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EARTH ROTATION, REFERENCE SYSTEMS IN GEODYNAMICS AND SOLAR SYSTEM

JOURNEES 1995 ☆

SYSTEMES DE REFERENCE SPATIO-TEMPOR

☆ Warsaw, Poland, 18-20 September,

VALIDATION OF THE IERS STANDARD TROPOSHERIC MODEL

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1. INTRODUCTION

Although in recent years a great progress has been achieved in understanding of and modelling the influence of the atmosphere on satellite laser ranging systems (SLR), the atmosphere still remains a source limiting the accuracy.

At present, the formula of Marini and Murray (1973) is commonly used by the IERS Analysis Centers, NASA and others in SLR. The authors of the formula have tested its accuracy checking it against the 634 ray-tracing radiosonde profiles in the USA. Their results show that the formula for the atmospheric correction is a nearly unbiased estimator of the spherically symmetric ray-trace correction.

Janes *et al.* (1991) and others point out that the above mentioned formula has a limited accuracy, especially at large zenith angles. We have carried out an additional analysis of the atmospheric correction in SLR.

2. BACKGROUND

It is well-known that the atmospheric correction $\Delta\rho$ to the measured range can be written as follows

$$\Delta\rho = 10^{-6}\int_0^l N dl, \qquad (1)$$

where N is the group refractivity and the integration is performed along the ray path l between the ground station (l=0) and infinity.

At optical frequencies the group refractivity N is given by

$$N = 80.343 f(\nu)\frac{P}{T} - 11.27\frac{e}{T}, \qquad (2)$$

where P, T and e are the total pressure (in mbar), temperature (in K), and water vapour pressure (in mbar) in the air, and $f(\nu)$ is a known function of frequency. The values P, T and e vary along the ray path l.

We represent the group refractivity N at any point P (H, φ, λ) of the atmosphere by a function N (H, φ, λ), where φ and λ are the latitude and longitude of the point P, correspondingly. At any height H above the sea level we can write the refractivity N as a Taylor series about the position of the ranging station P_o $(H, \varphi_0, \lambda_0)$ (Mironov, 1994).

Using such expansion of N we can write

$$\Delta\rho = \Delta\rho_{1s} + \Delta\rho_{1g}, \tag{3}$$

where

$$\Delta\rho_{1s} = 10^{-6}\int_0^l N(H,\varphi_0,\lambda_0)dl, \tag{4}$$

represents the spherical correction to the measured range, and

$$\Delta\rho_{1g} = 10^{-6}\sum_{k=1}^{\infty}\int_0^l N_k(H,\varphi_0,\lambda_0)dl, \tag{5}$$

represents the correction to the measured range due to the departure of the group refractivity N from spherical symmetry. N_k is the n-th order term in the Taylor expansion of the refractivity N.

3. SPHERICALLY SYMMETRIC CORRECTION

In our analysis of the spherically symmetric ray-trace correction $\Delta\rho_{1s}$ we used radiosonde data gathered in zone regions of Ukraine and Hungary in 1979 during clear daytime (K_d=468 balloons) and clear night-time (K_n=1170 balloons) conditions when laser ranging can be performed. The data consist of meteorological measurements of the atmospheric pressure P, temperature T and relative humidity RH. They were obtained by radiosonde balloons released from seven different locations in Ukraine and one location in Hungary. The profiles were ray-traced at different zenith angles and as well as range corrections $\Delta\rho_{1s}$ for ray banding were obtained. The scale and peculiarities of the corrections were investigated.

The Marini-Murray's formula was applied using only surface data for each balloon and the known zenith angles to obtain approximate atmospheric correction. The differences between the corrections obtained from the two algorithms were calculated for night-time and daytime separately. They are presented in Figure 1.

The results show that Marini-Murray's correction formula for spherically symmetric model of the atmosphere is a biased estimator. The value of the bias is about 13 mm in night-time and 27 mm in daytime for the zenith angle $z = 80^0$.

4. HORIZONTAL REFRACTIVITY GRADIENT CORRECTION

The sources limiting the accuracy in the spherical model are presently believed to be horizontal gradients. Saastamoinen (1972) suggested that these gradients are due to global latitude decrease in temperature from south to north. He has theoretically estimated the standard error from such sources to be less than 10 or 20 mm at 80^0 zenith angle. Gardner (1976) has evaluated the influence of the horizontal gradients from radiosonde data obtained from eight locations near Leonard-town, Maryland in January and February 1970. His results showed that the range correction for the horizontal refractivity gradient, which is sinusoidal function of the azimuth, had a peak-to-peak value of 40-60 mm at 80^0 zenith angle and 10-15 mm at 70^0. Bender (1992) believes that the local atmospheric conditions along the east coast of the USA are more likely to be responsible for that.

In our investigation of the departure of the group refractivity *N* from spherical symmetry radiosonde data obtained in Ukraine during clear night-time conditions from March to October, 1979 were used. The radiosonde balloons were released practically simultaneously from five separate locations approximately 200 km one from another. We investigated the scale and behaviour of the group refractivities *N*, the gradients of pressure and temperature and the slopes of isopycnic sources at various heights H above the sea level.

The results indicate that the surface of constant refractivity throughout the region and conditions considered do not acquire a general slope toward the equator due to the normal latitude decrease in temperature from south to north as it was assumed (Saastamoinen, 1972; Gardner, 1976). We believe that the regional peculiarities of the refractivity gradients predominate over the presumable general slope.

We have evaluated the effects of the horizontal refractivity gradients by computing the range correction $\Delta\rho_{1g}$. Its value depends on the height of the atmosphere which is taken into account in the computation of the horizontal refractivity gradients and zenith angle. The correction $\Delta\rho_{1g}$ has an azimuthal dependence. The results indicate that the correction of the refractivity gradient $\Delta\rho_{1g}$ is 30 mm when the satellite is near zenith angle equal to 80^0.

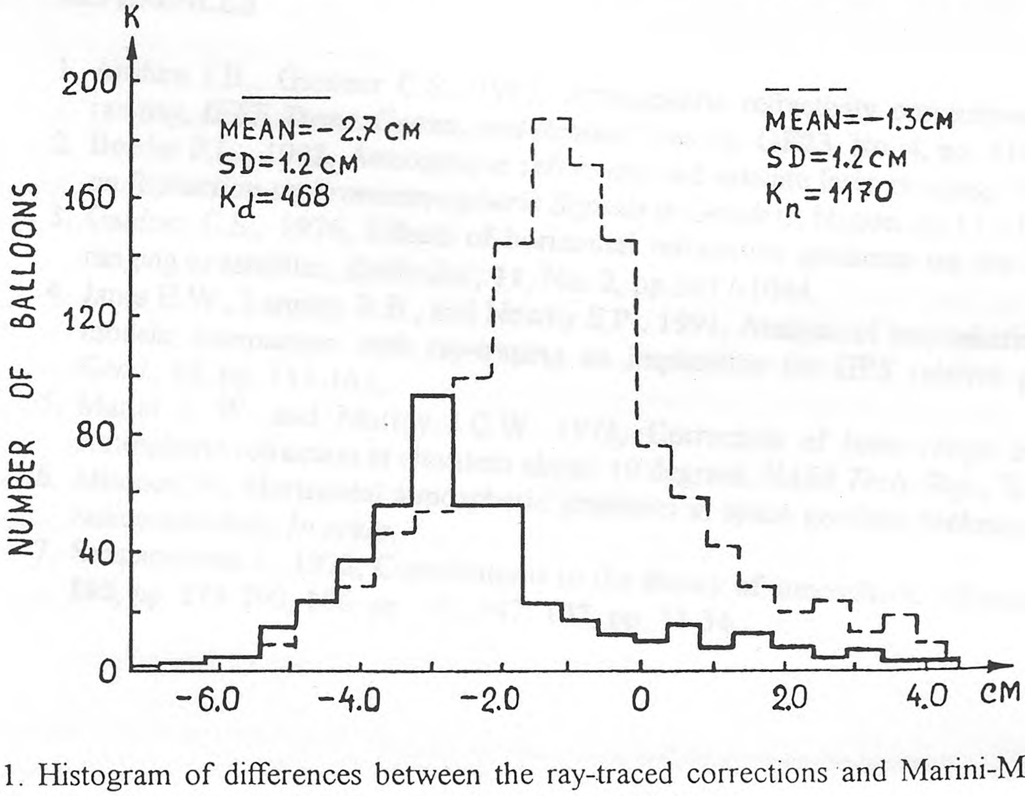

Figure 1. Histogram of differences between the ray-traced corrections and Marini-Murray's corrections: zenith angle $z = 80°$, laser wavelength $\lambda = 0.6943\ \mu$.

5. ERROR BUDGET FOR TROPOSHERIC RANGE CORRECTION IN SLR

The accuracy of the troposheric delay corrections in SLR measurements has been investigated by a number of authors. Bender (1992) has looked at its influence on the accuracy model of the departures of the atmosphere from the hydrostatic equilibrium. Abshire and Gardner (1985) evaluated the atmospheric turbulence effects on laser ranging observations.

We provided the following total estimates of the error budget for the troposheric range correction:

	$z = 0^0$	$z = 80^0$
– bias of the Marini and Murray formula	2 mm	13 mm
– horizontal gradients of refraction	0	30 mm
– departure form hydrostatic equilibrium	3 mm	17 mm
– turbulence of the atmosphere	0	3 mm
Total maximum error can amount	3.7 mm	35 mm

Error budget for the troposheric range correction in SLR depends on the zenith angle.

6. CONCLUSION

As SLR instrumental precision has been improved to the centimeter and even subcentimeter levels, the perspective of improvements of the IERS troposheric standard model is the use of regional and/or local values of the model parameters. It is also necessary to develop new instrumental methods.

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