Experiments on lightning data assimilation: preliminary results

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Abstract. This article is devoted to the analysis of the first results of the impact of lightning data assimilation on the numerical weather forecast. The article includes a description of the used algorithm and the results of the conducted numerical experiments for the convective storms over Krasnodar region of Russia observed in 2017. Numerical weather prediction model WRF-ARW (Weather Research and Forecast) and lighting data gathered from WWLLN (Worldwide Lightning Location Network) are used [1. 2]. It was found that the average absolute errors of the temperature, atmospheric pressure, humidity, precipitation and wind are reduced. It is shown that the configuration of prognostic precipitation fields and their intensity is much closer to the observations. This is especially clearly seen for shallow precipitation (0-7 mm).

Introduction
Threat rapidly evolving atmospheric phenomena, such as convective processes damage many economic branches, forestry and agriculture. They are of utmost danger for the human life, aviation, electric mains, energy substations, oil storages, launchers, etc. Dangerous natural phenomena (thunderstorms, hail, showers) damage spheres of life which is valued for more than 750 milliard rubles every year. In the Russian Federation only direct losses of agricultural products amount about 9 milliard rubles. The more dangerous natural phenomena greatly damaging branches of economy are thunderstorm and hail processes.

Long-lasting rains, showers and hail often lead to strong inundations, mud flows, mudslides and other exogenous processes, destruction of many farmlands by hail, lightning striking of electric mains, planes, energy systems, initiation of fire in forests, highly inflammable materials. Thus the problem of risk decrease of natural disasters is very important.

However now reliable automated numerical technologies for prediction of deep convection and the phenomena accompanying it (showers, hail, wind gusts and others) do not exist. This is partly due to the fact that the physical processes in the atmosphere that make a significant contribution to the formation and development of convective clouds are not fully studied.
In recent years the number of special lightning detection networks has increased worldwide. They provide information on the coordinate, time, type of discharge and etc. For instance there are WWLLN and regional networks (in Russia – networks of High-mountain Geophysical Institute. Main Geophysical Observatory and others) [2, 3, 4].

For now, in order to improve the quality of convection forecasting, various technologies have been used to assimilate the lightning data in numerical weather prediction models.

This article is devoted to the analysis of the first results of the impact of lightning data assimilation on the numerical weather forecast.

**Methodology**

**Lightning Data Assimilation Technique.** Let us describe the lightning data assimilation technique used in this study. The procedure uses two main hypotheses. The first is that WWLLN captures 100% of thunderstorms in the domain of interest. The second is that at the point where WWLLN did not capture the lightning flash there is no deep convection. If a thunderstorm was observed and predicted, the cell remains unchanged. In other cases, the scheme acts as a trigger enhancing convection at points where lightning was observed and reducing convection in areas where lightning was not observed. The scheme is on for the first 24 hours of the forecast. The characteristics of shallow and deep convection in a cloud used in this procedure is fully described in [5].

**WRF-ARW Configuration.** The WRF-ARW version 3.9.1 [1] is used as a numerical weather prediction model. The forecasts were calculated for the area of Krasnodar Region of Russia (42.5-47 N; 36.5-41.5 E) with a spatial resolution of 18 km. Such spatial resolution requires parameterization of convection. The following parametrization of physical processes was used in the calculations: convection - Kain – Fritsch, Cloud microphysics - NSSL 2 – moment Scheme with CCN Prediction, Radiation - RRTMG Shortwave and Longwave Schemes, Processes in the soil - Unified Noah Land Surface Model, Planetary boundary layer - Bougeault– Lacarrere Scheme (BouLac) [6, 7, 8].

**Result Analysis**

**Analysis of vertical profiles of humidity and temperature.** The process of how the procedure works is demonstrated in this subsection. We analyzed the vertical profiles of humidity and temperature at the points where thunderstorms were observed in seven examples of forecasts and their differences. Comparing them we concluded that in LTNG experiments the humidity in the lower part of the atmosphere has increased. It even exceeded 1.1 g/kg during the 6 to 12 hours of the forecast. The differences in some atmospheric layers reached 0.3 g/kg. Then it began to subside most likely due to precipitation. During the intensive convection the temperature of the lower troposphere also noticeably changed. The isotherm of 20 °C as the base of Cb. arose instead of the isotherm of 10 °C. The isotherm of -20 °C as the upper boundary of the cloud also rose (up to 10 °C). These diagrams explain how data lighting data assimilation works at the points where lightning was observed.

**Analysis of absolute errors.** In order to present the effect of using the data assimilation technique in numerical weather prediction model we demonstrate the absolute errors of seven forecasts. The estimations are calculated for 48 hours over Krasnodar Territory of Russia during the summer 2017 (May 31. 7. 22. 23 June. July 20. August 22. September 23). For these dates, absolute errors of surface air temperature, water vapor, pressure, precipitation and wind speed at 10 m level are calculated according the methodology from [9]. The evaluation results are shown in the Table 1. All evaluations were carried out for BASE forecasts (no lighting assimilation) and LTNG (using lighting assimilation). The data from 20 synoptic stations are used for the for the error estimation. Table 1 presents the estimates of the absolute errors of surface air temperature, humidity, pressure, wind speed at 10 m and precipitation for all seven forecasts. In the table, smaller errors are indicated. It can be seen that the mean absolute errors for all meteorological characteristics in LTNG experiments are reduced. The absolute error of precipitation values did not decrease only for the forecast on July 20.
2017. For the same date, errors in the prediction of surface pressure also did not decrease. Nevertheless, even in this forecast, errors in the prediction of surface temperature, the ratio of water vapor and wind speed decreased. We did not give other statistical estimates due to the limited space in the article. but we can say that all the statistical estimations in LTNG experiments are significantly decreased, especially on the first day of the forecast. We analyzed, but also because of the limited space in the publication, we do not give the time changes of absolute errors of temperature. Humidity and pressure at the points where thunderstorms were observed. In LTNG experiments all predicted variables are closer to the observational data within 48 hours forecasts.

**Table 1.** Absolute errors of forecasts of surface temperature (°C). water vapor (g/kg). pressure (hPa). precipitation (mm) and wind speed (m/h) at 10 m level

| Advance time, h | May. 31 2017 | June. 7 2017 | June. 22 2017 | June. 23 2017 | July. 20 2017 | August. 22 2017 | September 23 2017 |
|-----------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                 | base | lting | base | lting | base | lting | base | lting | base | lting | base | lting | base | lting | base | lting |
| **Surface temperature, °C** |       |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 0               | 0.4  | 0.2  | 0.5  | 0.7 | 0.6  | 0.4  | 0.2  | 0.2 | 0.3  | 0.6 | 0.3  | 0.2  | 0.7 | 0.5 |
| 3               | 0.6  | 0.5  | 1.3  | 0.9 | 0.6  | 0.1  | 0.7  | 0.7 | 0.2  | 0.3 | 0.2  | 0.2  | 0.1 | 0.3 |
| 6               | 0.5  | 0.1  | 2.6  | 1.5 | 0.2  | 0.4  | 0.3  | 0.2 | 0.3  | 0.0 | 0.1  | 0.2  | 0.0 | 0.1 |
| 12              | 2.1  | 1.2  | 0.7  | 0.7 | 0.2  | 0.2  | 0.4  | 0.1 | 0.6  | 0.2 | 0.7  | 0.2  | 0.2 |
| 24              | 0.5  | 0.5  | 0.9  | 1.0 | 0.2  | 0.6  | 0.5  | 0.5 | 0.9  | 0.2 | 0.2  | 0.2  | 1.3 | 0.7 |
| 48              | 0.2  | 0.3  | 0.6  | 0.9 | 0.6  | 0.4  | 1.2  | 0.2 | 1.3  | 0.8 | 0.2  | 0.3  | 1.3 | 0.6 |
| **Surface water vapor, g/kg** |       |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 0               | 0.5  | 0.3  | 0.5  | 0.4 | 0.5  | 0.6 | 0.6  | 0.5 | 0.4  | 0.2 | 0.2  | 0.3  | 0.3 | 0.1 |
| 3               | 0.6  | 0.5  | 0.7  | 0.3 | 0.5  | 0.3  | 0.6  | 0.4 | 0.3  | 0.2 | 0.2  | 0.3  | 0.3 | 0.2 |
| 6               | 0.5  | 0.4  | 0.4  | 0.2 | 0.4  | 0.3  | 0.5  | 0.7 | 0.4  | 0.3 | 0.4  | 0.3  | 0.5 | 0.4 |
| 12              | 0.5  | 0.7  | 0.6  | 0.6 | 0.5  | 0.5  | 0.4  | 0.7 | 0.5  | 0.3 | 0.5  | 0.3  | 0.4 | 0.3 |
| 24              | 0.6  | 0.5  | 0.6  | 0.4 | 0.6  | 0.3  | 0.5  | 0.2 | 0.7  | 0.3 | 0.5  | 0.4  | 0.5 | 0.3 |
| 48              | 0.7  | 0.7  | 0.6  | 0.5 | 0.7  | 0.5  | 0.4  | 0.3 | 0.4  | 0.4 | 0.4  | 0.4  | 0.6 | 0.5 |
| **Surface Pressure, hPa** |       |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 0               | 0.6  | 0.5  | 0.8  | 0.6 | 0.4  | 0.3  | 0.6  | 0.5 | 0.5  | 0.5 | 0.5  | 0.4  | 0.5 | 0.4 |
| 3               | 0.6  | 0.6  | 0.8  | 0.6 | 0.4  | 0.4  | 0.9  | 0.7 | 0.6  | 0.6 | 0.5  | 0.4  | 0.5 | 0.4 |
| 6               | 0.6  | 0.6  | 0.9  | 0.6 | 0.5  | 0.5  | 1.0  | 0.7 | 0.6  | 0.6 | 0.4  | 0.6 | 0.5 |
| 12              | 0.7  | 0.6  | 0.9  | 0.8 | 0.6  | 0.5  | 1.1  | 0.9 | 0.9  | 0.8 | 0.8  | 0.6 | 0.6 | 0.5 |
| 24              | 0.9  | 0.7  | 1.0  | 0.9 | 0.8  | 0.8  | 1.1  | 0.8 | 0.9  | 1.0 | 0.8  | 0.6 | 0.8 | 0.6 |
| 48              | 1.1  | 1.0  | 1.1  | 1.0 | 0.9  | 0.8  | 1.3  | 1.0 | 1.0  | 0.9 | 0.7  | 1.0 | 0.7 |
| **Wind speed at 10 m, m/h** |       |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 0               | 1.4  | 1.4  | 1.4  | 1.5 | 1.6  | 1.5  | 1.6  | 1.7 | 1.6  | 1.8 | 1.7  | 1.7 | 1.7 |
| 3               | 1.3  | 1.1  | 1.3  | 1.6 | 1.4  | 1.7  | 1.7  | 1.6 | 1.7  | 2.0 | 1.9  | 1.8 | 1.9 |
| 6               | 1.6  | 1.4  | 1.5  | 1.7 | 1.5  | 1.8  | 1.8  | 1.7 | 1.9  | 1.9 | 1.4  | 1.3 |
| 12              | 1.3  | 1.1  | 1.3  | 1.5 | 1.6  | 1.6  | 1.4  | 1.6 | 1.5  | 1.8 | 1.7  | 1.6 | 1.7 |
| 24              | 1.6  | 1.5  | 1.6  | 1.7 | 1.7  | 2.0  | 1.8  | 2.0 | 1.8  | 2.1 | 2.0  | 1.9 | 1.8 |
| 48              | 1.8  | 1.3  | 1.4  | 2.0 | 1.9  | 2.0  | 2.1  | 2.0 | 2.1  | 2.2 | 1.7  | 1.7 |
| **Precipitation, mm** |       |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 12              | 0.7  | 0.6  | 0.6  | 0.3 | 1.3  | 1.2  | 2.0  | 1.7 | 1.4  | 1.0 | 0.6  | 0.8 | 1.0 |
| 24              | 1.8  | 1.1  | 1.8  | 1.2 | 2.0  | 1.3  | 1.3  | 1.4 | 2.0  | 1.6 | 1.2  | 1.1 | 0.8 |
| 48              | 2.1  | 1.6  | 4.0  | 3.5 | 3.7  | 2.9  | 3.4  | 2.4 | 3.8  | 1.8 | 2.0  | 1.7 | 1.3 |
Analysis of precipitation 12 h forecasts.

This section includes the analyzes of the maps of precipitation forecasts obtained over the Krasnodar Territory. The plots (Figure 1) are shown for BASE (left column) and LTNG (right one) experiments. On the maps predicted precipitation are shaded contour isolines are Global Precipitation Climatology Project (GPCP) [10]. Synoptic icons indicate thunderstorms gathered from WWLLN (yellow: 0-8 h, beige: 9-15 h, red: 16-24 h during the day). First of all, in the left column you can see the field configuration of shallow precipitation (0-7mm) are wider than etalon. Data assimilation made the areas of convection more accurate compared to GPCP observations. This trend can be traced in all seven forecasts. In our opinion, these results are the most important.

May 31, 2017

June 7, 2017

June 22, 2017
September 23, 2017

Figure 1. Precipitation Forecasts made for Krasnodar region of Russia. Left – BASE experiment, right – LTNG experiment

Summary

Thus for the first time in Russia the results of experiments on the effect of lightning data assimilation on the convection forecast are presented. Described the procedure used for the data assimilation. Estimations of the absolute errors for temperature humidity wind rains and pressure computed over Krasnodar region for seven convective events in 2017 are presented. According to the preliminary results it was found that lightning assimilation helps to improve the short-term forecast of air temperature pressure relative humidity and rain. It concerns not only its forecast estimations. The lightning assimilation technique makes the cumulus precipitation localization more accurate.

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