Journal of Geophysical Research, Space Physics Vol. 74, No. 9, May 1, 1969

Latitudinal Cutoff of VLF Signals in the Ionosphere

R. L. Heyborne

Department of Electrical Engineering
Utah State University, Logan, Utah 84321

R. L. Smith and R. A. Helliwell

Radioscience Laboratory
Stanford University, Stanford, California 94305

The polar-orbiting OGO 2 satellite, receiving 18-kHz manmade VLF signals from the ground, shows a latitudinal cutoff of these signals between roughly 50° and 70° invariant latitude. The signal cutoff ranges from 10 to 40 db magnetic field attenuation and is frequently followed by strong noise believed to be auroral hiss. In about half of the cases the VLF signals from the ground again become detectable beyond the region of noise generation. There is a tendency for the cutoff to be more pronounced during the daytime than during nighttime, and the latitude of the cutoff tends to decrease with increasing *Kp*. Onset of the attenuation effect is sometimes as large as 40 db over a distance as small as a few kilometers. It is concluded that the latitudinal cutoff occurs over the ionospheric rather than the subionospheric portion of the path.

Introduction

Since 1966 it has been known that manmade VLF signals from the ground as observed in polar-orbiting satellites tend to be cut off above a geomagnetic latitude in the vicinity of 60° [*Heyborne*, 1966]. Various recent studies have related this VLF cutoff to the observation that whistlers received in polar-orbiting satellites also tend to be cut off above a geomagnetic latitude of approximately 60°. *Carpenter et al.* [1968] have shown that the latitude of the cutoff of whistlers reaching the satellite after one or more passages across the equator is closely connected with the position of the plasmapause. However, this study did not show over what parts of the whistler path attenuation was taking place. Also the variability in occurrence and uncertainty in the strength of the whistler sources prevented determination of the magnitude profile of the cutoff.

The purpose of this report is to give some preliminary results of a study of the latitudinal cutoff of manmade VLF signals near 18 kHz that traveled over the 'short' path to the OGO 2 satellite. As in the previous study, the cutoff occurred between roughly 50° and 70° invariant latitude. The signal cutoff, which ranged from 10 to 40 db magnetic field attenuation, frequently was followed by strong noise, suggestive of auroral hiss, peaking at auroral latitudes. In about half the observations the VLF signals from the ground again became detectable beyond the region of noise generation (i.e., in the region of the polar cap).

A loop antenna was employed to detect the signals; other details of the satellite receiver are given elsewhere [*Ficklin et al.*, 1965]. In this particular experiment, the OGO 2 sweep-frequency receiver was fixed-tuned to nearly 18 kHz so that both stations NPG (radiating 250 kw from Jim Creek, Washington) on 18.6 kHz, and station NAA (radiating 1000 kw from Cutler, Maine) on 17.8 kHz were normally received simultaneously. The bandwidth of the receiver was approximately 500 Hz. Another receiver on the satellite was tuned to NPG only.

The satellite was in a polar orbit with an apogee height of 1507 km and a perigee height of 415 km. Only the cutoffs observed in the northern hemisphere, where the transmitters are located are considered in this report because of the complications due to a cutoff in the southern hemisphere related to the minimum gyrofrequency [see *Heyborne*, 1966].

Experimental Results

Examples of the latitudinal propagation cutoff are shown in Figure 1. The three examples

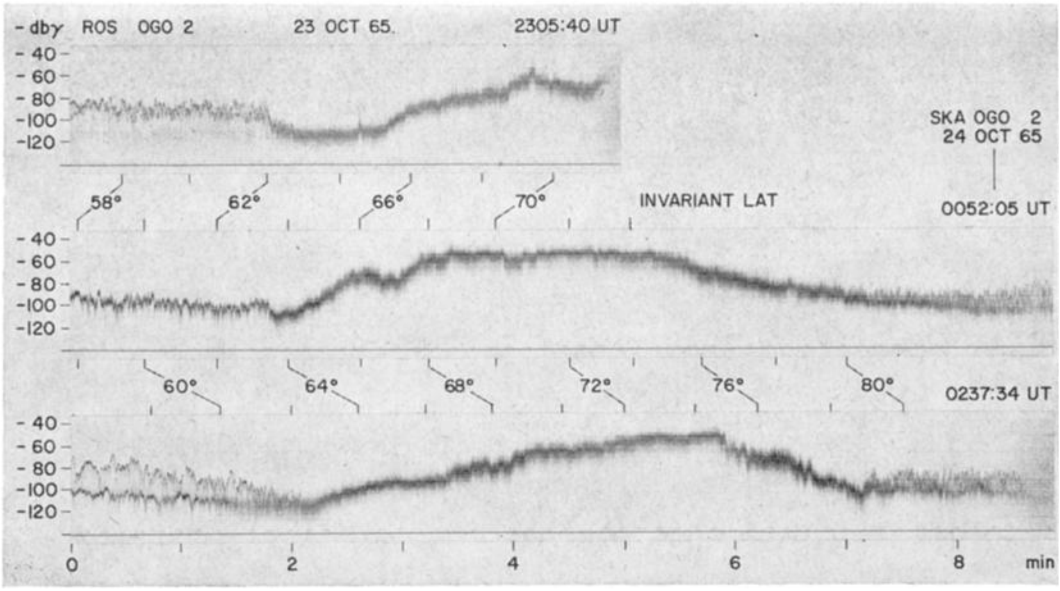

Fig. 1. Examples of the latitudinal propagation cutoff, aligned approximately with respect to the time of maximum decrease of signal strength. In the top and bottom records both stations NPG and NAA are present. In the middle record only NAA was being received. In each example the decrease in signal strength occurring near 1.8 minutes from the beginning of the record is followed by an increase in background noise.

are aligned approximately with respect to the time of maximum decrease of signal strength that occurs at roughly 1.8 minutes from the beginning of the record. In the top and bottom records both stations NPG and NAA are present. The fading patterns for the two stations are qualitatively similar but different in detail. In the middle record only NAA (frequency shift modulation) was being received. The invariant latitude for each of the three records is shown by the scale between the records. In each of the three examples the decrease in signal strength occurring near 1.8 minutes is followed by an increase in the background noise. In the top panel the cutoff of the signal is followed by a 1-minute period of relative quiet, corresponding to a satellite travel distance of roughly 400 km. The noise then increased to a value well above the previous level of the ground signals, before the recording was terminated by telemetry failure. In the middle panel the noise peaks between 68° and 75° invariant latitude, and as it fades away the signal from NAA is observed to return at about 80°. Because the noise may exceed the ground signal by a considerable factor, it is not clear whether the signal is in fact entirely absent during reception of the noise.

The track of the subsatellite point corresponding to the top record is shown in Figure 2, in which dipole magnetic coordinates are superimposed on a Mercator projection of the earth. It is seen that the satellite is roughly equidistant from the two transmitters. Examination of an expanded version (not shown) of the top record of Figure 1 shows that before 1.8 minutes NAA is on the average a little stronger than NPG, but that NPG disappears into the noise about 10 seconds later than NAA. This slight difference in fadeout times is not yet understood, but it is not considered significant for the purposes of this study since the corresponding latitude change is about ½°.

More accurate data on the amplitude of the NPG signals appearing in the top record of Figure 1 were obtained on the second receiver and are plotted on an expanded time scale in Figure 3. It is seen that the field strength decreases very abruptly at about 23h07m29s UT. The magnitude of the step at this time is about 15 db, and the slope is estimated to be about 16 db/sec, or roughly 2 db/km. A more gradual

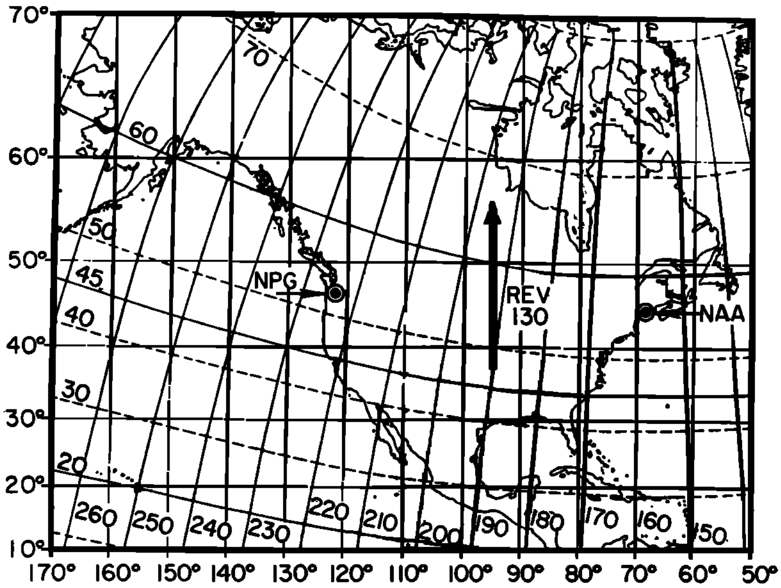

Fig. 2. The track of the subsatellite point corresponding to the top record in Figure 1. Dipole magnetic coordinates are superimposed on a Mercator projection of the earth.

decrease follows, and the over-all change in field strength from the beginning of the drop at 28 seconds to loss of the signal is about 40 db. A summary of 17 such observations obtained in October 1965 is given in Table 1, which shows the latitude range and the db change observed. The difference between daytime (1600 LMT) and nighttime (0400 LMT) data is not very pronounced, but there is a tendency for the larger changes to occur during daytime (24.5

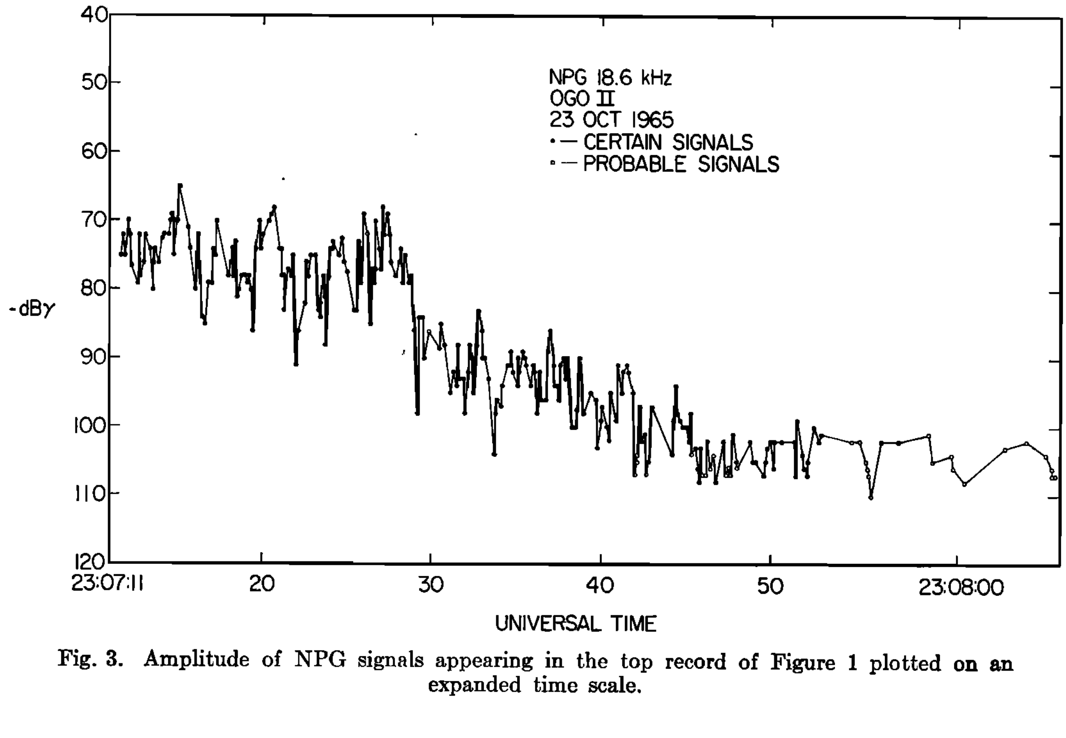

Fig. 3. Amplitude of NPG signals appearing in the top record of Figure 1 plotted on an expanded time scale.

TABLE 1. Latitudinal Cutoff Data for NPG and NAA during October 1965

Approx. Local Time	Starting Latitude, deg		Cutoff Latitude, deg		Signal decrease, db	
	Range	Median	Range	Median	Range	Median
1600 LMT (10 cases)	50–73	60	54–77	66.5	15–40	24.5
0400 LMT (7 cases)	40–69	57	50–74	64	10–32	18
Both (17 cases)	40–69	58	50–77	64	10–40	20
Kp Range						
0–2 (quiet)	50–77	69	59–77	75	10–32	17
2–4 (moderately disturbed)	40–63	57	50–73	60	12–40	22

db) than during nighttime (18 db). Division of these data into quiet ($0 < Kp < 2$) and moderately disturbed ($2 \lesssim Kp \leq 4$) groups show a trend in which the latitude of observation decreases (12°–15°) with increasing *Kp*. A similar trend has been reported for the position of the plasmapause by *Carpenter* [1966].

Discussion and Conclusion

It seems clear that the latitudinal cutoff occurs over the ionospheric rather than the subionospheric portion of the path. First, there is no evidence that cutoffs of the magnitude and sharpness reported here are observed in ground recordings of VLF intensity as a function of distance. Second, the frequent return of the signal to the satellite at latitudes *above* the cutoff demonstrates that the cutoff must occur over the ionospheric segment of the path.

The cutoff just described may be related to the cutoff of whistlers observed on the Alouette 1 and 2 satellites [*Carpenter et al.*, 1968]. On these satellites an electric antenna was employed, and both lower hybrid resonance anomalies as well as whistler cutoffs were observed in close association with the plasmapause. Comparison of the present data with plasmapause locations suggests a close association in many instances, but some discrepancies have been observed that are not yet understood and are still under study.

Because the propagation path is located below the satellite [*Heyborne*, 1966], we must look for an attenuation mechanism below about 1000 km altitude. One factor of possible importance is the change in wave impedance connected with a decrease in electron concentration at the knee. However, assuming the very large reduction of two orders of magnitude in electron concentration, and that the power density of the transmitted wave remains constant, the magnetic field strength would decrease only 10 db [*Helliwell,* 1965], whereas the changes range up to 40 db, with a median of 20 db. Furthermore the electric antennas employed on Alouette 1 and 2 would see an increased electric field if this were the only propagation factor involved in both experiments. Of course, it is possible, and perhaps likely, that the cutoff of the long whistlers on Alouette 1 and 2 is related to failure of propagation along the magnetospheric portion of the path outside the knee. Signals propagating within the plasmasphere would probably be reflected if they encountered the plasmapause. The large change in electron concentration in the ionosphere near the knee will cause reflection of energy in a region just above such a change. This mechanism is probably responsible for at least the initial drop in VLF signal amplitude.

Another explanation is an increase in absorption in the lower ionosphere. The association of intense noise with the signal cutoff supports this suggestion. Thus the noise could be caused by a flux of particles with a component capable of increasing the electron concentration in the lower ionosphere. We estimate the total integrated absorption required during daytime is about 50 db and that this value could be obtained with a relatively modest increase in *D*-region electron concentrations of perhaps a factor of 2.

The noise that follows the cutoff of signals from the ground resembles the auroral zone hiss reported by others [*Jørgensen,* 1966, 1968; *Gurnett,* 1966]. Thus the peak hiss intensity at 18 kHz is of the order of -60 db γ in a 500-Hz bandwidth, corresponding to a magnetic spectral density of $0.5 \times 10^{-9}\gamma^2$/Hz. This value is consistent with data on auroral hiss reported from the same experiment on OGO 2 [*Jørgensen,* 1968] and is typical of the peak of noise measured with Injun 3 at 8.8 kHz [*Gurnett,* 1966]. The latitudes of observation are likewise comparable. We conclude therefore that the noise reported here is that generally identified as auroral hiss.

The phenomenon reported in this report is important for several reasons. In communications between satellite and ground at VLF, the signal-to-noise ratios would be reduced in the auroral regions. The cutoff in signal propagation from the ground provides a new tool for the study of ionospheric properties. The rapid onset of the attenuation effect, sometimes occurring over a distance as small as a few kilometers indicates the presence of a sharp latitude discontinuity in one or more parameters of the ionosphere. Spatial resolution of this order would be difficult to obtain using other techniques, such as riometers. The close association of intense noise with an absorption effect offers a new approach to the study of the mechanism of generation of this noise. A combination of noise measurements and absorption measurements may eventually provide new information on the particle distribution and the amount of dumping into the lower ionosphere.

Acknowledgment. This research was supported in part by the National Aeronautics and Space Administration under contracts NAS 5-3093 and NGR 05-020-288 and grant NSG 174/SC-05-020-008 at Stanford University and in part by the National Science Foundation, under grant GK-1597 at Utah State University.

References

Carpenter, D. L., Whistler studies of the plasmapause in the magnetosphere, 1, Temporal variations in the position of the knee and some evidence on plasma motions near the knee, *J. Geophys. Res., 71,* 693. 1966.

Carpenter, D. L., F. Walter, R. E. Barrington, and D. J. McEwen, Alouette 1 and 2 observations of abrupt changes in whistler rate and of VLF noise variations at the plasmapause—A satellite-ground study, *J. Geophys. Res., 73,* 2929, 1968.

Ficklin, B. P., M. E. Mills, L. E. Orsak, L. H. Rorden, and R. H. Stehle, Description and operation of the instruments for the Stanford University/Stanford Research Institute experiment (5002) to be flown on the POGO satellite, *Tech. Mem. 2, SRI Project 4424,* Stanford Research Institute, Menlo Park, Calif., March 1965.

Gurnett, D. A., A satellite study of VLF hiss, *J. Geophys. Res., 71,* 5599, 1966.

Helliwell, R. A., Whistlers and related ionospheric phenomena, Stanford University Press, 1965.

Heyborne, R. L., Observations of whistler mode signals in the OGO satellites from VLF ground station transmitters, Ph.D. thesis, SEL-66-094, Radioscience Lab., Stanford Electronics Labs., Stanford University, Stanford, Calif., November 1966.

Jørgensen, T. S., Morphology of VLF hiss zones and their correlation with particle precipitation events, *J. Geophys. Res., 71,* 1367, 1966.

Jørgensen, T. S., Interpretation of auroral hiss measured on OGO 2 and at Byrd Station in terms of incoherent Cerenkov radiation, *J. Geophys. Res., 73,* 1055, 1968.

(Received January 22, 1969.)