DETERMINATION OF THE CHARACTERISTICS OF INVERSION REFLECTING LAYERS IN THE TROPOSPHERE ON CHANGES IN THE SIGNAL INTENSITY ON THE NEAR-EARTH OVER-THE-HORIZON ROUTES IN THE MIDDLE LATITUDES

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Abstract: *The methodology for determining changes of altitude, elevation velocity, and reflection coefficient of the elevated inversion layer in the troposphere is examined based on the results of observation of VHF signals on over-the-horizon (OTH) routes. Estimations of the elevation velocity and reflection coefficient of the elevated inversion layers on the results of measuring of the levels of VHF signals in the zone of the near geometric shadow in the middle latitudes and the meteorological sounding data using balloons are obtained.*

Keywords: Reflection coefficient; Inversion layer; Troposphere; VHF signals; Meteorological data.

1. INTRODUCTION

For the middle latitudes were Ukraine is located, when receiving VHF radio waves in the zone of the near geometric shadow, there are daily changes in the level of the received signal due to a change in the refractive properties of the troposphere [1, 2]. At the same time, in the spring-autumn period strong signal intensity variations apparently associated with the presence of elevated inversion layers and the resulting multipath in the propagation channel were observed.

The research focuses on using the different nature of the signal behavior on the over-the-horizon path to diagnose the troposphere condition, i.e. to solve the inverse problem: according to the characteristics of the signal - to determine the characteristics of the troposphere. In particular, the article analyzes the behavior of the signal in the presence of inversion reflective layers. The authors used the reception of a VHF television signal (wavelength about 1.7 m) on the over-the-horizon route. However, for these purposes, the reception of VHF signals from broadcasting stations (wavelength about 3m) can also be used. The experimentally obtained characteristics of fading (frequency of occurrence and depth), as well as the altitude of the inversion layers, were specified for the middle latitudes. It should be expected that they will be different for the tropical zone. However, the revealed general patterns and methods of obtaining them will remain unchanged. In this paper, we propose a method for estimating the reflection coefficient, changes in the altitude, and its velocity for the elevated inversion layer in the troposphere by observing VHF signals in the shadow and penumbra zones and sets forth preliminary experimental results.

2. DATA AND METHODS

The model of the Earth's equivalent radius is one of the most widely used for accounting for tropospheric refraction. In the framework of this model, refraction is taken into account by introducing a refractive index linearly depends on altitude [1, 2]. The presence of inversion layers, are elevated relative to the Earth's surface can lead to the appearance at the point of reception not only a direct signal from the transmitting point, but also reflected from these layers [2]. The signal from the TV station transmitter gets to the receiver not only along the direct path, but also after reflection from the inversion layer elevated to a height h_s. A schematic representation of the propagation channel is shown in fig. 1.

It is shown the case of one elevated inversion layer presence although, in the general case, there can be several of them. The change in the radius of curvature for the raised inversion layer due to refraction in the troposphere is also taken into account in the framework of the model of the equivalent radius of the Earth a_e. It should be noted that a_e in the framework of the considered model [1, 3]:

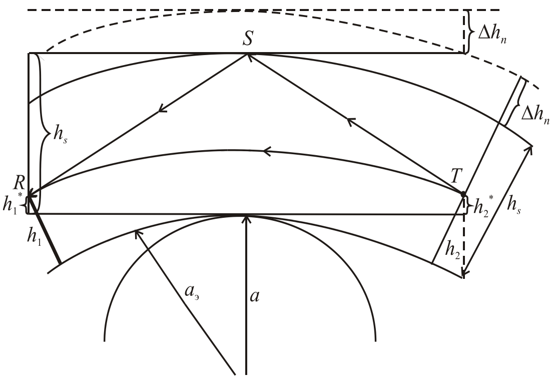

Fig. 1. *Schematic representation of the propagation channel.*

$$a_e = \frac{a}{1+ga} \tag{1}$$

where a - Earth radius;

g - Refractive index gradient.

The received signal can be written as a superposition of two rays: direct and reflected from the inversion layer:

$$\dot{\mathrm{S}}_{\mathrm{out}} = \dot{\mathrm{S}}_{\mathrm{in}}\dot{\mathrm{V}} + \dot{\mathrm{S}}_{\mathrm{in}}\dot{\rho} \tag{2}$$

$\dot{\mathrm{S}}_{\mathrm{in}}$- Emitted signal taking into account the linear attenuation factor;

$\dot{\mathrm{V}}$- OTH signal attenuation factor;

$\dot{\rho}$- Reflection coefficient from the layer.

The attenuation factor at the receiving point $\dot{V}_{out}$ can be written as:

$$\dot{V}_{\mathrm{out}} = \frac{\dot{S}_{\mathrm{out}}}{\dot{S}_{\mathrm{in}}} = \dot{V} + \dot{\rho}$$

and his module

$$\dot{V}_{\mathrm{out}} = \left|\dot{V}_{\mathrm{out}}\right| = V\sqrt{1 + \gamma^2 + 2\gamma\, cos(\Delta\phi + \phi_0)} \tag{3}$$

Where $\gamma = \rho/V$- Relative reflective index;

$\Delta\phi = \frac{4\pi h_1^* h_2^*}{\lambda R}$ phase difference between the waves, direct and reflected from the layer.

ϕ_0- Additional phase shift upon reflection from the layer,
moreover, h_1^*, h_2^* - The reduced heights of the corresponding points relative to the inversion layer are defined as:

$$h_1^* = h_s - h_1 - \Delta h_1 \qquad h_2^* = h_s - h_2 - \Delta h_2 \tag{4}$$

where h_1, h_2, h_S, Δh_1, Δh_2- The height of the corresponding points, the inversion layer, as well as their increment due to refraction, the latter within the framework of the model under consideration are defined as [3]:

$$\Delta h_1 = \frac{R^2}{2a_e}\left(\frac{h_s-h_1}{2h_s-h_1-h_2}\right)^2 \qquad \Delta h_2 = \frac{R^2}{2a_e}\left(\frac{h_s-h_2}{2h_s-h_1-h_2}\right)^2 \tag{5}$$

Fluctuations in the temperature of the Earth's surface and air masses observed after the sun sets and somewhat later in its rise can lead to the inversion layer vertical moving. The altitude profile of the gradient of the refractive index was estimated from balloons data on temperature, humidity, and pressure. Observation of the interference pattern of the received signal taking into account relations (3-5) makes it possible to approximately determine the increment in the height of the raised inversion layer Δh_n:

$$\Delta h_n = \frac{(h_1^*+h_2^*)}{2}\left[\sqrt{1+\frac{n\lambda R}{(h_1^*+h_2^*)^2}}-1\right] \tag{6}$$

where n - The observed number of half-periods of fluctuations of the received signal amplitude due to the displacement of the raised inversion layer in the troposphere to a height Δh_n.

With a known observation time, the period of these fluctuations, Δt_n one can estimate the speed of elevation or descent of the inversion layer:

$$\upsilon = \frac{\Delta h_n}{\Delta t_n} \tag{7}$$

The relative reflection coefficient from the inversion layer γ can be estimated from measurements of the maximum and minimum levels of the received signal with periodic change:

$$\gamma = \frac{1-V_{\min}/V_{\max}}{1+V_{\min}/V_{\max}} \tag{8}$$

and the reflection coefficient from the layer ρ is obtained using experimentally obtained data on the values of the attenuation factor.

Theoretically expected estimates of the reflection coefficient from a layer with a stepwise change in the refractive index by ΔN can be obtained using the relation [4]:

$$\rho \approx \frac{\Delta N}{2\theta_n^2} \tag{9}$$

which is true for small, but still greater than the angle of total internal reflection angles of meeting with the layer θ_n defined by the ratio:

$$\theta_n = \frac{h_2^* + h_1^*}{R}$$

Viewing angles corresponding to total internal reflection $\theta_n \leq \sqrt{2\Delta N}$

where ΔN - Expressed in N units, and θ_n - In milliradians.

The above relations make it possible to determine the reflection coefficients from the layer from the logged interference structure of the signal on the OTH route, the hop of refractive index and the characteristics of dynamics of its height changes.

3. EXPERIMENT RESULTS

Experimental studies in the mid-latitudes (Ukraine) of signal levels of TV stations on OTH routes made it possible to establish that interference phenomena in the received signal can be associated with multipath in the propagation channel. The most frequent it is observed from late spring to early fall. The measurements carried out during the spring-summer period (from May to August), when the presence of inversion layers is most likely. During observations, deep interference fading or received signal amplitude fluctuations, with a constant period were observed.

As an example, the characteristic behavior of the signal in the presence of inversion reflecting layers on the over-the-horizon propagation path is shown in fig.2. There is characteristic deep fading (up to 30 ... 40 dB) with a period of up to several hours.

In approximately 3% -5% of cases, in the morning hours of the summer months after sunrise, the level of the received signal decreased significantly below the average value. This, apparently, is due to the fact that the corresponding points: the transmitting one in Belgorod (height 175 m) and the receiving one in Kharkov (height 30 m) are located on different sides relative to the inversion reflective layer. The analysis of the data show that in the mid-latitudes the inversion reflective layers are located, as a rule, at heights of 50 ... 650 m, have a difference in the refractive index from -0.33 to -0.105 N-units. Moreover, the speed of their vertical movement is from units to several hundred meters per hour. Interfering with a direct signal, they lead to the appearance of fading from a depth of 3dB to 23dB.

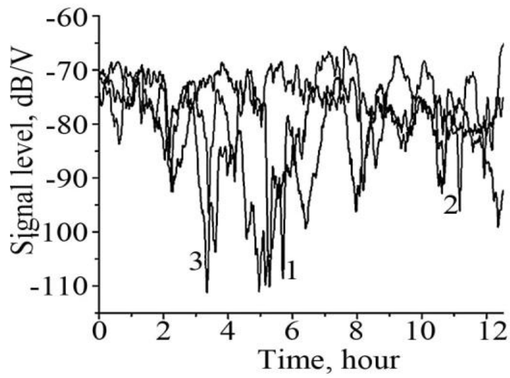

Fig. 2. *Behavior of the VHF signal on the over-the-horizon route in the presence of inversion layers: signals during: 1-st, 2- nd and 3-rd November.*

Experimental studies were carried out in the middle latitude (Ukraine). Their goal is to show the possibility of using the proposed approach to analyze the case when inversion reflective layers are present in the troposphere, which manifests itself in periodic signal fading on the over-the-horizon path.

Studies have shown that the characteristics of the troposphere are slightly influenced by 12-year cycles of solar activity - fig. 3. However, trend changes in the refractive index do not exceed 1% for middle latitudes. Fig. 4. shows its behavior on an interval of more than 7 years.

Comparisons of the behavior of the refractive index for the middle latitudes and Vietnam [4] show that they have both general regularities (daily and seasonal changes) and differences (a larger spread of refractive indices for middle latitudes - in summer, and for the tropical zone - in winter).

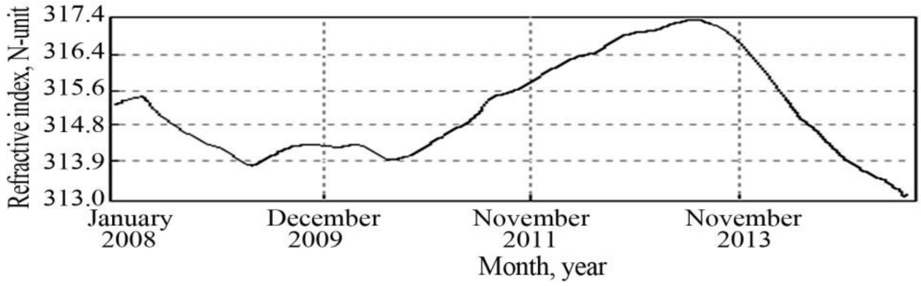

Fig. 3. *The behavior of the refractive index for Ukraine.*

As an illustration, figs. 4, 5 show the changes in the refractive index for the middle latitudes and for the tropical zone, Ukraine and Vietnam.

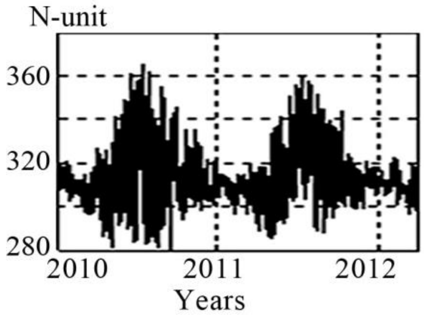

Fig. 4. *Seasonal change in the refractive index for Kharkiv city (steppe zone) over several years.*

Similarity of refractive index behavior makes it possible to use the methods developed and tested in the middle latitudes (Ukraine) to study the tropospheric features for the tropical zone (Vietnam).

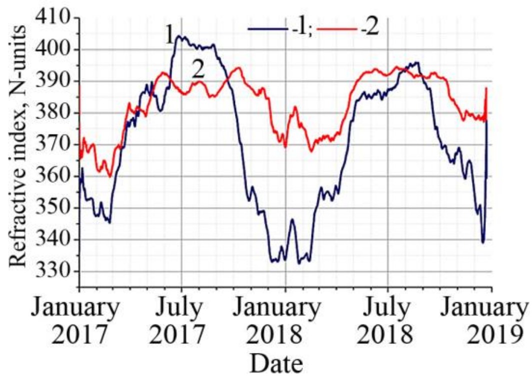

Fig. 5. *Seasonal change in the mean values of the refractive index after smoothing over 30 days: 1- Hanoi; 2-Ho-Chi-Minh.*

Fig. 6 shows the histograms (b) and the distribution functions (a) of the gradient of the effective refractive index in the layer the radio wave is propagated (1) reflection coefficient of the layer (2), the depth of signal fading (3), the altitude of the inversion reflecting layer (4) and its speed of movement (5). The integral distribution functions are given on a scale linearizing the normal distribution law. In this case, the value of the process (abscissa) is centered and normalized to rms value.

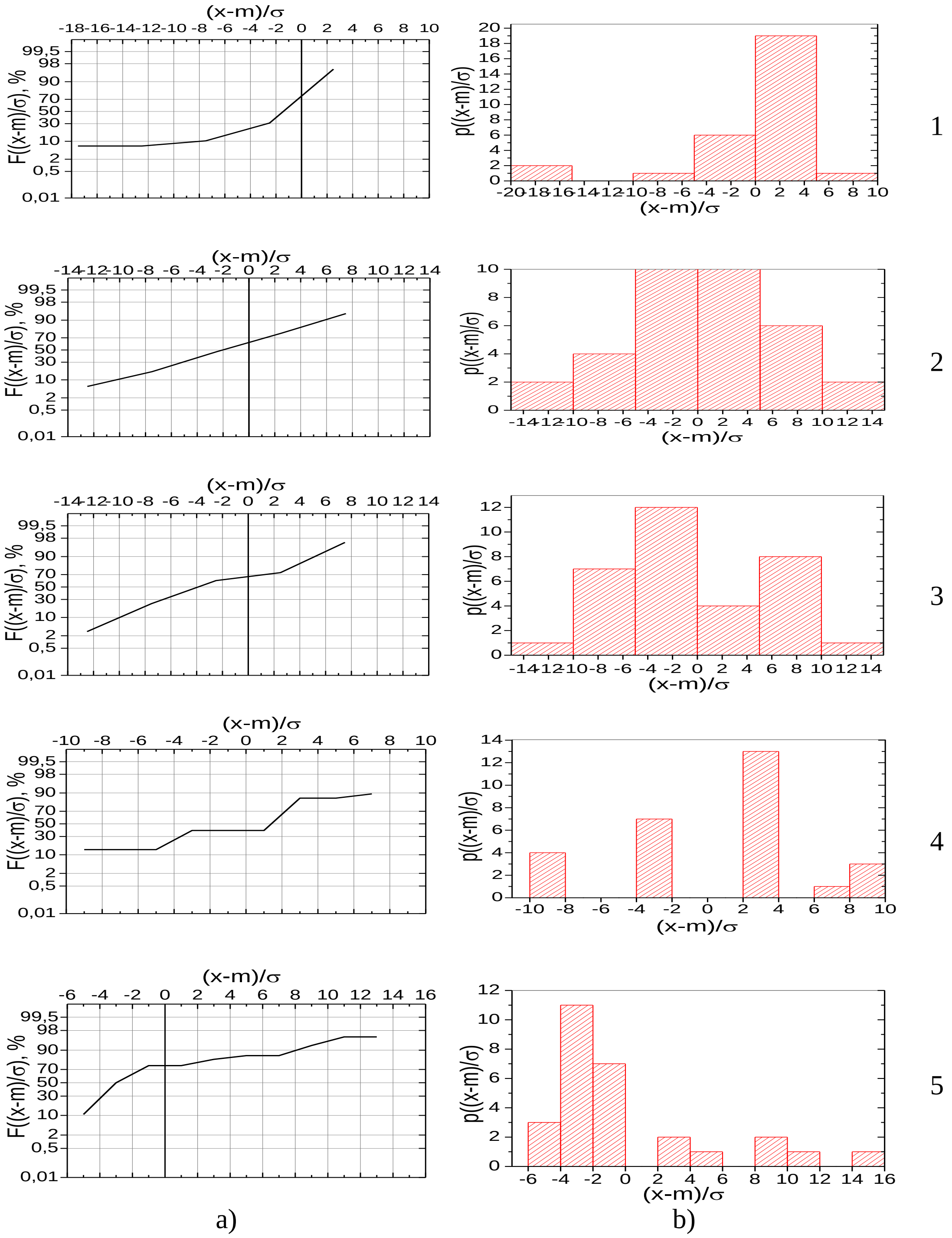

Fig. 6. *Characteristics of the inversion layers and the signals reflected from it propagating on the OTH path: distribution functions (a) and histograms (b) of the gradient of the effective refractive index of the layer (1), reflection coefficient from the layer (2), fading depth (3), and the altitude of the inversion reflective layer (4) and its speed of movement (5).*

It is seen, that if the distributions of fading, reflection coefficient, and layer heights are satisfactorily described by the normal distribution law, then the distribution of its displacement velocity differs significantly from the standard model. The results of the statistical processing of the data are given in table 1.

Table 1. *Numerical characteristics of reflective inversion layers according to experiment.*

Parameter	Drop max/min ΔV, dB	layer height at 1 am h_s, m	Mean gradient g_N	Relative reflection coefficient, γ	Reflection coefficientρ, dB	height increment, Δh_+	half period duration Δt, hour	layer lifting speed $\Delta h_+/\Delta t$, mph
Mean	10,35	369,64	-0,0529	0,5080	-24,08	67,32	2,03	38,41
Standard. error	0,81	34,15	0,0031	0,0301	0,720	12,75	0,141	6,81
Median	10	450	-0,048	0,5195	-24,021	35,02	2	24,87
Moda	7	450	-0,049	0,3825	-16,665	34,84	1,5	
RMSE	4,74	180,7	0,0164	0,1757	3,8824	67,45	0,813	36,05
Dispersion	22,43	32655,4	0,00027	0,0309	15,07	4550,2	0,662	1299,5
Excess	0,471	-0,541	5,924	-0,515	-0,518	6,376	-0,853	1,921
Asymmetry	0,858	-0,389	-2,386	0,170	0,0487	2,592	0,374	1,684
Interval	19,5	600	0,072	0,669	14,474	258,69	3,25	131,95
Minimum	3,5	50	-0,105	0,1987	-31,139	23,77	0,5	9,27
Maximum	23	650	-0,033	0,8678	-16,665	282,46	3,75	141,22
Sum	352	10350	-1,532	17,2735	-698,4	1885,0	67,15	1075,568
Score	34	28	29	34	29	28	33	28

The results of processing of the received signals of a HF (175 MHz frequency) TV channel (the Belgorod – Kharkiv OTH route with a length of 71 km) according to the developed method, as well as data of aerological sounding of the height of the inversion layer location made it possible to establish that fading with a depth of more than 10 dB is observed in less than 40% of cases, and over 20 dB no more than 5%. The height of the reflective inversion layer in approximately 85% of cases does not exceed 0.5 km. In this case, the differences in the refractive index in the layer are, as a rule, 6-14 N units. The range of variation of reflection coefficients from inversion layers ranged from -20 dB to -32 dB. Moreover, the most probable (with a probability of about 0.6) values of the relative reflection coefficient ranged from 0.4 to 0.8. The estimates obtained are in satisfactory agreement with the theoretically expected ones. The speed of change of the height of the inversion reflective layer obtained using ratios in approximately 70% of cases lies within 10-30 mph.

4. CONCLUSIONS

1. A technique is proposed for studying the characteristics of inversion layers in the troposphere from the characteristics of signal fading along the over-the-horizon path. It has been shown theoretically and experimentally confirmed that the

selected spectral components of fluctuations of the signal received on the over-the-horizon path make it possible to estimate the relative reflection coefficient from the layer, and hence the difference in the refractive index in it, as well as the altitude of its location and the speed of its vertical movement. This approach, based on the use of spectral analysis of the signal structure on over-the-horizon paths to study the structure of layers in the troposphere, was proposed for the first time and for the first time made it possible to obtain their characteristics (number, frequency of occurrence, average altitude and speed of its vertical movement, as well as the difference in refractive index in the layer) for the middle latitudes. A similar approach can be successfully used to study the characteristics of layers in the tropical zone of Vietnam.

2. Experimental studies carried out in the middle latitudes using the radiation of TV centers made it possible to establish that in most cases the number of inversion layers does not exceed 2 with a difference in the refractive index at the layer boundary of 6 ... 14 N units. The height of their placement for mid-latitudes, as a rule, does not exceed 1 km, and the lifting speed of several hundred meters per hour.

3. A standard Gaussian model can be used to describe fading statistics, reflection coefficients, and altitudes of inversion layers. At the same time, the distributions of the effective gradient of the refractive index in the layer, which is essential for the propagation of radio waves and the velocities of the inversion layers, differ from the Gaussian models.

4. The features of the behavior of the signal on the over-the-horizon path, which are characteristic of various states of the troposphere, were established, and classification criteria were formulated that would allow the signal behavior to diagnose the refractive state of the troposphere and study the frequency of occurrence of various situations. The obtained quantitative estimates are typical for the middle latitudes and will be different for the tropical zone, however, the formulated classification criteria will make it possible to use the approach proposed by the authors to study the features of the troposphere of the tropical zone using emissions from television centers and VHF broadcasting stations on over-the-horizon routes, which opens up new opportunities for studying the radio-climatic features of Vietnam.

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TÓM TẮT

XÁC ĐỊNH ĐẶC ĐIỂM CỦA LỚP PHẢN XẠ NGƯỢC TRONG TẦNG ĐỐI LƯU DỰA TRÊN CƯỜNG ĐỘ TÍN HIỆU THEO ĐƯỜNG TRUYỀN DẪN GẦN CHÂN TRỜI TẠI CÁC VĨ ĐỘ TRUNG BÌNH

Phương pháp xác định sự thay đổi độ cao, vận tốc nâng và hệ số phản xạ của lớp phản xạ ngược trong tầng đối lưu được nghiên cứu dựa trên kết quả quan trắc tín hiệu VHF theo đường truyền gần chân trời. Ước tính vận tốc nâng và hệ số phản xạ của lớp phản xạ ngược dựa trên kết quả đo đạc mức tín hiệu VHF ở gần vùng che khuất hình học trong khu vực vĩ độ trung bình và dữ liệu bóng thám không thu được.

Từ khóa: Hệ số phản xạ; Lớp phản xạ ngược; Tầng đối lưu; VHF; Dữ liệu khí tượng.

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