Trend analysis of foF2 over a mid latitude American station Adak using about data set of one decade

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Abstract : In this paper the diurnal variation in foF2 for a mid-latitude station for about one-decade is shown. This paper confirms that the foF2 value depends on time and solar activity/sunspot number. The value of foF2 decreases during morning time and increases during night time. The paper also confirms that there is direct relationship between sunspot number and ROC of foF2 during night hours and inverse relationship between morning hours, whereas no significant variation is shown during the day time**.**

Index Terms **- foF2, sunspot number, diurnal variation.**

I. INTRODUCTION

The Earth ionosphere is weakly ionized plasma region of the upper earth's atmosphere extending from about 50 to 1000 km above the ground. This layer is made of smaller amount of atoms and molecules in neutral as well as in ionized state. Therefore this region is termed Ionosphere as well as weakly ionized plasma region, containing sufficient amount of free electron of density ranging from 10^2 to 10^5 per cubic centimeter and is capable for the reflection of high frequency radio waves. The topmost region of ionosphere lying above E-region is F-region. This region splits into F1 and F2-regions during the daytime. Since F-region contains free electrons and positive ions, so it is very important in the propagation of radio waves. According to the dependency of atmospheric temperature, the boundary line between F1 and F2 layer varied. The positive ions found in F1-region are mainly N, O_2^+, whereas O^+ ions are found in F2-region (Piggott & Rawer, 1961). In radio propagation, the limiting frequency or critical frequency (fo) is that highest magnitude of frequency below which a wave component is reflected by the ionospheric layer and above which it penetrates it. Its value depends upon electron density of ionosphere and is given by the formula

$$fo = 9\sqrt{N}$$

Where N is maximum electron density per cubic metre and fo is in Hz. (https://en.wikipedia.org/wiki/Critical_frequency).

The critical frequency of F2 layer i.e., foF2 were derived and analyzed by different researchers in different year across the globe. The trend results were derived by Mikhailov & Marin (2000) and Martin et al. (2001) for the time period of 1965-1991 and concluded that the foF2 trend depends on the geomagnetic latitude. They showed that foF2 has strong negative trends at higher latitudes and small positive or negative trends at lower latitude side. When seasonal variations are small and ignorable, the foF2 shows the diurnal variations. According to their foF2 analysis the occurrence of long-term increment/decrement in geomagnetic activity causes negative and positive foF2 trends. In the period of 1965-1991 the geomagnetic activity was corresponding increasing and for the period of 1955-1965 geomagnetic activity was decreasing. Mikhailov and Marin (2000) proposed a method to reveal the analysis of foF2 trends. In this analysis they used the observations taken by ionosonde at 30 different European, North American and Asian stations. Danilov and Mikhailov (1998) proposed an approach to derive long term trends of F2-rergion parameters and using this approach Danilov and Mikhailov (1999) analyzed the data set for Northern hemisphere stations and they got a consistent picture of foF2. These observations demonstrated the variety of foF2 trends in a systematic way with local time, season and geomagnetic latitude.

The foF2 trends were found negative at 22 stations of global ionospheric stations including Argentine Islands and Port Stanley with the consideration of solar cycle maxima and minima. The most important conclusion of this analysis was that the correlation coefficient between foF2 and A_p was maximum and significant with the hours of the day (Danilov and Mikhailov, 1999, 2001), when the negative phase of most probable ionospheric storm was occurred. The entire period of 1948 to 1994 was split to 18 running intervals with same 30 years length: 1948-1977, 1949-1978 and so on to understand the foF2 non-geomagnetic trends. Mikhailov and Marin (2000, 2001) gave the concept of the annual mean deviation of foF2 in contrast of solar activity index R12 and it has a correlation with geomagnetic index A_p. The seasonal and diurnal dependency of foF2 trends was given by Danilov and Mikhailov (1998, 1999 and 2001) and Mikhailov and Marin (2000, 2001). During recent years the observed foF2 trends are caused by positive trends in ionospheric disturbances intensity. Alfonsi et. al., (2002) obtained results from this analysis, all the ionospheric stations included in the analysis showed a long-term decrease of foF2 between –0.1 MHz and –0.2 MHz. Rishbeth (1990), indicated a decrease of foF2 around –0.1 MHz due to the mesospheric-thermospheric cooling caused by the increasing emission of the greenhouse gases. The propagation of radio waves through ionosphere directly depends on F2 layer maximum electron density and it rely on the critical frequency foF2. The method to derive the long term trends independent of geomagnetic

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activity was proposed by the earlier author (Danilov, 2002a, & 2002b). was applied by Danilov (2003) for studying the foF2 observations in the period between 1958 and the mid-nineties at 23 ionospheric stations. These stations were located at middle and high latitudes of the eastern hemisphere. The results obtained for 23 stations were found to be negative consistently. The result obtained for two stations (Alma-Ata and Sodankyla) provide a strong deviation of slope from the other stations, whereas the rest of 21 stations shows the negative value of slope from 0.00062 tp 0.00196 per year.

Other researchers also found the trends of critical frequency of F2-region around the globe. In this paper we tried to find the trends of foF2 on a specific station and also showed how it varies with the sunspot number.

II. DATA SET AND SITE DESCRIPTION

To study about the critical frequency of F2-region in mid latitude region we have used a particular station ADAK. It is a city in the state Alaska of USA, whose geographic location is 51.76°N in latitude and 176.62°S in longitude. This city covers the total area of 330 square kilometer, out of which 317 square kilometer is land area and remaining area is covered by water. It is situated in sub-polar oceanic climate zone, so high winds, and cyclonic storms are often observed in this city. In winter season, wind gusts are of 100 knots and in summer fog comes over north pacific and from Bering Sea. The long-term data of F2-region for this particular station is available and is retrieved from UKSSDC (UK solar system data centre). On this data centre, the data sets are uploaded from different ionosonde stations worldwide. Here in present study the foF2 data of about one decade i.e., from 1957 to 1965 of Adak is retrieved and is analyzed. The method of analysis used in this paper is described in the next section.

III. DATA ANALYSIS AND METHODOLOGY

As we have mentioned in previous section that to study about the critical frequency of F2-region, we have chosen an American station Adak (Lat. 51.76°N and Long. 176.62°S) and its data set are retrieved from the UKSSDC. The retrieved from this centre was available on hourly and daily basis for the entire study period. In our study we divided 24 hour time period into three time region, morning time, day time and night time. The morning time is from 00:00 to 06:00 hr., day time is from 06:00 to 19:00 hr. and night time is from 19:00 to 24:00 hr.

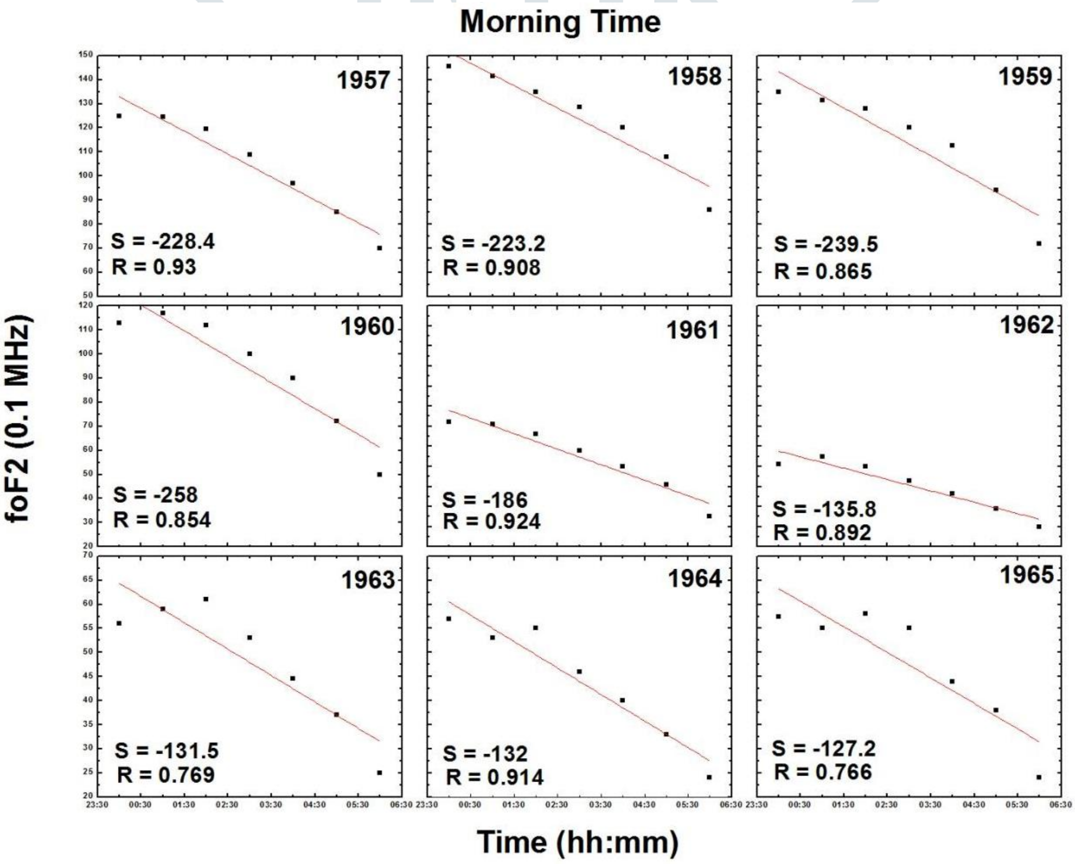


Fig. 1

So we divide the above retrieved data of foF2 into these three time period. After dividing or separating the data into three regions we calculate the medium value of each hour for a particular month (January) for separately for each year. After it we plotted the medium value against the hour for January month for each year and each time region, separately. After it we fitted the above plotted graphs linearly and obtain the slope, adjusted correlation coefficient (R) and P value for each year and for time period for the study period. Also we obtain the percentage of confidence level (%CL) by using the P value. The slope and R value is shown in each graph (Fig. 1, 2 and 3), whereas R and %CL is shown in Table 1. To establish a relation between rate of change (ROC) of foF2 and sunspot number, the graphs for it are also shown for each time period (Fig. 4). The result and conclusions are discussed in next section of this paper.

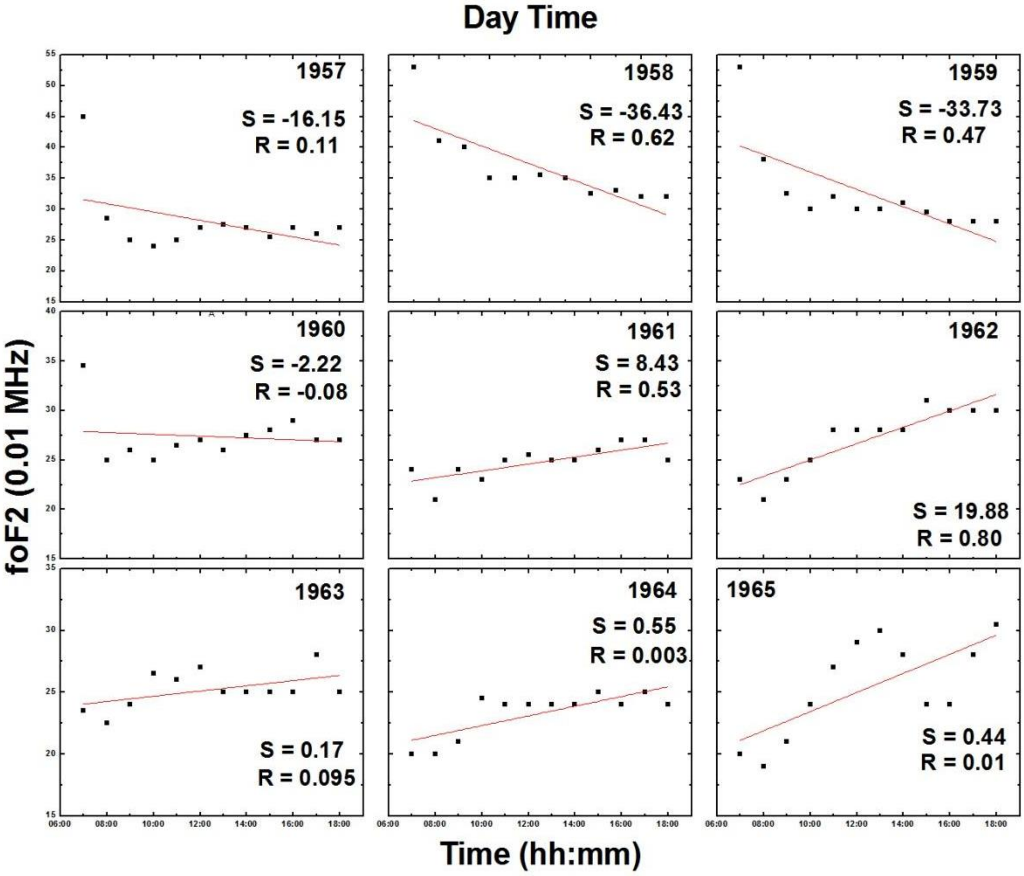

Day Time
foF2 (0.01 MHz)
1957
S = -16.15
R = 0.11
1958
S = -36.43
R = 0.62
1959
S = -33.73
R = 0.47
1960
S = -2.22
R = -0.08
1961
S = 8.43
R = 0.53
1962
S = 19.88
R = 0.80
1963
S = 0.17
R = 0.095
1964
S = 0.55
R = 0.003
1965
S = 0.44
R = 0.01
Time (hh:mm)

Fig. 2

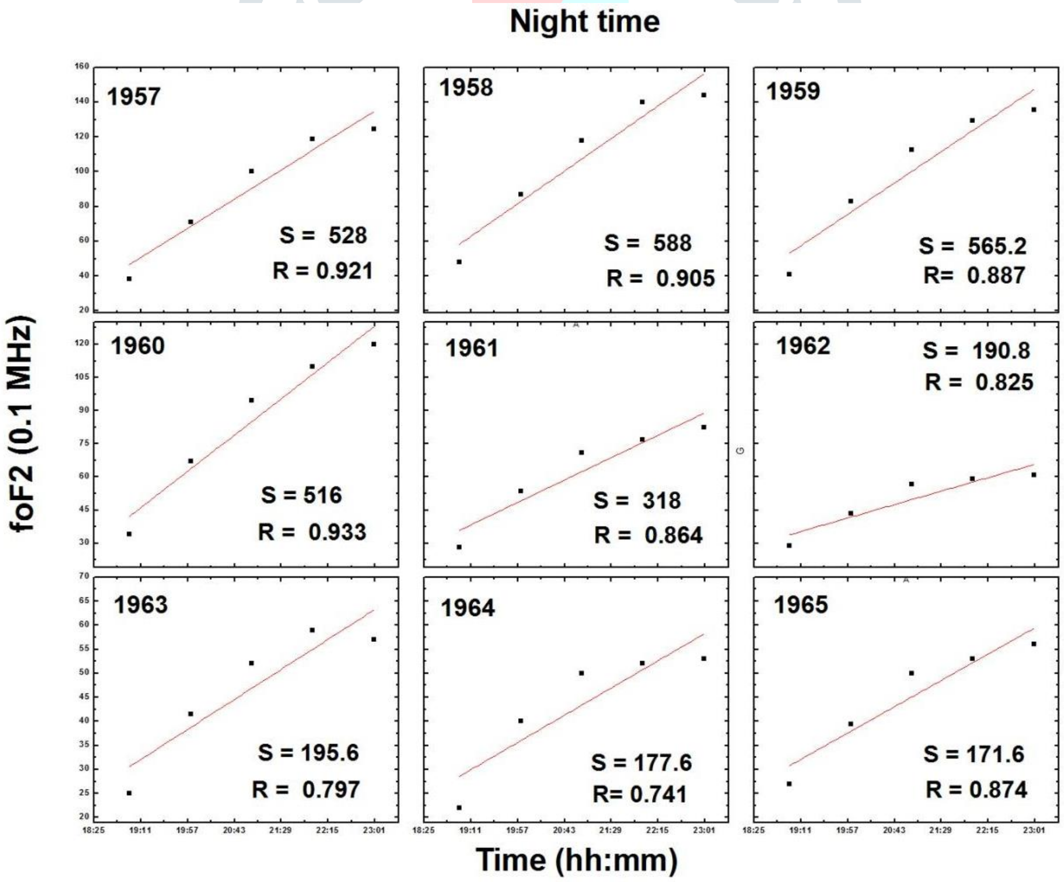
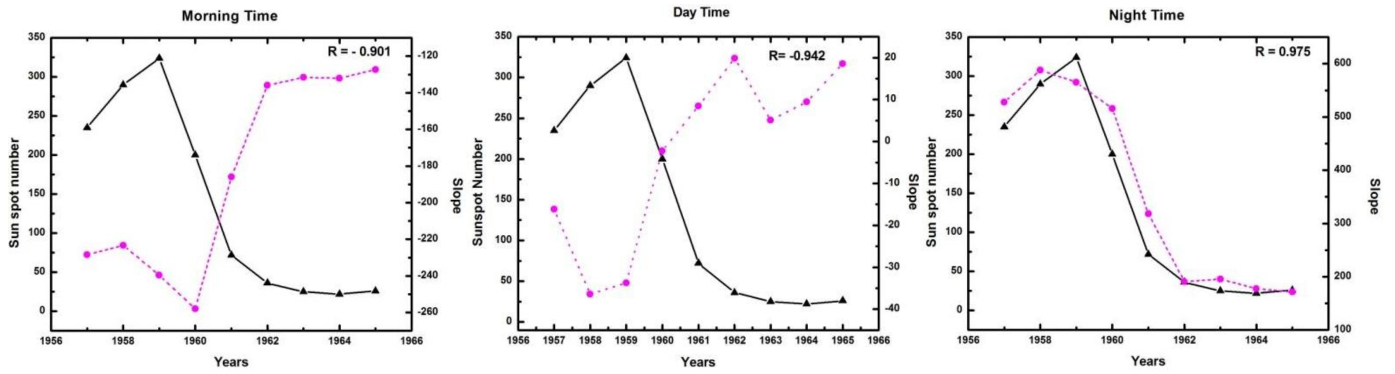

Night time
foF2 (0.1 MHz)
1957
S = 528
R = 0.921
1958
S = 588
R = 0.905
1959
S = 565.2
R= 0.887
1960
S = 516
R = 0.933
1961
S = 318
R = 0.864
1962
S = 190.8
R = 0.825
1963
S = 195.6
R = 0.797
1964
S = 177.6
R= 0.741
1965
S = 171.6
R = 0.874
Time (hh:mm)

Fig. 3



(a) (b) (c)

Fig. 4

IV. RESULTS AND DISCUSSION

As we have mentioned that the entire study period is divided into three time region. So here we will discuss their result one by one. Here to eliminate the

Table 1

Year	Morning time		Day time		Night time	
	R	% CL	R	% CL	R	% CL
1957	0.9307	99.9722	0.1111	84.5680	0.9215	98.7490
1958	0.9083	99.9437	0.6289	99.7810	0.90573	91.8400
1959	0.8656	99.8510	0.4739	99.2030	0.8877	98.9350
1960	0.8541	99.8170	-0.0807	31.8270	0.9335	99.5200
1961	0.9240	99.9649	0.5321	99.5720	0.8648	98.5860
1962	0.8927	99.9160	0.8083	99.9957	0.8253	97.5030
1963	0.7898	99.4100	0.1790	90.4940	0.7975	97.3620
1964	0.9145	99.9527	0.5538	99.6670	0.7417	96.1450
1965	0.7670	99.3920	0.4500	98.9880	0.8748	98.7430

4.1 Morning time

It is clear from Fig. 1 that the value of foF2 decrease linearly with time during the morning hour. The ROC of this value ranges from 127 to 258 with the confidence level of above 99% with R value 0.75 to 0.9. The highest rate of decrement is found to be in 1960 and lowest in 1965. Figure 4a shows that there is inverse relation between the ROC of foF2 value and sunspot number. It means as the activity increases the ROC of critical frequency decrease of vice versa. The variation of sunspot number is shown by solid line, whereas variation of ROC of foF2 is shown by dotted line.

4.2 Day time

The variation of foF2 for January month against the hour or diurnal variation of medium value of critical frequency of F2-region for a specific month (January) during the day time is shown in Fig. 2 from 1957 to 1965. This figure shows that the value of foF2 may either decreases or increases during the study period but no significant value is obtained. Since the adjusted value of correlation coefficient is very small during this period. So we are unable to say anything about this period. The significant value is obtained only in 1962 with the confidence level of 99.9% and during this period an increment is shown by foF2 with ROC of about 2 MHz per year. However the ROC value of foF2 and sunspot number shows an inverse relation (Fig. 4b) but this value can't be helpful for us since it is not upto the desired level of significancy.

4.3 Night time

Figure 3 shows the diurnal variation of foF2 during the night time. It is clear from figure that the result obtained during this time is just opposite to that of morning hours. During this period the medium value of foF2 increases linearly as the time increases and this increment is faster than the decrement observed during the morning time. The result shows that the ROC in foF2 values varies from 171 to 588 with the confidence level above 95%. The R value ranges from 0.74 to 0.92. The highest and lowest increment in critical frequency is found in 1958 and 1965 respectively. The ROC in foF2 is directly related to sunspot number, which is clearly observed from Fig. 4c. This figure shows that as the value of sunspot number decreases or increases, the ROC of foF2 changes in the same manner, which again proves the dependency of foF2 on solar activity.

The above results conclude that the critical frequency of F2-region depends on time and solar activity/sunspot number. During morning hours, foF2 decreases and during night time it increases with the passage of time. The results also conclude that there is direct relationship between sunspot number and ROC of foF2 during night hours and inverse relationship between morning hours, whereas no significant variation is shown during the day time.

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