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A Nowcasting System for Lightning/Thunderstorms in the Upper Volga Region of Russia

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Abstract — **Deployment of nowcasting systems gathering both meteorological and atmospheric electricity data may be considered now not only as a means of improving forecast quality, but also the basis for the development and verification of the electrical modules of weather-forecast and climate models. During 2013–2015, a regional system for nowcasting hazardous fast-developing meteorological phenomena has been developed and deployed in Nizhny Novgorod region of Russia. It uses a multi-station regional system for lightning detection, a network for measuring the quasi-static electric field, as well as the infrastructure and algorithms for collecting and processing meteorological and radar data. The functioning of the system is made possible by one-day forecast on the basis of the WRF model. In the computations, two grids are used, the outer 3-km grid covering the European Russia and the inner 1-km grid covering the Nizhny Novgorod region; these grids provide sufficient resolution to describe the convection. Three stations for the thunderstorm detection, equipped with Boltek Stormtracker devices, have been deployed. A number of the most intense thunderstorms which occurred during the convective season of 2015 have been analyzed. Accuracy of nowcasting results is estimated.**

Keywords—lightning location; WRF model; thunderstorms; atmospheric electricity.

I. INTRODUCTION

The development of nowcasting (prediction for less than 6 hours) systems on the basis of the systems of mesoscale numerical weather forecast with a short refresh cycle and the assimilation of regional observations data (radar, automated meteorological stations, sodar, satellites etc.) is one of the most important problems of modern hydrometeorology. A particular effect from the introduction of such systems is being connected with the improvement of the reliability of the short-term forecasting of precipitation and wind gusts, forecasting of weather conditions at airports, released storm warnings. A promising way to construct a nowcasting system is to combine assimilation of meteorological data obtained from a regional network of automated meteorological stations, and thunderstorm detection data including the data of lightning location systems [Kohen et al., 2011; Liu and Heckman, 2010].

II. INSTRUMENTATION

During 2013–2015, the regional system for nowcasting hazardous fast-developing meteorological phenomena has been developed and deployed in Nizhny Novgorod region of Russia. It includes a multi-station regional lightning detection system [Kuterin et al., 2014], a quasi-static electric field measuring network, and collected meteorological and radar data.

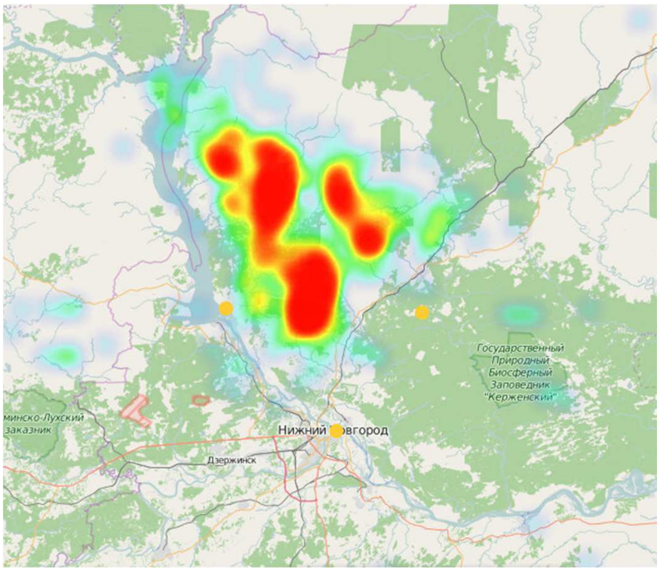

Fig. 1. Lightning location system data for a thunderstorm on June 25, 2016 from 8.20 to 8.30 UTC. Nizhny Novgorod is in the center. Three yellow dots represent observation points The scale of the map is 150x150 km.

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Three stations for the thunderstorm detection, equipped with Boltek Stormtracker devices, have been deployed. The observation points are identified in Figure 1. The distance between the points is from 50 to 60 km. The frequency range of the receiving antennas is rather wide – from 10 to 100 kHz. The infrastructure for collecting and processing data has been built and adjusted. The algorithms and necessary software have been developed for the thunderstorm detection stations and for the central processor of the system.

For the determination of the lightning discharge point the combine method is used which is based on the superposition of time-of-arrival and magnetic direction finding techniques. Using the measured azimuths and arrival times for each discharge, the most probable lightning flash locations are determined by minimizing an error function:

$$\mathrm{E}(P_t) = \sum_{\substack{i,j=1\ldots N\\ i\neq j}} \left[\left(T_i - T_j\right) - \frac{\rho\left(P_t, P_i\right) - \rho\left(P_t, P_j\right)}{c} \right]^2 +$$

$$+\xi \sum_{i=1\ldots N} \gamma_i \left(\varphi\left(P_i, P_t\right) - \varphi_i\right)^2 ,$$

$$\mathrm{tg}(\varphi_B) = \frac{2\sum B_i^N B_i^W}{\sum \left(B_i^W\right)^2 - \sum \left(B_i^N\right)^2} ,$$

where N is the number of records in a single spatio-temporal cluster, φ_i is the discharge azimuth for i th record, $\varphi(P_i, P_t)$ is the azimuth of the point P_t from the point P_i, $\gamma_i \in [0,1]$ is the coefficient of determination accuracy of the azimuth φ_i, ξ is the relative confidence coefficient of the magnetic finding method as compared to the time-of-arrival method.

An operation of the system is provided with the use of the high-resolution mesoscale model WRF [Dementyeva et al., 2015a; Dementyeva et al., 2015b; Dementyeva et al., 2014a; Dementyeva et al., 2014b]. The system is based on the one-day forecast of the WRF model. In the computations two grids are used, the outer 3-km grid covering the European Russia and the inner 1-km grid covering the Nizhny Novgorod region; these grids provide sufficient resolution to describe the convection. As initial and boundary conditions, the atmospheric state data based on the predictions of the global model GFS 0.5° are currently employed, and starting from 2016, data obtained from GFS 0.25° will be used.

The processing of the received data implies the use of efficient algorithms on high-performance computers for predicting the course and intensity of thunderstorm cells and fronts. The data are transferred via Internet to the server at IAP RAS. The operation of the system is supported by the operational forecasting with the help of the mesoscale non-hydrostatic numerical model Weather Research and Forecasting (WRF). The computations are performed using nested grids (a 25 km grid step for European Russia, a 5 km grid step for a region of 500 km by 500 km and a 1 km grid step for Nizhny Novgorod region).

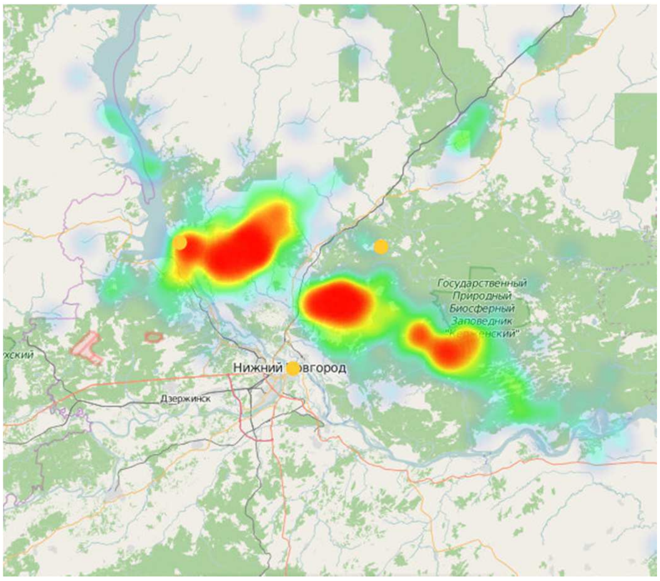

Fig. 2. Lightning location system data for a thunderstorm on July 5, 2016 from 8.20 to 8.30 UTC. Nizhny Novgorod is in the center. Three yellow dots represent observation points The scale of the map is 150x150 km.

III. ANALYSES AND RESULTS

A number of the most intense thunderstorms which occurred during the convective season of 2015 have been analyzed. Two examples of lightning location system data during intensive thunderstorms are presented in Figures 1 and 2. For the second case of a thunderstorm occurred on July 5, the radar echo is also presented. It is seen that the thunderstorm consists of several sells. The lightning location data help to monitor the motion of the most active zones of a thunderstorm.

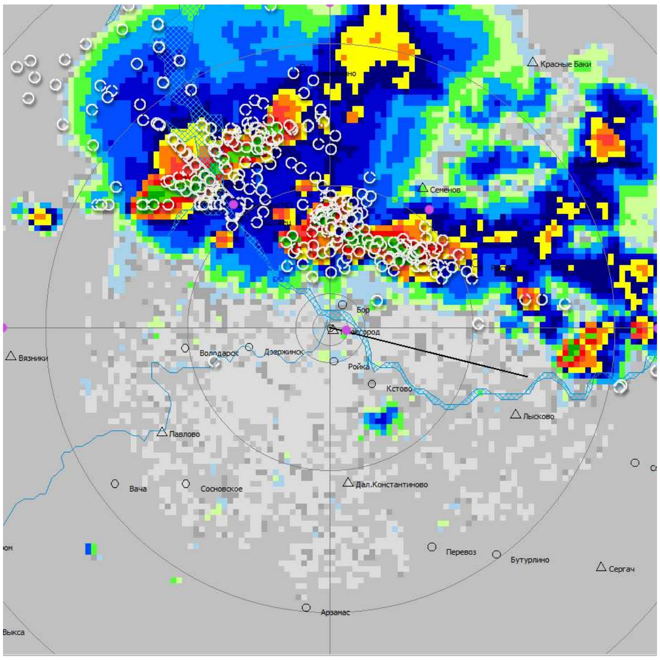

Fig. 3. Radar echo for an intensive thunderstorm on July 5, 2016. Nizhny Novgorod is in the center. The scale of the map is 210x210 km.

Fig. 4. Electric field sensors in Nizhny Novgorod: 1 – fluxmeter ostrten IAPRAS roof; 2 – fluxmeter on IPMRAS roof; 3 – f luxmeter on UNN roof; 4 – Aerology station “Nizhny Novgorod”;5 – Meteorological radar.

Analysis of electric field measurements in Nizhny Novgorod give us an additional information on the behavior of electrically active clouds and thunderstorms. The location of electric field sensors is shown in Figure 4. The fluxmeters register the electric field in the frequency band 0 ÷ 10 Hz and have sensitivity ±50 kV/m. An example of simultaneous registration of electric field perturbations during the most intensive thunderstorm of a season 2015 in Nizhny Novgorod region, which occurred on June, 01-02, is presented in Figure 5. According to fluxmeters data, the thunderstorm started at about 23:00 local time (20:00 UTC) and lasted almost 8 hours. The averaged records of a quasistatic field allowed us to get in particular an information on the velocity of the main charges moving in a thunderstorm cloud. For example, at the beginning of a thunderstorm event of 1-2 June the velocity was equal about 15 m/s.

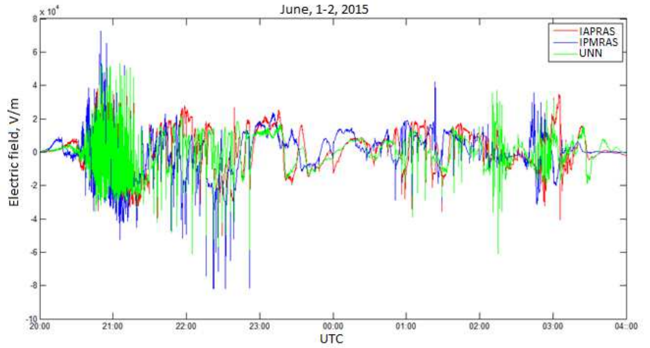

Fig. 5. Electric field fluctuations during most severe thunderstorm in a season 2015 in Nizhny Novgorod region, June, 01-02. Data were registered by 3 fluxmeters simultaneously.

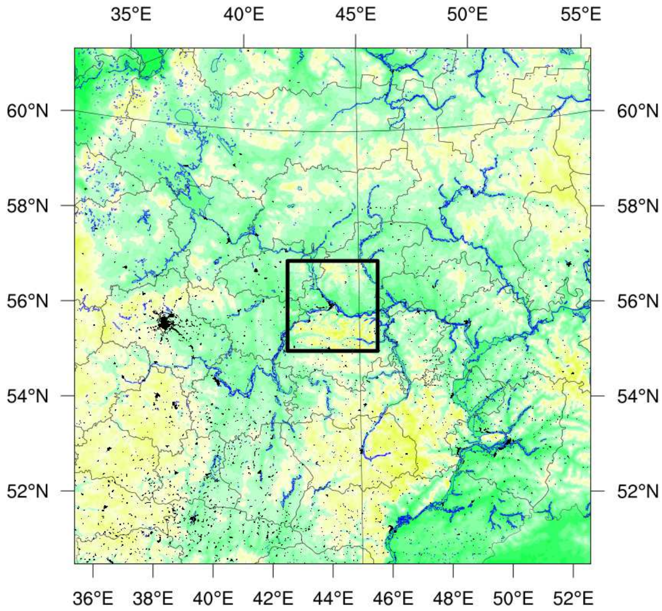

Fig. 6. A set of embedded grids of the forecast. The external grid has a step of 3 km, the internal one has a step of 1 km.

The processing of the experimental data obtained with electrostatic fluxmeters makes it possible to study spectral characteristics of perturbations of the electric fields of clouds and to analyse the statistical characteristics of convective clouds and mesoscale systems in mid-latitudes (see, e.g., [Klimenko et al., 2013]).

As was noted above, an operation of the nowcasting system is provided with the use of the high-resolution mesoscale model WRF. We have chosen the strategy of two embedded grids: the external grid covered the European part of Russia (the area of 1200 * 1200 km size with a step of 3 km), and the internal one of 210 * 210 km size with a step of 1 km (see Figures 6-8).

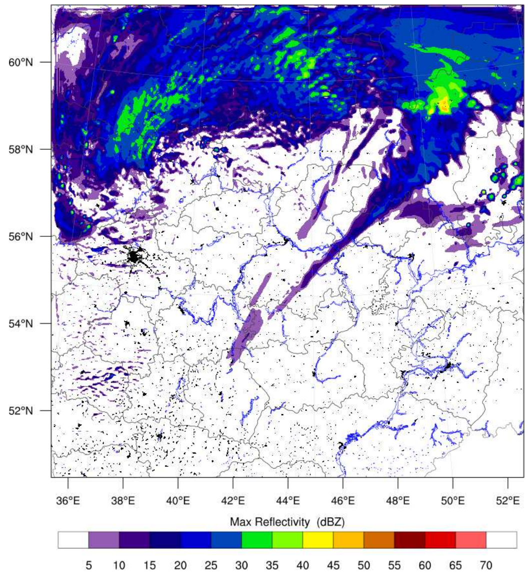

Fig. 7. Maximim radar echo for the external grid (case study).

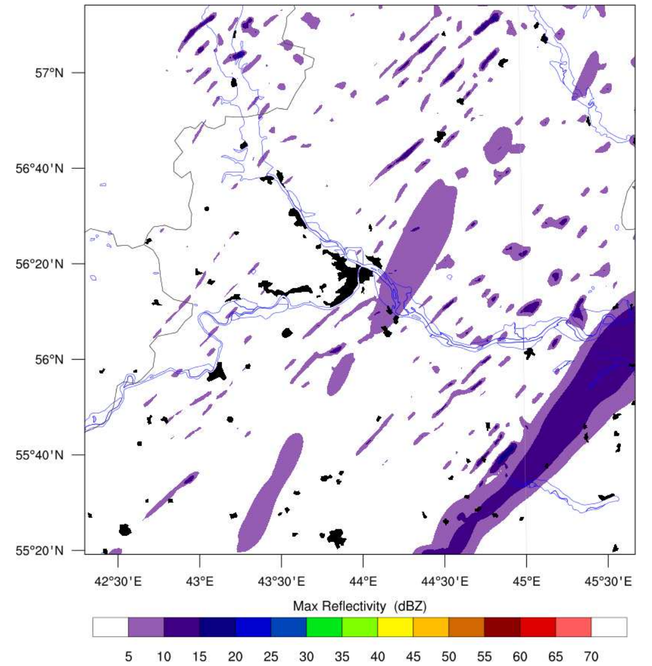

Fig.8. Maximim radar echo for the internal grid (case study).

The module of electric parameters calculations have been proposed earlier [Dementyeva et al., 2015a; Dementyeva et al., 2015b]. It was suggested that the non-inductive mechanism of charge generation and separation plays a key role in thundercloud electrification processes. Also the charge densities of solid-phase hydrometeors are assumed to be proportional to their mass in elementary air volume. According to the models by Saunders and Takahashi, particles change the sign of charge while getting into the lower part of thundercloud from the upper and vice versa. Electrical neutrality in the vertical air column was supposed in the course of vertical charge separation due to collisions between falling graupels and carried upward ice crystals. Electric potential and electric field can be found as a solution of a 3D Poisson equation. We have made an automatic modelling for several thunderstorms in Nizhny Novgorod region. The results of calculations were compared with data of observations and radar data. This comparative analysis shows quite a good spatial and temporal correlation between predicted and observed parameters of the thunderstorms (Figure 9).

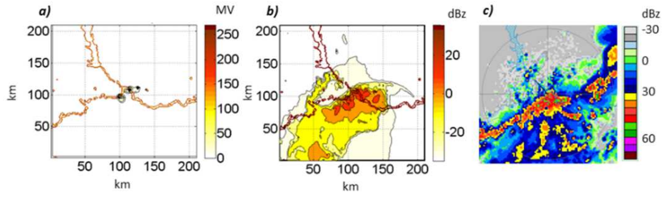

Fig. 9. (a) Calculated maximum in the vertical column voltage, (b) calculated integral radar echo and (c) measured radar echo of clouds at the time of the beginning of an intensive thunderstorm 01.06.2015, 20:10 UTC. The scale of the map is 210x210 km.

It is expected that in the near future the deployed nowcasting system will be the basis for the development and verification of the electrical modules of weather-forecast and climate models.

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