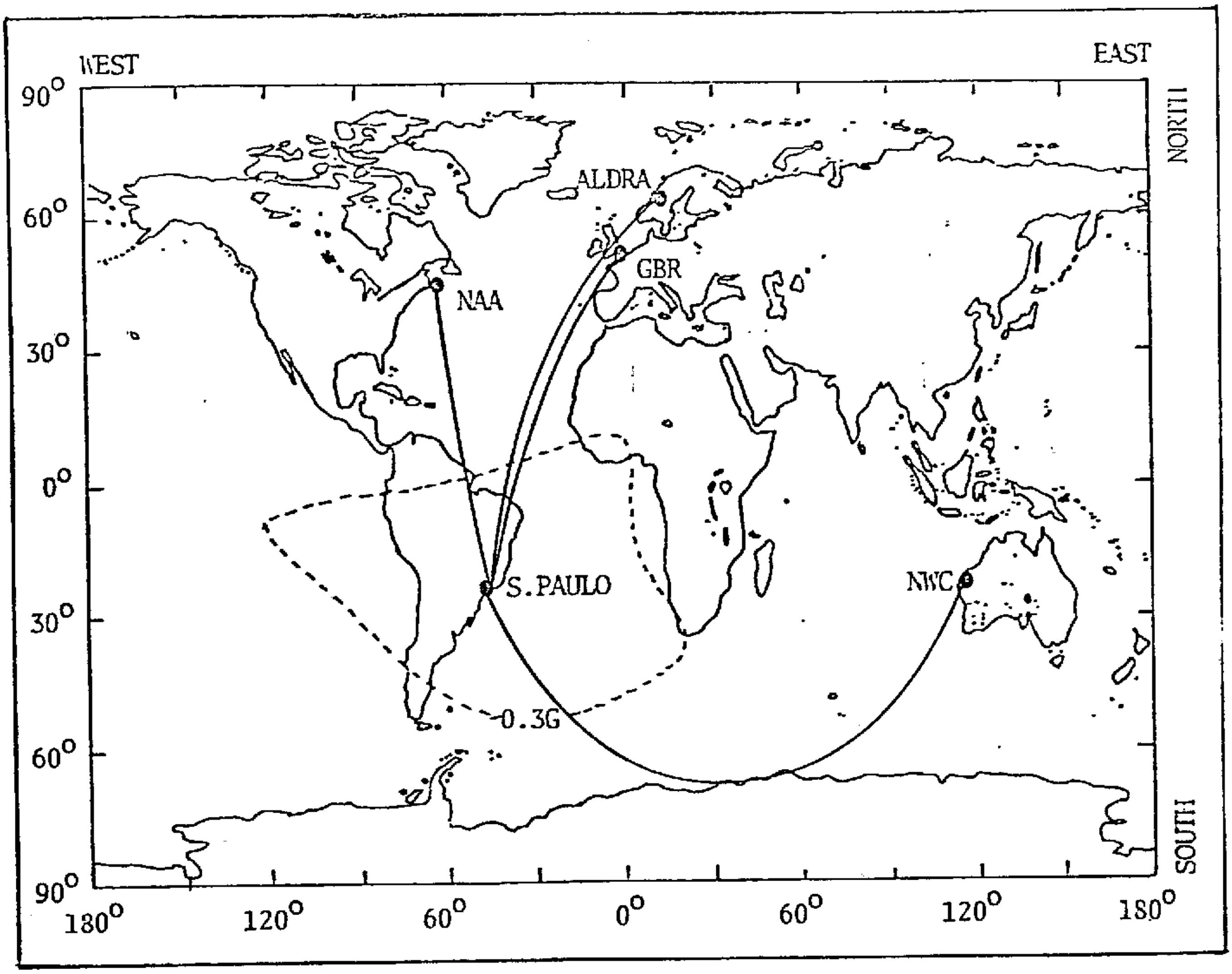

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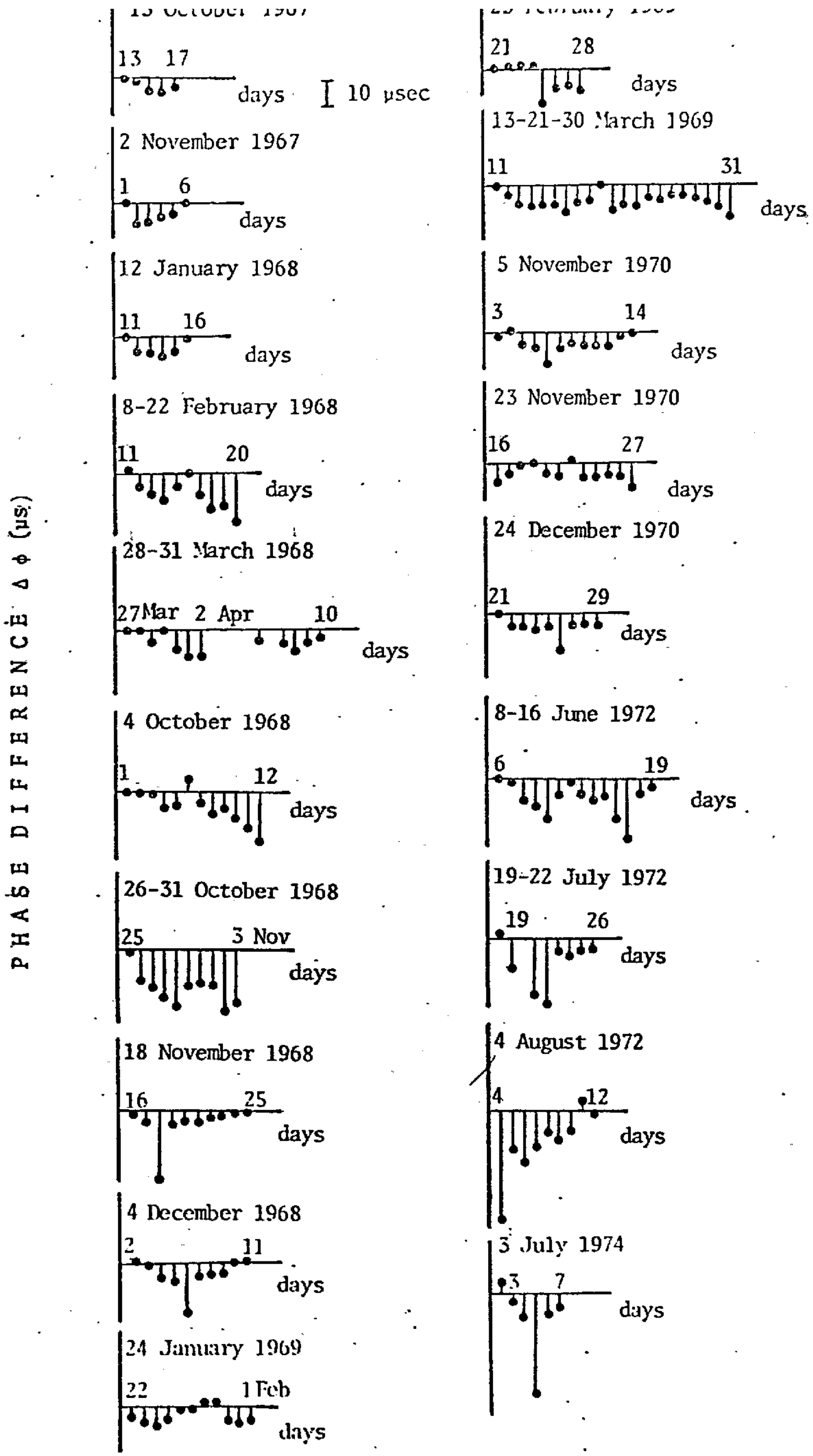
Fig. 1


PHASE DIFFERENCE Δ φ (μs)
10 μsec
13 17 days
2 November 1967
1 6 days
12 January 1968
11 16 days
8-22 February 1968
11 20 days
28-31 March 1968
27Mar 2 Apr 10 days
4 October 1968
1 12 days
26-31 October 1968
25 3 Nov days
18 November 1968
16 25 days
4 December 1968
2 11 days
24 January 1969
22 1 Feb days
21 28 days
13-21-30 March 1969
11 31 days
5 November 1970
3 14 days
23 November 1970
16 27 days
24 December 1970
21 29 days
8-16 June 1972
6 19 days
19-22 July 1972
19 26 days
4 August 1972
4 12 days
3 July 1974
3 7 days

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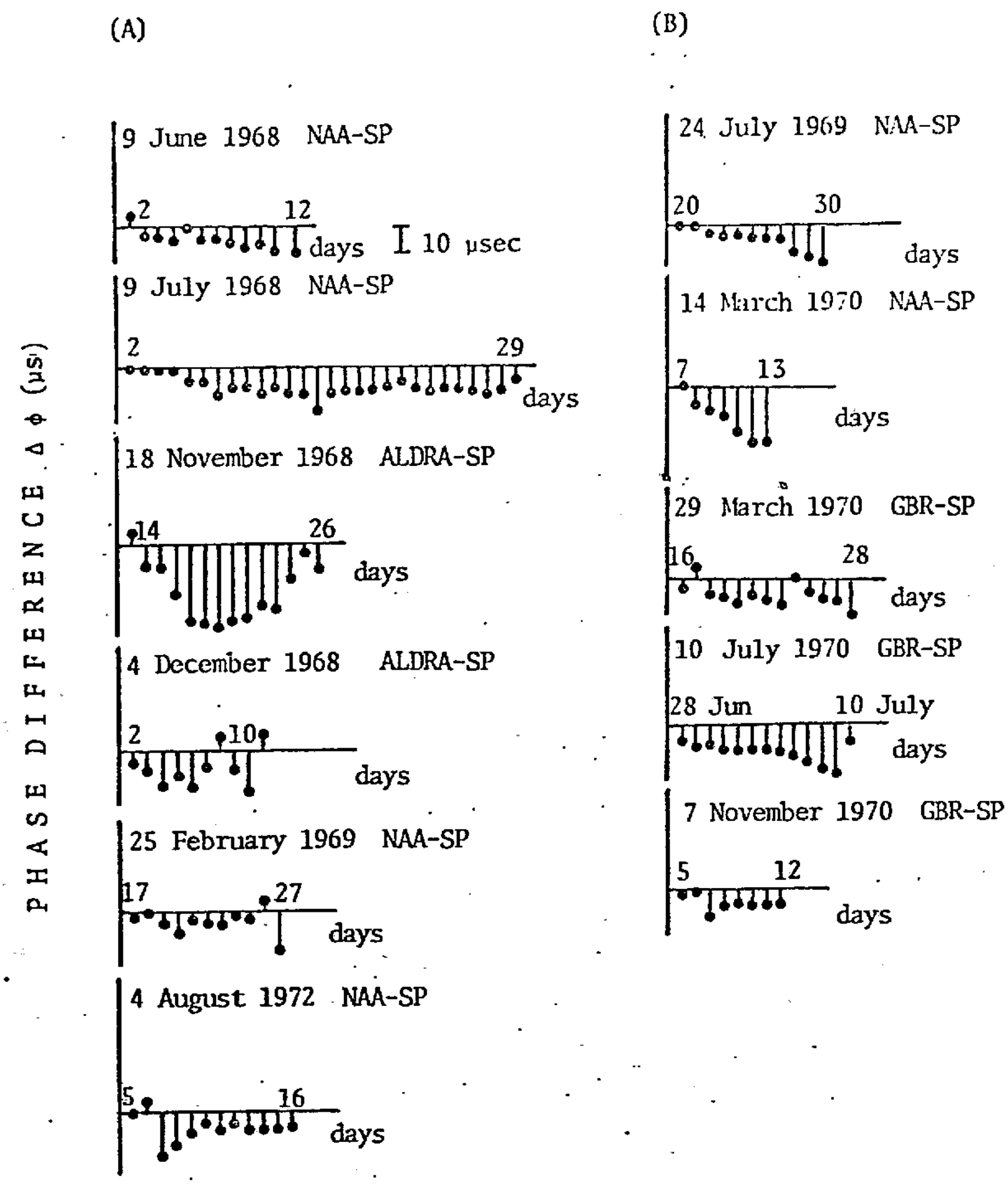
(A)
(B)
PHASE DIFFERENCE Δφ (μs)
9 June 1968 NAA-SP
2
12
days
10 μsec
9 July 1968 NAA-SP
2
29
days
18 November 1968 ALDRA-SP
14
26
days
4 December 1968 ALDRA-SP
2
10
days
25 February 1969 NAA-SP
17
27
days
4 August 1972 NAA-SP
5
16
days
24 July 1969 NAA-SP
20
30
days
14 March 1970 NAA-SP
7
13
days
29 March 1970 GBR-SP
16
28
days
10 July 1970 GBR-SP
28 Jun
10 July
days
7 November 1970 GBR-SP
5
12
days

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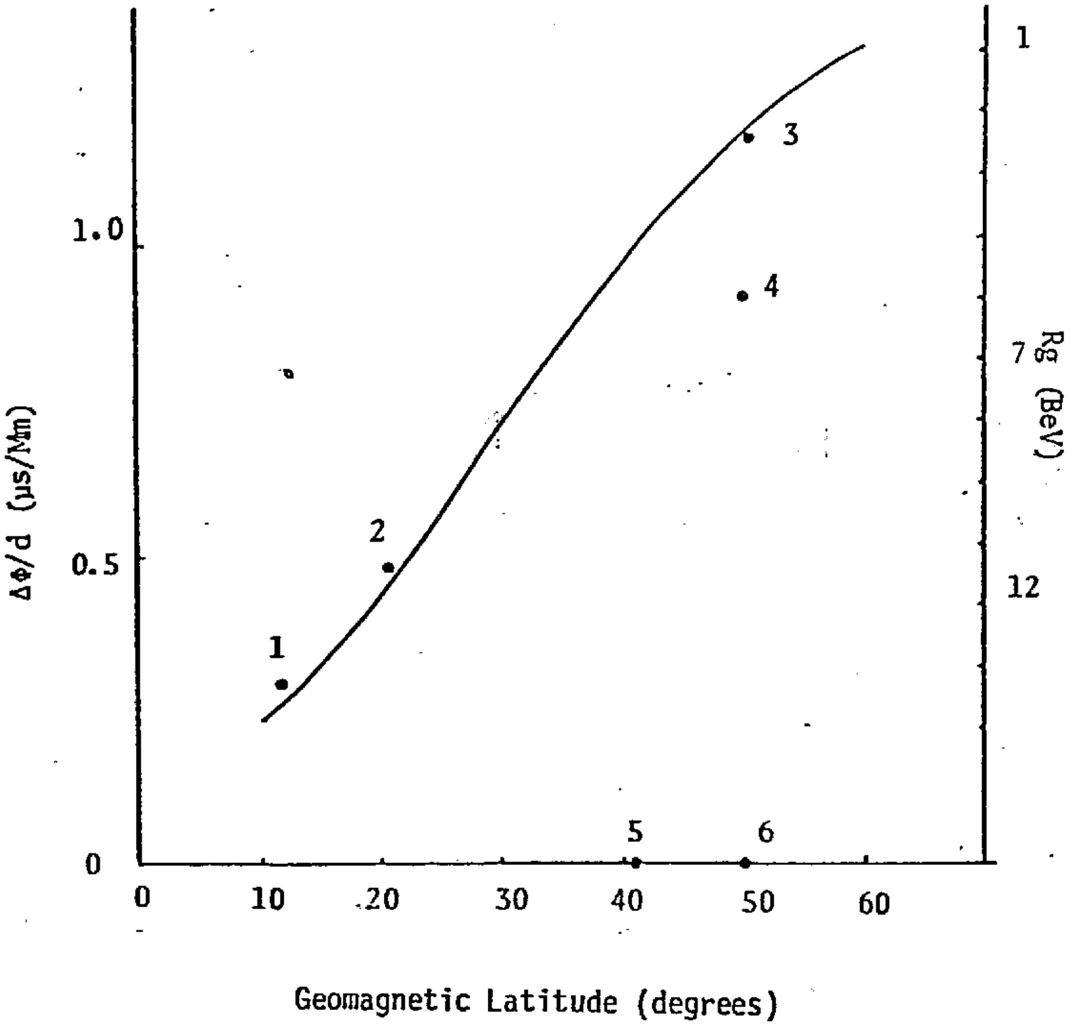

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Fig 4

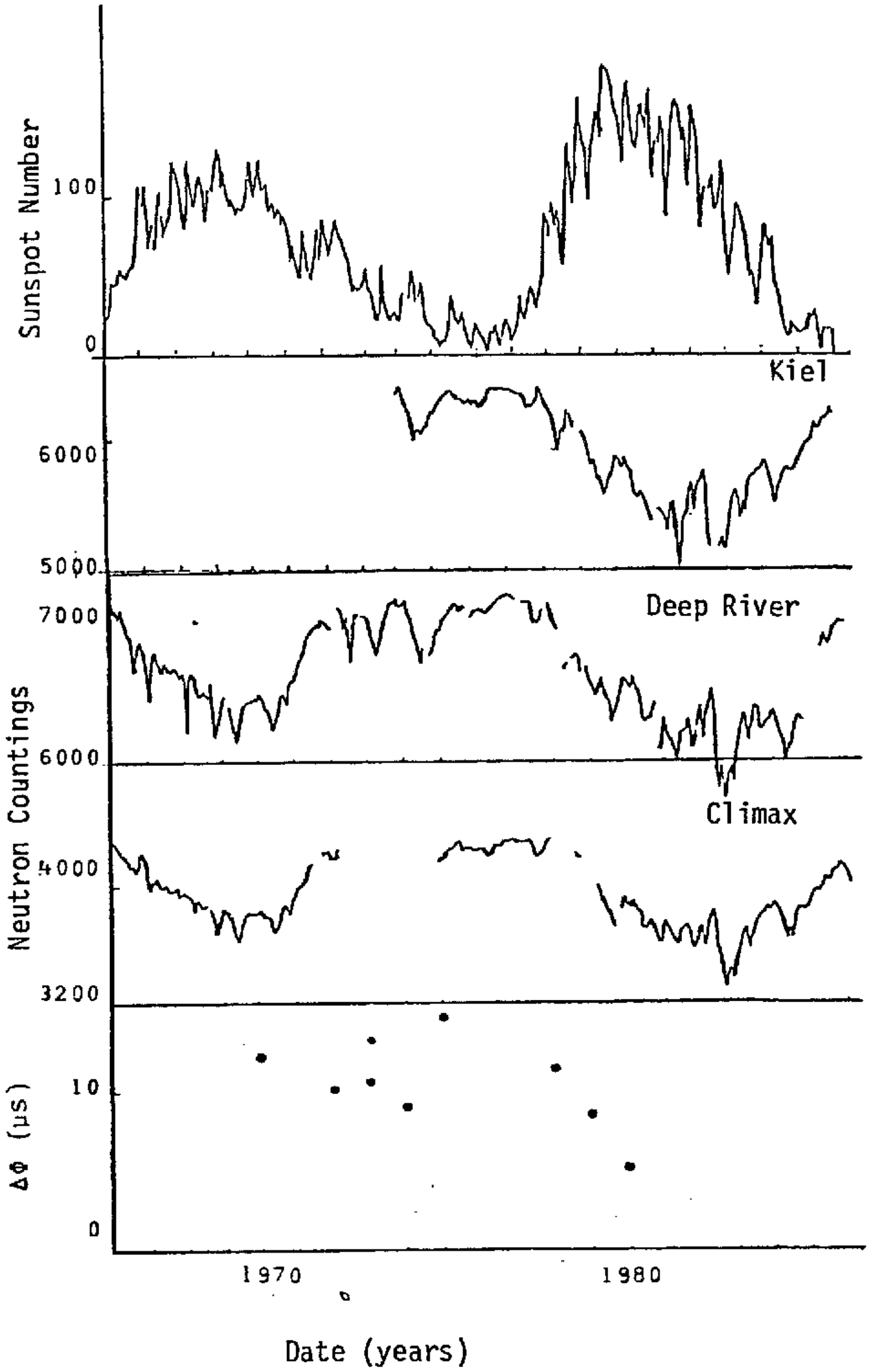
Sunspot Number
100
0
Kiel
6000
5000
Deep River
7000
6000
Climax
4000
3200
Neutron Countings
ΔΦ (µs)
10
0
1970
1980
Date (years)

Fig. 5

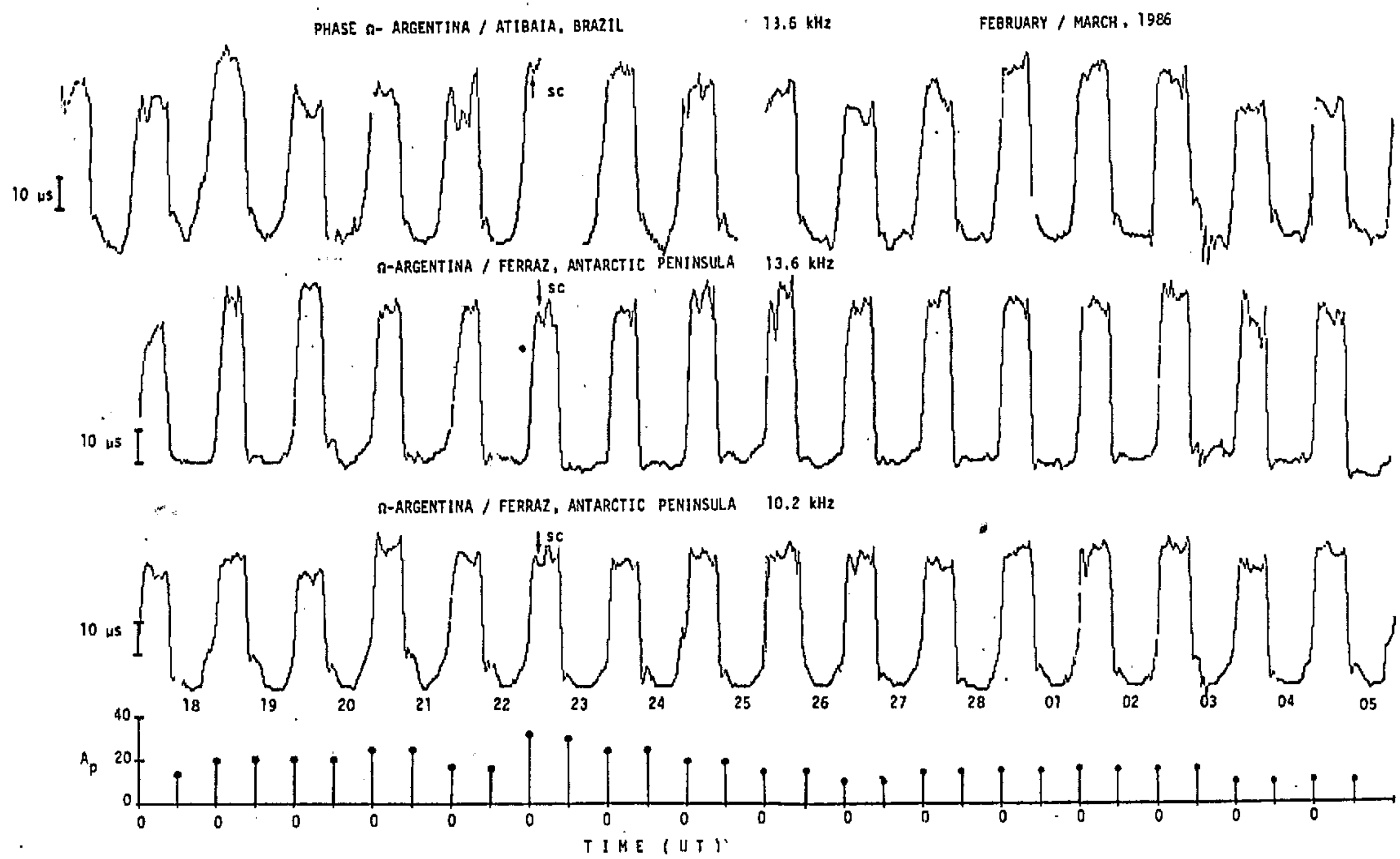

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Fig 6

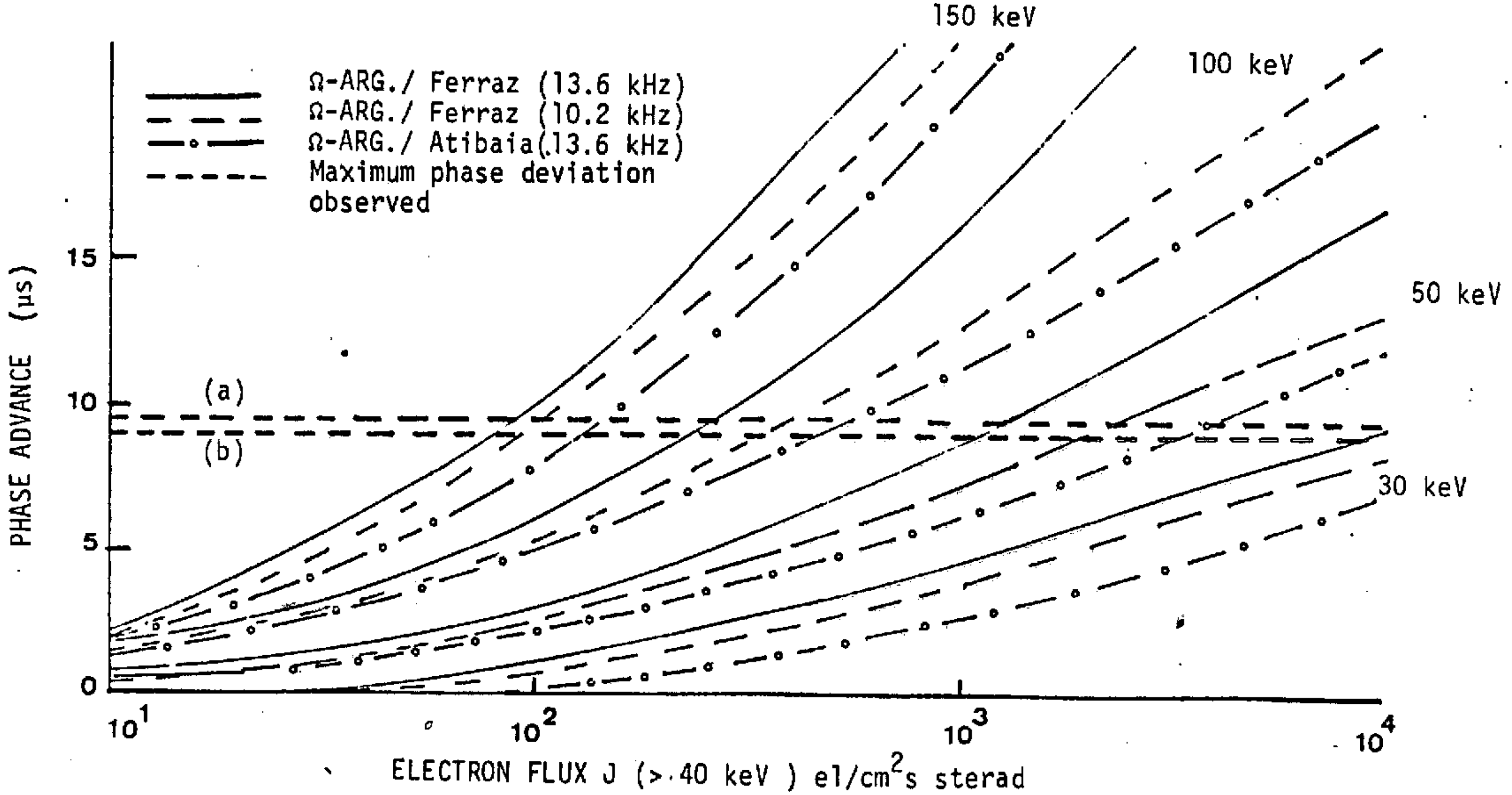
Ω-ARG./ Ferraz (13.6 kHz)
Ω-ARG./ Ferraz (10.2 kHz)
Ω-ARG./ Atibaia(13.6 kHz)
Maximum phase deviation observed
150 keV
100 keV
50 keV
30 keV
(a)
(b)
PHASE ADVANCE (μs)
15
10
5
0
10^1
10^2
10^3
10^4
ELECTRON FLUX J (>.40 keV) el/cm^2s sterad

Fig 7

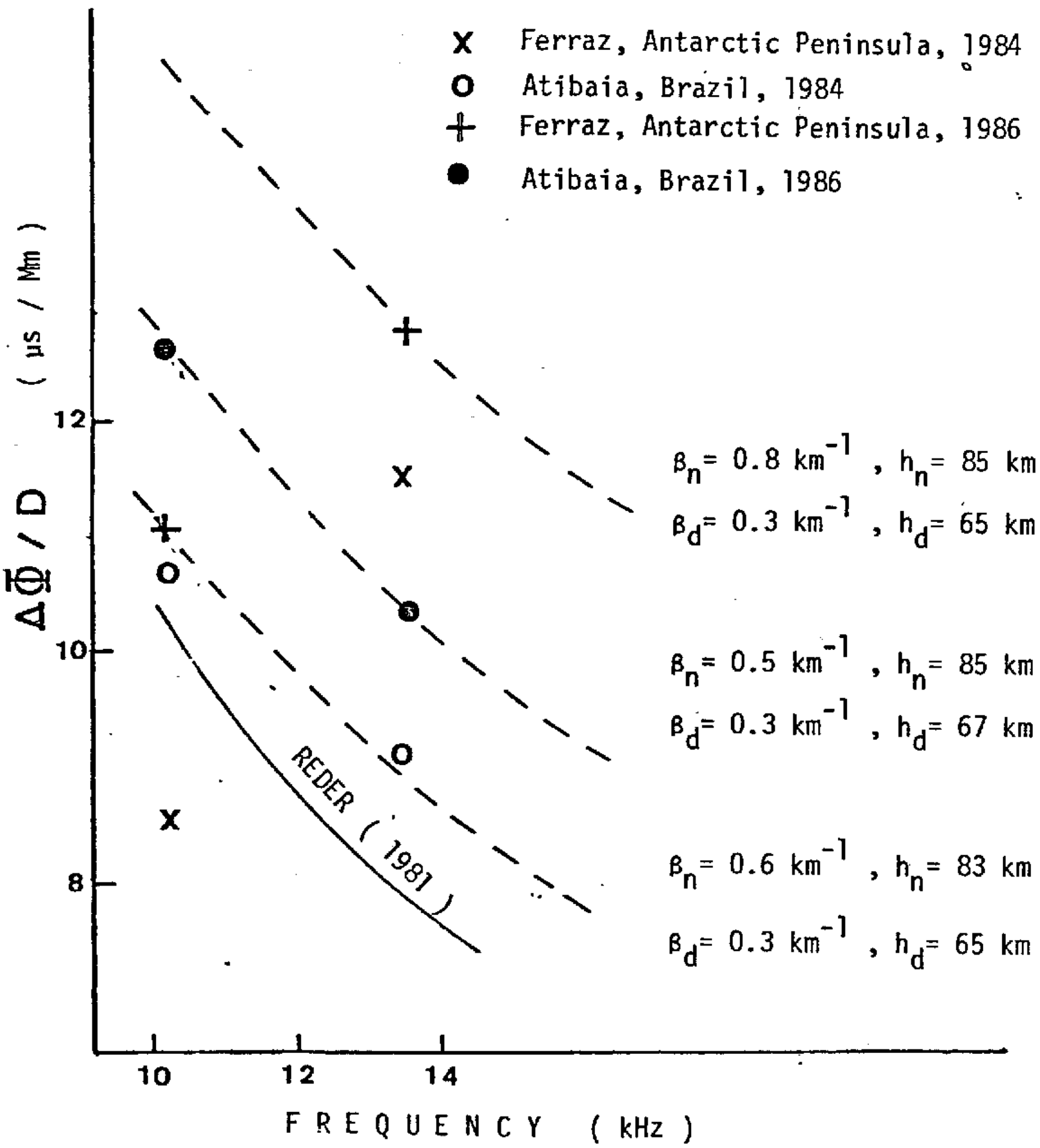

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Fig. 8

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L.R.Piazza, A.Mendes da Costa, P.Kaufmann
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