

EFFECTS OF GEOMAGNETIC ACTIVITY ON DAILY DEVIATION PATTERNS OF THE IONOSPHERIC CRITICAL FREQUENCY FOF2

E.Mizrahi⁽¹⁾, Y.Tulunay⁽²⁾, A.H.Bilge⁽³⁾

⁽¹⁾Department of Mathematics, Faculty of Sciences and Letters, Istanbul Technical University, Maslak Istanbul, TURKEY. Research Assistant

⁽²⁾Faculty of Astronautics and Aeronautics, Middle East Technical University, Ankara, TURKEY. Prof.Dr.

⁽³⁾Department of Mathematics, Faculty of Sciences and Letters, Istanbul Technical University, Maslak Istanbul, TURKEY. Prof.Dr.

SUMMARY: *The deviations of the ionospheric critical frequency foF2 from monthly medians is a measure of the ionospheric variability and it can be used in designing prediction and forecast algorithms. In the present work we used the foF2 data of 13 European stations from high latitudes to mid and low latitudes, over the period 1958-1998 to study the deviations from monthly medians. It is observed that the positive and negative deviations have distinct features and they are modelled as different stochastic processes by their dependency on the smoothed sunspot number R_{12} , on the latitude, and on the geomagnetic activity indices A_p and Dst . These deviations are then classified by using the l_2 norm of the daily deviations as a quantitative criteria and qualitative observations for full data, quiet days and for disturbed days are given.*

KEYWORDS: *foF2, ionospheric critical frequency, ionospheric variability, geomagnetic activity indices A_p and Dst , classification.*

1. INTRODUCTION:

The prediction, forecasting and the determination of reliability bounds of the ionospheric critical frequency foF2, is important for planning in HF communication, radar and navigation systems. The deviations from monthly medians of the ionospheric critical frequency foF2 denoted by $\Delta foF2$, is accepted as a measure of the ionospheric variability [1], and it can be used in designing prediction and forecast algorithms[2].

In the present work we used the foF2 data of 13 European stations from high (56.4N-67.8N) to mid (45.5N-55.5N), and low (37.9N-42.7N) latitudes over the period 1958-1998. The stations are respectively: Kiruna, Lycksele, Arkangelsk, Uppsala, Sverdlovsk, Moscow, Kaliningrad, Slough, Dourbes, Lannion, Poitiers, Novokazalinsk and Ashkhabad. As a first step we analysed the data for outliers and eliminated a number of presumably wrong data. In the line of our previous experience we used local time correction to eliminate the longitudinal dependency. In previous works we have already shown that the positive and negative deviations of foF2 from monthly medians have different characteristics [1], namely the positive deviations ($\Delta foF2^+$) are more or less independent of the smoothed sunspot number R_{12} except at high latitudes, while the negative deviations ($\Delta foF2^-$) have a clear R_{12} dependency. Here we analysed their behaviour in detail by considering the positive and negative deviations as separate processes and we studied their dependency on the latitude, on R_{12} , on months (seasons) and on the geomagnetic activity index A_p . Actually the dependency of foF2 on geomagnetic activity could be studied as well using Dst index. However we have observed that the amplitude of the negative variations depend more or less linearly with A_p , while this dependency is quiet non-linear with Dst .

¹ E.Mizrahi, mizrahi1@itu.edu.tr

² Y.Tulunay, ytulunay@itu.edu.tr

³ A.H.Bilge, bilge@itu.edu.tr

In this work we first classified the daily variations curves, based on their dependency on R_{12} , the geographic latitude, and months (seasons), using the l_2 norm of the daily deviations as our quantitative criteria. After this clustering we made qualitative observations for: full data (all days), quiet days and disturbed days. Here the days with $A_p < 6$ are considered as quiet [3] while the days with $24 < A_p < 30$ or $18 < A_p < 24$ are considered as disturbed days. Extremely disturbed days with $A_p > 30$, being very rare, it has been difficult to make any healthy comment. We have seen that daily variations patterns for the same R_{12} range, at low and mid latitudes are similar. However at high latitudes the variations at Kiruna (67.8N) shows no similarity to the variations at Arhangelsk (64.4N) and Lycksele (64.6N). This dissimilarity is less accentuated for negative deviations. This anomaly needs further investigation. The present work involved handling of hourly data from 13 stations for 41 years, which amounts to the classification of $24 \cdot 365 \cdot 41 \cdot 13 = 4.669.080$ items using MATLAB. The present paper is an abbreviated version of [5].

2.DEPENDENCIES OF NEGATIVE AND POSITIVE DEVIATIONS:

It is well known that the variations of foF2 have a strong dependency on the smoothed sunspot number R_{12} , especially the monthly medians can be quite well represented even with a model linear in R_{12} . The detailed structure of the dependency of the deviations from monthly medians on R_{12} is less known. The variation of the smoothed sunspot numbers with years is given in Figure 1.

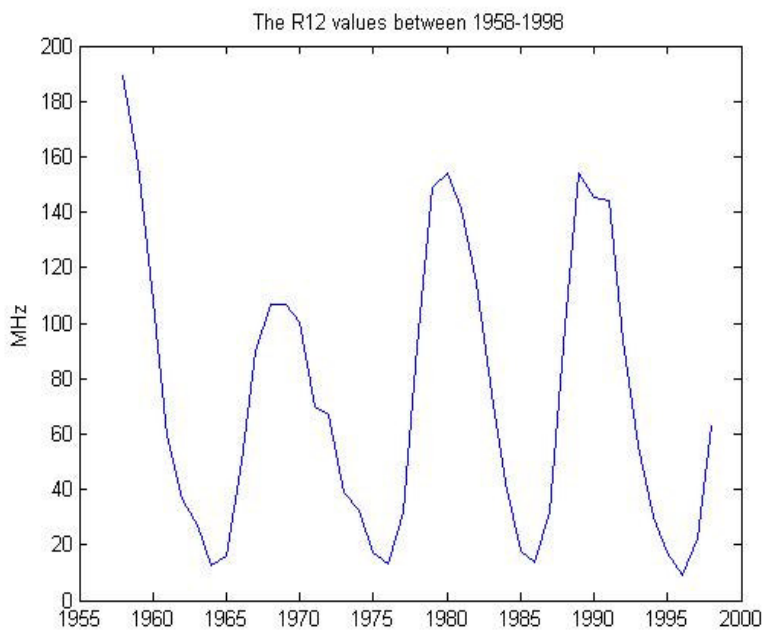


Figure 1. The R_{12} values between 1958-1998

R12 Dependency: In previous works we have noticed that the maximum and minimum values of positive and negative deviations, i.e. the sup-norm of the deviations, have quite different characters. As a representative example we present below in Figure 2, the deviations from monthly medians for a mid-latitude station, Dourbes (50.1N-4.6E), for local time 24.00, for two representative years, 1986 and 1976 which correspond respectively to a maximum and minimum of solar activity. A qualitative observation shows that the positive deviations have nearly the same maximal deviations in high and low solar activity periods, but the maximal negative deviations are much stronger in periods of high solar activity.

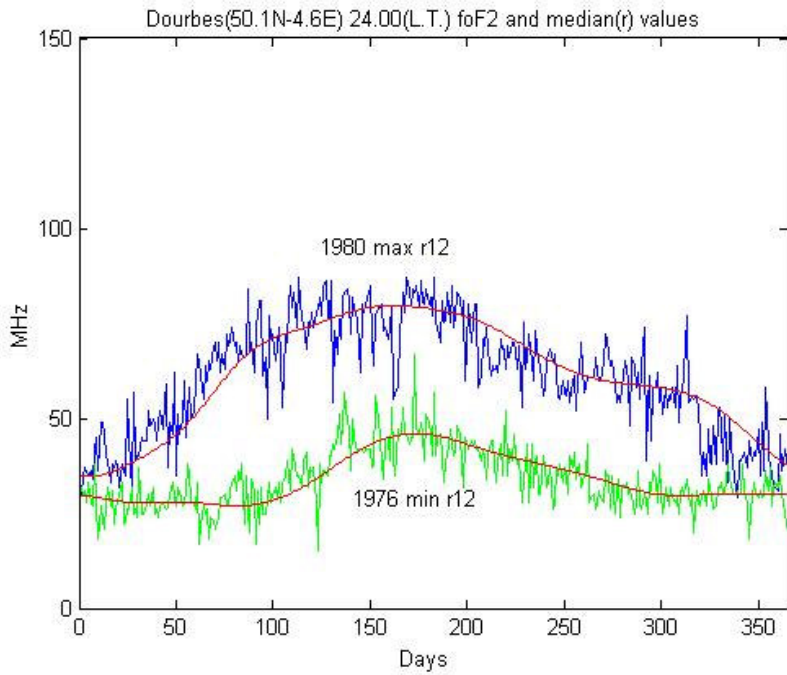


Figure 2. The foF2 and median values of a mid latitude station Dourbes at local time 24.00 in the years 1980 and 1976.

As opposed to the sharp discrepancy of the sup-norm of positive and negative maximal deviations with respect to their dependency on R_{12} , in the l_2 norm, which represents some type of average, this distinction is less accentuated. In Figure 3, below, which shows the median of the l_2 norm of the deviations for all years and all stations, it can be seen that positive deviations are less sensitive to extreme values of R_{12} .

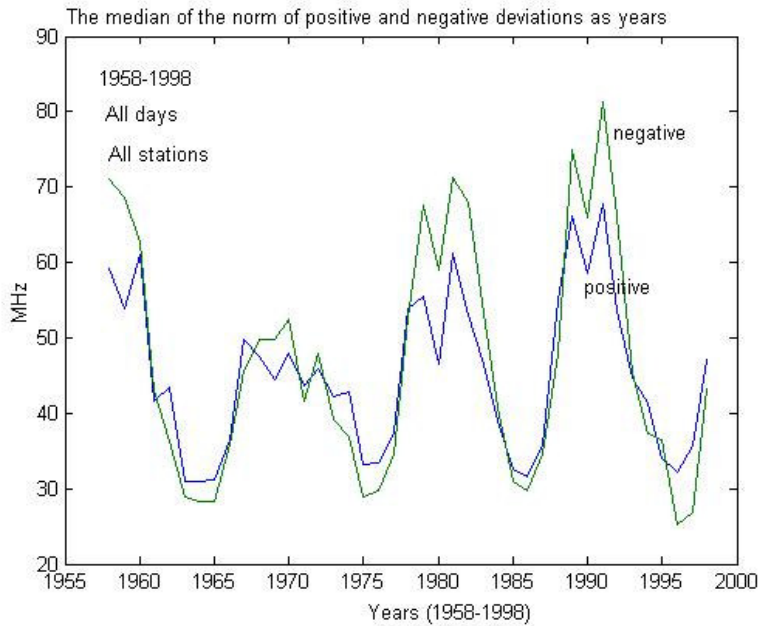


Figure 3. The median of the norm of positive and negative deviations by years for all stations.

We expected that the dependency of the negative deviations would disappear in quiet days. But our investigation showed us that the dependency of the negative deviations and the dependency of the positive deviations at high latitudes, remains at magnetically quiet days with $A_p < 6$ [4].

Seasonal dependency: We superposed the data of 13 stations and 41 years and we studied its dependency on to months. We observed that here also the positive and negative deviations should be considered as different processes. The graph of the positive deviations shows that the minimum occurs in June and July while the graph of the negative deviations shows that the minimum occurs in July and August (Figure 4).

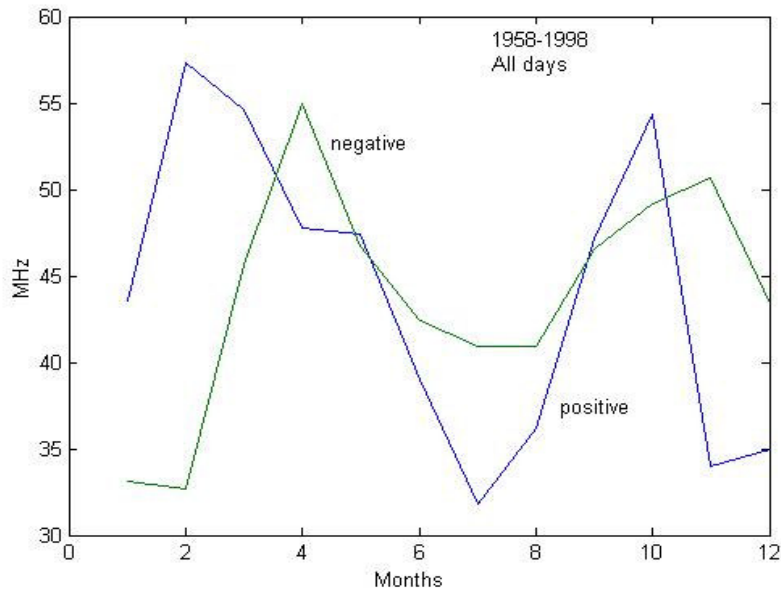


Figure 4. The median of the norm of negative and positive deviations by months for all stations and all years.

Latitude dependency: The graph of the positive deviations shows a maximum at high latitudes (60-65N) and mid-night time (22-05L.H⁴), and a local maximum at mid latitudes (50-55N).

The graph of the negative deviations shows that the stations with latitude less than 55N at night time are similar while stations with latitude more than 55N decrease linearly at day time. The maximum observed at day time in the station with latitude 55N disappears after 15.00L.H (Figure 5).

⁴ L.H.: Local Hour

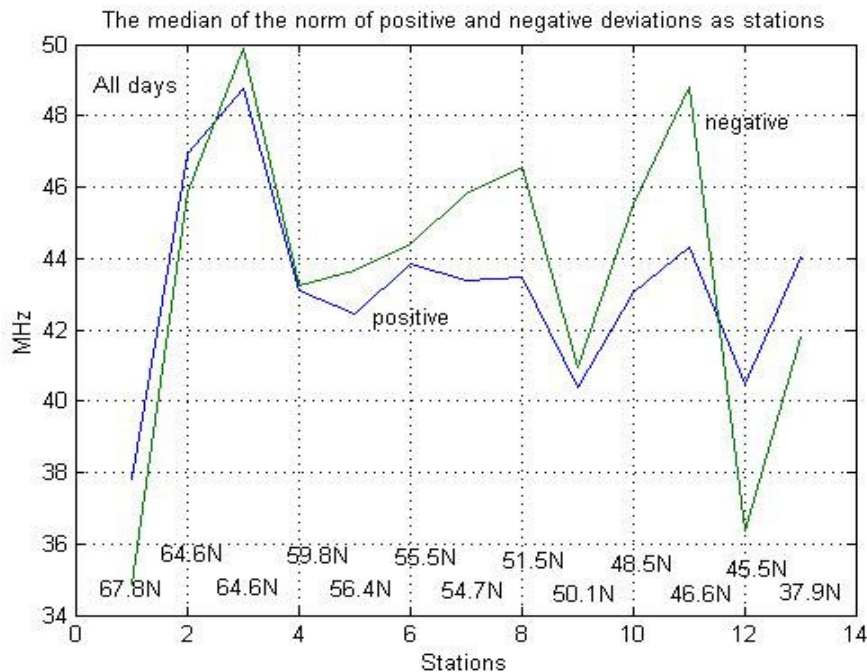


Figure 5. The median of the norm of positive and negative deviations by stations for all years.

3. CLASSIFICATION OF DAILY VARIATION CURVES WITH RESPECT TO SEASONAL AND LATITUDE DEPENDENCY:

- **Classification with respect to latitude:** The l_2 norm of the daily variations with respect to latitudes has been investigated. At high latitudes, it is observed that the data from Lycksele and Arkangelsk look alike while data from Kiruna is dissimilar. Mid latitude stations (Uppsala, Sverдловsk, Moscow, Kaliningrad, Dourbes and Slough between 59.8N-50.1N) show a good similarity as well as low latitude stations (Lannion, Poitiers, Novokazalinsk and Ashkhabad 48.7N-37.9N).
- **Classification with respect to months (seasons):** We grouped the negative and positive deviations with respect to months using the seasonal dependencies mentioned in Part 2.

Positive deviations: February, March, April and May form our first group while June, July and August are our second group. September and October which show similarities form our 3rd group while November, December and January form the 4th group.

Negative deviations: Since the graph of the negative deviations has a slight shift with respect to positive deviations; March, April, May and June form our 1st group. July and August are the second group while September, October and November are the 3rd group. Finally December, January and February are our 4th group.

4. THE PROPERTIES OF THE DAILY VARIATION CURVES AS FUNCTIONS OF STATIONS AND R_{12} :

We made a qualitative observation for all days, quiet days with low geomagnetic activity index, disturbed days and extremely disturbed days with high geomagnetic activity index, with respect to latitude and R_{12} . First we get the R_{12} values by year and grouped them in ranges. We get 4 ranges for R_{12} values in 41 years.

R_{12} Range 1: $9.1 < R_{12} < 29.5$									
1963	1964	1965	1975	1976	1985	1986	1995	1996	1997
27.3	12.3	16.3	17.4	13.4	17.9	13.8	17.3	9.1	22.7

R₁₂ Range 2: 29.5 < R₁₂ < 62.6										
1961	1962	1966	1973	1974	1977	1984	1987	1993	1994	1998
59.4	36.6	49.7	39.0	32.2	32.0	42.2	32.1	55.6	30.2	62.6

R₁₂ Range 3: 62.6 < R₁₂ < 106.9										
1967	1968	1969	1970	1971	1972	1978	1983	1988	1992	
89.7	106.6	106.5	100.4	69.7	66.8	91.4	74.7	98.5	93.7	

R₁₂ Range 4: 106.9 < R₁₂ < 185.5										
1958	1959	1960	1979	1980	1981	1982	1989	1990	1991	
189.5	157.5	108.0	148.6	154.2	141.3	114.3	153.9	145.5	144.0	

Table1. Ranges of the smoothed sunspot number R₁₂ for 1958-1998

- Qualitative observation for all days:** For positive deviations, at higher latitudes, the amplitudes of the daily variation curves depend on R₁₂, these amplitudes decrease towards lower latitudes and at low latitude stations the daily variation curves are nearly independent of R₁₂.
For negative deviations at all latitudes there is a nice linear shift of the curves with R₁₂.
For positive deviations at all latitudes there is a single mid-day peak at about 10.00-12.00L.T.
For negative deviations, at Kiruna and Lycksele stations (respectively 67.8N, 64.6N) there is a single afternoon peak at about 16.00-18.00L.T. At Arkangelsk (64.4N) there are two peaks at about 13.00L.T. and 19.00L.T. These two peaks persist at mid and low latitudes while sharpness of the afternoon peak decreases with the latitude.
- Qualitative observations for quiet days with Ap<6:** For positive deviations, at high latitudes there exists a linear R₁₂ dependency while at low latitudes this dependency disappears. At mid latitudes medium R₁₂ ranges get together towards high R₁₂ ranges.
For negative deviations, at high and mid latitudes the R₁₂ dependency is more linear while at low latitudes this dependency become to be slight. At high latitudes low R₁₂ ranges get together while at mid latitudes there is a shift towards high and low R₁₂ ranges.
The mid-day peak persist with in positive deviations.
The double peak at mid-day and afternoon continue to exist for negative deviations.
- Qualitative observations for disturbed days with 18<Ap<24:** For positive deviations, however the data is not too reliable to make any further comment a slight R₁₂ dependency is observed. R₁₂ ranges become to get all together. This behaviour increases by the decrease of the latitude.
For negative deviations, the R₁₂ dependency is more linear at all latitudes. There is a shift towards high and low latitudes. At high and mid latitudes only two groups of R₁₂ ranges is observed. At low latitudes high R₁₂ range is separated from the other ones.
- Qualitative observations for disturbed days with 24<Ap<30:** For positive deviations, at all latitudes, however the data is not too reliable to make any further comment there is no R₁₂ dependency and all R₁₂ ranges get together.
For negative deviations, at all latitudes, the R₁₂ dependency is non-linear and extreme high R₁₂ range is separated from low and mid R₁₂ ranges which are together.

5.CONCLUSION: We studied separately the positive and negative deviations from monthly medians of the ionospheric critical frequency foF2, obtained from 13 different European stations between 1958-1998, at each hour, using the l₂ norm of the daily deviations as a quantitative criterion, for all days, for quiet days and for magnetically disturbed days.

We classified the daily variation curves, based on their dependency on R₁₂, month, latitude and geomagnetic activity, for each hour, for negative and positive deviations. As we noticed

similarities on the values of the ranges 2 and 3 of R_{12} we decided to group R_{12} values in 3 ranges and we get finally:

- 1) 3 ranges for R_{12} ,
- 2) 4 groups for months
- 3) 3 groups for latitudes: a) 35N~50N, b) 50N~60N, c) 60N~68N
- 4) 2 groups for magnetic activity: $A_p < 6$ quiet days and $A_p > 6$ disturbed days.

The corresponding tables are given below.

MAGNETICALLY DISTURBED DAYS			
POSITIVE DEVIATIONS			
	LOW LATITUDE	MID LATITUDE	HIGH LATITUDE
LOW R_{12}	3.1738-10.5276	3.3134-6.3828	0-4.0391
The Mean	6.5127	4.6533	1.2999
MID R_{12}	4.7890-9.5860	3.8213-8.4721	0-10.3178
The Mean	7.3108	5.7710	3.1103
HIGH R_{12}	3.8122-8.7083	3.9693-12.2772	0-9.2309
The Mean	6.3133	7.1970	5.0612
NEGATIVE DEVIATIONS			
	LOW LATITUDE	MID LATITUDE	HIGH LATITUDE
LOW R_{12}	2.1572-6.4254	4.0531-6.3212	0-5.4078
The Mean	4.4379	5.1158	2.6925
MID R_{12}	4.3070-10.1874	5.2904-11.5473	0-13.9665
The Mean	7.1132	8.3925	6.2211
HIGH R_{12}	3.2219-10.1182	8.1101-16.8111	2.5492-19.2727
The Mean	6.9425	11.6381	11.0923
MAGNETICALLY QUIET DAYS			
POSITIVE DEVIATIONS			
	LOW LATITUDE	MID LATITUDE	HIGH LATITUDE
LOW R_{12}	0-3.2472	1.7412-4.5470	0-3.5957
The Mean	1.1519	3.0861	1.1601
MID R_{12}	1.4479-4.3361	2.9651-7.0173	0-7.9591
The Mean	3.0026	4.8089	3.5417
HIGH R_{12}	0.8670-5.7773	4.3589-9.3757	1.6212-10.8677
The Mean	2.8724	6.0719	7.1419
NEGATIVE DEVIATIONS			
	LOW LATITUDE	MID LATITUDE	HIGH LATITUDE
LOW R_{12}	0-4.8171	0-1.2507	0-0.0817
The Mean	1.4666	0.2445	0.0037
MID R_{12}	1.5225-7.4787	0-3.2258	0-1.9668
The Mean	3.4127	1.0135	0.2456
HIGH R_{12}	0-3.6108	0-2.1039	0-1.8170
The Mean	0.8762	0.7162	0.2247

Table 2. Classification of the positive and deviations in magnetically disturbed and quiet days with respect to R_{12} dependency.

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