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'Hisslers': Quasi-Periodic ($T \sim 2$ s) VLF Noise Forms at Auroral Latitudes

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The previously reported 'hissler' phenomenon has been studied by means of broad band VLF data from antarctic ground stations and from the polar-orbiting Ogo 2 and Ogo 4 satellites. Hisslers are quasi-periodic broad band VLF auroral noises that typically present a falling-tone characteristic on frequency-time spectrograms and often appear in minute-long sequences with spacing between individual bursts of the order of 2 s at a given frequency. The falling tones do not usually overlap in time; instead a new one tends to develop as the previous one ends. The falling-tone noises are a feature of auroral hiss, in that they occur during time intervals when hiss is observed at ground stations and in portions of space where hiss is observed on polar-orbiting satellites. A survey was made of 1500 Ogo 4 magnetic loop antenna records from the vicinity of Alaska and of the Antarctic. Hisslers were observed at various points from 58° invariant latitude to the mid polar cap, occurring on approximately 40% of the passes. Hisslers were observed from Ogo 4 in various local time and latitudinal sectors of the auroral oval, but there was some evidence of a concentration near $\Lambda = 75°$ and in the premidnight sector. At Byrd, Antarctica ($L \sim 7$), hisslers are frequently observed prior to the expansion phase of a substorm and during a part of the expansion phase when hiss is detectable on the ground. The study suggests that centers of hissler activity are present on nearly all days, that they may be somewhat localized in space, and that they may be active for periods of several hours.

Broad band VLF noise is a regular feature of both satellite and ground observations at auroral latitudes and is associated observationally with various evidence of high-latitude particle precipitation [e.g., *Martin et al.*, 1960; *Gurnett*, 1966; *Morozumi and Helliwell*, 1966; *Jorgensen*, 1966; *McEwen and Barrington*, 1967; *Flint*, 1968; *Hughes and Kaiser*, 1971]. This high-latitude noise, frequently called 'auroral hiss,' may exhibit wide temporal and spatial variations in detail but is not generally recognized as containing quasi-periodic fine structure. The present study discusses the occurrence of such fine structure and identifies it as a relatively common phenomenon. The fine structure typically presents a quasi-periodic falling-tone characteristic on frequency-time spectrograms, with spacing between individual falling tones of the order of 2 s at a given frequency. At ground stations the tones or noise elements appear in sequences lasting from minutes to several hours. Satellite data suggest that centers of falling-tone activity may be somewhat localized in space but may be active for periods of several hours.

Figure 1 shows frequency (0–10 kHz) versus time records of two examples of the phenomenon, one (above) recorded at the U.S. station Byrd, Antarctica (70° invariant latitude), and the other at the USSR station Vostok (86° invariant latitude). A 10-s interval is marked below each of the panels. On the upper record the sloping noise elements initially appear against an intense background of broad band noise, and there is a gradual change in the lower limiting frequency of the elements with time. On the lower record the activity is more complex, exhibiting much fine structure and an apparent increase with time in the lower limiting frequency of some of the noise elements. In the upper record a typical separation between elements is 2 s, and in the lower record it is about 3 s.

The falling-tone noises are a feature of auroral broad band hiss, in that they occur during time intervals when such hiss is observed at ground stations and occur in portions of space where auroral hiss is observed on polar-orbiting satellites. *Siren* [1972] has suggested that the noises be called 'hisslers,' in recognition of the whistlerlike appearance of some examples on spectrograms. The phenomenon actually exhibits a great variety of forms, but the term hissler will be used for convenience in this report.

Hisslers were first noted by *Morozumi and Helliwell* [1966] and were described in some detail in an oral presentation by Leif Owren at the 1969 spring U.S. URSI meeting in Washington, D. C. An example of a hissler observed at Byrd, Antarctica, during the expansion phase of a substorm was recently shown by *Carpenter et al.* [1971]. *Siren* [1972] has described a 'fast' hissler that exhibits an extremely rapid variation in frequency with time but not an extended series of repetitions. The purpose of this paper is to provide a preliminary description of hisslers received at both high-latitude ground stations and on polar-orbiting satellites. The study was conducted during a visit by one of the authors (I.U.) to Stanford University.

SOURCES OF DATA AND METHOD OF ANALYSIS

A primary source of data was broad band VLF recordings at the antarctic stations Byrd (80°S, 120°W), Plateau (80°S, 40°E), and Vostok (78°S, 107°E). An extensive statistical treatment was not possible in the time available, but many records of the kind illustrated in Figure 1 were examined, particularly those from Byrd station. These records were frequently supplemented by slow-speed chart recordings containing continuous information on VLF noise, ionospheric absorption, geomagnetic field perturbations, etc.

The other principal source of data was satellite real time recordings of broad band VLF from the Stanford University/Stanford Research Institute ac magnetic field experiments on the polar-orbiting satellites Ogo 2 and 4. Records from nearly 1500 Ogo 4 satellite passes over the auroral oval were examined, roughly half from near College, Alaska, during the period August to November 1967 and half from near Byrd, Antarctica, during the period March to September 1968. The Ogo 4 orbit is inclined at 86°, with perigee of ~400 km and apogee of ~900 km.

An example of a satellite frequency-time record (0–12.5 kHz) is shown in the top panel of Figure 2. A ~1-min sequence

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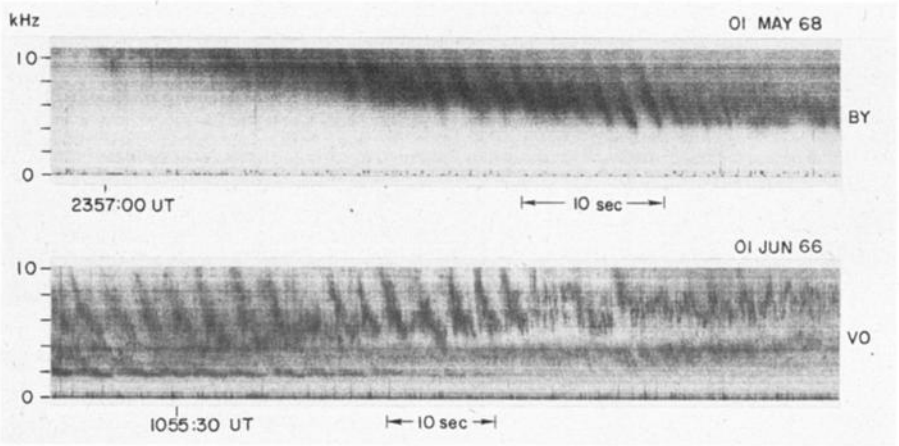

Fig. 1. Frequency-time records illustrating hisslers observed at the antarctic high-latitude ground stations Byrd (Λ = 70°) and Vostok (Λ ~ 86°).

of hisslers begins near 1427 UT and is preceded and followed by other forms of hiss activity.

EXPERIMENTAL RESULTS: GROUND OBSERVATIONS

Recognition of hisslers on frequency-time records is often complicated by the presence of background noise but is facilitated by the repetitive broad band nature of the signals and their frequent tendency to extend below the limiting frequency of the background noise. In Figure 1, upper panel, the noise activity at first appears relatively unstructured, but hissler elements become clearly evident as the lower frequency limit of the noise reaches ~6 kHz. In Figure 3, middle panel, the extension of hisslers below a background noise band is particularly well defined between 0202 and 0203 UT.

The ground station records suggest that hisslers are detectable at Byrd, Antarctica (Λ ~ 70°), on nearly every austral winter night. The activity may last from a few seconds to several hours. Observed intervals between successive hissler elements are in the range 0.5–10 s; the most common periods are between 2 and 4 s. The frequency range of hisslers is of the order of 5 kHz; a typical hissler element extends from ~5 to 10 kHz, but the frequency limits usually vary with time, often with a period of 30–90 s. This characteristic is illustrated in Figure 4 by records from Vostok station for June 1, 1966. On the upper panel a hissler sequence beginning shortly after 0918 UT shows a relatively large fluctuation in low-frequency limit during a period of 1–2 min. This type of variation continued throughout several hours of hissler activity. In Figure 3, bottom panel, on a compressed time-scale record from Byrd station, the hissler low-frequency limit falls from ~12 to ~3 kHz in ~2 min and then rises irregularly to ~10 kHz in ~8 min. Details of the upper frequency limits of hisslers are not yet well known. A few examples have been found to extend above 15 kHz; occasionally, the activity is limited to narrow bands, as is shown near 2 kHz in Figure 4, lower right.

Hissler elements often exhibit complex internal variations in slope and intensity. Variations on a time scale of the order of ~100 ms are evident in the second and third panels of Figure 2, which show Ogo 4 satellite and Vostok ground spectrograms recorded 40 min apart, respectively.

A typical hissler event lasts several minutes and occurs within a longer period of regular auroral hiss activity on the ground. Hisslers are frequently observed during the ~1-hour-long hiss events that occur in the premidnight sector prior to the expansion phase of substorms. They also occur during the expansion phase itself, as was suggested by the *Carpenter et al.* [1971] illustration.

The best-defined long-enduring ground observations seen

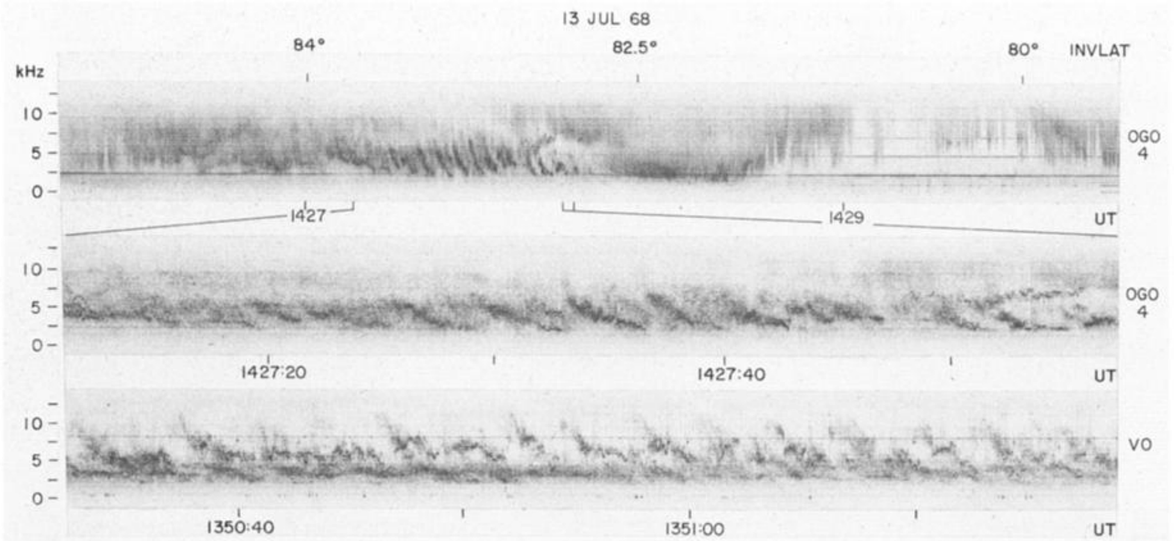

Fig. 2. Frequency-time records comparing hisslers observed from the Ogo 4 satellite (upper and middle panels) and the ground station Vostok, Antarctica (lower panel). See Figure 7*a* for details of the satellite position with respect to the ground station. The ground and satellite records are separated by ~40 min in time.

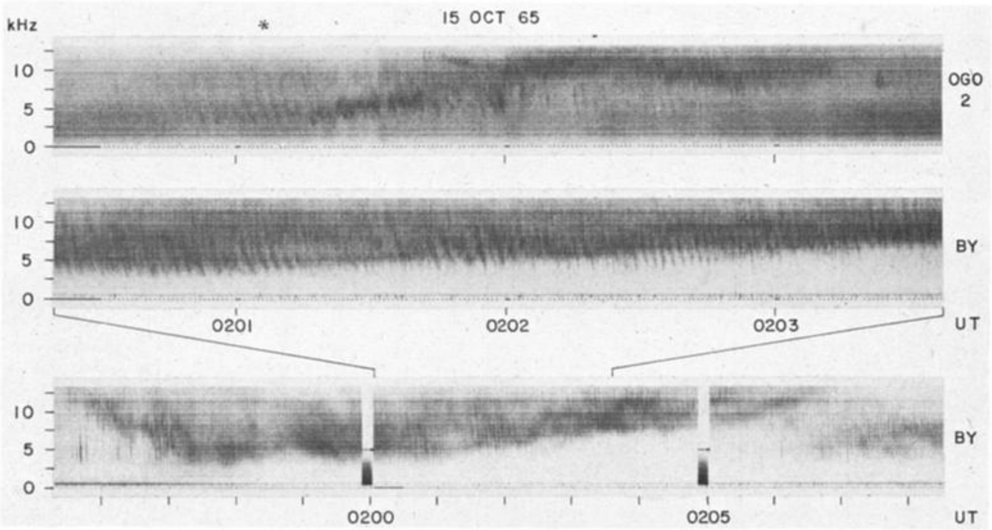

Fig. 3. Frequency-time records showing simultaneous recordings of hisslers on the Ogo 2 satellite (upper panel) and on the ground at Byrd, Antarctica (middle and lower panels). Some details of the rendezvous are shown in Figure 7b.

thus far, lasting from tens of minutes to several hours, have occurred during intervals of deep quieting (Kp = 0–1) following moderate or moderately severe magnetic disturbance. This was true for the case of Figure 4 and the lower panel of Figure 1, all recorded on June 1, 1966, at Vostok. The two panels of Figure 4 are separated by roughly 15 min, whereas the activity of Figure 1, lower panel, occurred 1½ hours later. The long-enduring hisslers indicated in the lower two panels of Figure 3 were also observed during intervals of deep quieting, as were the examples in the third panel of Figure 2, recorded on July 13, 1968.

Detailed information on the frequency-time characteristics of hisslers is difficult to obtain because of the diffuseness, fine structure, and general variability of the elements. Typically, there is a roughly linear variation in frequency with time, although Figure 2, bottom panel, shows hisslers with fine structure that on occasion exhibits a flat or even rising characteristic. Successive hissler elements do not exhibit the dispersion or variation in travel time with frequency characteristic of echoing whistlers. In many cases the frequency-time curves are approximately constant from element to element (period independent of frequency), whereas in others there are changes in the curves with time or between successive several-minute-long hissler groups.

Frequently, a hissler element terminates abruptly and is followed immediately by another element, as illustrated in Figure 4, lower left. *Siren* [1974] remarked that successive hissler elements do not usually overlap in time (exceptions may occur when trains of hisslers of distinctly different intensity or frequency range appear to occur simultaneously). The frequency range of a typical hissler is ~5 kHz; this fact and the nonoverlapping condition suggest that the inverse of the hissler slope, $\Delta t/\Delta f$, should vary from case to case roughly as T/B, where T is the time between successive elements and B is the hissler frequency range. Crude measurements of $\Delta t/\Delta f$ were made at $f \sim 5$ kHz on a number of the better-defined events found in this study. The hisslers exhibited values of T ranging from ~0.5 to 4 s. The measured values of $|\Delta t/\Delta f|$ (in seconds per kilohertz), shown in Figure 5a, are such that $|\Delta t/\Delta f| \sim 0.2T$, in rough agreement with the relation deduced from the nonoverlapping condition and the observation that the hissler frequency range B is typically ~5 kHz.

A search has been made of simultaneous records from the Byrd, Antarctica/Great Whale, Canada, conjugate pair, in hopes of determining whether hisslers appear simultaneously or nearly simultaneously at opposite ends of a field tube. This effort has not yet succeeded, owing in part to seasonal differences in reception of hiss at ground stations and to the frequent lack of conjugacy of auroral hiss at the two stations [*Hudson*, 1971].

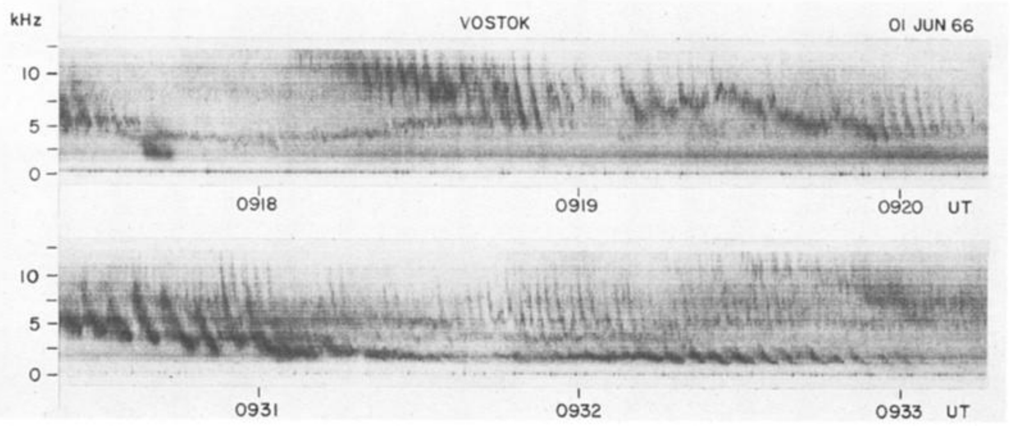

Fig 4. Frequency-time records from a period of long-enduring hissler activity at Vostok, Antarctica. The period was one of relatively deep quieting following moderate magnetic disturbance.

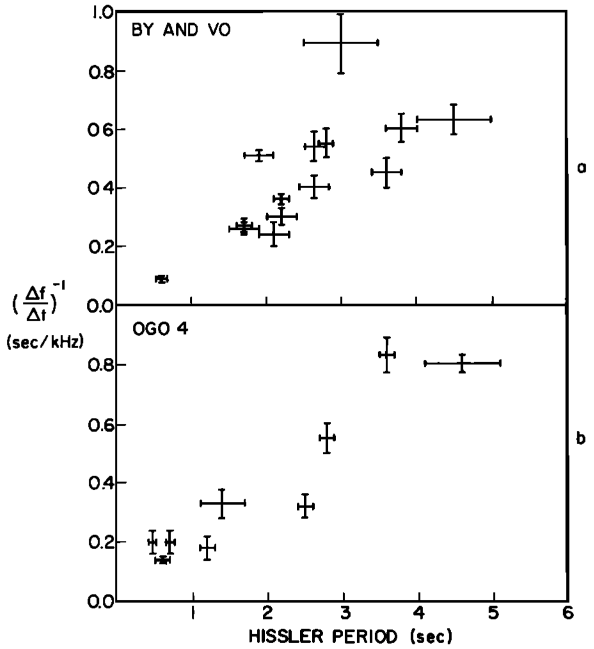

Fig. 5. Plot of the magnitude of $\Delta t/\Delta f$, the inverse slope of the hissler, versus the separation between successive hissler elements, showing the tendency for the slope to decrease with increasing element separation. (*a*) Results from a number of the better-defined hissler events observed at ground stations Byrd and Vostok, Antarctica. (*b*) Results from the best-defined hisslers found in the Ogo 4 satellite records.

SATELLITE OBSERVATIONS

General features. In Ogo 4 satellite records obtained by using a magnetic loop antenna, hissler activity has been observed at various points from 58° invariant latitude to the mid polar cap. Data were examined from 342 passes near Byrd, Antarctica, that cover 82 days in the period March 2 to June 12, 1968, and from 548 passes near Ulaska, Alaska, that cover 90 days in the period July 31 to November 27, 1967. Well-defined examples of hisslers were found on ~25% of the days and on ~6% of the passes. Less well defined examples were found much more frequently, on 65% of the days and 37% of the passes. The poor definition in many such cases may be due to the presence of other forms of hiss that propagate to the satellite from nearby source regions. Allowing for the subjectivity of judgement in hissler identification, we suggest that hissler activity was present in the high-latitude ionosphere on at least half the days of our data sample.

T. Laaspere (personal communication, 1974) reports that detectable hisslers are extremely rare in broad band Ogo 4 and Ogo 6 VLF data acquired by using electric antennas. As an explanation he suggests that in the electric field data of auroral hiss, intense lower hybrid resonance (LHR) effects may tend to mask weak hissler structure that might be present. The present study supports Laaspere's suggestion, in that most observed hisslers are within the range 2-12 kHz, which is also the approximate range of the LHR frequency along Ogo 4 and Ogo 6 orbits.

As a tentative indication of regions of hissler activity, Figure 6 shows in coordinates of invariant latitude versus invariant local time the portions of Ogo 4 orbits along which particularly well defined hisslers were observed in the vicinity of Byrd, Antarctica. There are 20 cases, representing about 2% of the 800 passes involved. It is possible that goodness of hissler definition is indicative of closeness to the source or field line sector of the hissler wave activity, and to that extent Figure 6 indicates a tendency for hisslers to occur near Λ = 75° and in the afternoon-evening sector.

Satellite events are frequently quite complex but generally resemble the type of hissler recorded on the ground. This characteristic is illustrated in Figure 2 by a comparison of the middle panel, observed from Ogo 4, and the bottom panel, recorded within an hour at Vostok station (simultaneous recordings were not available). Figure 7*a* shows the satellite track (1425-1439 UT) and the nearby position of Vostok (VO) in coordinates of invariant latitude at 1000 km versus invariant longitude [*Evans et al.*, 1969]; a solid bar parallel to the track indicates hissler activity.

Simultaneous Ogo 2 and Byrd ground recordings of hisslers are illustrated in Figure 3. (In Ogo 4 data, no such example was found, although 110 simultaneous broad band recordings at Byrd and on Ogo 4 in nearby orbit were examined. VLF hiss was present on all 110 of the satellite records but in only six of the ground recordings. Among those six cases, hiss appeared at the same time on the ground and in the satellite in only two, and then the details were not similar.) The Ogo 2 data in the top panel of Figure 3 were obtained by using a small backup loop prior to the deployment of the main loop antenna. In spite of the correspondingly low sensitivity and generally poor signal to noise ratio the Ogo record shows clear indication of hissler details that also appear on the Byrd record just below. The map of Figure 7*b* shows the observing intervals and the position of Byrd some 500 km from the subsatellite track. An asterisk marks a time of detailed similarity in the upper panels of Figure 3. In this case, hissler activity was observed on the satellite throughout the interval in which broad band hiss was present. That the satellite moved in and out of a spatially limited region of hissler activity is suggested by the fact that there was no interruption of hissler activity on the ground similar to that on the satellite. The time-compressed longer-period ground record shown on the bottom panel of Figure 3 indicates the long-enduring quality of the hissler event.

The frequent failure of a ground receiver to detect hiss spec-

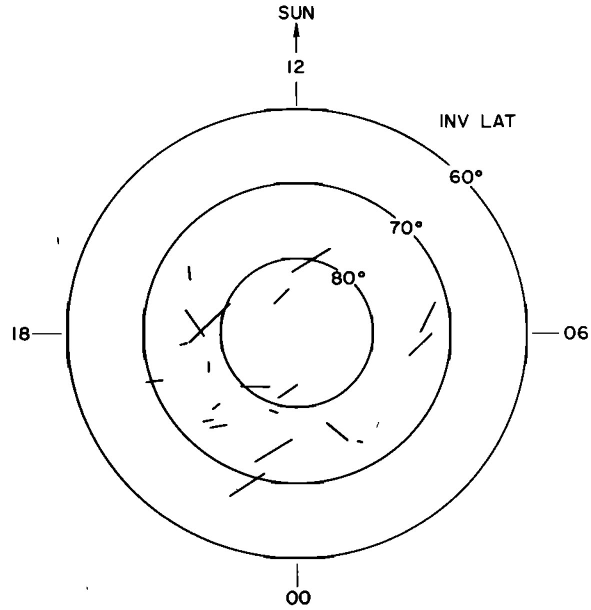

Fig. 6. Plot in coordinates of invariant latitude versus local time of the segments of Ogo 4 satellite orbits along which particularly well defined hisslers were detected. Some 20 examples are shown, taken from a survey of 800 passes in the vicinity of Byrd, Antarctica.

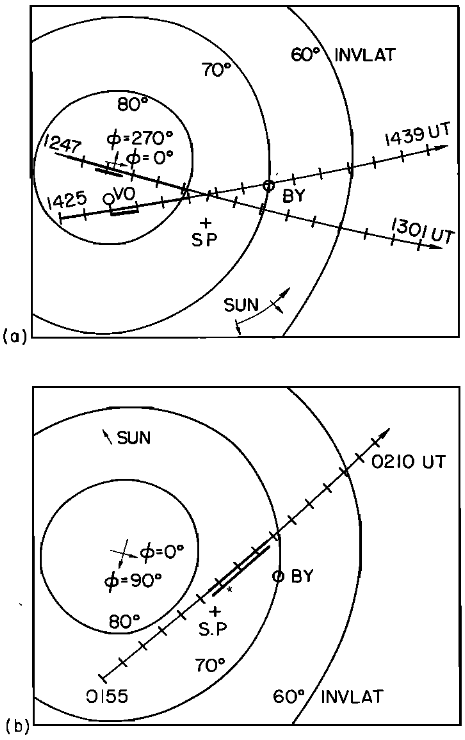

Fig. 7. Plot in coordinates of invariant latitude versus invariant longitude [*Evans et al.*, 1969] showing the relation between satellite hissler observations and the ground stations Byrd and Vostok. A thick line along the subsatellite track shows the presence of auroral hiss. A solid bar alongside the track indicates a region of hissler activity. The geographic south pole is indicated as SP, and the position of Vostok is indicated as VO. (*a*) Results for two successive Ogo 4 passes on July 13, 1968. (*b*) Results from an Ogo 2 pass on October 15, 1965. See text for further details.

tra similar to those received simultaneously on polar-orbiting satellites [e.g., *Jorgensen*, 1968] is not yet well understood. The lack of correlation has been attributed variously to limitations of the ground region illuminated during a particular hiss event [*Jorgensen*, 1966], ionospheric absorption, and unfavorable wave normals of the downcoming waves [*Ungstrup*, 1971]. It may be significant that the relatively few recorded similarities between hisslers detected on satellites and at nearby ground stations (see Figures 2 and 3 and the map of Figure 7) occurred during periods of sudden, relatively deep quieting following moderate disturbance. On such occasions the waves may have experienced reduced attenuation in the earth-ionosphere wave guide, and although they were generated in what are probably spatially limited areas, they may have thus illuminated unusually large regions on the ground.

In satellite hisslers, intervals between successive elements vary from ~0.2 to 5 s, the most common period being about 1 s. The effects of both variations in satellite position and temporal variations may be present. Within a hissler event the element separation and slope may remain nearly constant for minutes and then may change abruptly. In other cases the period and slope may change gradually, the slope decreasing as the period increases. Figure 5*b* shows measurements of inverse slope versus period (measured at ~5 kHz) for the best-defined satellite events. The relation is broadly similar to that found in the ground events (Figure 5*a*).

Features of hisslers within the auroral hiss belt and as a function of magnetic activity. On nearly all passes, polar-orbiting satellites encounter a high-latitude auroral hiss belt that is very approximately coincident with the auroral oval [*Gurnett*, 1966; *Scarabucci*, 1969; *Hughes and Kaiser*, 1971; *Laaspere and Johnson*, 1973]. When hisslers are observed within this belt, they may be present over the entire range of hiss observations, as is true in the case of Figure 7*b*, but they are more commonly present in only part of the hiss region. An example of this is shown in Figure 2, top panel, which represents an Ogo 4 pass to relatively high invariant latitudes under condition of deep magnetic quieting (the subsatellite track is shown in Figure 7*a*). Well-defined hisslers appear for less than a minute near about 83° invariant latitude. Most of this activity is shown on an expanded scale in the middle panel of Figure 2. Near 1428 UT (top panel) the activity changes abruptly from hisslers to a more impulsive form of hiss. Such changes frequently take place within a time of the order of 1 s. Some such changes may be due to automatic gain control action in the log compressor receiver, but a significant number probably represent a spatial limit or structure in hissler activity. This is suggested in Figure 7*a*, which shows a similar localization of detectable hissler activity on the orbit of Figure 2 and on its immediate predecessor. Generally, hisslers observed on Ogo 4 follow auroral hiss statistics [e.g., *Gurnett*, 1966; *Hughes and Kaiser*, 1971; *Laaspere and Johnson*, 1973], being observable in quiet times at relatively high latitudes and, as was noted, being frequently observed near 75° invariant latitude. They occur with somewhat greater intensity and frequency during periods of increased magnetic activity, when there is also a tendency for occurrence over a wider range of latitudes and extension to a lower limiting latitude. The satellite observations, in particular of similar locations of hissler activity on successive passes, suggest a long-enduring spatially localized process that may be fixed in sun-earth coordinates. On some days, hisslers were observed over all or part of the hiss belt on three or four consecutive passes.

CONCLUDING REMARKS

The hissler has thus far escaped attention, partly because in both satellite and ground records it must compete with other types of auroral noise (on satellites with electric antennas the hissler is rarely detected). From the present study we deduce that the hissler is in fact a common phenomenon. Hisslers appear to be involved in the substorm process, since they are frequently observed at ground stations prior to and during the expansion phase of substorms. On the other hand, exceptionally long-enduring and detailed hissler events have been observed during deep quieting following disturbance.

A better descriptive model of the hissler is needed. Multipoint ground measurements, including direction finding, would be desirable. Rocket and satellite measurements are needed, although the simultaneous detection of hisslers and the particle population involved in their production is complicated by spreading of the hissler waves away from what may be a spatially limited (and hence elusive) region of wave generation. An attempt has been made by one of the present authors (I.U.) to correlate hisslers observed on Ogo 4 with precipitating low-energy electrons observed on the same satellite. The correlations have thus far not been successful, owing to the infrequent detection of hisslers on the satellite and the limited temporal overlap of data from the two experiments.

Experimenters using polar-orbiting satellites have successfully correlated day side auroral hiss with soft ~100-eV electron fluxes in the cusp region [*Gurnett and Frank*, 1972; *Hoffman and Laaspere*, 1972] and have correlated evening side hiss with 'inverted V' particle events [*Gurnett and Frank,* 1972]. However, no detailed connection has been established between particle activity and the fine structure of hiss ($T \lesssim 1$ s), possibly because of the wave-spreading effect mentioned above and limitations on the time resolution of the satellite experiments.

The observed properties of hisslers suggest that an emitting region develops in the upper ionosphere at high latitudes and that it then moves or evolves so as to produce a noise band whose center frequency decreases with time, typically by ~5 kHz within ~2 s. When the emission terminates, a new emitting region appears to become active and to produce a new noise form, similar to the previous one. It is hoped that more can be learned of the nature of this emission process and that because of its frequent occurrence at certain ground locations, the hissler can become a new type of radio probe of the high-latitude ionosphere.

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