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Statistical properties of the deviations of f_0F_2 from monthly medians

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Abstract
The deviations of hourly f_0F_2 from monthly medians for 20 stations in Europe during the period 1958-1998 are studied. Spectral analysis is used to show that, both for original data (for each hour) and for the deviations from monthly medians, the deterministic components are the harmonics of 11 years (solar cycle), 1 year and its harmonics, 27 days and 12 h 50.49 m (2nd harmonic of lunar rotation period L_2) periodicities. Using histograms for one year samples, it is shown that the deviations from monthly medians are nearly zero mean (mean < 0.5) and approximately Gaussian (relative difference range between %10 to %20) and their standard deviations are larger for daylight hours (in the range 5-7). It is shown that the amplitude distribution of the positive and negative deviations is nearly symmetrical at night hours, but asymmetrical for day hours. The positive and negative deviations are then studied separately and it is observed that the positive deviations are nearly independent of R_{12} except for high latitudes, but negative deviations are modulated by R_{12}. The 90% confidence interval for negative deviations for each station and each hour is computed as a linear model in terms of R_{12}. After correction for local time, it is shown that for all hours the confidence intervals increase with latitude but decrease above 60°N. Long-term trend analysis showed that there is an increase in the amplitude of positive deviations from monthly means irrespective of the solar conditions. Using spectral analysis it is also shown that the seasonal dependency of negative deviations is more accentuated than the seasonal dependency of positive deviations especially at low latitudes. In certain stations, it is also observed that the 4th harmonic of 1 year corresponding to a periodicity of 3 months, which is missing in f_0F_2 data, appears in the spectra of negative variations.

Key words f_0F_2 – *critical frequency – variability*

1. Introduction

The ultimate goal of the work related to the ionospheric critical frequency f_0F_2 is prediction and forecast. However determination of reliability bounds is also important for planning in HF communication, radar and navigation systems. The median values for each hour can be considered as a first approximation to the data. The prediction of the median values, based on standard trigonometric expansions and parabolic models in terms of the 12 month smoothed sunspot number R_{12}, proves to be satisfactory, with the mean square errors in the range of 3-7% (Baykal, 1998; Bilge and Tulunay, 1998). The estimation of the actual hourly values of f_0F_2 is called «forecasting», and it deals with neural network (Tulunay *et al.*, 2000) and feedback methods (Bilge and Tulunay, 2000), in addition to more standard autocorrelation techniques (Stanislawska *et al.*, 1999). In this paper, we concentrate on the deviations of f_0F_2 from monthly medians, denoted by $\Delta f = f_0F_2 -$

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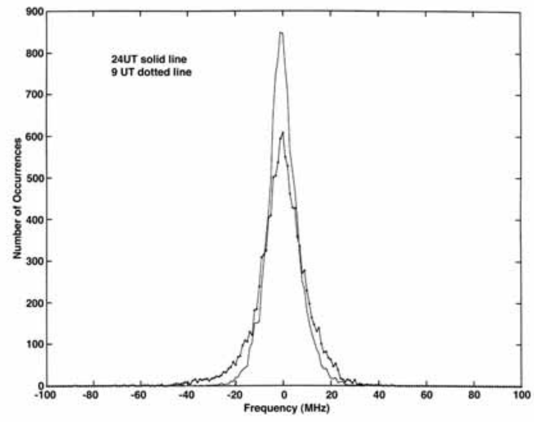

Fig. 5. Comparison of the histogram plots of the deviations from monthly medians for Rome at 24 UT and 9 UT.

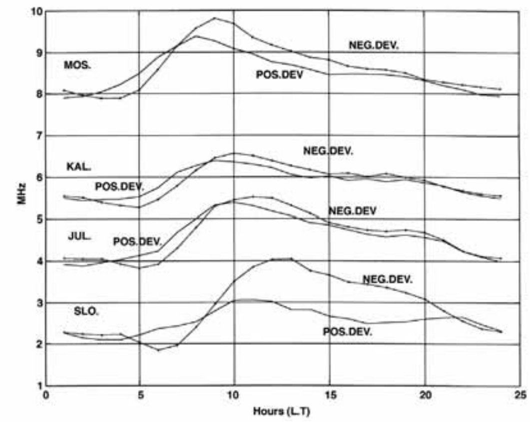

Fig. 6. Positive (solid line) and negative (dotted line) deviations for Slough, Juliusruh, Kaliningrad, Moscow (in the 50°N-57°N latitude band). Plots are shifted each by 2 units.

that in night hours the negative deviations are below the positive deviations, while in day time the roles are reversed. The local time dependency can also be seen as a shift of the crossing points as we move longitudinally. We have obtained similar graphs for each latitude group in table I, where the similarities of the shapes of the curves inside each group justify the subdivisions with respect to latitude.

3.4. *Seasonal dependency*

As we worked with 1-year samples in the statistical analysis, we overlooked the seasonal dependency of the deviations. We can however make certain qualitative remarks based on our time domain plots and our frequency spectra. The time domain plots of Δf given in fig. 7a,b show that at high latitudes, for example Uppsala, both positive and negative deviations have seasonal dependency while at lower latitudes, for example at Rome, only negative deviations have seasonal dependency. The amplitudes are higher during equinoxes. This is consistent with the spectral analysis results given in fig. 3b, where it can be seen that the periodicity of 6 months has higher power for negative deviations.

3.5. *Long-term trend analysis*

In previous sections, we considered ($\Delta f^{+/-}$) as a function of R_{12}. It is also of interest whether there is a trend irrespective of the solar conditions. For this purpose, we selected years with R_{12} = 100, R_{12} = 50 and R_{12} = 20 in rising and falling phases, obtaining 6 data groups. For example for R_{12} = 100 in the falling phase we have the years (1960, 1970, 1982, 1991). In each data group we take the difference of the data for consecutive years that we denote as $\delta\Delta f^{+/-}$. For example, if there is an increase in $\Delta f^{+/-}$ from 1982 to 1991, at a given hour and station, the corresponding entry in $\delta\Delta f^{+/-}$ will be positive. The relative «strength» of the positive values in $\delta\Delta f^{+/-}$ will be an indication of an increasing trend. In order to quantify these trends, we separated the positive and negative parts of $\delta\Delta f^{+/-}$ and computed their norms, denoted as n_p and n_m. If the ratio n_p/n_m is larger than 1 there is a trend to increase from one year to the next in the same group, while if n_p/n_m is less than 1 there is a trend to decrease. We found that for positive deviations from monthly medians the ratio n_p/n_m

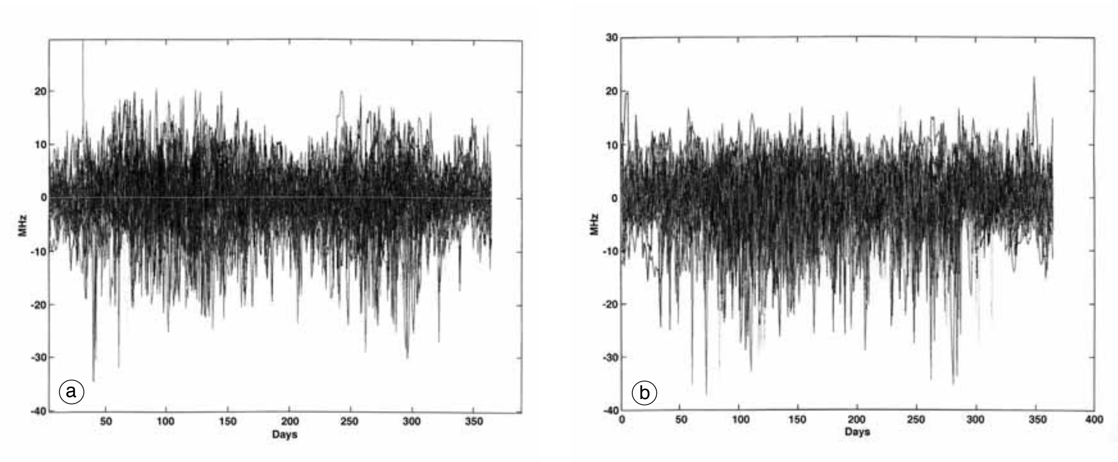

Fig. 7a,b. Yearly variation of the positive and negative deviations for Uppsala (high latitude) and Rome (low latitude).

is larger than one for 15 out of 17 times, while for negative deviations from monthly medians, it is larger than one only for 10 out of 17 times. Thus we can conclude that for positive variations there is a trend to increase with time irrespective of the solar conditions. In the literature, linear trends in f_0F_2 are tied to the lowering of the F_2 layer caused by the increasing greenhouse effect (Bremer, 1992) and the increase in magnetic storm activity (Clilverd *et al.*, 1998; Danilov, 2001).

4. Modelling positive and negative variations separately

For each station year and hour, we computed the 90% confidence interval, *i.e.* the value $(\Delta f^{+/-})_c$ such that $(\Delta f^{+/-})$ is less than $(\Delta f^{+/-})_c$ with a probability of 0.9, for the given station, hour and year. We have seen that these upper deciles for positive deviations are virtually independent of R_{12} and we decided to investigate the negative deviations. In general $(\Delta f^{-})_c$ for a given hour (UT) is expected to depend on R_{12}, the latitude and longitude of the station and the month of the year. As we worked with yearly samples of data, we lost the information related, for example, to the semi-annual and seasonal dependencies. On the other hand, the time domain plots in fig. 6 suggest that the longitude dependency reflects in a shift of the curves, hence using a local time correction we may assume that $(\Delta f^{-})_c$ is a function of the latitude, local time and R_{12}. We shall look for a linear model with respect to R_{12}.

As an example, in fig. 8 we show $(\Delta f^{-})_c$ for Sverdlovsk for each hour as a function of R_{12}. The data are quite scattered, but we can still look for a linear trend using least squares approximation: For each station and each hour we obtained the slope and the intercept of an approximating line, by minimizing the least squares error between the data and the linear model. For selected representative stations and hours these errors range between 9.9% and 21.3%, which indicates the existence of some linear trend. As a result, we obtain a model where we express the 90% confidence interval in terms of R_{12} as below.

$$(\Delta f^{-})_c \text{ (latitude, local time, } R_{12}) = \\ = \text{A (latitude, local time) } R_{12} + \\ + \text{B (latitude, local time).} \tag{4.1}$$

Where the «coefficients» A and B depend on the latitude and local time. In order to analyse the dependency on the latitude, we evaluate $(\Delta f^{-})_c$

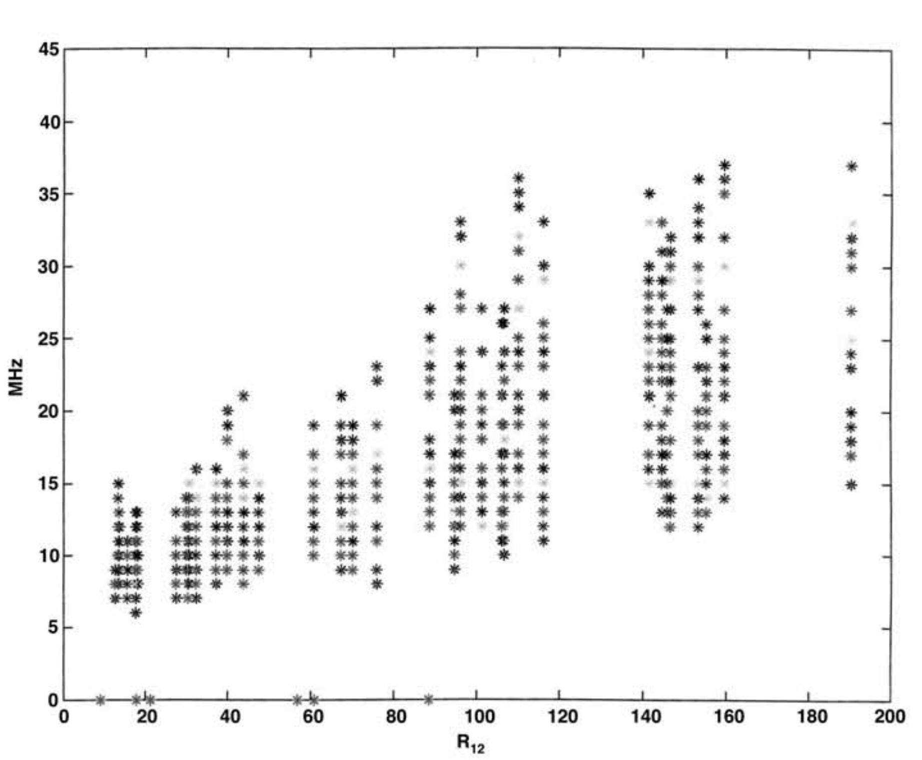

Fig. 8. Upper deciles of Δf^- for Sverdlovsk, with respect to R_{12} for all hours.

as given by eq. (4.1) for a representative value of R_{12}, say the median, corresponding to $(R_{12})_{\text{median}} = 62.63$. This gives a representative value of (Δf^-) that we denote as $(\Delta f^-)_m$ given below.

$$(\Delta f^-)_m \text{ (latitude, local time)} =$$

$$= \text{A (latitude, local time)}(R_{12}) \text{ median} +$$

$$+ \text{ B (latitude, local time)}.$$

Note that $(\Delta f^-)_m$ is a function of two variables only. For each station, we plot $(\Delta f^-)_m$ with respect to local time and present the results in fig. 9a-d grouped with respect to their latitudes. It can be seen that the graphs for stations between 60°N-70°N are less coherent, the maxima are located at 12-14 LT, and the amplitudes are less than 14 MHz. For the stations in the 50°N-57°N band, the variations are extremely coherent, there is a distinct peak at 12 LT, and the amplitudes reach 18 MHz. Down to 45°N-51°N band, all graphs have a peak again around noon, but their amplitudes seem to have a shift, their respective maxima ranging from 10 to 16 MHz. In the lowest latitude band, 40°N-43°N, the peaks are located around 10-11 LT, the maxima range from 7 to 14 MHz, but the lowest value of 7 MHz, for Tortosa is questionable, because the data for Tortosa has large gaps. The incoherency of the graphs of equal latitude/different longitude stations shows that the local time correction at high latitudes may not compensate for spatial dependency. On the other hand, graphs for lower latitude station groups are coherent; hence we may say that local time correction is successful at least below 60°N latitude. We also note that the variation curves shift up with latitude up to deviations have larger amplitude at 12 UT and the histograms are wider at daytime. The negative deviations are modulated by R_{12} at all latitudes, but positive deviations have a R_{12} dependency only at high latitudes. Also from the frequency spectrum we observed that the 27 days periodicity disappears at night time (24 UT). At high latitudes both positive and negative deviations have seasonal dependency while at low latitudes positive deviations are nearly independent of season. The longitude dependency reflects as a shift with respect to local time.

We quantified the R_{12} dependency of the positive and negative deviations as a linear model for the %90 confidence interval for each station. We found that the positive deviations were rather independent of R_{12}, and we computed representative values for the upper deciles of negative variations for each station and local time. On the other hand, we found an increase in the 90% confidence intervals of positive deviations after elimination of R_{12} effects, which were not apparent in the negative deviations.

For stations below 60°N, the longitude dependency was eliminated by a local time shift and the upper deciles have a coherent behaviour for stations grouped according to latitudes. The location of the peaks moves from 11 LT to 14 LT from south to north, and the peak amplitudes start from 10 MHz, increase to 18 MHz and then decrease to 16 MHz above 60°N. This latitude dependency agrees with recent investigations where Kouris *et al.* (2000) also observed an increase in MUF with latitude followed by a decrease above 60°N.

As we worked with 1 year samples of data for the study of the deviations from monthly medians, we overlooked any seasonal dependencies in the quantitative study of the deviations. Seasonal variations appeared only in frequency spectra. Semi-annual (Rishbeth *et al.*, 2000) variations as well as the seasonal variations of the hysteresis effects (Buresova and Lastovicka, 2000) are discussed in the literature.

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