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Power spectrum analysis of sferics from lightning

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Power spectrum analysis has been applied to the data on lightning activity collected by very low frequency atmospherics analyzer stations of Roorkee and Pretoria. Some well-defined oscillations in the thunderstorm activity and sferics activity corresponding to 24, 12 and 8 h periodicities have been observed. The diurnal variation of sferics activity is found to follow the pattern of the diurnal variation of potential gradient observed at other land stations.

1 Introduction

Sferics are electromagnetic pulses generated by lightning strokes. The very low frequency (VLF) component (< 30 kHz) of sferics propagates in the atmospheric waveguide between the earth's surface and the lower ionosphere, and it can reach several thousand kilometres before its strength decays below the noise level. The atmospheric waveguide being a dispersive medium modulates the waveform of the sferics during its propagation. Measurement of the waveform and the direction of arrival of an individual sferic allow the determination of the position of the lightning stroke. The mathematical method developed for using sferics in locating thunderstorm centres, which is being used by the VLF atmospherics analyzer (VLFAA) of Roorkee and Pretoria stations, is given in detail elsewhere[1].

2 Data analysis

The VLF atmospherics analyzer is made up of four parts, namely, antennas, analyzer, computer and plotter. The loop antennas are tuned to a frequency of 9 kHz for the determination of the angle of incidence of atmospherics. The whip antenna delivers signals to three narrow band receivers tuned to 5, 7 and 9 kHz.

In the analyzer an atmospherics is analyzed whenever its spectral amplitude at 5 kHz exceeds the noise level of the instrument. Four parameters are measured in the analyzer: (1) angle of incidence, (2) group delay time (GDD) (6-8 kHz), (3) spectral amplitude ratio (SAR) (9/5 kHz), and (4) spectral amplitude (SA) at 5 kHz. These four parameters are transferred to the computer. The computer collects data for each measuring period and fits a Gaussian to the GDD, SAR and SA and determines the statistical parameters of each thunderstorm activity centre. From the three independent measurements (GDD, SAR and SA) and by applying the propagation model, the distances to the thunderstorm activity centres are determined. The location and strength (No. of sferics/min) of each thunderstorm centre are plotted in real time on a world map and also printed out. Each station is capable of detecting thunderstorm centres in a range of 4000 km during daytime and at distances of 10,000 km during nighttime due to improved atmospheric propagation conditions at night.

Data from the VLFAA stations of Pretoria and Roorkee were obtained for the period January to March 1984. Getting a continuous set of observations from the Indian station was difficult mainly because of frequent electricity failure. Three months of Pretoria data were obtained for the purpose of making comparative studies. Of all the VLFAA stations in the world (Berlin, Tokyo, San Miguel, Waldrof, Pretoria, Tel Aviv, Payrene and Georg. V Neu Mayer), Roorkee and Pretoria stations have identical systems. Both are tropical stations—Roorkee located at 29.52°N, 77.59°E and Pretoria at 25.44°S, 28.12°E. The observations used for the present analysis are: (1) number of thunderstorms detected every hour, and (2) intensity of global lightning activity in terms of number of sferics received per minute during a particular hour.

Power spectrum analysis was employed on the present data[2], X_i, where $i=1$ to N was considered as a series of N equally spaced observations; in this case, number of thunderstorms/h and sferics/h. All serial co-variances for lags o to m time units, $m < 40\% \ N$, were computed. Cosine transforms were computed for these $m+1$ lag co-variances to yield $m+1$ "raw estimates" of the power spectrum. The raw estimates were smoothed by a 3-term moving average with weights equal to 1/4, 1/2 and 1/4 to yield the smooth estimates of the power spectrum. The spectrum obtained was that of red noise.

To test the statistical significance, the 5% and 95% red noise significant levels were computed First the red noise null continuum was obtained by

$$R_k = S\left[\frac{1-r_1^2}{1+r_1^2-2r_1\cos(\pi k/m)}\right]$$

k varies from $k=0$ to m, r_1 is the lag one correlation coefficient and S is the average of all $m+1$ raw spectral estimates. Next the degrees of freedom (ν) was computed by

$$\nu = (2N - m/2)/m$$

From the table giving the percentage probability points of x^2/ν distribution (here x is the standard normal variate), the values of 95% and 5% points corresponding to the computed degrees of freedom, were obtained. These values were $p_{0.95}$ and $p_{0.05}$. The 95% confidence limit for the null continuum was obtained by multiplying $p_{0.95}$ with the local value of null continuum for each wave length in the spectrum. In a similar manner, the 5% confidence limit was also obtained. With the 95% and 5% confidence limits superposed on the smooth estimate the spectrum was examined. If any spectral estimate exceeds 95% confidence limit then the spectral estimate corresponds to an oscillation that is contained in the series.

3 Results

Figures 1 and 2 show the spectra of the number of thunderstorms observed every hour by the Pretoria and Roorkee VLFAA stations respect-

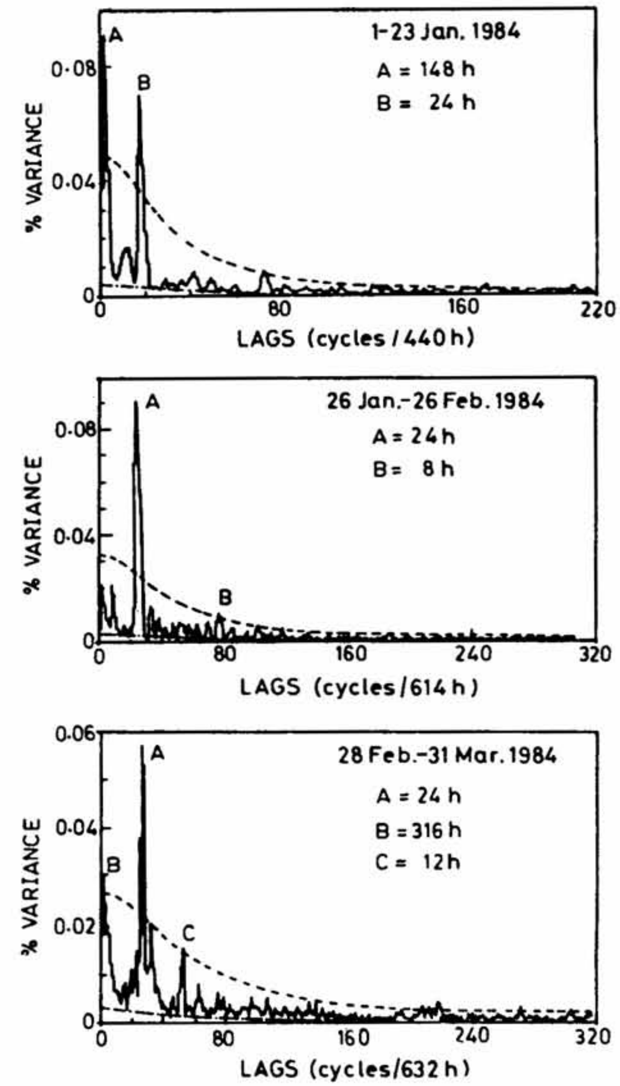

Fig. 1—Spectrum of the number of thunderstorms located by the VLFAA of Pretoria station (— smooth estimates, --- 95% confidence limit, and —·— 5% confidence limit)

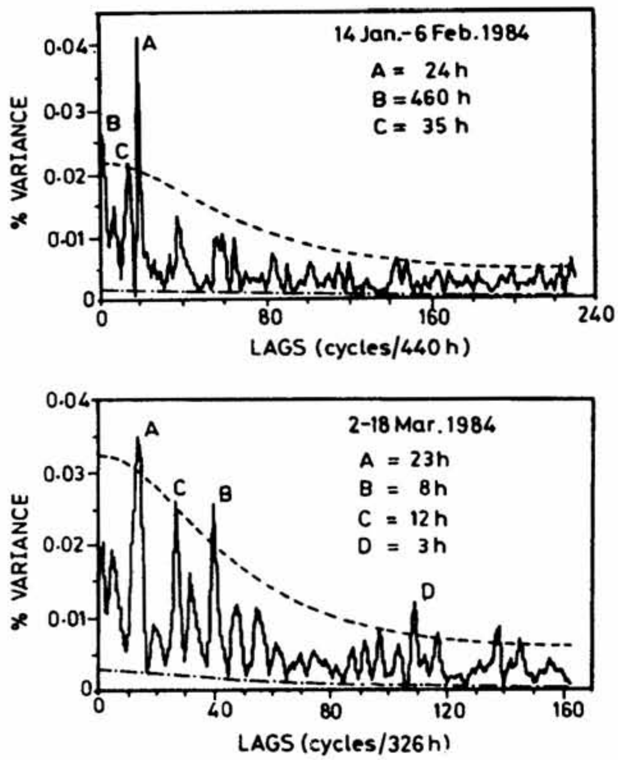

Fig. 2—Spectrum of the number of thunderstorms located by the VLFAA of Roorkee station (— smooth estimates, --- 95% confidence limit, and —·— 5% confidence limit)

ively. Figures 3 and 4 show the spectra for the number of sferics/h observed by the Pretoria and Roorkee VLFAA stations respectively. In all these figures the 95% and 5% confidence limits have been superposed on the smooth estimates. The spectral estimate exceeding the 95% confidence limit corresponds to an oscillation that is contained in the series, the periods of these oscillations have been calculated and indicated in Figs. 1-4. Table 1 gives the duration for which the data have been analyzed, number of hours of observations, number of lags, and observed periods of oscillation.

4 Discussion

From the above analysis it is seen that the most predominant oscillation is a 24 h oscillation. This

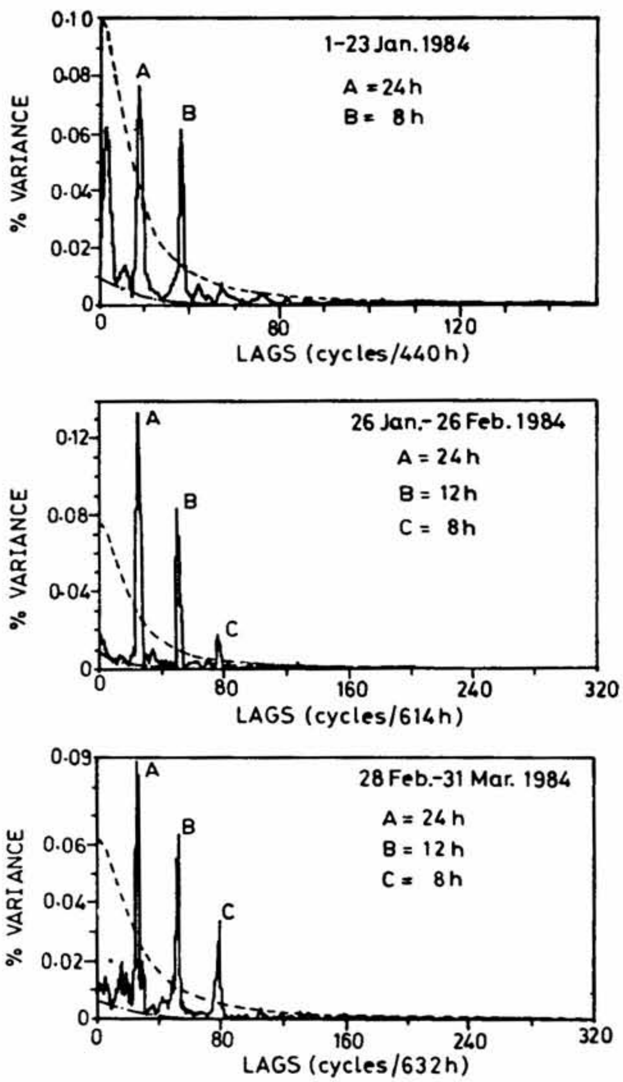

Fig. 3—Spectrum of the number of sferics/h observed by the VLFAA of Pretoria station (—— smooth estimates, --- 95% confidence limit, and —·— 5% confidence limit)

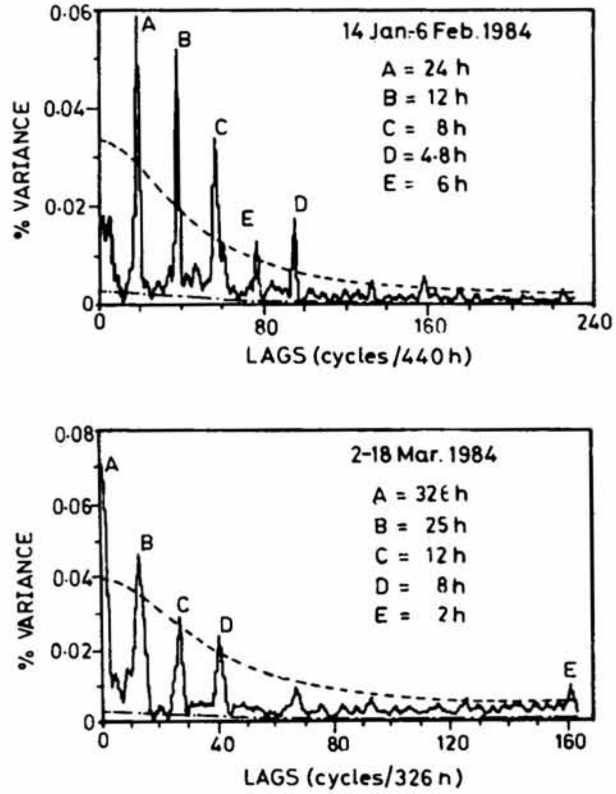

Fig. 4—Spectrum of the number of sferics/h observed by the VLFAA of Roorkee station (—— smooth estimates, --- 95% confidence limit, and —·— 5% confidence limit)

Table 1—Thunderstorm and sferics periodicities observed at Pretoria and Roorkee

Duration of observations	No. of hours of data	No. of lags	Periodicity of oscillation h
Pretoria thunderstorms			
1-23 Jan. 1984	552	220	148, 24
26 Jan.-26 Feb. 1984	768	307	24, 8
28 Feb.-31 Mar. 1984	792	316	316, 24, 12
Pretoria sferics			
1-23 Jan. 1984	552	220	24, 8
26 Jan.-26 Feb. 1984	768	307	24, 12, 8
28 Feb.-31 Mar. 1984	792	316	24, 12, 8
Roorkee thunderstorms			
14 Jan.-6 Feb. 1984	576	230	460, 24, 35
2-18 Mar. 1984	408	163	23, 8, 12, 3
Roorkee sferics			
14 Jan.-6 Feb. 1984	576	230	24, 12, 8, 5, 6
2-18 Mar. 1984	408	163	326, 25, 12, 8, 2

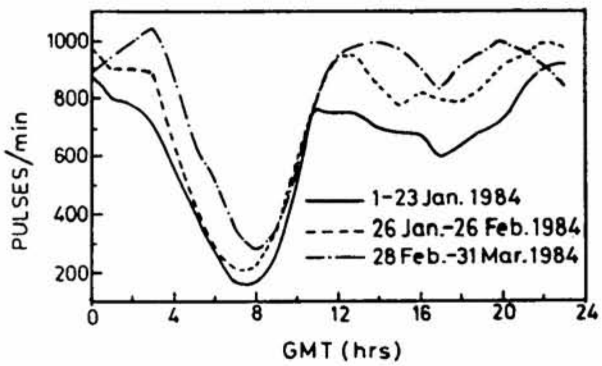

Fig. 5—Diurnal variation of sferics rate observed at Pretoria

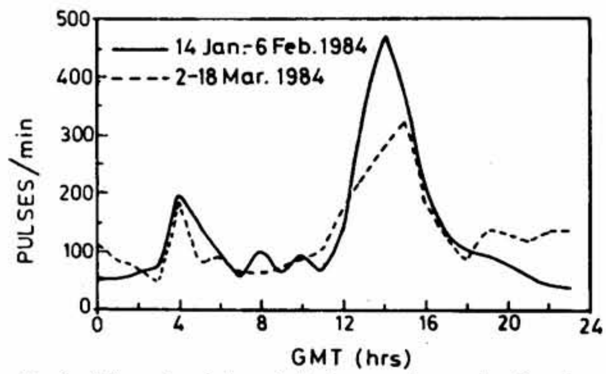

Fig. 6—Diurnal variation of sferics rate observed at Roorkee

is true for the sferics rate and the number of thunderstorms observed both at Pretoria and Roorkee stations. Two other oscillations of less importance are also evident and these correspond to 12 h and 8 h periodicities. The diurnal variations of sferics rates observed at Pretoria and Roorkee are given in Figs 5 and 6 respectively. The diurnal variation of the sferics activity over Pretoria shows one minima and the nature is similar to the "Potsdam" type[3] of diurnal variation of vertical electric field on the ground. The diurnal variation of sferics over Roorkee shows two maxima and two minima and the nature is similar to the "Kew" type[3] of diurnal variation of vertical electric field on the ground. Such a similarity is there because the diurnal variation of vertical electric field on the ground follows the global thunderstorm activity. It is also seen that the diurnal variation of sferics activity observed over Pretoria follows the diurnal variation of high frequency atmospheric radio noise derived from thunderstorm activity at about six different locations (Ohira, Japan; Boulder, USA; Kekaha, USA; Singapore; Cook, Australia; Enkoping, Sweden) during the years 1959 to 1970; the diurnal variation of VLF sferics observed over Roorkee shows a different characteristics. Atmospheric radio noise is composed of radio waves coming directly from lightning discharges occurring near the observation point and of radio waves coming from distant places by long ionospheric propagation paths. The magnitude of the two components, the local component and the propagated component of the sferics, determines the characteristics such as diurnal and seasonal variations. This may be the reason for the observed difference of the diurnal characteristics of the Pretoria and Roorkee sferics and also for the 12 h and 8 h minor periodicities in the oscillations.

Some other minor periods like 3, 5 and 6 h are seen in the Roorkee data. Roorkee is located on the foothills of the Himalayas and the observations are for the winter season when there is a lot of activity over the Himalayan ranges. The minor periods observed over Roorkee could therefore be due to winter thunderstorms over the Himalayas. The other periods that were observed are 6.2, 13.2, 13.6 and 19.2 days. Nothing much can be said about these periods as longer periods of observations are required for drawing any conclusion.

The seasonal variation of the sferics activity in two different hemispheres can be clearly seen in Figs 5 and 6. There is an increase in atmospherics activity from January to March over Pretoria, while there is a decrease in atmospherics activity during the same months over Roorkee. Pretoria is a southern hemisphere station where the season is going from summer to winter, and Roorkee is a northern hemisphere station where the season is going from winter to summer.

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