S. Afr. T. Antarkt. Nav., no. 5, 1975

Diurnal variation of ELF and VLF noise observed on a low-altitude satellite at the invariant latitude of Sanae

A.R.W. Hughes
Department of Physics
University of Natal
King George V Avenue, Durban 4001

The diurnal variation in the frequency of occurrence of radio noise at 0,75, 3,2 and 9,6 kHz is derived from 1 259 passes of Ariel 4 through the invariant latitude interval 59-60° Λ for magnetically quiet ($K_p \leq 2_+$) periods.

Die daaglikse variasie in die voorkoms van radioruis by 0,75, 3,2 en 9,6 kHz word afgelei van 1 259 metings deur Ariel 4 in die invariante breedtegraad-interval 59-60° Λ vir tye wat magneties stil is ($K_p \leq 2_+$)

The interpretation of ELF and VLF noise records at a station such as Sanae presents a number of problems, one of which is the fact that the noise propagates beneath the ionosphere and at a given time the records consist of noise contributions from higher and lower latitudes and earlier and later local times.

At higher latitudes than Sanae (Λ = 59,9°) noise is generated in the vicinity of the auroral oval while noise from lower latitudes may be generated inside or close to the plasmapause. The location of the auroral oval and the plasmapause vary with magnetic local time and with the level of magnetic disturbance, so that for example under extremely disturbed conditions the region of generation in the auroral oval may move over the station and lie to the low latitude side. Because of these difficulties it is instructive to study data from satellites in orbit above the F-region of the ionosphere. In this paper we study the ELF and VLF data from the Ariel 4 satellite which is in a circular orbit at an altitude of about 600,km.

Ariel 4 experiment

The ELF and VLF experiment employed a magnetic loop antenna and included four frequency channels at 750 Hz, 1,5 kHz, 3,2 kHz and 9,6 kHz. There were other channels at higher frequencies but they need not concern us here. The two lower frequency channels had bandwidths (to 3 dB points) of 500 Hz and the other two had bandwidths of 1 kHz. Each channel had a logarithmic response with 75 dB dynamic range. From each channel the peak, mean and minimum signals in successive 28 second periods were recorded on magnetic tape within the satellite. The tape, which normally contained data from a single revolution of the satellite (96 minutes), was replayed when the satellite was in the vicinity of a satellite tracking station. The peak, mean and minimum circuits had time constants of 0,01, 30 and 0,1 seconds respectively. Here we have used data from the mean circuits only. A more complete description of the experiment is given by *Bullough, Denby, Gibbons, Hughes, Kaiser & Tatnall* (1975).

Part of a typical record from an Ariel 4 pass is shown in Fig. 1. It shows two regions where noise is frequently present. There is one at medium latitudes which may extend from 20° to 65° Λ with a peak in intensity which normally occurs between 45° and 65° Λ. At higher latitudes, there is a narrow (~5° Λ) region where the noise

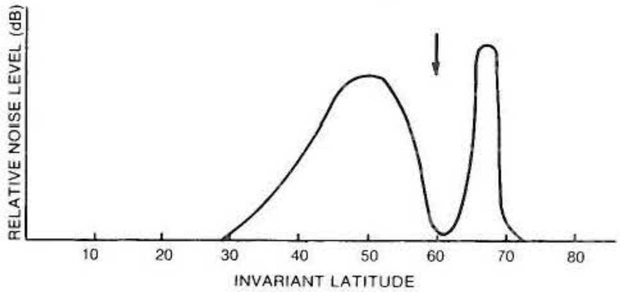

Fig. 1. A typical Ariel 4 record showing the two regions where ELF and VLF noise is frequently observed. The arrow gives the location of Sanae.

at certain local times can be very intense. Each of these regions has its own characteristic behaviour which is a function of frequency and local time. These may be summarized as follows:

Medium latitude noise

During magnetically quiet times plasmaspheric ELF hiss (*Thorne, Smith, Burton & Holzer,* 1973) is observed which is most probably generated inside the plasmapause close to the equatorial plane by the cyclotron resonance instability (*Kennel & Petschek,* 1966; *Etcheto, Gendrin, Solomon & Roux,* 1973). The hiss then fills the plasmasphere at lower L-values by unducted propagation. (*Thorne & Kennel,* 1967). There is a peak in the intensity of the noise between 500 and 600 Hz (*Tsurutani & Smith,* 1975) which is typically 10 to 20 dB lower at 2 kHz. It occurs at all local times though it occurs very much less frequently during the hours about midnight. During magnetic storms the noise is not limited to ELF frequencies but extends above 10 kHz. Its intensity is closely linked to the phases of the storm (*Bullough, Hughes & Kaiser,* 1969) and the location of the maximum in intensity moves to lower latitudes as the plasmasphere is eroded.

High latitude hiss

This emission appears to be associated with auroral precipitation and is sometimes called auroral hiss. There is some statistical evidence *(Hughes & Kaiser,* 1971) that in fact the region of generation may lie to the high latitude side of the auroral oval and on open field lines. For some time auroral hiss has been thought to be Cerenkov radiation from auroral electrons (*Ellis,* 1957; *Jorgensen,* 1968) but there are a number of indications that this is not so (*English & Hughes,* 1974; *Swift & Kan,* 1975). Swift and Kan suggest that the hiss may in fact be due to the excitation of a whistler mode instability by an electron beam.

On a satellite, high latitude hiss is a most common phenomenon (*Hughes, Kaiser & Bullough,* 1971) at auroral latitudes, and it exhibits two maxima in occurrence, one in the afternoon and the other before midnight. The main observational difference from medium latitude noise is the low intensity of the ELF frequencies. One of the interesting features of this emission is that it rarely occurs on the ground. In a particular study by *Srivastava & Swift* (1972) simultaneous observations of noise were made on the satellite Injun 5 and on the same field line on the ground: of eleven hiss events recorded on the satellite only one was observed on the ground.

The diurnal variation in ELF and VLF noise

The diurnal variation in the occurrence of noise at 750 Hz (Fig. 2) and 3.2 kHz (Fig. 3) is derived from mean readings on 1 259 satellite intersections of the invariant latitude (Λ) interval 59° to 60° Λ at all local times in the Southern Hemisphere. The data were recorded during the period 11 December 1971 — 19 March 1972. Fig. 2 gives the frequency of occurrence of signals greater than $10^{-10}\gamma^2$ Hz^{-1} (equivalent to a power spectral density of 4,8 x10^{-14} Wm^{-2} Hz^{-1}) for the

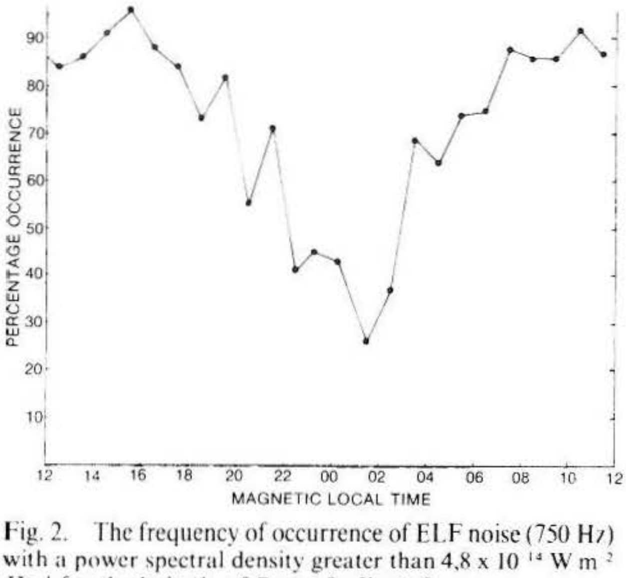

Fig. 2. The frequency of occurrence of ELF noise (750 Hz) with a power spectral density greater than 4,8 x 10^{-14} W m^{-2} Hz^{-1} for the latitude of Sanae for $K_p \leqslant 2_+$.

planetary magnetic index $K_p \leqslant 2_+$. This shows that there is a probability of 60 per cent or more that noise greater than $10^{-10}\gamma^2$ Hz^{-1} will be observed between about 03 h and 22 h MLT (magnetic local time). The probability of receiving noise is at a maximum between 08 h and 18 h MLT and lowest about the hours of midnight. The pattern of occurrence is typical of noise generated within the plasmasphere.

In Fig. 3 the diurnal variation in occurrence at 3,2 kHz (upper curve) and 9,6 kHz is given for a signal threshold of 4,8 x 10^{-14} W m^{-2} Hz^{-1}. To obtain a significant number of counts it is necessary to use a threshold 20 dB lower than that used for 750 Hz. In each of the two curves in Fig. 3, in contrast to Fig. 2, the maximum in occurrence can be seen between 20 and 22 h MLT and this is clearly due to high latitude noise. At this time there is a maximum in occurrence of high latitude hiss which corresponds to the approach of the auroral oval to its greatest low latitude extent. There is a second maximum in occurrence of high latitude hiss in the afternoon (*Hughes et al.,* 1971) but this lies at much higher latitudes (~76°-78° Λ) and therefore does not influence the occurrence pattern of $\Lambda = 59°$-60°. The secondary peak at 3,2 kHz between 05 h and 07 h MLT may be due to chorus, which would

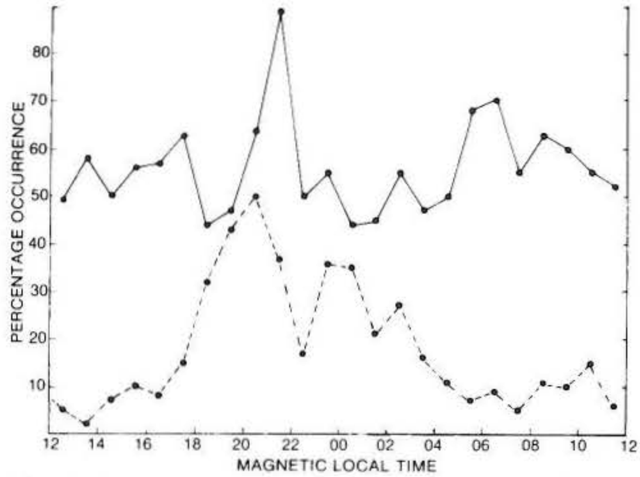

Fig. 3. The frequency of occurrence of noise at 3,2 kHz (upper curve) and 9,6 kHz with a power spectral density greater than 4,8 x 10^{-16} W m^{-2} Hz^{-1} for the latitude of Sanae for $K_p \leq 2$.

not normally make a large contribution to the mean reading circuits but when added to the mid-latitude noise is sufficient to produce a peak in the occurrence pattern at this time.

Conclusion

It is hoped that the occurrence patterns given in this paper will be of value to observers on the ground in drawing up observing schedules and in discussing their results. It has not been possible to reproduce all the available statistics here. However, researchers interested in obtaining occurrence statistics at other signal thresholds, for different levels of magnetic disturbance, or for other latitudes, should contact the author directly.

References

Bullough, K., Denby, M., Gibbons, W., Hughes, A.R.W., Kaiser, T.R. & Tatnall, A.R.L. ELF / VLF emissions observed on Ariel 4. *Proc. R. Soc. Lond.* A, **343,** 207-226, 1975.

Bullough, K., Hughes, A.R.W. & Kaiser, T.R. Satellite evidence for the generation of VLF emissions at medium latitudes by the transverse resonance instability. *Planet. Space Sci.,* **35,** 363, 1969.

Ellis, G.R. Low-frequency radio emission from the aurorae. *J. atmos. terr. Phys.,* **10,** 303, 1957.

English, H.W. & Hughes, A.R.W. An attempt to explain satellite observations of high latitude VLF hiss in terms of generation by incoherent Cerenkov radiation. In *Space Research* **XIV**, 359. Berlin, Akademie-Verlag, 1974.

Etcheto, J., Gendrin, R., Solomon, J. & Roux, A. A self-consistent theory of magnetospheric ELF hiss. *J. Geophys.,* **78,** 8150, 1973.

Hughes, A.R.W. & Kaiser, T.R. VLF emissions and the aurora. In *The Radiating Atmosphere,* edited by B.M. McCormac, 336. Dordrecht, Holland, D. Reidel Publ. Co., 1971.

Hughes, A.R.W., Kaiser, T.R. & Bullough, K. The frequency of occurrence of VLF radio emissions at high latitudes. In *Space Research* **XI**, 1323. Berlin, Akademie-Verlag, 1971.

Jorgensen, 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.

Kennel, C.F. & Petschek, H.E. Limit on stably trapped particle fluxes. *J. geophys. Res.,* **71,** 1-28, 1966.

Srivastava, R.N. & Swift, D.W. VLF hiss and the visual aurora. *Trans. Am. Geophys. Union (USA),* **53,** 498, 1972.

Swift, D.W. & Kan, J.R. A theory of auroral hiss and implications on the origin of auroral electrons. *J. geophys. Res.,* **80,** 985-992, 1975.

Thorne, R.M. & Kennel, C.C. Quasi-trapped VLF propagation in the outer magnetosphere. *J. geophys. Res.,* **72,** 857, 1967.

Thorne, R.M., Smith, E.J., Burton, R.K. & Holzer, R.E. Plasmaspheric hiss. *J. geophys. Res.,* **78,** 1581, 1973.

Tsurutani, B.T. & Smith, E.J. Inner zone hiss and electron losses. *J. geophys. Res.,* **80,** 600, 1975.

(Received 6 November 1975)

(continued from p 9)

Ravich, M.G. & Soloviev, D.S. Geology and petrology of the mountains of central Queen Maud Land (eastern Antarctica). *Transactions of the Scientific Research Institute of Arctic Geology,* Ministry of Geology of the USSR, 141. Leningrad, 1966. (Translated from the Russian by N. Kaner, Israel Program for Scientific Translations, and published in Jerusalem pursuant to an agreement with the National Science Foundation, Washington D.C.)

Robin, G. de Q. Seismic shooting and related investigations. *Norw.-Br.-Swed. Antarct. Exped., Scientific Results,* **V.** Norsk Polarinstitutt, Oslo, 1958.

Roots, E.F. Preliminary note on the geology of western Dronning Maud Land. *Norsk Geol. Tidsskr.,* **32,** 19-33, 1953.

Roots, E.F. Geology of western Queen Maud Land. *American Geographical Society, Map Folio Series,* **12,** Sheet 6, 1969.

Turner, F.J. & Verhoogen, J. *Igneous and metamorphic petrology.* Second edition. New York, McGraw-Hill Book Company, 1960.

Van Autenboer, T. & Loy, W. Recent geological investigations in the Sør-Rondane Mountains, Belgicafjella and Sverdrupfjella, Dronning Maud Land. In *Antarctic geology and geophysics,* edited by R.J. Adie, 557-562. Oslo, Universitetsforlaget, 1972.

Winkler, H.G.F. *Petrogenesis of metamorphic rocks.* Second edition. New York, Springer-Verlag, 1976.

(Received 25 February 1976)