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Determination of Troposphere Characteristics Using Signals of Satellite Navigation Systems

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Abstract—Based on two-frequency phase measurements of GNSS signals by ground-based receivers, zenith delays of radio signals in the troposphere are estimated. These estimates are compared with the NCEP/NCAR reanalysis data on weather fields. It is shown that the standard deviation in the values of zenith delays obtained in both ways is about 1 cm on average. According to our calculations, such a level of accuracy permits one to study the interday and intraday dynamics of the troposphere. The temporal resolution of estimates based on the GNSS data is 2 h, which makes it possible to organize atmosphere monitoring using a ground-based network of satellite tracking systems.

Keywords: troposphere, refraction of radio waves, reanalysis, GNSS, zenith delay.

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1. INTRODUCTION

It is well-known that forecasting the meteorological situation requires taking into account atmospheric processes of synoptic and diurnal scales because they have a significant effect upon the dynamics and energy properties of all layers of the atmosphere [1]. In connection with this, methods for the operative monitoring of the atmosphere are of undoubted interest.

Among all technologies that make it possible to probe the low atmosphere, the application of signals of satellite navigation systems has a number of advantages. These are the possibility of continuous 24-h monitoring, high temporal resolution of measurement data, and the relative cheapness of the receiving equipment. In the United States, Japan, and Western Europe, many studies are devoted to variations in the three-dimensional fields of water vapor content in the troposphere using networks of ground-based GPS receivers [2–4] and others.

The work of navigation systems is based on ground measurements of the phase of a signal emitted by a navigation satellite. The phase path from the satellite to the ground-based receiver is measured with an accuracy of several millimeters [5].

The measured phase is a result of the radioscopy of the atmosphere and, consequently, offers information characterizing the state of atmospheric layers. This information is determined by the height profile of the refractive index which, in turn, is connected with meteorological parameters such as the partial pressure of dry gases P, temperature T, and water vapor pressure e [6]:

$$N = 77.6890\frac{P}{T} + 71.2952\frac{e}{T} + 375463\frac{e}{T^2}. \quad (1)$$

Formula (1) is often completed by inverse compressibility coefficients of dry gases and water vapor close to unity [7, 8]. The numerical expressions for them were presented in [9].

Different values of the refraction index lead to different time delays of radio signals in the atmosphere. The vertical (or zenith) tropospheric delay ZTD, which can be defined via an integral of the refractive index [9]

$$ZTD = \int_{\text{receiver}}^{H\max} N \times 10^{-6} dh \quad (2)$$

can serve as a parameter characterizing this action in the troposphere.

This integral is taken from the height of the receiver's antenna to a certain maximal height H_{max} (usually, about 100 km). Higher layers yield such small delays in the neutral atmosphere that they are lower than the measurement accuracy. The height distribution N is known if the profiles of dry-gas pressure P, temperature T, and wet-vapor pressure e are known.

In Kazan there is a network of GPS–GLONASS receivers spatially separated by distances from 1 to 35 km. It was shown in [10] that the refractometric method and radiomeasurements of signals of the GPS–GLONASS GNSSs by the use of a network of