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ATMOSPHERIC RADIATION, OPTICAL WEATHER, AND CLIMATE

Variations in the Atmospheric Integrated Water Vapor from Phase Measurements Made with Receivers of Satellite Navigation Systems

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Abstract—Variations in the atmospheric integrated water vapor obtained from the phase measurement by satellite navigation systems' receivers are discussed. The comparison between numerical weather reanalysis fields and solar photometer measurements has shown an agreement with a relative deviation of less than 10%. Intraseasonal processes of 3–45 days in length significantly contribute to variations in the atmospheric integrated water vapor; their amplitude is 1–4 kg/m^2. Variations with periods from 3 to 10 days are the most frequent.

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INTRODUCTION

The integrated water vapor (IWV), equal to the amount of water in an atmospheric column with the a unit cross-sectional area, is of importance for climatology and the regional prognosis of the radiation balance of the atmosphere [1, 2]. Water vapor plays an important role in atmospheric thermodynamics. For example, high-resolution spatial-temporal data on atmospheric water content is necessary for exact forecasting of radiation forcing [2, 3]. Traditional radiosonde observations or systems of meteorological satellites fail to provide a sufficient resolution.

One of the common remote IWV sensing techniques is the use of signals from global navigation satellite systems (GNSS) [4, 5]. This approach has significant advantages: all-weather; comparatively low cost of the user instrumentation; global coverage, high temporal resolution, and high density of stations combined in a variety of networks. One such network is in Kazan [6]. Using its data, the possibility of studying time variations in the atmospheric IWV is shown in this paper.

At the present time, IWV variations of different scales have been studied by different methods. Global processes of the dynamics of moisture content are considered in [7], using space microwave radiometry data. The data show the connection of the processes with the interaction of the "atmosphere–ocean" system and cyclogenesis. The quantitative dependence of atmospheric water anomalies on cyclogenesis is described in [8], based on microwave measurements from polar-orbital satellites. It is shown in [9] that the strong surface gradient of IWV is a good indicator of the positions of fronts in midlatitude cyclones over oceans.

More local IWV variations are studied with the help of GPS. For example, daily cycles of IWV in the coastal city Marseilles are analyzed and breeze circulation effects are described in [10]. The IWV distribution over China is considered in [11] on the basis of GPS data, where annual, diurnal, and half-diurnal IWV harmonics in different regions of China are shown.

Determining the IWV from GPS measurements is based on estimating the zenith tropospheric delay (*ZTD*) of satellite-emitted electromagnetic waves. This parameter is equal to the difference between the magnitude of the satellite signal phase path measured by a ground-based receiver and the geometric distance between the satellite and the receiver. Since signals are propagated in the atmosphere, the difference between the phase and the geometric distance is determined by delays in the troposphere and ionosphere [12]:

$$\Phi - S = \cancel{I} + \varepsilon,$$

where Φ is the measured phase path between the satellite and receiver; S is the geometric distance; T is the tropospheric delay; I is the ionospheric delay; and ε is the measurement error, including also the phase ambiguity and errors caused by the receiver clock offset at the satellite and receiver [6]. Strictly speaking, the tropospheric delay is a commonly accepted term. Actually, this radio signal delay is determined by the whole neutral atmosphere. The contribution of the troposphere as the densest layer is more than 75%. The data on satellite orbits, necessary for the calculation of the geometric distance, is available on the server of the International GNSS Service [15].

The ionospheric delay is excluded because of its dependence on the signal frequency (observations are conducted at two frequencies only [6, 12]). The tropospheric delay T at small elevation angles of "satellite–antenna" radio paths can attain several tens of meters. In the case of vertical path (an elevation angle of 90°)