

Anthropogenic impact signatures revealed in the travelling ionospheric disturbances by regional GPS interferometry

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Abstract. With the technique of the radio interferometry of the navigational satellite signals, we investigate the travelling ionospheric disturbances generated by large urban agglomeration. We resolve detailed structure of the ionospheric disturbances field and attribute disturbances to particular atmospheric wave sources in the agglomeration. Wave generation efficiency revealed from the observational data well agrees with the theoretical prediction derived from energetic considerations.

1. Introduction

Presently, in the whole world big attention is paid to the monitoring of natural environment. Continuously growing population of the whole Earth, increasing anthropogenic load of the nature, intensive exploitation and consumption of natural resources results in degradation of the natural environment, primarily in the most populated regions with well-developed industrial and urban infrastructure. This problem has a lot of issues, some of them are related to a special thermal regime established in large urban areas [1, 2]. Some of them are mentioned in this brief introduction.

Due to high consumption of electrical and thermal energy, organic fuel as well as relatively low albedo of urban landscapes in the solar spectrum, big city is a strong concentrated source of the heat which is deposited in the surrounding atmosphere. Besides, lots of water vapor, soot, urban dust, aerosols etc. emitted in the atmosphere by the city, strongly influence thermal and radiation balance in the atmosphere [3]. All of that causes notable perturbations of natural distributions of the atmospheric air pressure, temperature and humidity in different regions, including the polar ones [4, 5]. These perturbations to a significant extent determine regional atmosphere dynamics, local climate in the city and region and air mass transfer in it. They can also generate atmospheric waves of different types [4, 6] which can reach ionospheric heights [6] under certain circumstances.

Central industrial region of Russia, as one of the most populated and developed regions of the Russian Federation, is characterized by complicated ecological situation and is one of the most problematic from the ecological point of view. Due to that, the city of Moscow where huge population and industry is concentrated within relatively small compact area is a strong source of perturbations of the natural environment in the region.

For that reason, techniques of the instrumental monitoring of the atmospheric dynamics in the city and the region become especially important. These techniques should combine both in situ



measurements and remote sensing of the atmospheric parameters, providing characterization of the environment in average at different scales.

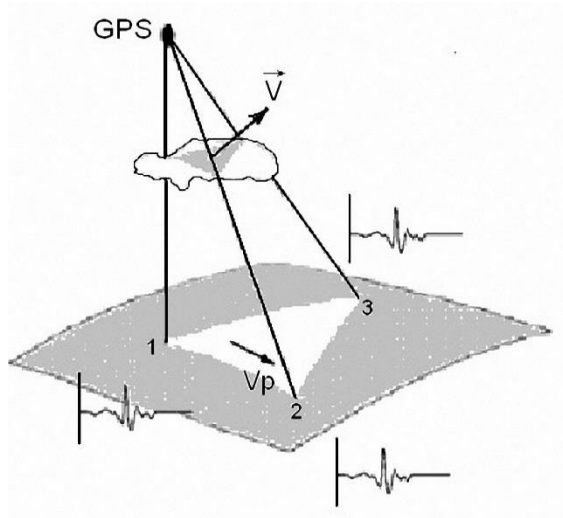


Figure 1. Schematic view of GNSS radio interferometric experiment.

2. Measuring and data processing technique

For detection of the ionospheric inhomogeneity in the GNSS satellite interferometric experiment we register changes of phases of the two navigational signals [7] with the frequencies L1 and L2 with several two-frequency professional GNSS receivers in at least three points (1, 2 and 3, see the Figure 1). Synchronous records of the signals at the observation points are then processed with correlation analysis technique. Similar phase variations in the different records are detected and interpreted as impact of the ionospheric disturbance, traversing the signal trajectory from the satellite to each receiver. Time difference between the appearances of these events at different observing stations is used to estimate the projection of the travel velocity of the disturbances on the ground. Using many GNSS satellites and receivers, one can retrieve all the three components of the travel velocity of the ionospheric object. Any of high orbital GNSS satellites can be used in the experiment, such as GPS, GLONASS and others.

The method of detection of ionospheric disturbances applied in this study is based on the utilization of combination of two registered phases L1 and L2 of the signals of the Global Navigational Satellite System (GNSS) beacons and further signal filtration for the detection of waves with typical periods longer than 5 minutes [7-10] (1)

$$I = \frac{1}{40.308} \frac{f_1^2 f_2^2}{f_1^2 - f_2^2} [(L_1 \lambda_1 - L_2 \lambda_2) + K + \delta L], \quad (1)$$

where f_1 , f_2 are operating frequencies of the Global Positioning System (GPS), respectively 1575.42 and 1227.6 MHz; L_1 , L_2 are the signal phases at these frequencies; λ_1 , λ_2 are the wavelengths, m. K is a constant due to phase definition ambiguity, δL is an instrumental error of phase path difference measurement. The time derivative of the Total Electron Content (TEC) $dI \cdot dt^{-1}$ is a key informative parameter of the method. This allows us to detect quasi-periodical signals without elimination of the phase definition ambiguity.

For detection of the wave structures, the whole receiver network on the ground is structured into cells of three receiving stations each, at which the minimal data set sufficient for the processing is measured. For the analysis, series of measured TEC values (1), derived from phase measurements at each station in the cell are used together with corresponding zenith and azimuth angles known from sp3-files of navigational data. We can determine full vector of the wave structure motion V or its

projection onto the Earth surface V_p , as it is shown in the figure 1. Assessment of the accuracy of the GPS interferometry technique [8] and its modification [9-12], applied here, yields for the azimuth angle accuracy not worse ± 15 degrees, i.e. the 30 degrees sector in the worst geophysical situation. Important property of the method is its selectivity. This means that only those traveling ionospheric disturbances (TID) are detected which move in the directions not coincident with the observation direction.

In the present work, TID parameters were retrieved from three point registration of GPS signals registered on nine stations of GPS receiving network in the Moscow region. The network included three IGS stations [13] and six stations of navigational and geodetic support system of Moscow region [14] (figure 2). Analysis shows that for the satisfactory results not less than 6-8 measuring cells of three stations each should be used in the given network configuration.

Maximal amplitude of electron concentration variations are observed at the height of maximal electron concentration of the F2 ionospheric layer [8-10], which is assumed to be constant and equal to 250 km during the whole period under investigation [8, 10]. The projection of crossing point of the TID moving direction and level of maximal ionospheric concentration is called the sub-ionospheric point [8-10]. This technique allows determination if the TID position in the geographic coordinate system with the accuracy 0.5 degree or better [8-10].

Ionospheric disturbances revealed with correlation technique are then verified by the cluster analysis [11]. In the work we separated the clusters of the structures, i.e. TID with similar characteristic, observed not less that in three cells simultaneously. In fact, cluster analysis enables effective filtering of the TID not only in the space of their positions in the ground projections, but also in the space of velocities and directions.

As indicators of the ionospheric perturbed state due to solar-terrestrial connections in this study, we considered geomagnetic indices and indices of the solar activity [15]. During the whole observational period, the indices Kp and Dst characterize the ionospheric situation as moderately perturbed and account for it in the interpretation of the obtained data.

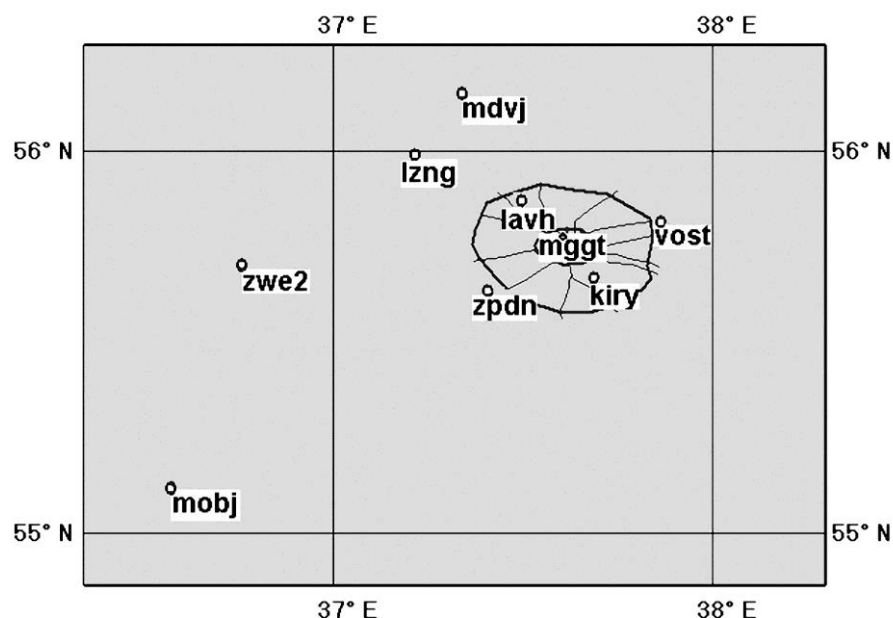


Figure 2. Location of the GPS receiver network in the Moscow region, used in our work. Stations code names are presented.

3. Main results

In this work, we present the results of the continuous radio-interferometric analysis of GPS signals registered during the summer period of 2010 year (97 days) on the Moscow regional GPS receiving network. We show that revealed TIDs group around Moscow and form the ring-shaped pattern (figure 3a). We consider empirical functions of the TID parameters (motion velocity and observed periods). We show that observed distributions of TID are formed by acoustical-gravitational waves and can be connected with a specific thermal regime in the Moscow region during the summer of 2010, in particular the urban heat island (UHI) caused by blocking anticyclone [16-18].

In the present study, we attempted to resolve internal structure of the TID spatial pattern, to retrieve the signatures of the corresponding structure of the heat source. In the Central Economic Region of Russia, the second largest industrial cluster except Moscow city is Tula, the administrative center of the Tula region separated from Moscow by a 200 km distance. Energy consumption of the Tula industrial cluster is roughly 10 times less than Moscow energy consumption. Thus, we expect proportionally less efficiency of the TID generation by Tula city. Both cities are located within the ring of TID, revealed in the Central Economic Region of Russia with our methods. Analysis of the internal structure is not an easy task, because of the limited accuracy of the direction of the TID motion determination.

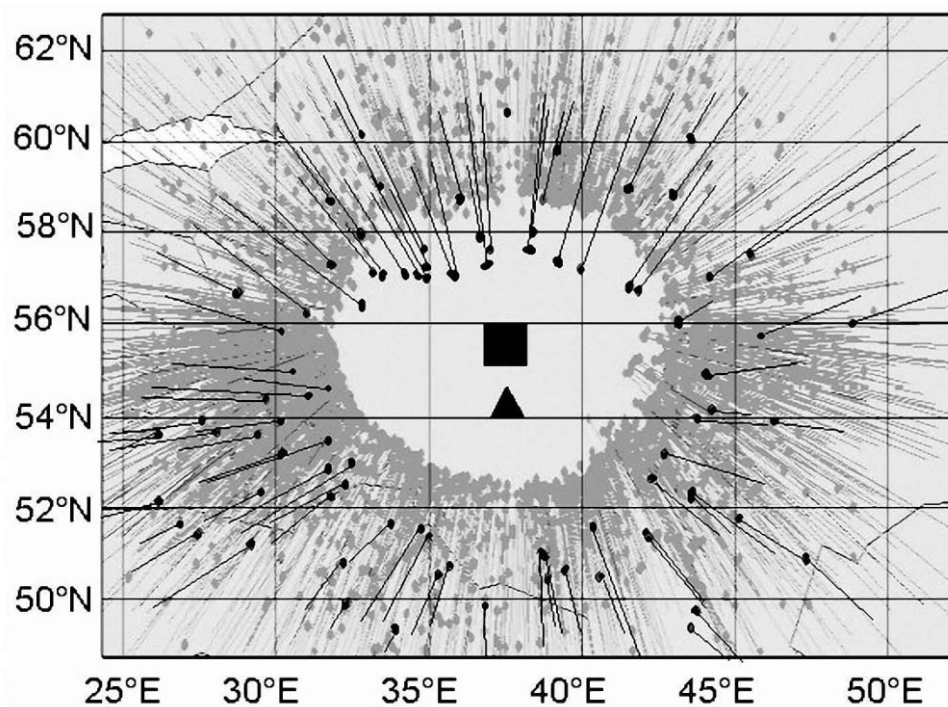


Figure 3. The ring of the travelling ionospheric disturbances (TID) detected in the Moscow region in conditions of summer 2010 [17, 18]. Some of detected waves attributed to the city of Tula as a possible source are marked with darker color. Points denote sub-ionospheric point, vector – direction and proportional value of TIDs speed. Square denotes Moscow center, triangle – the city of Tula.

However, large amount of statistical data collected in the 2010 summer (4000 events, figures 3 a-b) allowed us to filter the raw data with better precision. We searched for the TID which could be related to the acoustical-gravity waves coming from the source in the known location at 45°12' N; 37°37' E (Tula city). After that, we selected the most reliable data with minimal errors that allow to locate the source with the accuracy better than the distance between Moscow and Tula cities.

The results of such precise analysis for 2010 summer period are shown in the figure 3b. The square and the triangle are the marks of Moscow and Tula city centers, respectively. Red vectors denote TID whose source is probably Tula. TID periods and velocities are now indicated in the figure 3b. Points in the figures 3 a-b are the sub-ionospheric points projected on the ground. Our analysis unambiguously shows inhomogeneous structure of the TID ring around Moscow and reveals contributions of neighbouring sources. For Tula, we estimate its TID generation efficiency and contribution to the total TID field at 5-6% level of the whole background. Note that it is a bit less than our expectations based on energetic budget estimate, which predict corresponding efficiency at 10% level.

The TIS identified by us as generated by Tula group in the ring structure, too. Despite not the best configuration of the Moscow GPS network in 2010, it was still capable to provide the statistical data sufficient for localization of different TID sources and assessment of their contributions.

Our analysis shows that local anthropogenically driven atmospheric processes have complicated structure and should not be regarded as a result of action of a single source. Therefore, obtained results are very promising because give us a hope for well-planned and developed experiment for localization and identification of separate TID sources with GPS interferometry methods.

4. Conclusions and remarks

Complicated structure of the TID ring-shaped pattern is established and determined from thorough data analysis. Contributions of regional industrial centers surrounding Moscow were selected and estimated with regard to the common TID field formed mostly by the Moscow city itself. Estimated efficiency of TID generation by local sources is in good agreement with theoretical expectations derived from energy budget considerations.

Obtained results indicate close interaction between atmospheric and ionospheric disturbances in the Moscow region and surrounding regions, which can be related to mesoscale processes of air mass transport in the atmosphere.

5. Acknowledgements

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