DOI: 10.31401/WS.2022.proc.08

Dependence of the Ionospheric Scintillations Intensity of Cosmic Radio Sources on their Position in the Sky

Lytvynenko O., Panishko S., Derevyagin V.

URAN-4 Observatory, Institute of Radioastronomy NASU; uran4@te.net.ua

1. Abstract

Our report presents the results of the experimental dependence of the ionospheric scintillations intensity of cosmic radio sources on their position in the visible celestial hemisphere. The results refer to the mean geographical latitudes and decameter range of radio waves. The intensity of ionospheric scintillations is represented by the index S_4. We used the data obtained by us from long-term systematic observations of a group of compact space sources at the URAN-4 radio telescope. The selected space sources have right ascension coordinates that differ by 5 ... 7 hours, which ensures continuous radio astronomy monitoring of the ionosphere.

We used long series of data and statistical analysis. This was due to the strong stochastic variability of the ionospheric scintillations intensity in time intervals from an hour to several days and the seasonal-daily effect

For suppress the seasonal-diurnal influence data smoothing was applied over a time interval equal to a year. The obtained dependence of the scintillation index on the position of cosmic radio sources in the visible celestial hemisphere was demonstrated of the dominant role of the geomagnetic field.

Keywords: radio sources; ionospheric scintillations; geomagnetic field

2. Introduce

The presence of irregularities of the electron concentration in ionospheric plasma caused the scattering of radio waves which propagate through the ionospheric layer. As a result, on the Earth's surface the interference pattern occurs which moves and changes in time. Thereby amplitude and phase of received signal fluctuates. This is called amplitude and phase ionospheric scintillations. On the one hand, the scintillations carry information about heterogeneous structure of ionosphere and their dynamics. This is used in the investigations on physics of the ionosphere and cosmic weather. On the other hand, scintillations are interfering factor in the operation of the radio communication, radar, satellite navigation systems and also in the fulfilling of the radio astronomical studying.

Despite more than half a century of history of ionospheric scintillation investigations [Crane R. K., 1977, Aarons J., 1982, Yeh K. C., Liu C.H., 1982] and the successes achieved this topic remains relevant, including for improving efficiency of observations and data processing in decametric radio astronomy.

Purpose of this work was the experimental studying of the dependence of intensity of ionospheric scintillation of cosmic radio sources from their position on the celestial hemisphere. Research is related to the middle latitudes and decametric range of radio waves.

The scintillation index S_4 was used as a characteristic of the scintillation intensity:

$$S_4 = \langle u(t)\rangle^{-1}\sqrt{\langle (u(t) - \langle u(t)\rangle)^2\rangle},$$

u (t) – output signal of the radiometer that is proportional to flux density of radiation.

For space-homogeneous fluctuations of the electron concentration in the range F_{max} и E_s the model is known in which scintillation index is proportional to thickness of the scattering layer:

$$S_4 \propto h_0 \frac{1}{\cos\theta},$$

θ – zenith angle of cosmic source, h_0 – thickness of the scattering layer при θ = 0.

Space anisotropy of ionospheric irregularities that conditioned by geomagnetic field is another factor which influences on the character of radio wave scattering [Jun Liang, Weixing Wan, 1997, Bezrodny V.G., 1987]. Known results of the studying of influence of ionospheric irregularities anisotropy on scintillation intensity in general relate to the upper geographical latitudes [Bezrodny V.G. et al., 2008] and exposure experiments on ionosphere by powerful radiation [Erukhimov L.M. et al., 1979, Alimov V.A. et al., 2011], and also to another wave ranges [Milikh G. et al., 2008].

In this work it is considered experimental dependences of the ionospheric scintillation index S_4 from zenith angle θ of radio source and angle δ between geomagnetic field vector and line of sight of the radio source. Initial data was obtained during the long-term observations of group of the power cosmic radio sources on the RT URAN-4.

Radio telescope URAN-4 is an element of VLBI network of radio telescopes of decametric wave range «URAN» (Ukraine Radio Interferometers of Academy of Sciences) and it is placed near Odessa, Ukraine (geographical coordinates 46° 23' 50"N, 30° 16' 24"E). Frequency range of RT is 10-30 MHz. Phased array antenna consists from 128 broadband turnstile dipoles with two orthogonal linear polarizations. Antenna array has sizes 240 m along East-West direction and 28 m along Nord-South direction. Maximum effective area is 7300 square meters. The width of direction pattern in zenith direction at the frequency 25 MHz is 24° x 3°. Broadband phasing system of the antenna array provides automatic switching of the direction pattern within visible hemisphere. Used radiometer implemented as a short-base interferometer that allows suppressing the galactic noise.

Figure 1 shows the projection on a geographical map of the transillumination area of ionosphere during observations of radio sources on RT URAN-4. In the plane of geomagnetic meridian, Figure 2 presents the geometry of considered task about the dependence of intensity of radio source ionospheric scintillations from their position on the sky. For similar figure in the plane of geographical meridian the angle values will differ little from angle values in Figure 2, and instead of line of sight and geomagnetic field vector their projection on plane of the geographical meridian will used.

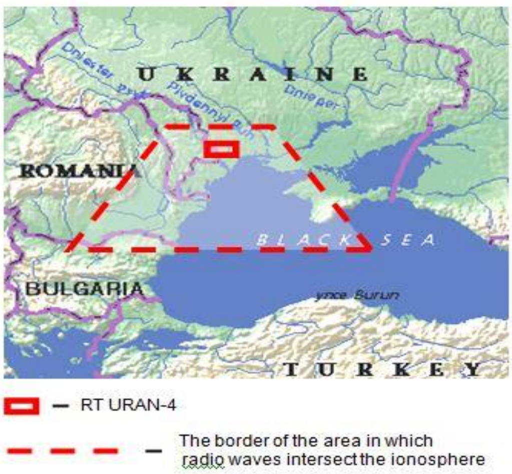


Figure 1. *Area of the ionosphere monitoring during the observation of power cosmic radio sources on the RT URAN-4. Limits of this area marked by dashed line and the rectangle – location of the RT URAN-4*

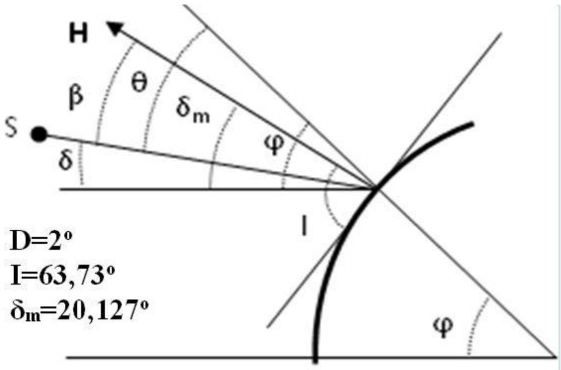


Figure 2. *Geometry of the considered effect. Here marked: D –magnetic declination; I – magnetic inclination;* ***H*** *– geomagnetic vector; δ_m – angle between* ***H*** *and equator plane, $\delta_m = I – (90^o – \varphi)$; $\varphi_g \approx \varphi$ – geographical latitude; S – source line of sight; θ – zenith angle of source; δ – angle between line of sight and equator plane; β – angle between* ***H*** *and line of sight*

3. Observations and data processing method

Observations of a source on the RT URAN-4 carry out simultaneously at two frequencies (20 and 25 MHz) by switching of antenna direction pattern (DP) to fixed positions on the line of source transit. These positions correspond to given hour angles of source and follow through fixed time intervals. As a result a source repeatedly crosses DP, example of observation of one radio source during day presents on the Figure 3. Each of such crossing (scan) registered by the receiving equipment.

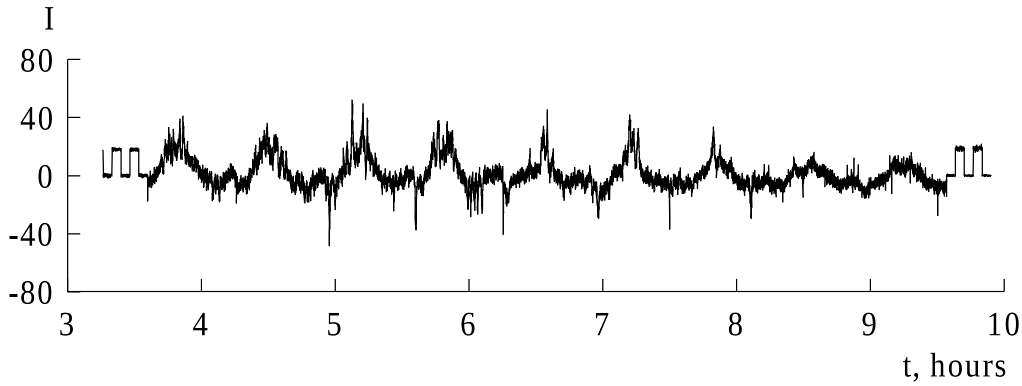


Figure 3.*Example of the record of the radio source 3C 274 passage through fixed positions of the RT direction pattern (scans) during day 05.01.2004 at the frequency 20 MHz. Impulse in the beginning and in the end of scans – calibration.*

Intensity of the ionospheric scintillations depends on many factors. These are direct influence of solar radiation, processes related with cosmic weather changes, interaction with troposphere and magnetosphere, anthropogenic influence, own dynamic processes in the ionosphere. Thus changes of scintillation characteristics in general have random character. The statistical approach is widely used in connection with this for studying of dependences in the scintillation behavior. Figure 4 shows separated radio source scans with weak and strong intensity of ionospheric scintillations that reflects the state of ionosphere during observations.

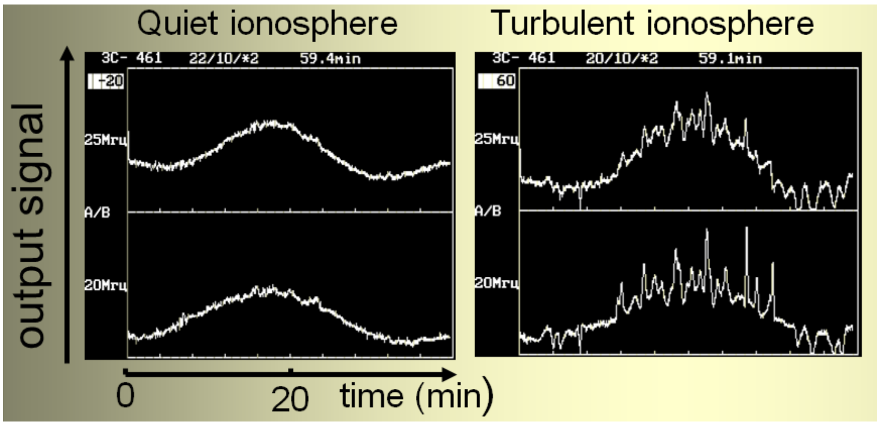


Figure 4. *Examples of separate records of radio source 3C 461 passage through RT direction pattern.*

Further the method of DP fitting used for processing of each individual scan that allows the determination of the radio emission flux and scintillation parameters including the one discussed here index S_4 (Figure 5). Moreover, the DP fitting allows suppressing some kind of interference.

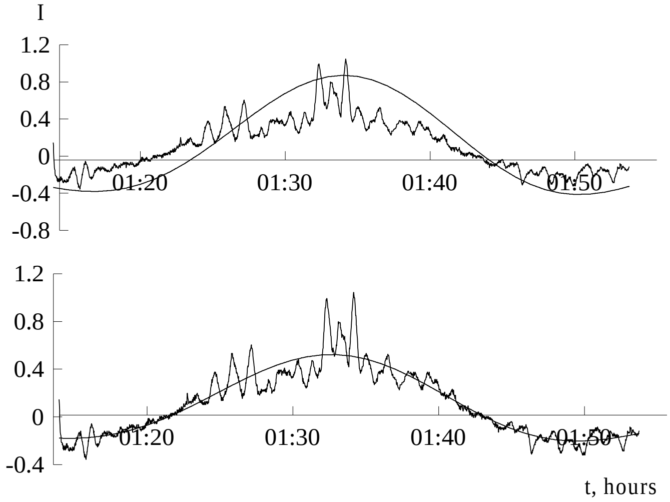


Figure 5. *Example of fitting of RT direction pattern function at the processing of the separate record*

In monitoring mode on the RT URAN-4 the long-term observations of group of the power cosmic radio sources were carried out among them two supernova remnants 3C 144 (Taurus A), 3C 461 (Cassiopeia A) and two radio galaxies 3C 274 (Virgo A), 3C 405 (Cygnus A). The radiometer as a short-base interferometer was used which suppresses the galactic noise. Data obtained on the radiometer was applied for the estimation of the ionosphere scintillation characteristics. Distances between sources on the right ascension are about 6-7 hours. This allows the carrying out observations around the clock. The general characteristics of the observed radio sources are presented in Table 1 such as equatorial coordinates (right ascension α and declination δ), flux density at two frequencies F, distance R, and also zenith angle in culmination time θ_0 and angle with magnetic field in culmination time $\beta_0 = \delta - \delta_m$.

Table 1. *General characteristics of observed radio sources*

Radio source	Coordinates, epoch 2000		F, Jy		R	θ_0	β_0
	α	δ	20 MHz	25 MHz			
3C 144	$05^h34^m31.4^s$	22°00'54"	3420	3420	2 кпс	24.4°	1.84°
3C 274	12 30 49.4	12 23 30	5300	4700	12 Мпс	34.0	7.36
3C 405	19 59 28.4	40 44 00	32000	31500	260 Мпс	5.7	20.54
3C 461	23 23 41.0	58 52 00	58000	51000	3400 кпс	-12.4	38.52

4. Results and their analysis

Analyzing the obtained data, we tried to elucidate the role of two effects in the distribution of the scintillation intensity of cosmic radio sources in the celestial hemisphere. The first effect is the dependence of the scintillation intensity on the thickness of the scattering layer (the thickness depends on the zenith angle of the source). The second effect is the features of radio wave scattering by anisotropic ionospheric inhomogeneities due to the presence of the geomagnetic field.

The first thing that can be done is for each source to obtain the dependence of the flicker index on the hour angle of the source (the hour angle of the middle of the scan).

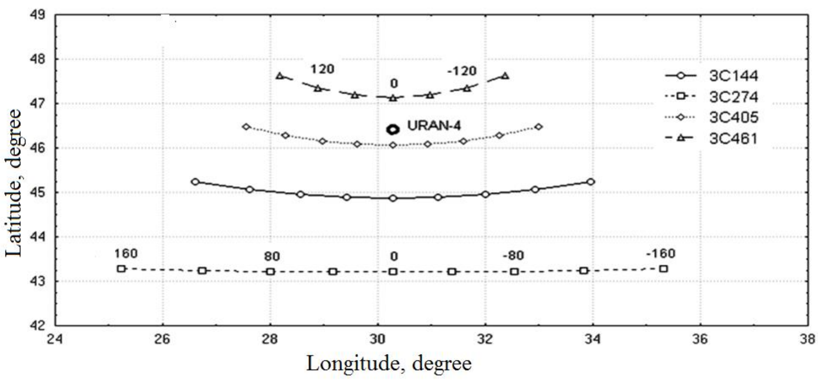
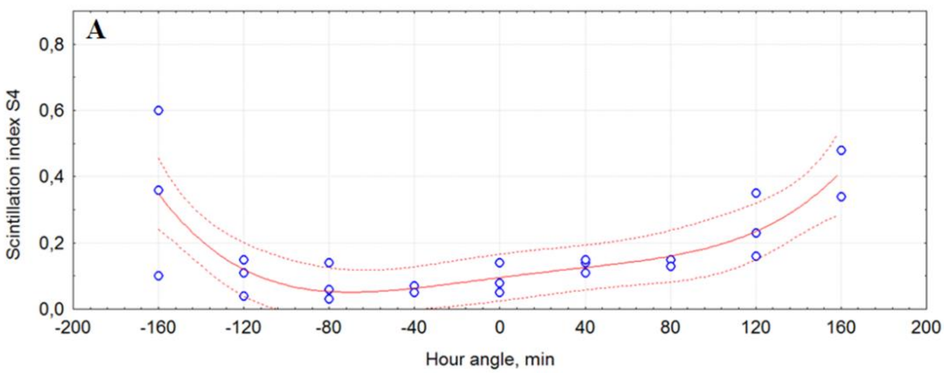


Figure 6. *Geodetic coordinates of points in which radio track of source-radio telescope crosses conditional surface* $F2_{max}$ *in ionosphere*

The lines in Fig. 6 are the tracks of the sounding of the ionosphere by the radio astronomical method. The icons are the fixed positions of the radio telescope beam, the numbers next to them are the values of the hour angles in minutes. Finding the beam in a fixed position (scan duration) for 3C 461 is 60 min., for other radio sources - 40 min.



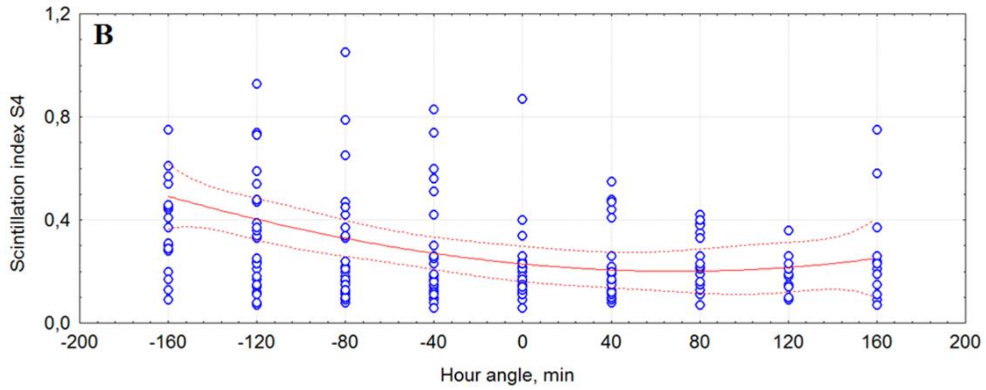


Figure 7. *Dependence of the scintillation index from hour angle for radio source 3C 405: left – sampling per first quarter of year; right – half-year sampling*

Figure 7 shows the dependences of the scintillation index on the hour angle of the source. We can expect a symmetric picture with respect to the zero hour angle if the changes in S4 were stationary over the observation period.

Data in panel A refer to the spring season Data in panel B mainly refer to the second half of the year. At short time intervals, S4 variations are strongly pronounced. As the time interval increases, the variations in S4 decrease. These variations are due to the strong seasonal-daily influence on the scintillation intensity, which violates the stationary nature of the change in S4. This is well confirmed by the long-term data series shown in Fig. 8 obtained with the URAN-4 radio telescope, in which the seasonal-diurnal effect is clearly manifested.

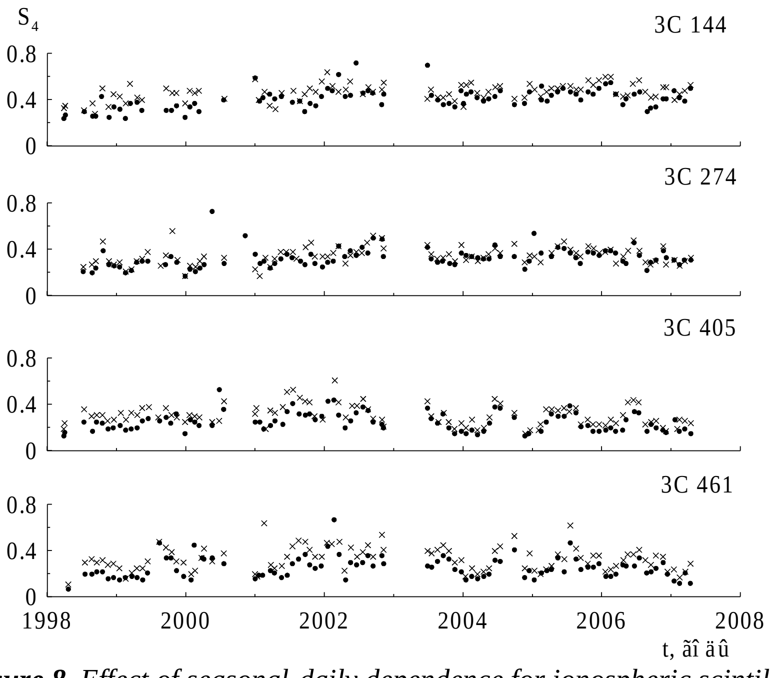


Figure 8. *Effect of seasonal-daily dependence for ionospheric scintillations intensity*

To reveal the dependence of the scintillation intensity on the position of the source in the celestial hemisphere, it is necessary to get rid of the seasonal-daily influence on the observation results. This can be done using samples that are multiples of one year. In this case, the averaged data will not depend on the seasonal-daily effect.

On Fig. Figure 9 shows the dependence of the mean values of the scintillation index on the hour angle of the source, obtained from a one-year sample. The symmetry of the graph indicates the suppression of the seasonal-daily effect. The data presented below were obtained from samples of several full years.

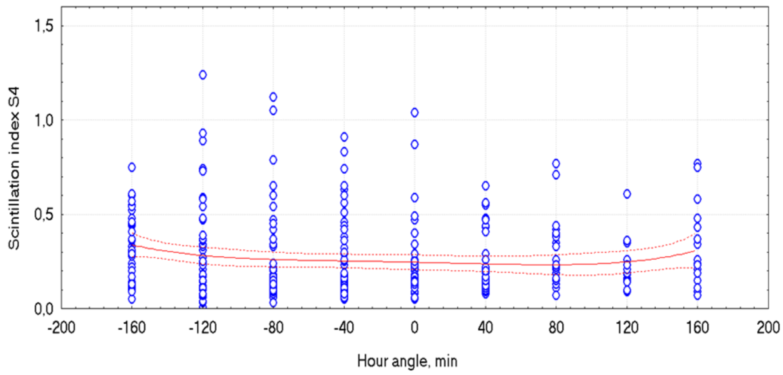


Figure 9. *Yearly sampling obtained for radio source 3C 405.*

The experimental dependence of the scintillation index on the zenith angle (Figure 10) for sources with a large angle β is close to the calculated curve obtained for the effect of changing the thickness of the scattering layer. For sources with β < 15o, the experimental dependence does not correspond to the calculated curve (it can be assumed that in this case the effect of anisotropy of ionospheric inhomogeneities, caused by the influence of the geomagnetic field, dominates).

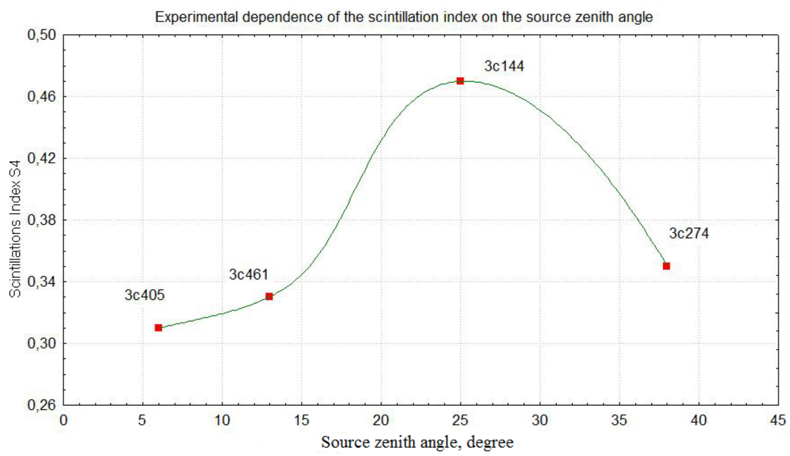


Figure 10. *Experimental dependence of scintillation index from source zenith angle obtained from observations on the RT URAN-4 during 1998-2007:*

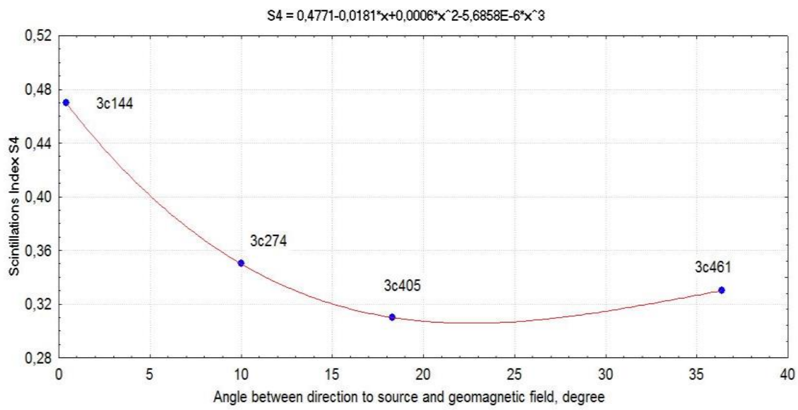


Figure 11. Experimental dependence of the average annual values of S4 on the angle β between the line of sight of the radio source and the geomagnetic field vector, obtained from observations on the URAN-4 RT from 1998 to 2007

It should be noted that the deviation of the line of sight of the source from the direction of the geomagnetic field β and the zenith angle of the source θ are related by a functional dependence, and the plots S4(β) and S4(θ) contain information about both the influence of the scattering layer thickness and the anisotropy of inhomogeneities. It is difficult to separate these influences on the basis of the results presented, but the analysis of the graphs shows that each of them has a monotonous section, which can be interpreted as related to the dominance of one of the influencing effects. The boundary of these sections lies in the region $\beta = 15^o$. Therefore, when estimating the scintillation intensity depending on the position of the radio source in the celestial hemisphere, one should use the graph S4 (θ) for $\beta > 15^o$, and the graph S4(β) for $\beta < 15^o$

5. Conclusions

1. To analyze the dependence of the intensity of ionospheric scintillations on the position of the radio source in the celestial hemisphere, we used data from long-term observations on the URAN-4 RT (geographic latitude 46o, decameter wave range).

2. Experimental dependences of the intensity of ionospheric scintillations on the zenith angle of the radio source θ and on the angle between the line of sight and the geomagnetic field vector β are obtained.
3. The boundary value β is determined, separating the positions of the source on the celestial hemisphere, for which either the effect of the thickness of the scattering layer or the effect of anisotropy of ionospheric inhomogeneities dominates.

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