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Short Period Variations of the Parameters of Ionospheric Scintillations on the Long-Time Observations of the Cosmic Radio Sources at the Decameter Radio Waves

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1. Abstract

On the observations of the power cosmic sources at the radio telescope URAN-4 (working frequencies 20 and 25 MHz) long-time rows of ionospheric scintillation parameters such as index, characteristic time and spectral index of the intensity fluctuations were obtained. As shown earlier the yearly mean values correlate with the indices of solar and geomagnetic activity, monthly mean estimations have well expressed seasonal-daily dependence. In this work the behavior of daily mean values of index and spectral index of the ionospheric scintillations during multiply solar cycles were analyzed. These values were compared with geomagnetic Ap-index. Daily mean estimations of the ionospheric parameters show significant variability but also they are regulated by processes in the ionosphere which caused the geomagnetic activity. Investigation of the relationship between several of the cosmic weather indicators allow to clarify the mechanisms of the formation of ionosphere irregularity structure that including caused the ionospheric scintillations.

Keywords: cosmic radio sources; ionospheric scintillations; time variations

2. Introduce

Passing through the Earth's ionosphere a radio wave from the cosmic radio source crosses a layer with electron density irregularities which cause the random phase fluctuations of the radio wave that leads to intensity fluctuations. Due to the movement of irregularities on the line of sight intensity fluctuations in the reception point observed as the time amplitude fluctuations of the radio signal which vary widely depending on the frequency, magnetic and solar activity, time of day, season and latitude. Together this makes *the effect of the ionospheric scintillations* [Aarons, 1982]. On the one side scintillations affect the quality of the radio communication, radar, satellite navigation systems, making radio astronomical observations. On the other side the scintillations are one of the manifestations of the cosmic weather. Comparison of different indicators of the cosmic weather can contribute to further investigations of the nature of heterogeneous structure of the ionosphere and their dynamics.

The purpose of this work is to study the relationship between the daily mean values of the ionospheric scintillation parameters obtained from long-term observations of the cosmic sources at the radio telescope URAN-4 with the geomagnetic Ap-index.

Basic ratios for description of the scintillation effect were obtained by the theory of the *thin phase screen* for the case of the single scattering of the radio waves [Rino, 1982]. In this model, it is that irregularities which revolt the phase of incoming wave are in the thin layer. Main characteristics of the scintillations are as follows [Yeh and Liu, 1982]:

scintillation index

$$s_4 = \sqrt{(\mathrm{I}(t) - \langle \mathrm{I} \rangle)^2 / \langle \mathrm{I} \rangle^2}; \tag{1}$$

autocorrelation function

$$\mathrm{B}(\tau) = \langle \Delta \mathrm{I}(t) \Delta \mathrm{I}(t+\tau) \rangle; \tag{2}$$

time spectrum of the intensity fluctuations

$$\Phi(\mathrm{f}) = \int_{-\infty}^{\infty} \mathrm{B}(\tau)\mathrm{e}^{-\mathrm{j}2\pi\mathrm{f}\tau}\mathrm{d}\tau, \tag{3}$$

that caused by

space spectrum of the ionospheric irregularities

$$\Phi_{\Delta N_e}(k) \propto k^{-p}. \tag{4}$$

Here: τ – time shift; f – frequency; p – spectrum slope index of the ionospheric irregularities (p = 4); k – wave number.

3. Observations and processing at the radio telescope URAN-4

Radio telescope (RT) URAN-4 (Figure 1) is a component of the interferometric system of the radio telescopes at the decameter wave range. It is located near city Odessa. From 1987 to present time the monitoring observations of the power cosmic sources (3C 144, 3C 274, 3C 405, 3C 461) have been made on the RT URAN-4 as single instruments at the frequencies 20 and 25 MHz [Derevyagin et al., 2005]. Since 1998, the digital form of radio sources records has been used.

Figure 1. *Radio telescope URAN-4*

An example of observations of one radio source is shown in the Figure 2. Several radio source records were registered during the day. Each record was processed separately by fitting of the calculating function of the direction pattern (DP) which is shown in the Figure 3.

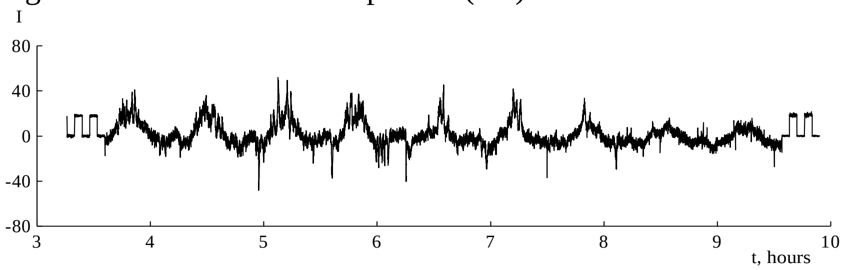

Figure 2. *Example of the observation record of radio source 3C 274 during day (05.01.2004) at the frequency 20 MHz*

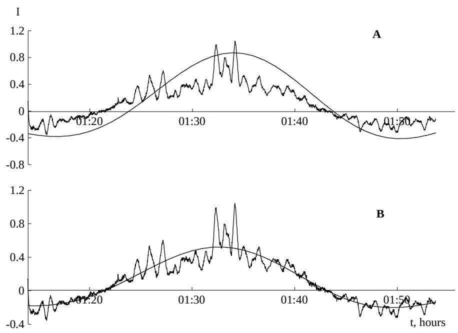

Figure 3. *Example of the fitting of the calculating DP function to the observation record:* ***A*** *– observing record and calculating DP function;* ***B*** *– observing record and fitting DP function*

All observing radio sources scintillate on the irregularities of the ionospheric electron concentration. The parameters of the ionospheric scintillations were obtained for each record, for this the high-frequency series of the intensity fluctuations was extracted from record in its central part. This series was used to calculate scintillation index SI; period ST (measured in seconds) was obtained as a shift of auto-correlation function of series when it reaches zero; spectral index SP was estimated from inclined part of the power spectrum of fluctuation series. An example of processing of the ionospheric scintillations is shown in the Figure 4. Processing results were placed in text files where they are available for analysis.

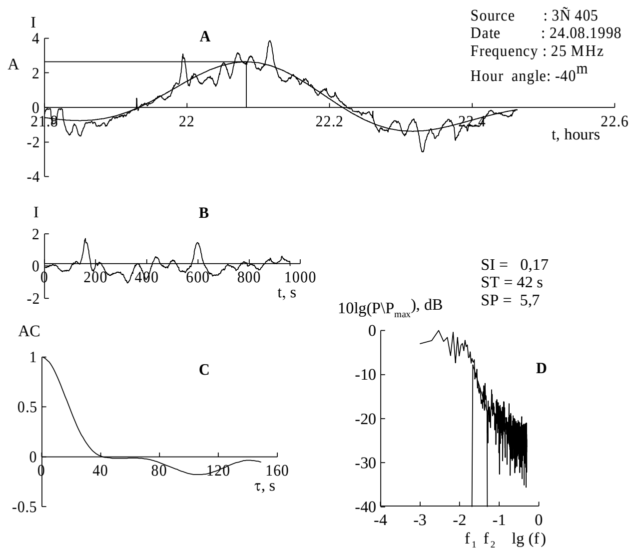

Figure 4. *Example of the proceeding of the radio source record:* ***A*** *– row obtained from observations with fitting direction pattern;* ***B*** *– high frequency part in the center of record (observation row without fitting DP) that associated with ionospheric scintillations;* ***C*** *– autocorrelation function;* ***D*** *– power spectrum of the signal scintillations*

4. Time variations of the ionospheric scintillation parameters and comparison with Ap-index

From 1987 to present the long series of the estimations of ionospheric scintillation parameters were obtained from the observations of the cosmic sources on the RT URAN-4 that allow to analyze a behavior of these values during different time intervals. Graphics of the yearly mean variations of the index SI, period ST and spectral index SP are shown in the Figure 5 for four observing radio sources. Here and further data at the frequency 20 MHz marked by crests and at the frequency 25 MHz – by circles. For comparison the graphics of yearly mean values of geomagnetic Ap-index and solar radio flux at wavelength 10.7 cm F10 are shown in the Figure 6 for considered time interval which covers three cycle of the solar activity – from 22 to 24 and also the beginning of 25. From the graphs you can see that yearly mean values of all parameters in general are changed accordingly to the solar cycles that show the influence of the solar activity on the heterogeneous structure of ionosphere.

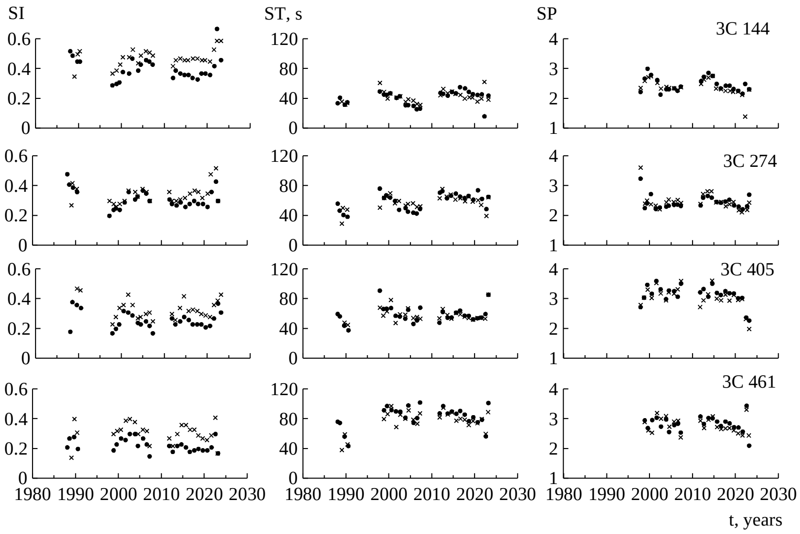

Figure 5. *Yearly variations of ionospheric scintillation parameters*

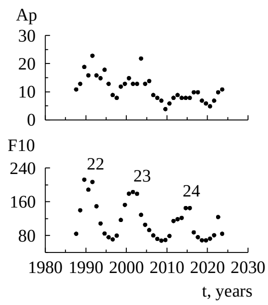

Figure 6. *Plot of the yearly mean values of the geomagnetic Ap-index and solar flux at the wavelength 10.7 cm F10. Numbers of solar cycles are given*

For monthly mean values the marked seasonal-daily dependence is characteristic for all ionospheric scintillation parameters of each observing radio sources [Lytvynenko and Panishko, 2015] that is shown in the Figure 7.

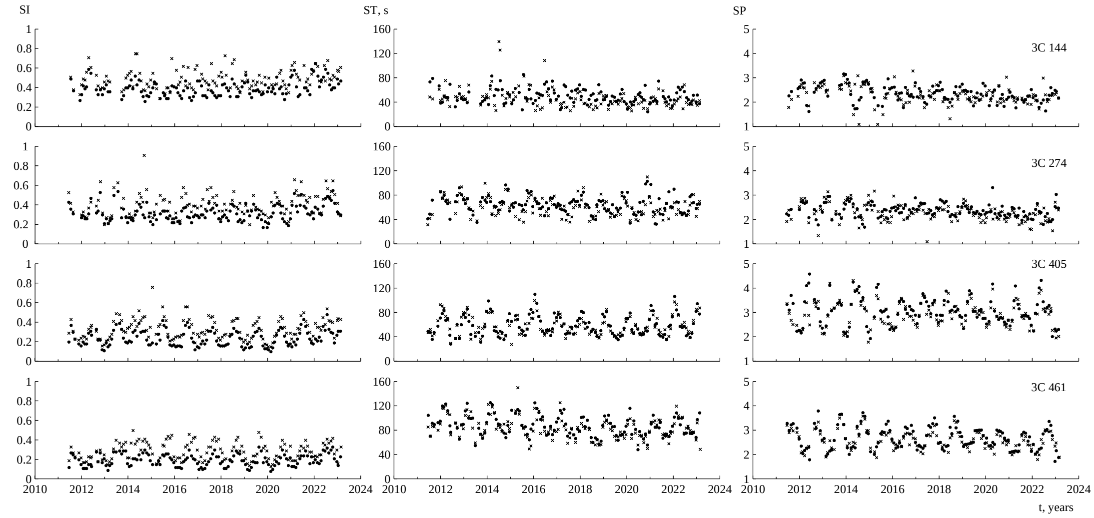

Figure 6. *Seasonal-daily dependence of the ionospheric scintillation parameters*

Because the data is not homogeneous the continuous intervals of 30 days or more have been selected to study the behavior of the daily mean values of the ionospheric scintillation parameters. There were 56 such intervals. The mean values of scintillation parameters and Ap-index were calculated for each of them. Geomagnetic index changed within 4..37 and solar flux within 67.3..183.7 (s.f.u.) during these intervals. Also correlation coefficients of the scintillation parameters with Ap-index were calculated. The examples of the daily mean values graphics of the index, period, spectral index and Ap-index are shown in the Figure 8. The graphs demonstrate significant variability of the scintillation parameters daily mean values. This reflects the nature of the ionospheric heterogeneous structure for which is characteristics high variability that caused by a large number of different factors.

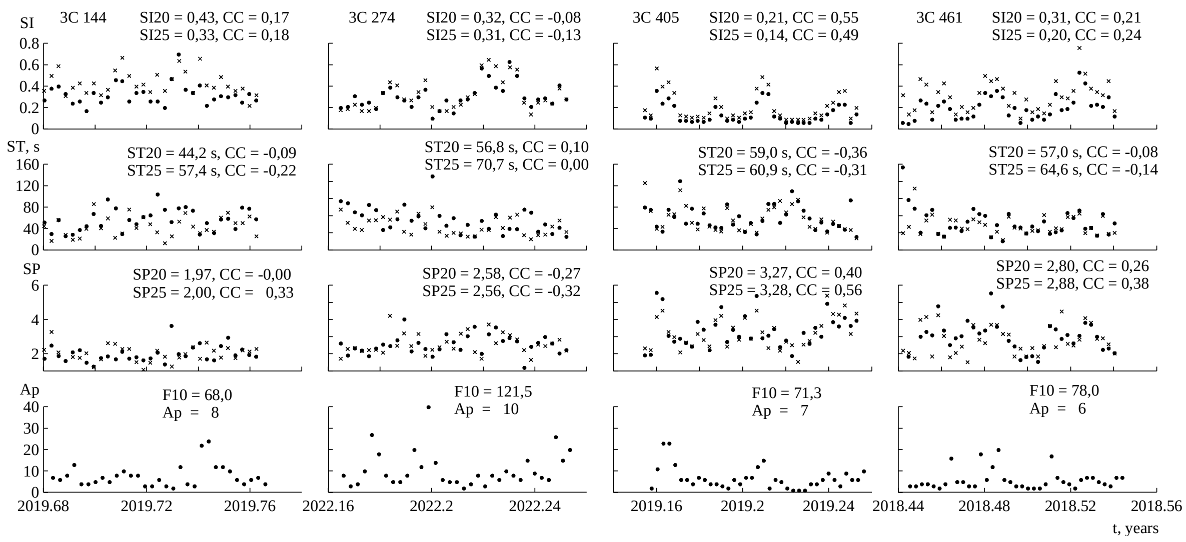

Figure 8. *Examples of daily variations of the ionospheric scintillation parameters for selected observing intervals. Mean values of the scintillation parameters, Ap-index solar flux F10 and correlation coefficients with Ap-index are given*

The Table 1 shows the minimum and maximum mean values of the scintillation parameters which observed for considered data intervals.

Table 1. *Limits of changing of the daily mean values of ionospheric scintillation parameters during considered time intervals*

Radio source	20 MHz			25 MHz		
	SI	ST	SP	SI	ST	SP
3C 144	0.41..0.43	39.7..50.4	1.96..2.73	0.29..0.33	46.8..57.4	2.00..2.81
3C 274	0.27..0.43	53.7..68.9	2.03..2.88	0.25..0.32	57.1..70.1	2.15..2.67
3C 405	0.19..0.52	40.5..83.1	2.41..3.86	0.13..0.38	35.3..79.8	2.67..4.06
3C 461	0.16..0.45	57.0..103.2	2.18..3.18	0.10..0.34	64.6..113.0	2.05..3.24

The minimum and maximum correlation coefficients of the scintillation parameters with Ap-index that calculated for selected data intervals are contained in the Table 2.

Table 2. *Minimum and maximum values of the correlation coefficients of the ionospheric scintillation parameters with the geomagnetic Ap-index*

Radio source	20 MHz			25 MHz		
	SI-Ap	ST-Ap	SP-Ap	SI-Ap	ST-Ap	SP-Ap
3C 144	-0.17..0.24	-0.20..0.18	-0.24..0.08	-0.40..0.25	-0.26..0.00	-0.29..0.33
3C 274	-0.10..0.28	-0.27..0.20	-0.10..0.33	-0.19..0.02	-0.27..0.06	-0.32..0.17
3C 405	-0.27..0.55	-0.27..0.51	-0.36..0.47	-0.31..0.50	-0.49..0.40	-0.29..0.56
3C 461	-0.34..0.36	-0.35..0.24	-0.52..0.22	-0.52..0.35	-0.30..0.46	-0.45..0.40

Data from Table 2 show no significant correlation of the scintillation parameters with Ap-index. The larger correlation coefficients are characteristics for radio source 3C 405 and 3C 461. You can note these sources observe near zenith whereas two others – at lower heights, that is, conditions for the occurrence of the scintillations may differ. The analysis of the daily mean values of scintillation index for four intervals of 13–28 days during 1998–2007 was carried out in the work [Lytvynenko and Panishko, 2017]. In some cases significant values of correlation coefficients with Ap-index were observed (0.60..0.80). Further research is required for the interpretation of the obtained results.

5. Conclusions

- According to the long-term observations at the decameter range of radio waves the ionospheric scintillation parameters such as index, period and spectral index of the fluctuations were obtained.
- In general yearly mean values of the parameters that obtained follow to the cycles of the solar activity.
- For monthly mean values seasonal-daily dependence is characteristic.

- Daily mean estimations of ionospheric scintillation parameters demonstrate significant variability. The comparison with geomagnetic Ap-index do not shows direct relationship between these values.

References

Aarons, J. (1982). Global Morphology of Ionospheric Scintillations, Proc. IEEE, Vol. 70, No 4, pp. 360-378.

Derevyagin, V.G., Isaeva, E.A., Kravetz, R.O., Litvinenko O.A., Panishko, S.K. (2005). Observations of power cosmic radio sources on the radio telescope URAN-4 during 1998-2004, Astronom. and Astrophys. Trans., Vol. 24, No 5, pp. 421-424, http://dx.doi.org/10.1080/10556790600631652.

Yeh, K.C., Liu, C.-H. (1982). Radio wave scintillations in the ionosphere, Proc. IEEE, Vol. 70, No 4, pp. 324-360.

Lytvynenko, O.A., Panishko, S.K. (2015). Seasonal variations of the ionosphere scintillations parameters obtained from the long observations of the power cosmic radio sources at the decameter wave range, Odessa Astronom. Publ., Vol. 28, No 2, pp. 235-237.

Lytvynenko, O.A., Panishko, S.K. (2017). Variations of ionospheric scintillation index for the short-time intervals observed on the power cosmic radio sources at the decameter wavelengths, RadioPhys. and RadioAstron., Vol. 22, No 4, pp. 304–309, DOI: https://doi.org/10.15407/rpra22.04.304.

Rino, C. L. (1982). On the application of phase screen models to interpretation of ionospheric scintillation data, Radio Science, Vol. 17, No 4, pp. 855-867.