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Coincident bursts of auroral kilometric radiation and VLF emissions associated with a type III solar radio noise event

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Abstract. This paper examines an isolated magnetospheric VLF/radio noise event that is highly suggestive of the triggering of terrestrial auroral kilometric radiation (AKR) by solar type III radio emission and of a close relation between AKR and broadband hiss. The solar type III burst was measured on polar HF riometers and was coincident with local dayside VLF/LF noise emission bursts at South Pole station. It was also coincident with AKR bursts detected on the AMPTE/IRM satellite, at the same magnetic local time as South Pole. On the basis of the close association of AKR and VLF bursts, and from geometrical considerations relating to wave propagation, it is likely that the AKR source was on the dayside and on field lines near South Pole station. The general level of geomagnetic activity was very low. However, an isolated magnetic impulse event (MIE) accompanied by a riometer absorption pulse was in progress when all of the VLF/radio noise bursts occurred. The very close association of the type III burst at HF with the AKR is consistent with external stimulation of the AKR, if a different, more immediate, triggering process than that implied by Calvert (1981) is invoked. It is suggested here that some of the HF solar radiant energy may decay into waves with frequencies comparable to those of the AKR by parametric excitation or some other process, thus providing the few background photons required for the generation of AKR by the Wu and Lee (1979) cyclotron maser instability. The AKR, perhaps by modifying the magnetospheric electron velocity distribution, might have produced the observed VLF emissions. Alternatively, the VLF emissions may have arisen from the same anisotropic and unstable electron distribution function responsible for the AKR. While the relationship of these emission features to the occurrence of the magnetic/absorption impulse may have been coincidental, the MIE could be a preconditioning agent for the ionosphere/magnetosphere plasma, making it susceptible to the external stimulation of the AKR.

Introduction

Auroral kilometric radiation (AKR) and auroral hiss are both electromagnetic emissions generated in the auroral ionosphere and often associated with inverted-V electron beams and discrete aurora (see review by *Gurnett* [1983]). Spacecraft penetrating the AKR source region observe general coincidences between these emissions in the typical nightside situation [*Bahnsen et al.*, 1987]. However, coincidences between individual bursts of AKR observed by distant spacecraft and of auroral hiss observed on the ground or in low-Earth orbit are not often observed, perhaps due to obscuration by wave propagation effects. Furthermore, coincidences between AKR and auroral hiss on the dayside have not been extensively investigated.

Another issue concerning these high-latitude ionospheric emissions is the stimulation of AKR by solar type III radio bursts [*Calvert*, 1981] or type II bursts [*Calvert*, 1985a]. Subsequent studies [*Farrell and Gurnett*, 1985; *Farrell et al.*, 1986] reported statistically significant correlations between solar type III bursts and the intensification and triggering of terrestrial AKR. *Calvert* [1985b] also argued that solar type III bursts were responsible for triggering some Jovian hectometric radiation events, but statistical studies have not supported this contention as well, and it remains unresolved [*Desch and Kaiser*, 1985; *Calvert*, 1985c]. Perhaps as a consequence, and also because no acceptable theory of the triggering of AKR at Earth by externally generated electromagnetic waves entering the AKR source region has yet emerged, little attention has been given to this effect. While type III/AKR triggering cannot be considered as significant an energy coupling process as others that drive the solar-terrestrial interaction, it is nevertheless important to understand the basic plasma physics that might cause such phenomena.

This paper presents an isolated geophysical event for which individual AKR bursts observed by satellite at 16 R_E are correlated with broadband VLF auroral hiss bursts observed on the ground. Furthermore, the simultaneous

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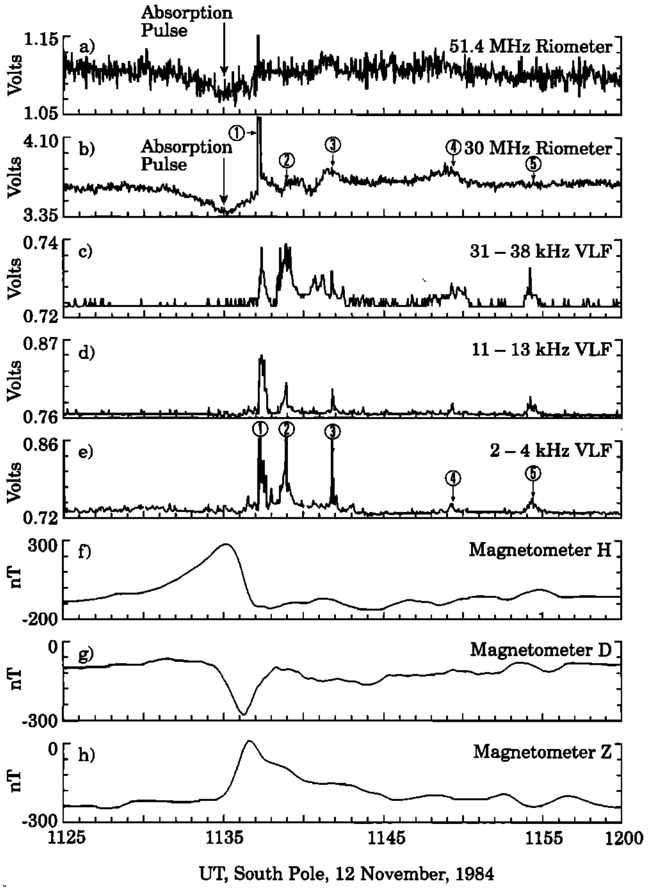

Figure 1. Riometer, VLF, and magnetometer data obtained at South Pole station between 1125 and 1200 UT on November 12, 1984. (a, b) A riometer absorption pulse peaking at 1135 UT, accompanies the (f–h) magnetic impulse. (e) The numbers 1–5 identify the peak times of broadband VLF noise spikes; all except burst 5 occur at times of riometer noise enhancements at 30 MHz (Figure 1b).

observation of solar radio noise is suggestive of the role of a triggering mechanism. The event was discovered during a search for occasions of simultaneous noise emission events measured with HF riometers and the broadband VLF receiver at South Pole (SP) station. Such events of auroral origin are relatively rare [*Singh*, 1992; *LaBelle*, 1989; *Ellyett*, 1969]. In the present instance, it is possible to trace the origin of the HF signal to a solar type III burst. Wave data from the AMPTE/IRM satellite show an AKR enhancement simultaneous with the HF and VLF signals.

Observations

Ground-Based Data

Figure 1 displays riometer, VLF, and magnetometer data obtained at SP between 1125 and 1200 UT (0755–0830 MLT) on November 12, 1984. An isolated, transient magnetic impulse event (MIE), peaking at 1135–1137 UT, is evident in all three components of the magnetometer data (bottom three panels). Such impulses have been taken as possible evidence of the ionospheric signature of transient magnetic reconnection at the dayside magnetopause [*Lanzerotti et al.*, 1986] or of traveling convection vortices caused by solar wind pressure pulses on the magnetosphere [*Friis-Christensen et al.*, 1988]. Extensive statistical studies of such events have been reported by *Lanzerotti et al.* [1991] and by *Konik et al.* [1994a, b].

The magnetic impulse in Figure 1 is accompanied by a riometer absorption pulse seen, in the top two panels, as decreases of signal voltage at 51.4 MHz (Figure 1a) and 30 MHz (Figure 1b). The maximum absorption (~0.4 dB at 30 MHz) occurs at 1135 UT, coincident with the peak in the *H* component magnetic variation. Absorption pulses, generally indicative of precipitating energetic electrons, often, but do not always, accompany such magnetic impulse events. Later discussion herein will consider the role that this event may have played in the occurrence of the radio wave emission activity.

Figures 1c–1e show that a series of spiky enhancements covering a broad range of frequencies in the VLF (3–30 kHz) and LF (30–300 kHz) bands occurred following the peak of the magnetic/absorption pulse. Broadband radio noise at these frequencies is characteristic of polar (auroral) hiss which is often associated with precipitating electrons [e.g., *Gurnett*, 1966; *Hoffman and Laaspere*, 1972; *Sazhin et al.*, 1993]. Unfortunately, wideband VLF data are not available to confirm the nature of the emissions. For later reference, the five most prominent spikes appearing in the 2–4 kHz channel (Figure 1e) are numbered. These spikes occur at the same times in the higher-frequency channels.

A similar series of burst increases occurs in the riometer signals during and following the recovery of the absorption/MIE event. This is especially evident in the 30-MHz data (Figure 1b) where the numbering from Figure 1e has been repeated. Burst 1, the most intense, occurs just after 1137 UT, at the same time as that in the VLF channels. The positive burst drives the 30-MHz riometer to saturation (~7 V, clipped in this figure at ~4.25 V for clarity). This burst at 51.4 MHz reached a level of ~1.17 V. Bursts 2, 3, and 4 appear at 30 MHz as only slight positive shifts above the background level prevailing prior to the event. These bursts are also closely correlated with those in the VLF channels; none, with the possible exception of burst 3, is evident at 51.4 MHz. Burst 5 in the VLF channels is not seen in the riometers.

Burst 1 was also detected by the 30- and 51.4-MHz riometers located at McMurdo (MM). Figure 2 shows the riometer data at both stations for both frequencies for the 2-min interval centered on 1137 UT. At this time the magnetic local time of the two stations was 0307 (MM) and 0807 (SP), though both were in full sunlight. Interference from a local radio transmitter caused the 30-MHz riometer at MM to be in saturation at various times, but fortunately there was a clear interval between 1137:07 and 1137:20 UT when the main noise burst occurred. Note in Figure 2 that the noise enhancement at 51.4 MHz is composed of two bursts at both stations, one peaking at 1137:09, the other at 1137:12 UT. The 30-MHz response at both locations is a single burst peaking at about 1137:12 UT.

Solar Data

The National Geophysical Data Center's compilations of Solar-Geophysical Data (1985a, b) list two reports of a solar radio noise burst occurring at the same time as riometer/VLF burst 1 (~1137 UT, Figure 1). The solar observatory at Upice, Czechoslovakia reported signals, classified as simple with no flux level given, at 33 and 29 MHz. At 33 MHz the start time and time of maximum are both listed as 1137.2 UT, with duration of 0.3 min. At 29 MHz the start time is 1137.2, the time of maximum is 1137.3, and the duration is 0.3 min.

The observatory at Weissenau, Germany, reported a solar burst in the 30–300 MHz band with a start time of 1137.1 and an end time of 1138.1 UT. It was classified a type IIIG (small group of (<10) bursts) of the highest intensity (>500 solar flux units where 1 solar flux unit (sfu) = 10^{-22} W/m^2-Hz). The source was a weak (1–8 Å) X ray flare detected on the GOES 6 satellite starting at 0957 UT and lasting beyond 1200 UT. The start of the flare was marked by a metric type IIIB (knotted emission) burst observed at Weissenau. Weissenau also reported type III activity in the interval from 1013 to 1026 UT.

Upon request, both observatories provided copies of their data. The Upice record (E. Markova, personal communication, 1993) was on slow-speed chart (not shown) from which it is not possible to resolve fine structure. The chart showed no evidence of additional solar noise through the end of the hour. The spectrogram from Weissenau is shown in Figure 3 for the interval 1137–1138 UT. The main solar emission appears shortly after 1137 UT as two closely spaced bursts (probably a fundamental-harmonic pair) covering a wide frequency range. This is followed by two fainter bursts of shorter duration and narrower frequency extent, one near 1137:40 UT, the other near 1138:05 UT. No other solar noise events were evident from 1130 to 1200 UT (H. Urbarz, personal communication, 1993). The peak solar noise intensity at 1137:09–1137:12 UT is estimated from the Weissenau data to be approximately 4 × 10^{-20} W/m^2-Hz (400 sfu), less than originally reported.

It seems reasonable to conclude from these solar data that the intense noise spikes at 1137.1 UT on the SP and MM riometers are solar type III bursts. However, it is not possible to confirm the nature of the weaker HF emissions numbered 2, 3, and 4 in Figure 1b). Tentatively, we identify them as being weak type III solar noise which, possibly owing to instrument sensitivity differences, were not detected by the Upice and Weissenau observatories (the Weissenau equipment is capable of detecting the type III with intensities as low as 50–150 sfu in general; the polar riometers appear to have a comparable order of sensitivity).

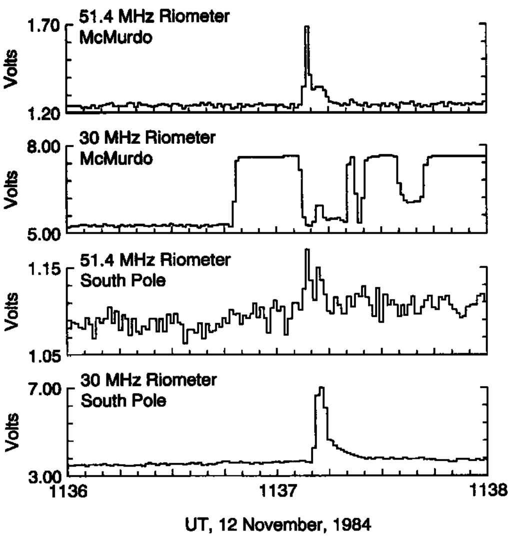

Figure 2. Riometer data at 30 and 51.4 MHz obtained at South Pole and McMurdo stations in Antarctica between 1136 and 1138 UT on November 12, 1984.

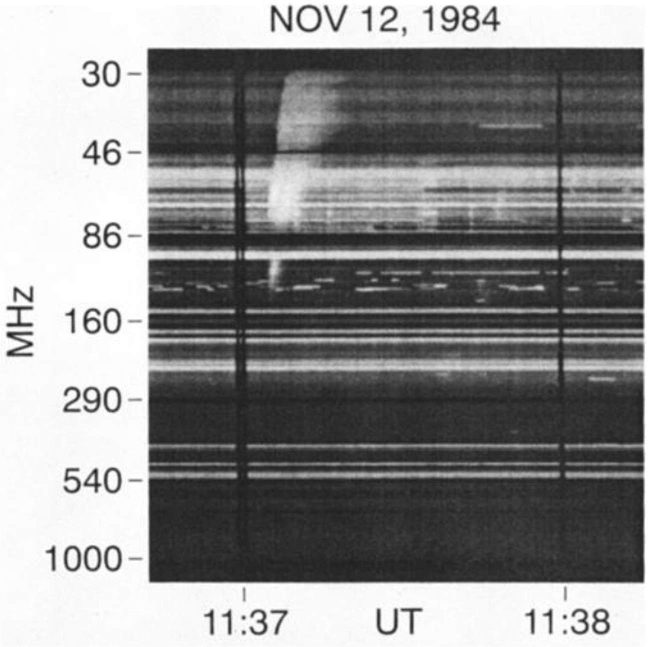

Figure 3. A portion of the solar radio spectrogram from the Weissenau observatory for the period 1137–1138 UT on November 12, 1984.

Satellite Data

At the time of this event the AMPTE/IRM satellite was in the magnetosheath outbound in the ecliptic plane and near the Earth's bow shock at 16 R_E on the morning side (~0830 MLT). The top three panels of Figure 4, depicting plasma density, energetic ion density (8.5–40 keV), and plasma velocity, show that the satellite crossed the bow shock into the solar wind near 1132 UT, just at the start of the ground level absorption/MIE event detected at SP. At ~1135 UT, near the peak of the ground-level impulse, the bow shock appears to have moved out, putting the satellite again in the magnetosheath for about 3 min. The satellite magnetic field data (bottom three panels of Figure 4) show that when AMPTE/IRM is unambiguously in the solar wind (e.g., 1140–1155 UT) the interplanetary field is roughly in the GSE y-z plane with B_z slightly positive and B_y slightly negative.

The plasma wave instrumentation on AMPTE/IRM covers the frequency range from 30 Hz to 5.6 MHz [*Häusler et al.*, 1985]. The top panel of Figure 5 is the wave spectrogram between 100 kHz and 5.6 MHz obtained by the high-frequency electric field receiver. Solar noise was not apparent within the frequency range of the instrument, but there was clear evidence of AKR (at AKR frequencies, solar type III noise is nearly constant in frequency, owing to the characteristic drift or temporal delay with frequency, and is often too weak to detect in the presence of the much stronger AKR). The main AKR emission begins near 1137 and extends to about 1143 UT, covering frequencies from ~250 to ~700 kHz. Several weaker bursts, more restricted in frequency, occur between 1150 and 1155 UT. (Artificial

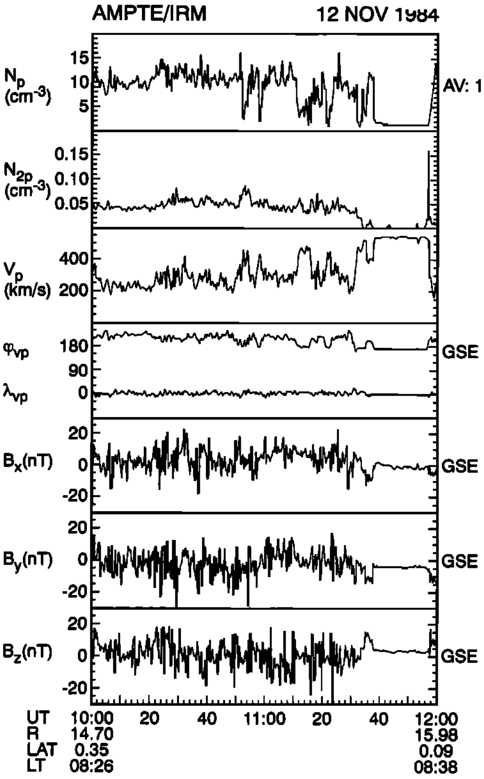

Figure 4. Plasma, energetic ion, and magnetic field data from the AMPTE/IRM satellite for the period 1000–1200 UT on November 12, 1984.

signatures having the form of segmented spikes appear throughout the wave data; an effort was made to eliminate these spikes in the integrated power plots below.) Unfortunately, no data were available from the ISEE satellites for this period.

The temporal relationships among the AKR, HF and VLF bursts are illustrated in Figure 5. The intensity of the AKR emission is shown in a narrow band (275–325 kHz) near the low frequency end of the spectrum (Figure 5c) and a broad band (230–700 kHz) covering the full range of the activity (Figure 5b). Figure 5d and 5e reproduce the South Pole, HF, and VLF records, respectively, from Figure 1. Ground level HF and VLF bursts 1, 2, and 3 all have prominent counterparts in the AKR data at about the same times. The association of AKR features with ground level bursts is less clear for the weaker variations labeled 4 and 5.

Discussion

The foregoing presentation of VLF, HF, and AKR emissions data is notable for several reasons: (1) The solar type III radio noise may have triggered the AKR; (2) the AKR emissions may have been generated on the dayside; (3) the correlation between AKR observed at 16 R_E and auroral hiss observed on the ground is unique; and (4) preconditioning of the ionosphere/magnetosphere environment by the effects of the transient impulse may have occurred.

Stimulation of AKR by External Sources

In general, type III emissions arrive at a location at progressively later times as the frequency decreases; that is, there is a characteristic drift or temporal delay in frequency. Thus a significant time delay, of order minutes to tens of minutes, would be expected between type III observed at HF and the triggering of AKR, if triggering occurred as described by *Calvert* [1981]; that is, when the type III frequency matches that of the AKR.

For that to be the case here, the causative type III would have had to occur well before the coincident AKR/VLF bursts. Type III noise bursts were reported by Weissenau at 0919 UT and at several times in the period from 1013 to 1026 UT. All of these bursts were also observed on the polar riometers but without any accompanying ground level broadband VLF hiss. Several of the Weissenau-reported bursts also appear in the AMPTE/IRM data but without any clearly accompanying AKR signatures.

We have no evidence that any of the earlier type III activity was responsible for the AKR/VLF bursts in the 1137 UT time frame. Rather than incorporate a speculative, but essentially unknown, time shift between some previously occurring type III and the AKR/VLF we have chosen to deal with the possible implications of the timing coincidences as observed; that is, the association between the type III at high frequency and the AKR/VLF bursts, as shown in Figure 5. These coincidences could be taken as evidence for a type of triggering previously not observed.

The principal generation mechanism of AKR is generally believed to be the cyclotron maser instability, first proposed by *Wu and Lee* [1979], which is usually discussed in the context of linearized Vlasov theory. Nonlinear interactions between plasma waves and particles may also be involved on occasion [e.g., *Pottelette et al.*, 1992; *Treumann et al.*, 1992]. In the cyclotron maser theory of AKR, reflected or trapped auroral electrons with energies from 1 to 5 keV can result in an instability which can amplify electromagnetic waves. The free energy that drives the instability is associated with a loss cone-type of distribution of the auroral electrons. It is implicitly assumed in this theory that a weak radiation field is already in existence in the source region. The occurrence of the instability implies that any electromagnetic signal with appropriate frequencies and wavelengths can be amplified in the region where the instability is operative.

The following scenario may be conjectured to explain the observed triggered emission of AKR. First, since the observed type III radiation is very powerful (at 30 MHz, photons have of the order 100 times more energy than AKR photons), part of its energy might decay into waves with frequencies comparable to those of AKR by parametric excitation or other processes. These electromagnetic waves are then further amplified by the cyclotron maser instability. Although the linear theory of cyclotron maser instability explains the initial amplification, the complete triggered emission process may involve nonlinear or other interactions which remain to be studied. Some simulations [e.g., *Kainer et al.*, 1990] support this conclusion.

An important and intriguing aspect of the phenomenon reported by *Calvert* [1981] is that the induced amplification continues even when the solar type III radio waves have diminished or ceased. This may also be the case for the present event in that the only identifiable solar noise event in observatory records was at 1137–1138 UT, whereas bursts of AKR continued to be emitted until near the end of the hour. However, it may be speculated that some of the later AKR

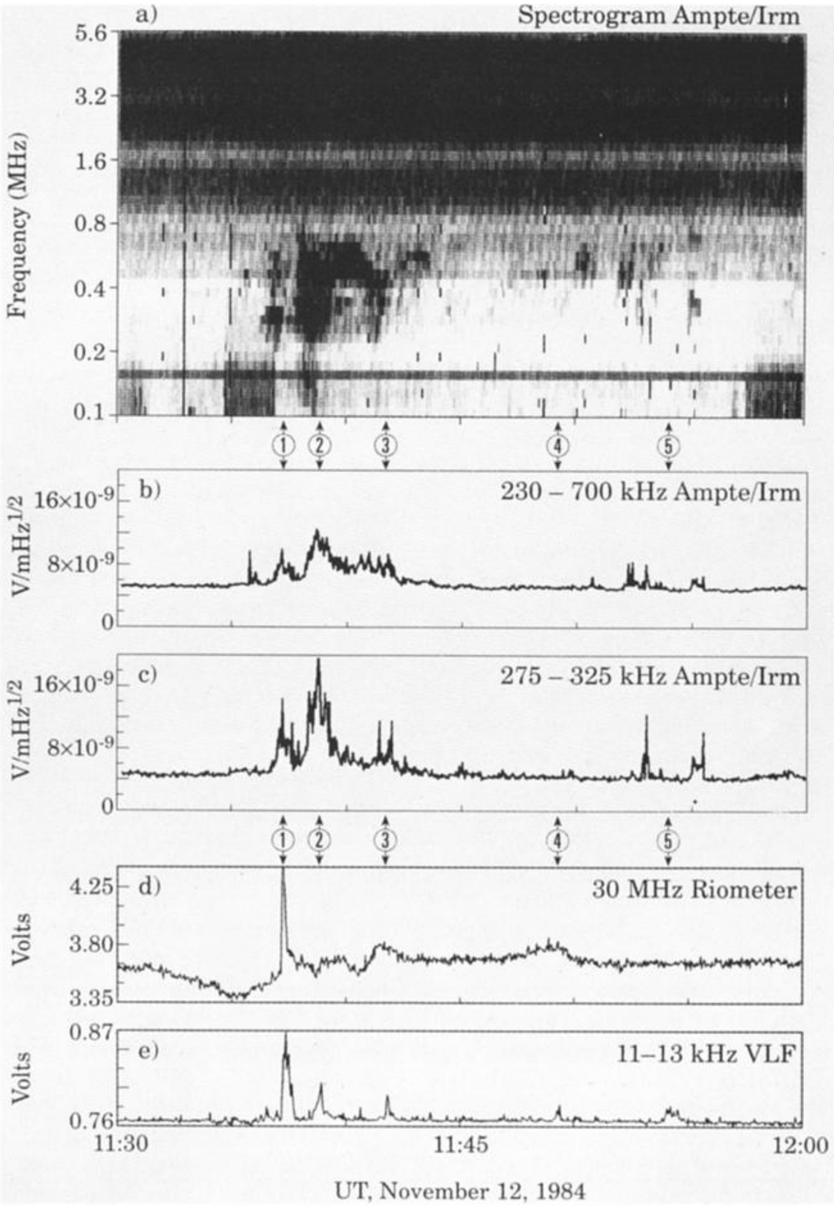

Figure 5. AMPTE/IRM wave data and South Pole riometer and VLF data for the period 1130–1200 UT on November 12, 1984.

bursts may also have been triggered by the arrival of new solar radiation, if SP riometer enhancements associated with bursts 2–4 are accepted as evidence of weaker solar noise. Future theoretical work should investigate whether an externally generated electromagnetic wave in the AKR band can induce enhanced emission of radiation in a plasma; and, more importantly, whether this induced emission can persist even after the external wave is terminated. In this connection, however, it is important to point out that, at frequencies in the VLF band, it is already well established that emissions triggered in the magnetosphere plasma by whistlers and groundbased transmitters repeatedly persist much longer than the triggering pulses [e.g., *Helliwell*, 1965; *Helliwell and Katsufrakis*, 1974]. Another issue for theoretical work would be the development of a mechanism to couple the high-frequency solar radio burst to the stimulation of AKR at a few hundred kilohertz, either via parametric decay or some other means. Other possible scenarios might also be investigated.

AKR Source Region

Most AKR is generated on the nightside at auroral latitudes in association with magnetospheric substorms [e.g., *Gurnett*, 1974]. However, because of the broad emission cone [*Green and Gallagher*, 1985] observations of AKR on the dayside, from nightside sources, are commonplace. There is also evidence for the existence of dayside AKR source regions at high latitudes [*Alexander and Kaiser*, 1976; *Kaiser and Alexander*, 1976; *de Feraudy et al.*, 1988]. A subsequent study [*Alexander and Kaiser*, 1977] placed the sources of dayside AKR in the polar cusp and adjacent magnetosheath regions (see also *Pottelette et al.* [1990]). *Alexander and Kaiser* [1977] also found that dayside AKR was most likely to occur during periods of substorm activity

(AE > 250 nT) and for IMF B_z southward. *LaBelle et al.* [1989], using AMPTE/IRM measurements, have confirmed the earlier statistical studies which showed that AKR occurrence favored the nightside, but that AKR was by no means absent from the dayside. More recently, *Pedersen et al.* [1992] concluded that transpolar arcs extending into the dayside may also be source regions for dayside AKR. Cyclotron emission generation favors a low-density situation (i.e., the ratio of electron plasma frequency to electron gyrofrequency < 0.2) which can be achieved in nightside auroral plasma cavities. Though less likely to occur on the dayside, such depletions cannot be ruled out.

The event examined here, in the interval from 1100 to 1200 UT on November 12, 1984, occurred during relatively quiet magnetospheric conditions. The IMF had a small northward component at about the time of the event, consistent with the low level of prevailing geomagnetic activity. This day was the third quietest of the month (*Kp* sum = 13+), with *Kp* = 2 for the 0900–1200 UT interval. Furthermore, the hourly mean value of the *AE* index for hour 11 was 84 nT and the hourly means for the five previous hours were below 200 nT. Thus the occurrence of this AKR event does not appear to satisfy the typical condition required for AKR generation in either nightside or dayside source regions, that is, a magnetospheric substorm or high level of activity. Rather, it seems that an unusual set of circumstances may have been in place to account for this case.

On the basis of the close correlation of AKR and VLF bursts, and from geometrical considerations relating to wave propagation, it is likely in this instance that the AKR source is on the dayside and on field lines in close proximity to SP. The broadband VLF bursts are almost certainly generated on the dayside and within about 1000 km of SP because signals propagating in the Earth-ionosphere waveguide over greater distances would be attenuated to the point of being unobservable. On the basis of straight-line propagation and typical AKR cone angles, it is highly doubtful that AKR generated in the nightside auroral zone would reach AMPTE/IRM (at 16 R_E in the ecliptic plane at 0830 MLT), much less could it illuminate a low-altitude (<2 R_E) dayside source region for VLF hiss in the vicinity of SP station.

Generation of Broadband VLF/LF Emissions

Magnetospheric electromagnetic wave emissions of a few hundred hertz to several tens of kilohertz are commonly observed on the ground and by satellite at high polar latitudes. Broadband emissions, which span the entire VLF range and extend into the LF, commonly termed auroral hiss, are often associated with discrete arc structures, the precipitation of low-energy electrons (<10 keV) and the presence of field-aligned currents [*Sazhin et al.*, 1993]. Auroral hiss is most often detected in the nightside magnetosphere, but is also observed on the dayside. The conventional explanations for auroral hiss involve the coherent amplification of radiation in the whistler mode as a result of a beam-plasma or loss cone instability [*Maggs*, 1976; *Wu et al.*, 1983]. The beam instability mechanism can only excite the whistler mode with oblique propagation whereas the loss-cone instability mechanism generates whistlers propagating along the ambient magnetic field lines.

Since obliquely propagating whistlers cannot reach the ground without being refracted, we infer that the VLF waves observed and discussed in the present paper must have parallel propagation. On the other hand, the cyclotron maser theory of AKR suggests that the amplified AKR prefers nearly perpendicular propagation. Thus, even if AKR and VLF are generated in the same source region due to the same cause, a spacecraft far from the source region may only be able to observe one of the two modes.

It is also possible that in the present case the observed AKR and VLF may have a causal relation. Indeed, *Melrose* [1986], noting the similarity of triggered AKR with triggered VLF signals, has invoked a VLF-like process for the triggering of AKR. The data in any case provide evidence of possible coupling between free space radiation in the form of AKR and whistler mode radiation in the form of VLF emissions (see also *Benson* [1985]). In one scenario, the enhanced AKR (stimulated by the solar type III radiation) would modify the magnetospheric electron velocity distribution so that a significant fraction of the low energy electrons initially outside the loss cone would enter the loss cone. Such a process would produce enhanced electron precipitation [e.g., *Calvert*, 1987] and could lead to VLF emissions. On the other hand, the AKR and VLF might result from the same anisotropic and unstable electron velocity distribution function. In this situation the AKR and VLF bursts would not be causally related, but might occur in near coincidence or at somewhat different times, as the data appear to show.

Preconditioning the Ionosphere/Magnetosphere

The magnetic impulse event (MIE) that occurred at about 1135 UT has all of the features that would fit the event selection criteria established in the statistical study of *Lanzerotti et al.* [1991]. In particular, the large amplitude, unipolar signature in the *Z* component indicates that this is a "classic" type of MIE that would be consistent with a field-aligned current passing nearly overhead in the ionosphere. The *Z* component deflection is more than a factor of 2 larger than the median amplitude reported in *Lanzerotti et al.* [1991]. The amplitude of the current in this event would be of the order of 4–5 × 10^{-7} A/m^2.

An extensive discussion of the possible origin(s) of the MIE is not appropriate here. It is, nevertheless, interesting to note that the spacecraft passed out of the magnetosheath into the solar wind at about the time of the measured MIE. This suggests that a pressure enhancement in the solar wind may have been present at the time of the impulse. However, consistent with the statistical conclusions of *Konik et al.* [1994a, p. 14,831] that magnetic reconnection at the magnetopause is likely to be responsible "for generating a minimum of 50%–70% to a maximum of 90% of the events," this MIE could also have been produced as a result of magnetic reconnection. Considering the amplitude arguments in a comparison of sudden commencements as measured at SP [*Konik et al.*, 1994b], one could conclude that magnetic reconnection accompanied a possible pressure change in the solar wind.

The relationship of the occurrence of the AKR and VLF bursts to that of the MIE/absorption impulse in progress at the time (1135 UT) may have been coincidental. Certainly the arrival of the type III noise burst was unrelated. On the one hand, this paper has argued that a special set of circumstances may have had to exist in order for the solar noise to trigger the AKR. The magnetic field-aligned current region that produced the MIE could be the "special" dayside plasma region in which the AKR was triggered, as the

AKR on the night side of the Earth is associated with field-aligned currents in the auroral current system. Alternatively, one could imagine a different scenario where the processes creating the MIE are solely responsible for producing the AKR and the VLF, independent of the type III.

Summary and Conclusions

We have studied a case of coincident bursty radio wave emissions spanning a very wide frequency range extending from the VLF to the HF, including AKR. The observations were made on the ground at high southern polar latitudes, at two solar observatories in central Europe, and on the AMPTE/IRM satellite at 16 R_E. The event occurred when both the satellite and South Pole station were on the dayside of the magnetosphere, at ~0830 MLT; the satellite was in the ecliptic plane and near the bow shock at the time.

The reports of low latitude solar radio observatories indicate that the HF emissions at SP were solar type III radio noise, and not of magnetospheric origin. The VLF/LF emissions at SP have the character of broadband auroral hiss, an emission type often associated with auroral arcs and the precipitation of kiloelectron volts energy electrons. Possibly the AKR modified the electron velocity space distribution to one that would favor the generation of broadband VLF/LF hiss, or both the AKR and VLF arose out of the same anisotropic and unstable distribution function.

Typically, AKR occurs during magnetospheric substorms or otherwise high levels of geomagnetic activity (e.g., $AE >$ 250 nT). Thus the occurrence of intense AKR in this event would be unusual, given the relatively weak level of geomagnetic activity ($AE <$ 100 nT), were it not for the presence of the solar radio noise. Also, there was a transient magnetospheric impulse in progress at the time.

The close association between the onsets of the HF, AKR and VLF/LF bursts suggests a causal relation, possibly involving triggering. We speculate that this event may be an example of the stimulation of AKR by solar type III noise. Triggering by the *Calvert* [1981] mechanism occurs when the type III signal reaches a frequency in the AKR band and thus is significantly delayed with respect to the arrival of the type III emission at HF. Possibly an unobserved type III occurred shortly before 1137 UT and triggered the AKR via the *Calvert* [1981] mechanism; this possibility is not too outlandish since type III bursts are known to occur in groups and can fall below the threshold of the instruments. Alternatively, the near-coincident occurrence of the HF, AKR, and VLF signals in this instance may be evidence for a different, more immediate, triggering process. For example, part of the type III radiant energy at HF may decay into waves with frequencies comparable to those of AKR by parametric excitation or other processes.

Special conditions may be needed for the above circumstances to occur since such events appear to be quite rare. Possibly, the existence of dayside field-aligned current, as evidenced by the MIE, provided the region in which the AKR triggering occurred. Thus such events might be produced by a solar type III event provided a sufficiently large dayside field-aligned current exists, whose precise origin is only incidental to the event. On the other hand, it is possible that the solar type III was incidental, with the AKR and VLF arising out of the processes that created the MIE.

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