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A LONG-TERM TREND IN THE F2-LAYER CRITICAL FREQUENCY AS OBSERVED AT ALMA-ATA IONOSPHERIC STATION

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Abstract

Monthly median values for the hours around local noon (10-14 LT) for the F2-layer critical frequencies (*foF2*) measured at Alma-Ata ionospheric station [43.25N, 76.92E], monthly mean values of solar radio flux at 10.7 cm (*F10.7*) and geomagnetic activity index *Ap* obtained via INTERNET (http://www.swpc.noaa.gov/) over the period from 1957 till 2012 are used to derive a picture of long-term changes in the upper ionosphere and to estimate their practical importance. Results of the investigation are discussed in the context of coupling between the solar and geomagnetic activity and the ionosphere at middle latitudes.

The aim of the study

The aim of the study is to derive a picture of long-term changes in the ionosphere (as regards the *foF2* trends), compare them with early observed and written in the number of articles, and evaluate their practical importance.

For this study we used monthly median values of the F2-layer critical frequencies *foF2* observed during almost 5 solar cycles, from 1957 till 2012. for the hours around local noon, i.e. the monthly median values were averaged over 5 hours, from 10:00LT till 14:00LT, Fig.1a. Monthly median values of the solar radio flux at 10.7 cm (*F10.7*) and index A_p are also used in the study as the characteristics of solar and geomagnetic activities strongly affecting the ionosphere (Figs. 1b,c).

4

Results

Figure 1 shows the well-known variations of the parameters where the dominating feature of the variations is effect of solar activity. A regression of the *foF2* with monthly mean radio flux *F10.7* was used assuming a two-degree polynomial dependence to define *foF2′* as a function of the radio-flux, Fig. 2a:

$$foF2' = a + b\times(F10.7) + c\times(F10.7)^2,$$

Thereafter, the effects of solar activity variations were removed from observed *foF2* to find monthly absolute deviations $\Delta foF2 = foF2_{obs} - foF2'$ to reveal possible long-term changes in the deviations, Fig. 2b.

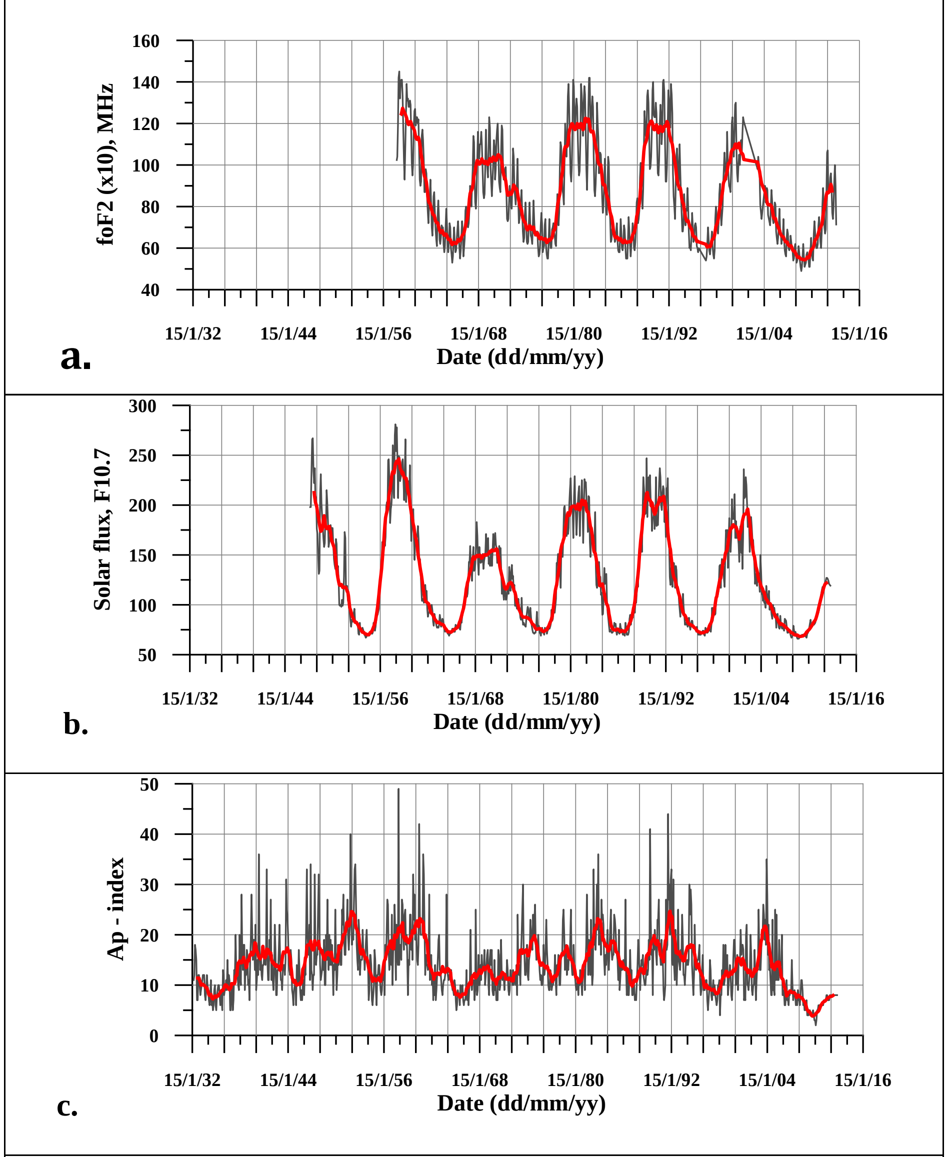

Figure 1. Monthly median *foF2* values for the hours around local noon (**a**), monthly median values of the solar radio flux *F10.7* (**b**) and index A_p (**c**).

5

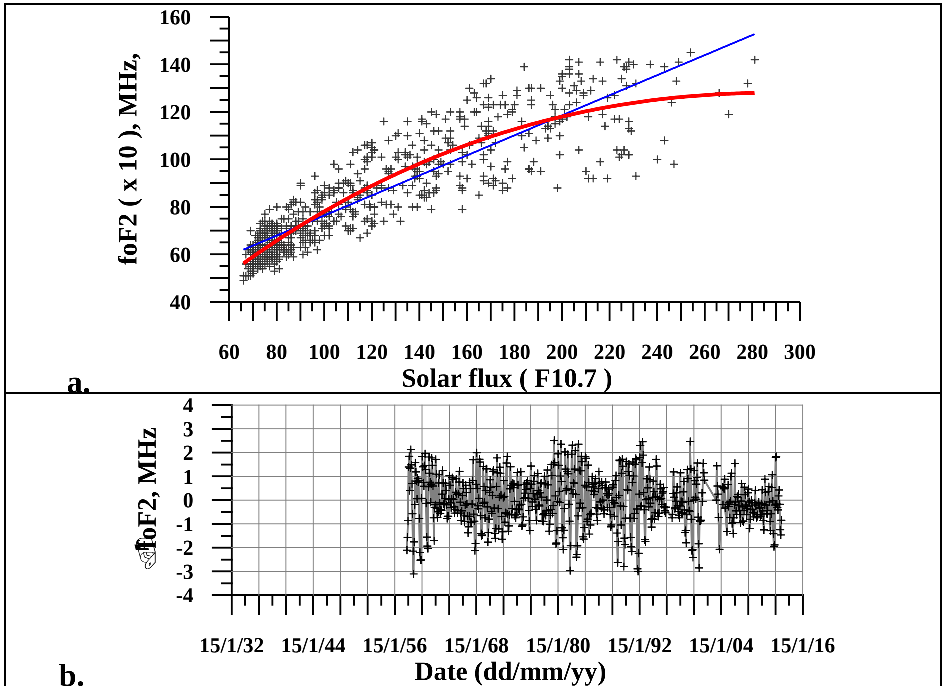

Figure 2. Monthly median *foF2* values for the hours around local noon (10-14LT) versus monthly mean *F10.7* values together with their regression lines (solid lines) (**a**), and monthly absolute deviations $\Delta foF2 = foF2_{obs} - foF2'$ (**b**) over the period from 1957 till 2012.

Figures 2b shows that a larger part of the $\Delta foF2$ variability is still linked to the seasonal variations in the ionosphere and the 11-year solar circle. Therefore, to obtain a picture of possible long-term changes in the upper ionosphere the 11-year (132 months) running mean values of the monthly absolute deviations ($\Delta foF2_{132}$) calculated using the data of all available years are used. After 11-smoothing, the available period for the analysis reduced to the period from 1963 till 2006. Considering long-term changes in the F2-layer in the light of solar and geomagnetic control the same filtering was applied to the *F10.7* and A_p data sets, the 11-year *F10.7* and A_p smoothing.

Figures 3 and 4 present the calculated $\Delta foF2_{132}$, $F10.7_{132}$ and Ap_{132}; linear fits give some general decreasing with a slope for the long-term *foF2* variations equal about -0.0038 MHz/year.

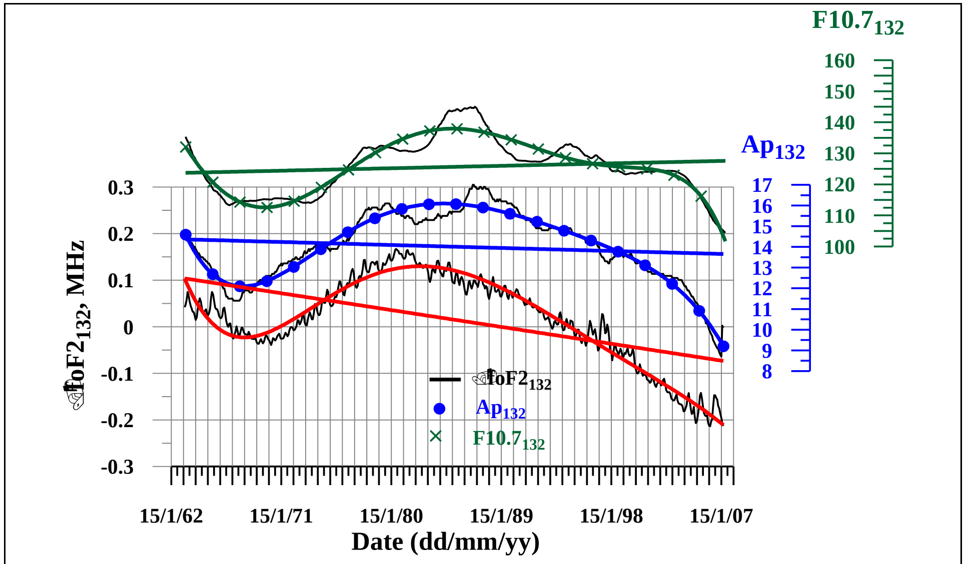

Figure 4. The 11-year running means of the $\Delta foF2_{132}$, $F10.7_{132}$ and Ap_{132} variations for the time period from 1963 till 2006.

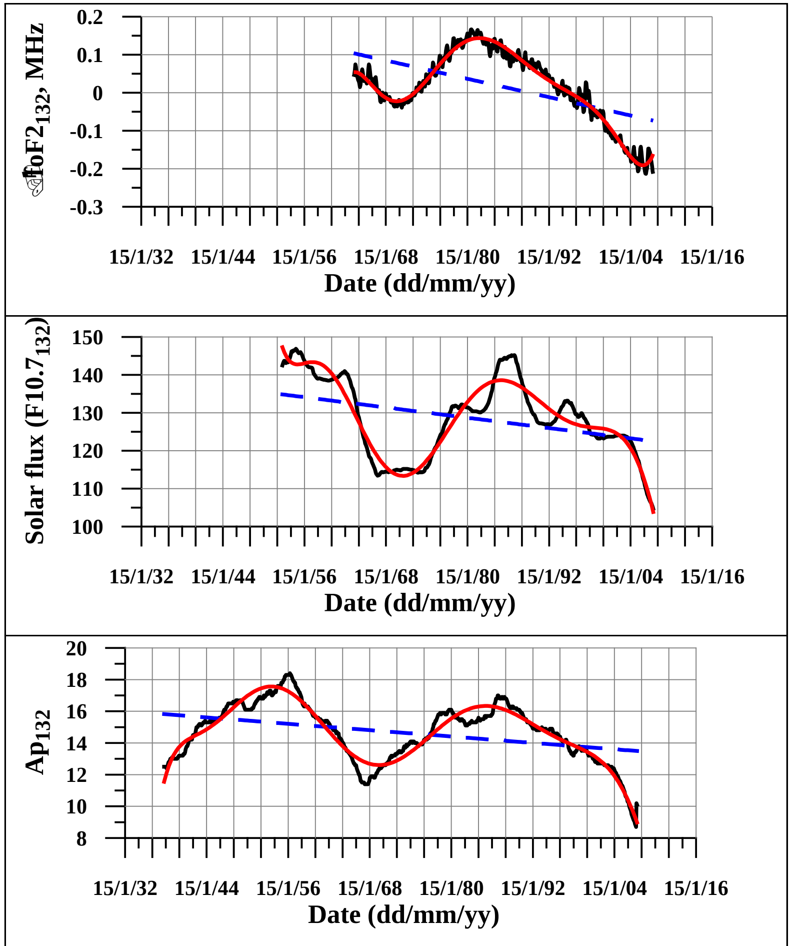

Figure 3. The 11-year running means of the $\Delta foF2_{132}$, $F10.7_{132}$ and Ap_{132} variations for the analyzed time periods.

By similar way as for *foF2* we correlate the monthly mean *Ap* and *F10.7*. Assuming a linear dependence Figure 5 demonstrates the observed A_p values (dark circles) versus *F10.7* together with theirs regression line (solid line), the part of the Ap variations caused by solar forcing, and absolute deviation ΔA_p variation. The coefficient of determination for the Fig. 5a is such that R^2=0.15798, which means that ~16% of the total variation in the geomagnetic field can be explained by the linear relationship between geomagnetic and solar activities (as described by the regression equation). The other 84% of the total variation in Ap falls to the Earth's own internal magnetic field variations, and to the part of solar forcing due to increased solar flare activity. In particular, Fig. 5c shows that a large part of the ΔAp variability is still linked to the 11-year solar circle, the ΔAp peaks are shifted to the falling phase of the 11-year solar cycle.

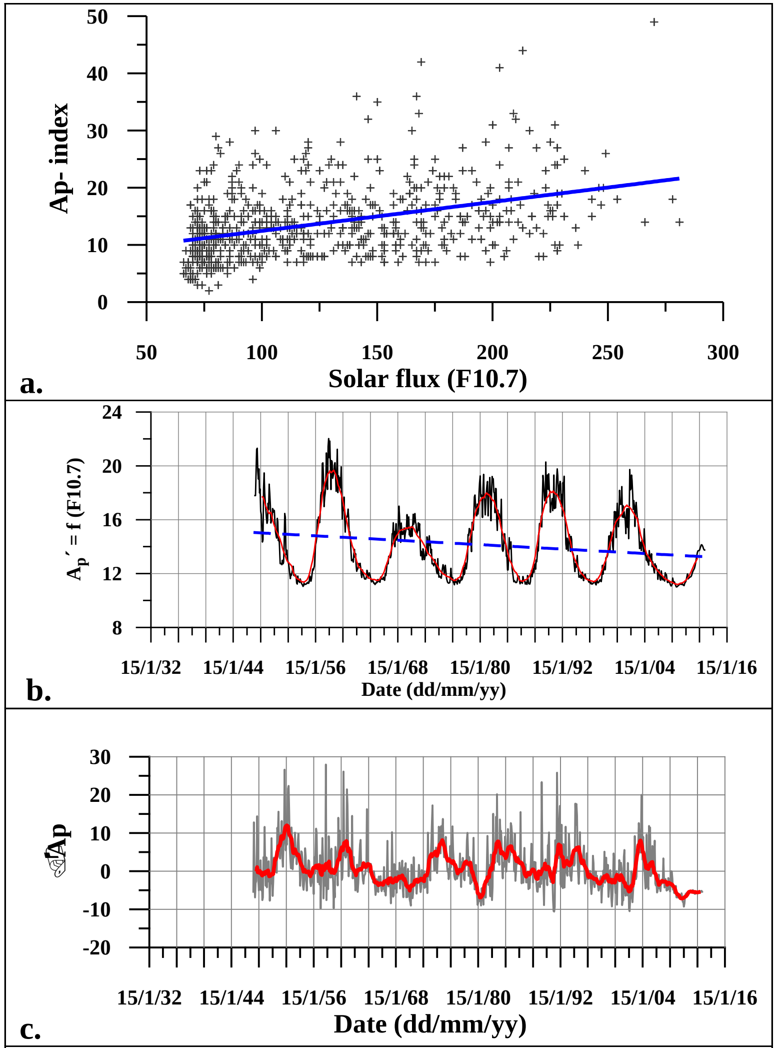

Figure 5. Monthly median A_p values versus monthly mean *F10.7* values together with their regression line (solid line) (**a**), a regular part $(A_p)'$ of the geomagnetic field variation due to the solar ionizing radiation (**b**), and monthly absolute deviations $\Delta A_p = A_p - (A_p)'$ (**c**) over the period from 1947 till 2012.

However, for this study, we used the median *foF2* values; it means that in advance we exclude any ionospheric disturbances. Of course, we realize fully that the ionosphere is controlled by the geomagnetic field. However, as the geomagnetic field itself is controlled by the solar forcing, on the one hand, and that we use the median (not disturbed) foF2 values, on the other hand, it seems that to exclude the geomagnetic part from long-term foF2 variations is problematically enough.

As a result of the study, we came to the conclusion that the Sun plays a central role in the solar-geomagnetic field and solar-ionosphere interactions. In addition to the most well-known 11-years the Sun also exhibits a cycle of about (30÷32)-years length and modulates every time series, the geomagnetic field and ionosphere variations, with the ~32-years quasi-period. The F2 critical frequency strongly depending from solar activity shows a negative trend in its long-term variations observed from 1957 till 2012; it is found that the trend magnitude is about -0.0038 MHz/year that is too small value to have some practical meaning. By the most part the sign (positive/negative) of the trend is to be in dependence from the phase (increasing/decreasing) of the solar activity long-term variations, as one can see in Fig. 3.

In addition to the material presented above, we derived a picture of long-term changes in the upper ionosphere but using only the annual mean *Ap*, *F10.7* and median foF2 values described as *Ap(12)*, *F10.7(12)* and *foF2(12)*. Figure 6, in a similar way as Fig. 3, shows the 11-year running means $foF2(12)_{132}$, $F10.7(12)_{132}$, *and* $Ap(12)_{132}$ variations for the analyzed time periods. Figure 7 gives the $F10.7(12)_{132}$, $Ap(12)_{132}$ and $foF2(12)_{132}$ variations for the same time period.

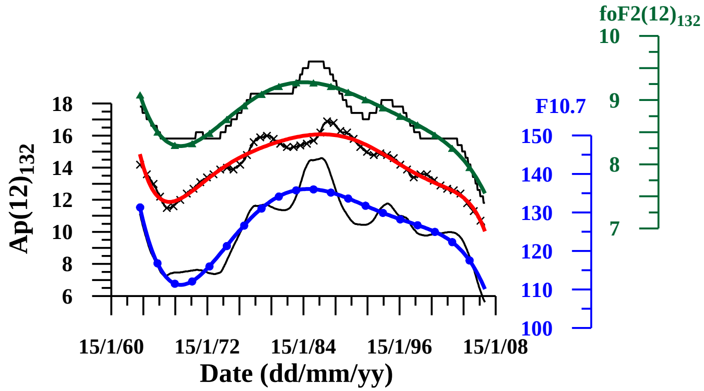

Figure 7. The *foF2(12)*$_{132}$, *F10.7(12)*$_{132}$ and *Ap(12)*$_{132}$ variations for the same period, 07.1963-08.2006.

All plots of Figs. 6 do not differ much from those shown in Figs.3 in their long-term development and support the already done resume. Additionally, we give the regressions between *foF2(12)*$_{132}$ and *F10.7(12)*$_{132}$ for different time periods. Figure 8a shows that for the whole time period (07.1963-08.2006) the regression line was in the form of a fork (the coefficient of determination R^2=0.81) that presumed not the same relationship between *foF2(12)*$_{132}$ and *F10.7(12)*$_{132}$ on different phases of the ~32-years cycle.

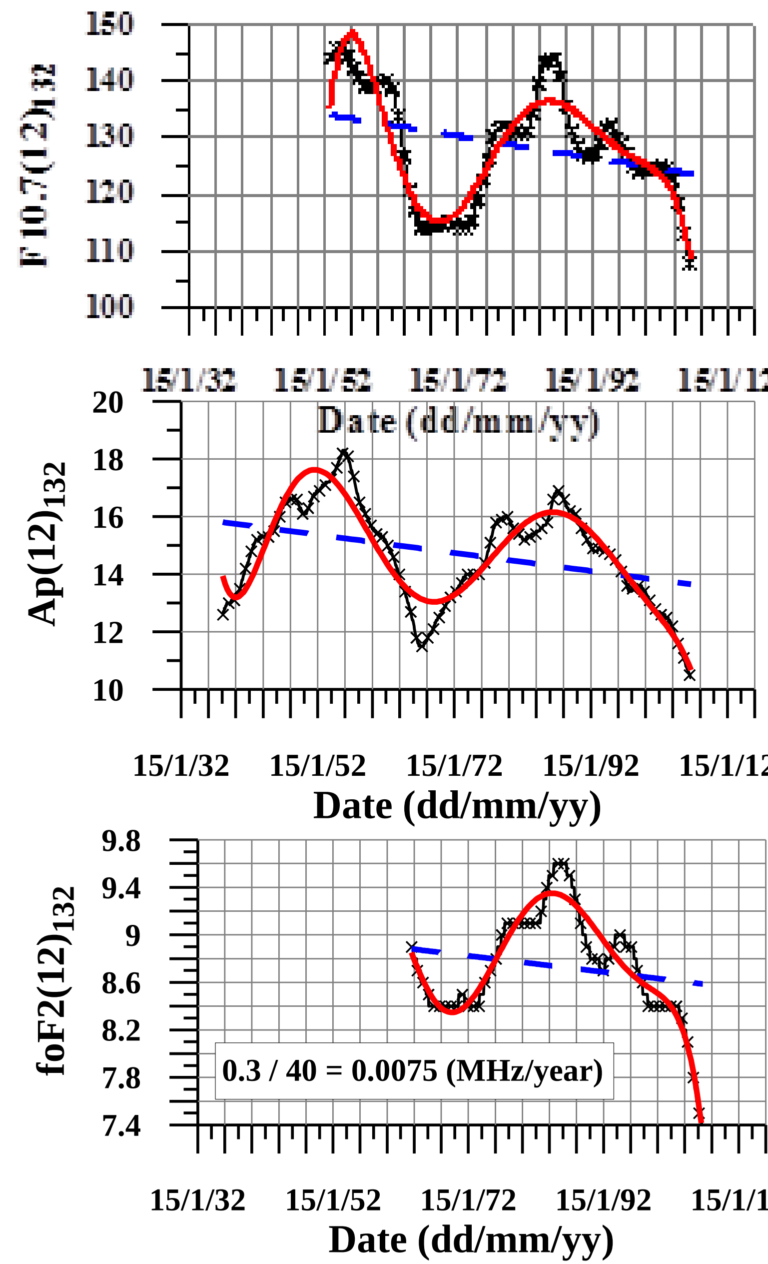

Figure 6. The 11-year running means of the *foF2(12)*, *F10.7(12)* and *Ap(12)* variations for the analyzed time periods.

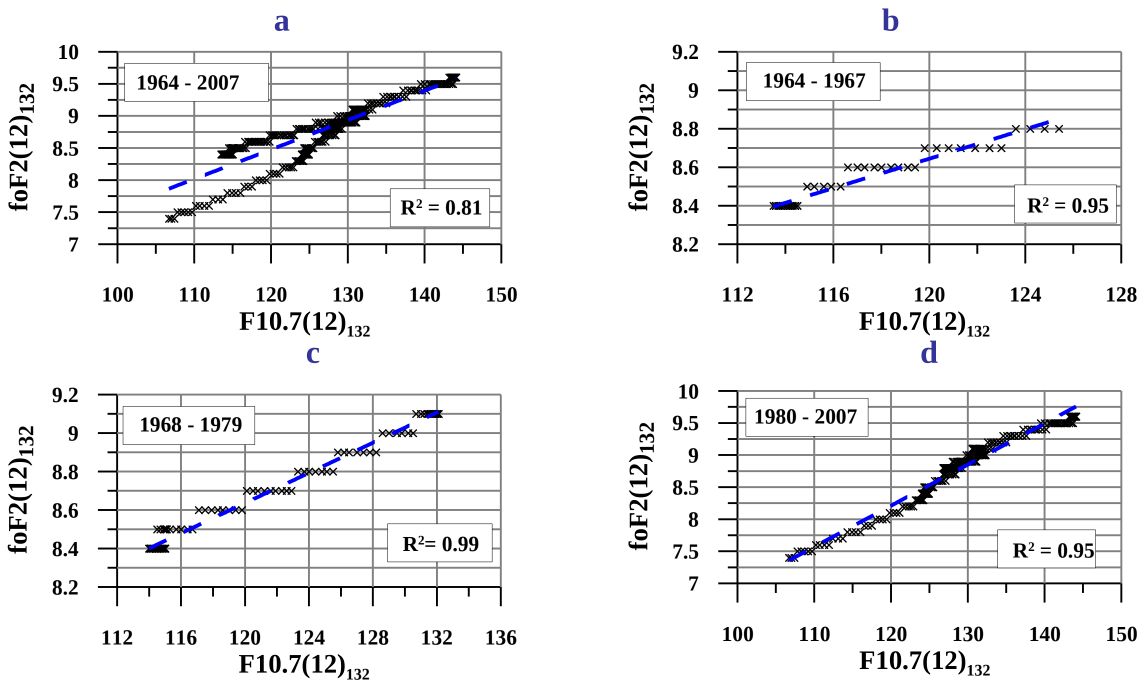

Figure 8. The *foF2(12)* values versus $F10.7(12)_{132}$ values together with their regression lines (solid lines) for different time periods.

Figures 8b, d show the linear relationship for the phases of decrease (1964-1967, 1980-2007) and increase (1968-1979) of the solar activity. It is found that 95% and 99% of the total variation in $foF2(12)_{132}$ can be explained by linear relationships between $foF2(12)_{132}$ and $F10.7(12)_{132}$ for decrease and increase phases correspondingly. The other 5% and 1% of the total variation in $foF2(12)_{132}$ remains unexplained.

CONCLUSION

In this study a picture of long-term changes in the ionosphere (as regards the *foF2* trends) was derived using the *foF2* data from midlatitude ionosonde station Alma-Ata [43.25N, 76.92E] observed during almost 5 solar cycles, from 1957 till 2012. It was concluded that the Sun plays a central role in the solar-geomagnetic field and solar-ionosphere interactions. In addition to the most well-known 11-years the Sun also exhibits a cycle of about (30÷32)-years length and modulates every time series, the geomagnetic field and ionosphere variations, with the ~32-years quasi-period. The F2 critical frequency foF2 strongly depending from solar activity show a negative trend in its long-term variations observed from 1957 to 2012; it is found that the trend magnitude is about -0.0038 MHz/year that is too small value to have some practical meaning. By the most part the sign (positive/negative) of the trend is to be in dependence from the phase (increasing/decreasing) of the solar activity long-term variations. It is found that 95% and 99% of the total variation in $foF2(12)_{132}$ can be explained by linear relationships between $foF2(12)_{132}$ and $F10.7(12)_{132}$ for decrease and increase phases correspondingly where $foF2(12)_{132}$ and $F10.7(12)_{132}$ are the 11-year running means of the annual *foF2* and *F10.7* values. The other 5% and 1% of the total variation in $foF2(12)_{132}$ remains unexplained.

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