SURVEY OF VLF-OMEGA TRANSMISSIONS RECEIVED DURING SUMMER IN THE ANTARCTIC PENINSULA

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Abstract: Preliminary results are presented for about one month of measurements of all existing VLF-Omega transmissions, performed by amplitude and phase tracking receivers controlled by atomic frequency standards operated at Brazilian Antarctic station Ferraz, in February 1984. For the purpose of comparison, simultaneous measurements were taken at Itapetinga Radio Observatory, near São Paulo by a single amplitude and phase tracking receiver. Basic propagation characteristics in phase variation, signal strength and nighttime modal interference were established for all transmissions, for at least three days each. A more detailed survey was performed on Omega-Argentina transmission, which was tracked for the whole period. These transmissions displayed systematic nighttime mode conversion effects, which are characteristic of the sudden phase delay peak at sunrise. The mean diurnal phase variation of Omega-Argentina transmissions, received at Ferraz, displayed diurnal phase variations much larger than expected at 13.6 kHz, and much smaller at 10.2 kHz. About 90 SID's produced by solar flares were measured for various transmissions. They were analyzed comparatively on different transmission paths. Although there were flare-produced proton particles detected at satellite altitudes during the observing period, no substantial change in diurnal phase variation was detected on Omega-Argentina transmissions received at Ferraz.

A complete survey of VLF-Omega transmissions was carried out at the Brazilian polar station "Comandante Ferraz", located in King George Island, Antarctic Peninsula (62°05′S, 58°24′W), in February 1984. The measurements were made by four VLF amplitude and phase receivers controlled by atomic frequency standards. Simultaneous observations were carried out at Itapetinga Radio Observatory, Brazil (23°11′S, 46°33′W), for the purpose of comparison.

The survey was intended to determine the signal quality (strength and phase behavior) of all Omega transmitters at 10.2 and 13.6 kHz. We also intended to verify a number of peculiar propagation anomalies found during an earlier experiment (1982/1983) with a mobile VLF equipment on board of Brazilian polar ship BARÃO DE TEFFÉ. These studies were also needed to obtain a background information for a 12-month survey (planned) for 1986.

Table 1 provides information on the Omega (Comm) signals received both at Ferraz and at Itapetinga. Only the transmissions from Omega-Japan and Omega-Australia were highly attenuated at both sites. Nighttime modal interferences were found at Ferraz, for Omega-Aldra (10.2 and 13.6 kHz), Omega-Liberia (10.2 kHz only) and Omega-Argentina (13.6 kHz only). It might be significant to notice that

Table 1. VLF-Omega transmissions received at Ferraz Station and Itapetinga Radio Observatory.

Transmitter frequency (kHz) and location Omega (Comm)	Ferraz (62°05′S–58°24′W) $\Delta\phi/d$ (μs/Mm)	Itapetinga (23°11′S–46°33′W) $\Delta\phi/d$ (μs/Mm)	Signal strength (Carrier level at maximum intensity) in dB: Ferraz Level	Ferraz Quality	Itapetinga Level	Itapetinga Quality	Nighttime modal interference: Ferraz	Itapetinga
Aldra–10.2	8, 8	9, 4	0	Unstable	−05	Unstable	Yes	Yes
13.6	8, 4	8, 6	+12	Good	+ 8	Good	Yes	No
(13°E–66°N)								
Liberia–10.2	13, 3	11	+05	Good	+05	Good	Yes	Yes
13.6	8, 9	8, 0	+10	〃	+08	〃	No	No
(11°W–06°N)								
Haiku–10.2	10, 8	10, 2	+12	Good	+12	Good	No	No
13.6	7, 9	8, 1	+15	〃	+10	〃	No	No
(158°W–21°N)								
North Dakota–								
10.2	10, 5	11, 0	+12	Good	+05	Good	No	No
13.6	7, 2	7, 4	+10	〃	+12	〃	No	No
(98°W–46°N)								
La Reunion–10.2	10, 6	11, 0	+10	Good	+05	Good	No	No
13.6	7, 9	8, 9	+05	〃	+ 8	〃	No	No
(55°W–43°S)								
Argentina–10.2	8, 5	10, 9	+08	Good	+12	Good	No	No
13.6	11, 3	9, 3	+10	〃	+10	〃	Yes	No
(65°W–43°S)								
Austràlia–10.2	—	—	+ 5	Bad	+10	Good	—	—
13.6	—	—	0	〃	+10	〃	—	—
(147°E–38°S)								
Japan–10.2	—	—	−15	Bad	+08	Good	—	—
13.6	—	—	−15	〃	+08	〃	—	—
(130°E–35°N)								

the two first transmissions are the only ones which cross the South Atlantic Anomaly (SAA). The anomalies for Argentina transmissions are discussed later.

The typical diurnal phase variations in microsecond/megameter for long-distance VLF propagation paths ($d \gtrsim 1$–2 Mm) were derived semi-empirically by REDER (1981), who obtained the plot shown in Fig. 1. In Fig. 2 we show the diurnal phase variations obtained for the various VLF-Omega (Comm) transmissions at Ferraz and Itapetinga, compared with REDER's (1981) predictions for "well behaved" paths. Except for Liberia (10.2 kHz), Argentina and Aldra (10.2 and 13.6 kHz) transmissions, all the other transmissions present plausible diurnal phase variations at Ferraz. At Itapetinga all transmissions can be considered as fairly well behaved.

The most striking anomalies were found at Ferraz for Omega-Argentina transmissions both at 10.2 kHz (too small) and at 13.6 kHz (too large), as compared with Reder's prediction and with signals received at Itapetinga, along a comparable path length (see Table 1). In Fig. 3, a sample of three days recording of 10.2 kHz phase is shown, exhibiting the considerably smaller diurnal phase variation obtained at Ferraz, compared with the Itapetinga data. The plots are smoothed out in a 10 min data

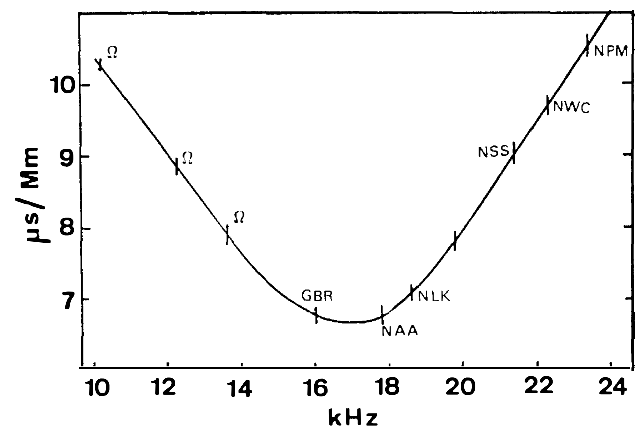

Fig. 1. *Diurnal phase variation, normalized to the distance, dependence on frequency predicted for well-behaved long-distance VLF propagation paths* (*REDER, 1981*).

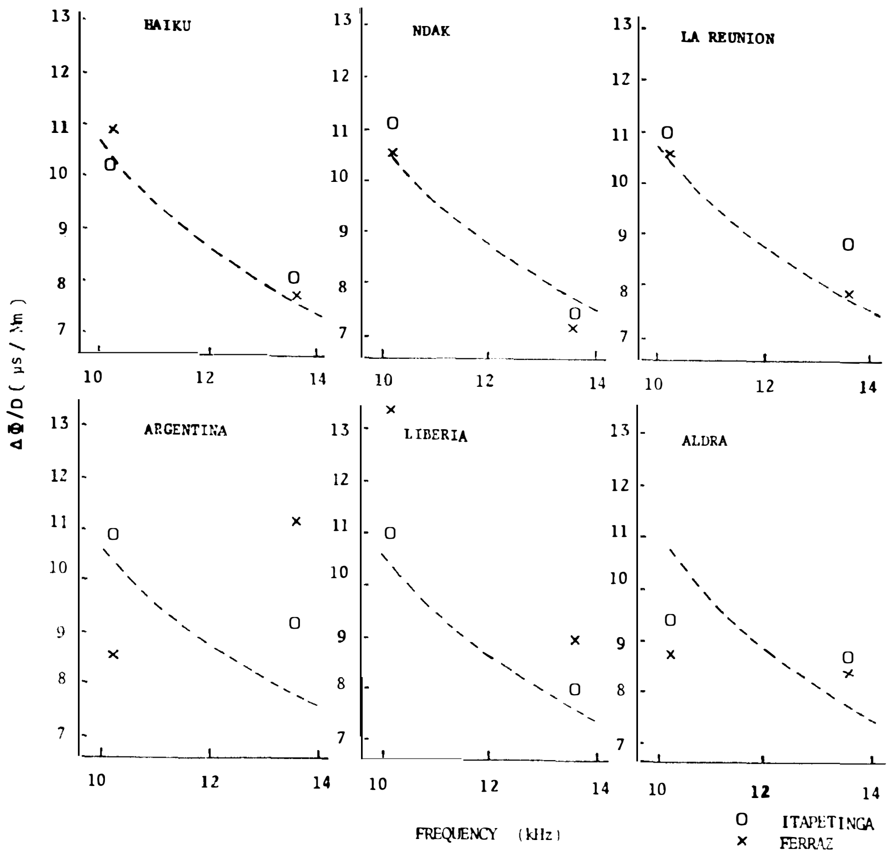

Fig. 2. *Diurnal phase variation, normalized to the distance, for VLF-Omega transmissions received in the Antarctic Peninsula during the summer, compared with the predicted variation* (*from Fig. 1*).

sampling.

The Omega-Liberia transmissions cross the South-Atlantic Anomaly, which produce a disturbance in the earth-ionosphere waveguide which might be responsible for the nighttime modal interferences and high diurnal phase variations observed at 10.2

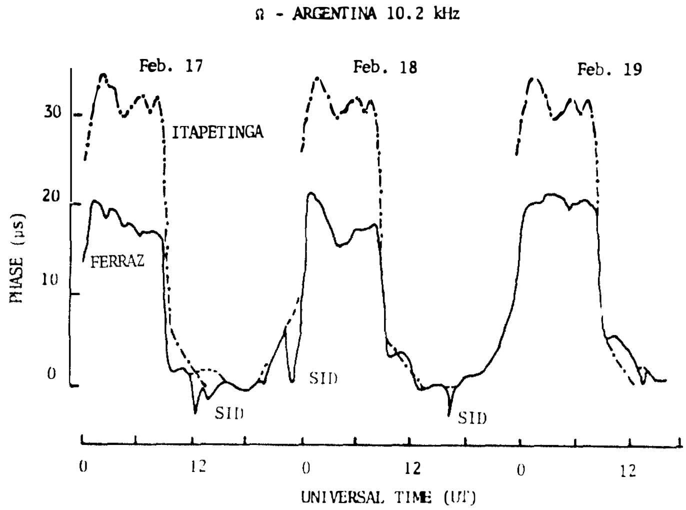

Fig. 3. Diurnal phase (in μs) of 10.2 kHz Omega-Argentina transmissions received at Ferraz Station (62°05′S, 58°24′W) (d=2.2 Mm) and at Itapetinga (23°11′S, 46°33′W) (d=2.8 Mm).

kHz at Ferraz. The diurnal phase variation, however, appears as normal at 13.6 kHz, which is not quite understandable.

The Omega-Argentina transmissions to Ferraz do not cross any known anomaly on the upper atmosphere. The propagation path runs along the coastline, but over water. The shortest distance from the south end of the Andes Mountain Range to the transmission path is about 200 km. Therefore, it might not be likely that such geographical discontinuity is important for producing standing waves at VLF (BARR and HELM, 1982). On the other hand, the typical diurnal phase variation established by REDER (1981) might be too much simplified, and the path we are considering is on the limit length of its validity.

Clear nighttime modal interferences were noticed in the 13.6 kHz transmissions from Omega-Argentina to Ferraz Station. They appeared as a nighttime slow phase advance, followed by a rapid phase delay peaking at the lower ionosphere sunrise time. The effect was observed for all days of the survey (11–29 February 1984). In Fig. 4 we show two examples of the effect, and in Fig. 5 there is a plot of the time of the day the peak phase delay was observed, against the date, exhibiting an excellent correlation as expected from the daily sunrise time predicted delay.

During the present survey about 90 SID's were detected at different transmission paths observed. The sun was particularly active in the period. However, no effects characteristic of particle precipitation were identified. In Fig. 6 there is a comparison of SPAs (sudden phase anomalies), expressed in normalized scale (μs/Mm) for the events observed simultaneously at Ferraz and Itapetinga, at 13.6 kHz. The data points are fairly well correlated. A few events with smaller phase advances at Ferraz can be explained by the larger mean solar zenith angle of the corresponding transmission path. The SID's obtained during the survey are now being analyzed in comparison with the X-ray fluxes and energy spectra produced by the solar flares, detected on board of SMM satellite.

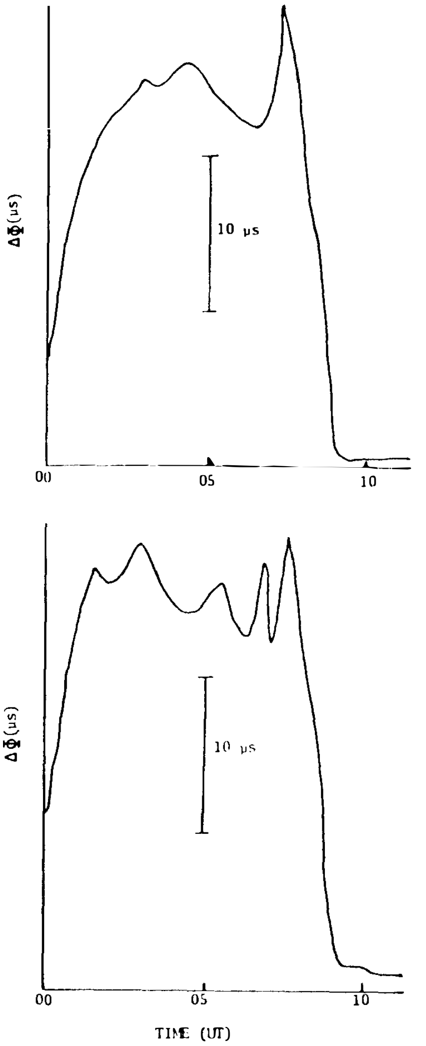

Fig. 4. *Nighttime modal interference effects on Omega-Argentina, 13.6 kHz, shown for two selected days. Upper: February 13, 1984, lower: February 17, 1984. Transmitter: Argentina (43°03′S, 65°11′W), receiver: Ferraz (62°05′S, 58°24′W). A sharp phase delay occurred at region's sunrise time (see Fig. 5), of about 2.8 μs/Mm.*

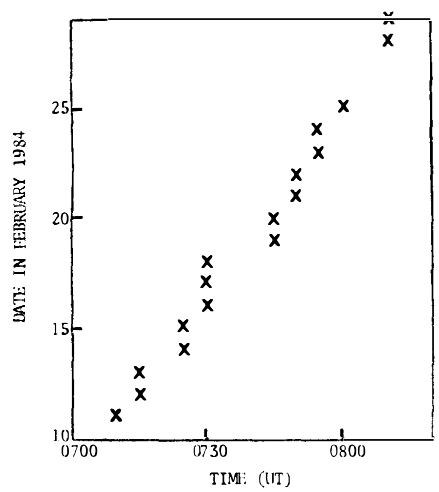

Fig. 5. *Plot of UT time occurrence of the peak phase delay (Fig. 4) of 13.6 kHz transmissions from Omega-Argentina, against the date of observation, confirming the association of the effect to the sunrise in the region.*

In summary, the VLF-Omega emissions (10.2 and 13.6 kHz) received at the Antarctic Peninsula during the summer are sufficiently strong and exhibit predictable diurnal phase variations for most transmissions. The very distant transmissions (Japan and Australia) are highly attenuated, due to possible effect of partial propagation on the ice. Nighttime modal interferences are noticed on transmission paths crossing the SAA (Aldra and Liberia), and also on Argentina, at 13.6 kHz. Omega-Argentina transmissions at 10.2 and 13.6 kHz present anomalous diurnal phase variations, which might be attributed to the relatively short propagation path. In spite of very pronounced solar activity in the period of observation (February 1984) there was no clear

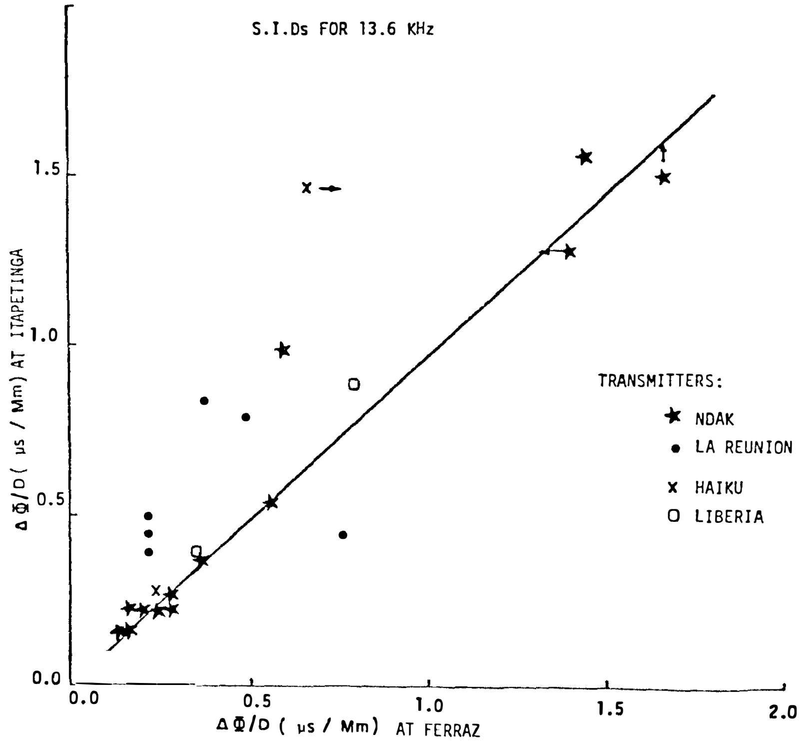

Fig. 6. Sudden phase advances (SPAs) observed simultaneously at Ferraz Station and at Itapetinga, on various Omega transmissions.

effect of particle precipitation on the transmissions monitored. This survey will be completed with a long-term observational program (12 months) under quiet sun conditions.

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