ATMOSPHERIC EFFECTS ON MEASUREMENTS OF DISTANCE TO EARTH ARTIFICIAL SATELLITES

N. Kablak, V. Klimyk, I. Shvalagin, U. Kablak

Space Research Laboratory, Uzhhorod National University
2a Daleka Str., 88000 Uzhhorod, Ukraine
e-mail: space@univ.uzhgorod.ua

This paper is devoted to the problem of accuracy increasing in allowing for Earth's atmosphere influences on results of daily ranging observations of the Earth artificial satellites (ASE). Atmosphere delays and their spatial-timely variations for spherical-symmetrical and nonspherical models of atmosphere were determined radiosounding data gathered during a year in Ukraine region using, developed valuing and analysis of models reductions to over of atmosphere, which recommended of IERS for processing distance-ranging observations of the Earth artificial satellites. Investigated and improved models of reductions to over of the atmosphere on the basis of discovered regional and local peculiarity's of influence atmosphere on the laser and radio ranging observations of the Earth artificial satellites.

INFLUENCE OF THE ATMOSPHERE ON PASSING OF AN ELECTROMAGNETIC WAVE

The correction in distance to ASE, which is necessary to be added the found distance to ASE, is represented by the difference between optical and geometrical (c) distance to ASE:

$$\Delta\rho = \int_S n(S)dS - \rho.$$

Frequently atmospheric correction represents as: $\Delta\rho = \Delta\rho_1 + \Delta\rho_2$, where $\Delta\rho_1$ is the correction for speed of wave distribution (propagation), $\Delta\rho_2$ is the correction for a bending trajectory (geometrical correction).

For an optical range the correction $\Delta\rho_L$ was calculated in two ways: by the method of numerical integration under the data of aerological sounding (probing) of the atmosphere and under Mariny Murray formulas. For a radio-frequency range the correction $\Delta\rho_R$ is also obtained by the method of numerical integration and under the Saastamoinen and Mariny Murray formula. From the given schedules it follows that in summer and autumn periods (May – October) the correction $\Delta\rho_R > \Delta\rho_L$, but in winter and vernal periods $\Delta\rho_R < \Delta\rho_L$. A reason of such difference is the temperature and the increase of damp in winter period.

The corrections $\Delta\rho_L$, calculated under Mariny Murray formula, in general, are close to the appropriate corrections obtained by the method of numerical integration.

The divergences between the values of the corrections $\Delta\rho_R$, calculated under the Saastamoinen formula, and the corrections obtained by the method of numerical integration, in a radio-frequency range are much more larger, than in optical range. A reason of such divergence is a considerable influence of partial pressure of water-vapours in a radio-frequency range.

INFLUENCE OF TEMPERATURE AND DAMP INVERSIONS ON ACCURACY DETERMINATION OF THE DISTANCE TO ASE

In all models determining the correction $\Delta\rho$ in distance at radioranging hearly, the temperature structure (profile) (course T with an altitude) reference atmosphere (RA) is used. In RA the atmosphere is divided into layers, within the limits of which the distribution of meteorologic parameters can be described within the framework of polytropic (lapse rate of temperature being constant), or isothermal models. The distribution is based on the results of processing of the long-term data of aerological probing of the atmosphere. In troposphere the linear decreasing of temperature with an altitude is received:

$$T(h) = T_0 - \gamma(h - h_0),$$

where $\gamma = 6.5°/\text{km}$ is mean lapse rate of temperature.

This relation is fair up to an altitude of the tropopause h_{1t}. Above h_{1t} it is received that temperature remains to a stationary value up to an altitude h_{1s}, since which the temperature increases again. The altitudes h_{1t} and h_{1s} change depending on a geographical latitude, seasonal changes and local features of the given point of observation. So, in Uzhhorod h_{1t} changes during one year in the limits from 8 up to 12.5 km.

Formula well sequences with the actual data for the day-time conditions of observations. But at night a high-altitude structure $T(h)$ is more composed.

At night the temperature inversions is much more (sometimes twice higher), than in the day-time at the expense of radiation inversions. The location and power of layers of inversions of temperature and damp using the data of night aerological explorations of atmosphere in Uzhhorod in 1999 is given in Figs. 1 and 2.

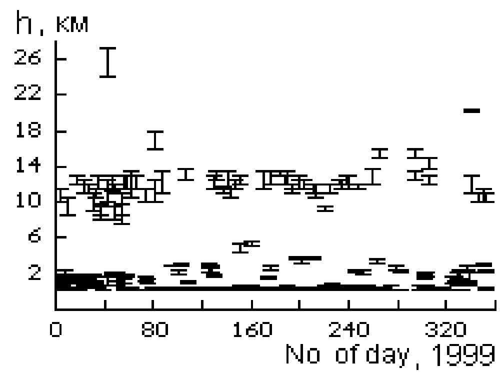

Figure 1. Power of layers of temperature inversion by the results of night observations in Uzhhorod

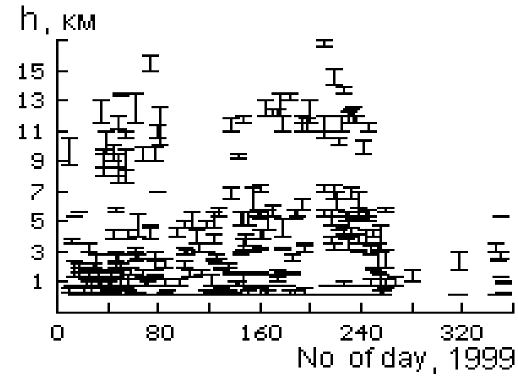

Figure 2. Power of layers of damp inversion by the results of night observations in Uzhhorod

The inversions of temperature in most cases result in appropriate inversions of partial pressure of water-vapour. But the location and power of inversions T and e not always coincide.

The analysis of the aerological data has shown that in atmospheric layers up to an altitude of 3 km of temperature inversion 73–97% of explorations of atmosphere are observed. The especially high-power inversions are observed at night in winter period, mainly at the expense of radiation inversions. In 1999 from 235 night explorations in Uzhhorod in 173 cases (74%) the inversion of temperature took place. The inversions in a layer of 8–18 km (high layer) take place at 20–40% of explorations, when the inversion was observed. In Uzhhorod in 1999 approximately in 40% of total dates with inversions the inversions in the upper layer (Fig. 1) were observed.

It is impossible to predict the existence of inversions at a particular altitude h only using the data of ground-based measurements. It is necessary to represent T by non-linear relation, which better sequences will actual values T and takes into account the inversions at a ground layer.

For estimation of the influence of inversion T and e (and, therefore, inversions N) on the atmospheric correction in distance $\Delta\rho$ using the aerological data for dates, when the high-power inversions e and T took place, we have calculated the corrections $\Delta\rho$, also under the same data – correction $\Delta\rho'$ by the eliminated inversions and correction $\Delta\rho_{\text{sas}}$, retrieved on ground parameters under the Saastamoinen formula.

The results of these calculations are Saastamoinen graphically in Fig. 3: the values of corrections $\Delta\rho$ (line) at nights, when inversion of temperature was observed, and at the same nights of value $\Delta\rho_{\text{sas}}$ (crosses), and also $\Delta\rho'$ – correction with the eliminated inversions of temperature (Fig. 3a) or damp (Fig. 3b). It is visible from Fig. 3 that in most cases $\Delta\rho$ is more than $\Delta\rho'$.

Under the data of explorations of atmosphere in Uzhhorod in 1999 the mean contribution of temperature inversion to the atmospheric correction is: $\Delta\rho - \Delta\rho' = 3$ mm $\pm$ 21 mm. The contribution to the atmospheric correction of damp inversion is much less: $\Delta\rho - \Delta\rho' = 4$ mm $\pm$ 5 mm.

With the increase of the intensity of inversion T and e the contribution $\Delta\rho - \Delta\rho'$ of inversion in the correction increases. By the results of observations in Uzhhorod in 1999 the lines of regression of correlation relations $\Delta\rho - \Delta\rho'$ (m) are obtained from intensities ΔT and Δe of inversion (Figs. 4 and 5).

DEVIATION OF AN ACTUAL CONDITION OF ATMOSPHERE FROM SPHERICALLY SYMMETRICAL MODEL

The source of essential errors at definition of the correction $\Delta\rho$ on the ground measurements and based on aerological meteorologic parameters of atmosphere is the use of spherically symmetrical model of atmosphere.

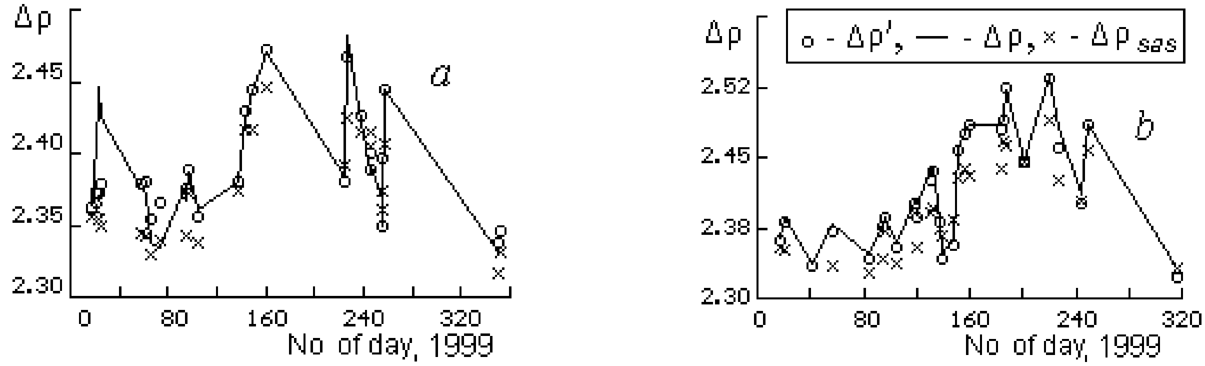

Figure 3. Change of the correction $\Delta\rho$ (meters) by results of night explorations of atmosphere in Uzhhorod in 1999 (line); ∘ – the same corrections with the eliminated inversions of temperature (a) or damp (b); × – corrections calculated by the Saastamoinen formula

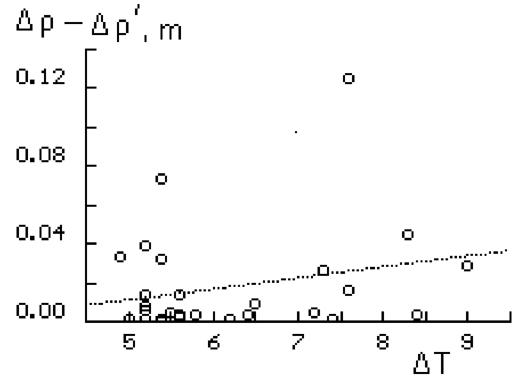

Figure 4. Correlation dependence of the contribution in the correction of temperature inversion from intensity of inversion ΔT

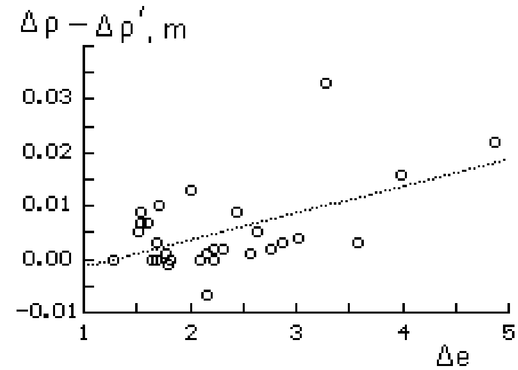

Figure 5. Correlation dependence of the contribution in the correction of damp inversion from intensity of inversion Δe

All papers devoted this problem have some lacks, in particular, small quantity of dates and points, small range of base distances between reference points. For the full analysis it is necessary to research horizontal lapse rates based on use a lot of data member, for different climatic conditions, and especially, in different scales: from 20–40 km, up to 600–800 km, as on large zenith distances ($85^\circ - 89^\circ$) the radio wave passes in atmosphere the distance of more than 800 km.

To estimate the deviation of a meteorological atmosphere from spherically symmetrical model it is necessary to select points $B(\varphi, \lambda)$ and $C(\varphi, \lambda)$, located in a direction of passing (zenith distance z) electromagnetic wave (ray) from reference point $A(\varphi, \lambda)$. It is possible to determine an altitude H_1 of an electromagnetic wave above point B and the altitude H_2 above point C. If there are results of synchronous aerological sounding of atmosphere in these three points, we shall find the differences of refraction indexes: $\Delta' N_{AB} = N'_A - N'_B$ at the altitude H_1 for points A, B and $\Delta'' N_{AC} = N''_A - N''_C$ at the altitude H_2 for A, C, *i.e.*, the difference of refraction indexes of spherical symmetrical model and meteorological atmosphere in reference point for given azimuth A and zenith distance z in some point defined by distance $r_1 = AB$ ($r_2 = AC$) or by altitude H_1 (H_2).

From 35 points located in 16 European countries we have selected seven groups of points (point A is the reference, points B and C are researched), obeying: a line ABC differs a little from sections of straight lines; the vectors AC have different azimuths $A \approx \arctan \dfrac{\Delta\varphi}{\Delta\lambda}$; distance r_1, and also r_2, for all triples of points A, B, C are approximately equal.

These seven groups of points and the appropriate lines ABC are shown in Fig. 6 in a system of geographical coordinates φ, λ. The reference points (A) are designated by large circles, points B – by daggers, C – by small circles. Mean distances from reference points: $AB = 300 \pm 80$ km, $ACE = 625 \pm 100$ km. Azimuths change in the limits: $-19^\circ \leq A \leq 29^\circ$. The results of calculation of the refraction differences ΔN at the altitude 6 km and

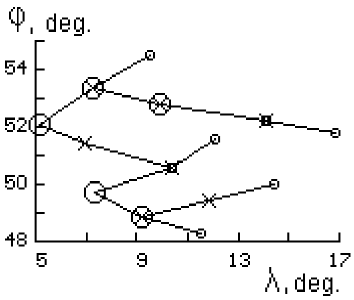

Figure 6. Geographical coordinates reference A (○) and researched B, C (×, ∘) points

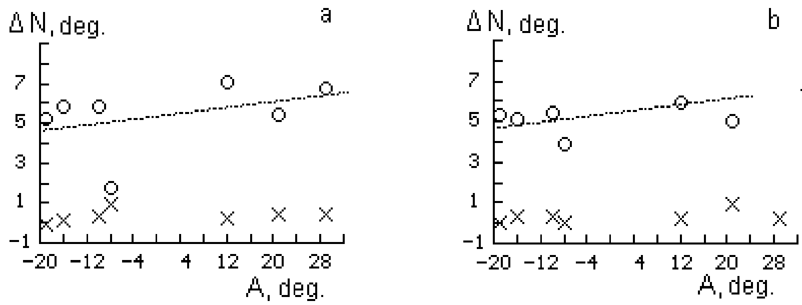

Figure 7. Differences ΔN of refraction indexes of spherically symmetrical model and meteorological atmosphere for different azimuths A (zenith distance $z = 88°$) at the altitude 6 km in points B (∘) and 26 km in C (×) at night (a) and in the day-time (b)

26 km (actually, the differences of refraction indexes of a ray from A ($z = 88°$) in points B and C of spherically symmetrical model and meteorological atmosphere) are shown in Fig. 7.

In the given interval of azimuths visibility (−20°, 30°) at the altitude of 6 km ($r_1 = 300$ km) some increase of ΔN is proportional to value A, but the correlation is weak. We present the equations of regression and appropriate regression coefficients shown just as a straight lines in Fig. 7, at night and in the day-time: $\Delta N_n = 0.03650 \cdot A + 5.357$, $\rho = 0.40$; $\Delta N_d = 0.03635 \cdot A + 5.409$, $\rho = 0.61$. Average on azimuth of value of differences:

H	day-time	night	mean
6 km	5.40 ± 1.63	5.46 ± 1.05	5.43 ± 1.37
26 km	0.35 ± 0.30	0.30 ± 0.27	0.33 ± 0.29

The results for night and day-time differ a little. Sure definition of relation for A value needs a lot of points. And as the A values do not essentially differ from zero, it is possible to make a general conclusion about the essential change of ΔN when the distance r from reference point to the cast in the direction of $z = 88°$ is increase. But for this purpose there are only three points (r; ΔN): (0; 0), (300; 5.4), (625; 0.3). Therefore, it is necessary to perform such researches for points with distances r of 150–300 km and 400–450 km.

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