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Simulation of Feedbacks between Threated Activity, Atmosphere Composition, and Regional Climate

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Abstract

The numerical model WRF-Chem was adapted and tested for the Black Sea region. WRF-Chem allows you to parameterize the concentration of NOx, and to analyze the contribution of lightning cells to the formation of ozone, the change in temperature fields. Model experiments for neutral stratification have shown that thunderstorm activity ambiguously affects ozone concentration and temperature. At the surface of the earth, the contribution of lightning discharges to the ozone concentration is minimal, and at an altitude of 10–12 km it increases significantly. The calculations demonstrate the importance of thunderstorm nitrogen oxides for the balance of ozone, associated gases, and also for the temperature distribution of the upper troposphere/ lower stratosphere.

Keywords: *atmosphere composition, regional climate, model WRF-Chem, temperature distribution, upper troposphere/ lower stratosphere.*

1. Introduction

Lightning activity creates extensive excitations of the atmospheric fields, causing dissociation and ionization of many atmospheric components (as is known, lightning is one of the main sources of nitrogen oxides in troposphere). In turn, nitrogen oxides can make a significant contribution to the redistribution of chemically and radioactive substances gases that affect temperature fields and, therefore, affect weather and climate change [Flatoy.1997]. Climate variability affects the distribution of thunderstorm clouds, resulting in the redistribution of the frequency of lightning flashes, which make a significant contribution to the concentration of nitrogen oxides [Price and Rin.1997]. Thus, continuous positive and negative relationships between thunderstorm activities are formed. Chemical composition of the atmosphere and changes in weather and climate [Jacob.1999].Both regional and global effects of these complex chains of bonds affect the composition and structure of the atmosphere [Price and Rin.1997]. Figure 1is a diagram of direct and inverse links between thunderstorm activity, atmospheric composition, temperature, and convection. Nitrogen oxides generated by lightning (NOx) effectively influence the acceleration of the formation of tropospheric ozone. This is due to the oxidation of carbon monoxide, methane and other hydrocarbons [Jacob.1999].In the stratosphere, ozone, on the contrary, begins to be destroyed by the action of nitrogen oxides. This ambiguity of the effect of nitrogen oxides on the ozone concentration causes increasing interest at altitudes corresponding to the region between the troposphere and the stratosphere (the so-called UTLS region-Upper troposphere/ lower stratosphere, which means "upper troposphere / lower stratosphere".) Numerical models of weather and climate prediction play a special role in predicting the number of lightning flashes, their coordinates, and the distribution over the atmosphere column and in space [Price and Rin.1997]. This article deals with numerical experiments performed using the WRF-Chem model (this makes it possible to evaluate the influence of the rate of formation of lightning flashes based on the (Price and Rind 1997), parameterization [Allen, 2002] modified by (Zhao and

Wang .2009), [Schumann, 2007] [Smyshlyaev, 1999]. The main task of this work is to study the sensitivity of atmospheric chemistry and temperature fields to disturbances associated with changes in the content of nitrogen oxides under the action of lightning discharges.

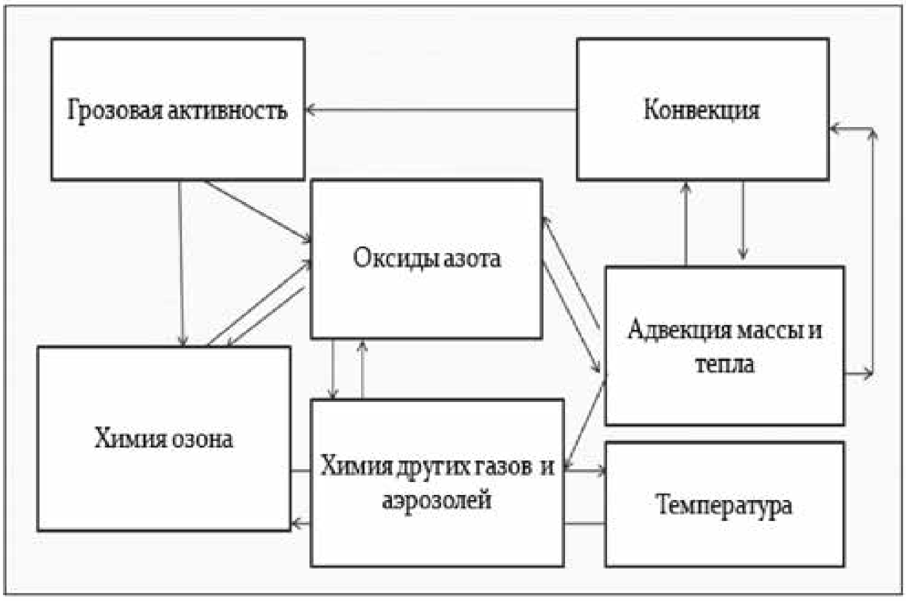


Figure 1. Direct and inverse relationships between thunderstorm activity, ozone, and temperature

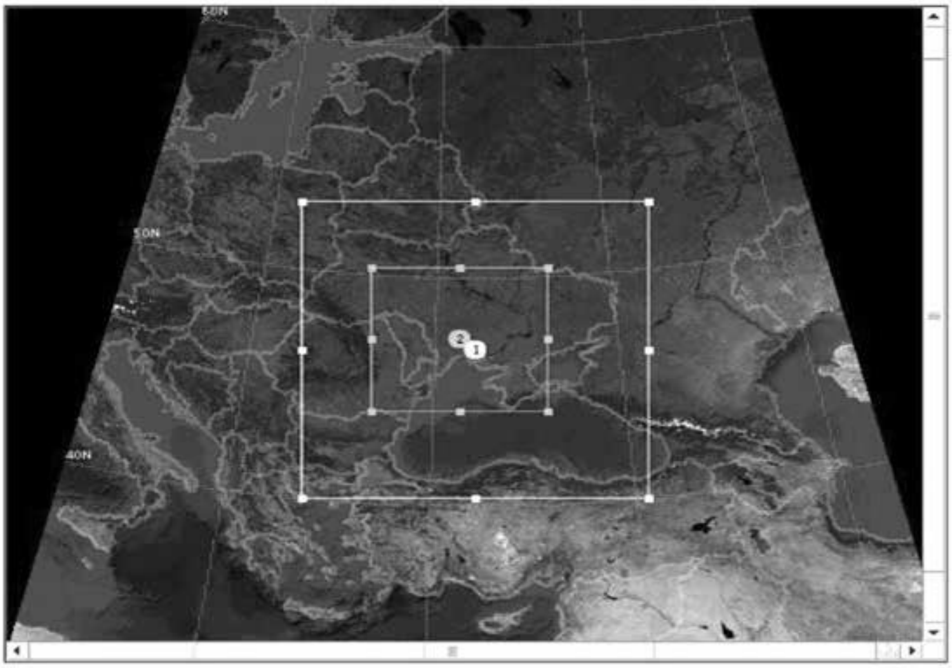
The purpose of this study is to adapt the regional WRF-Chem model for the selected region, to determine the relative contribution of LNOx to the total NOx concentration, to assess the feedback between lightning activity, ozone production (and other active gases), temperature and convection.

2- Model Study Methodology

The present study consists of analyzing both the meteorological and chemical fields of the atmosphere. Given that lightning flashes relate to the subgrid-scale phenomena, it is necessary to use regional models that are sensitive to small-scale processes. Taking these considerations into account, eight numerical experiments were conducted using the regional model The Weather Research and Forecasting model (WRF-Chem) version 3.5 to study the sensitivity of the atmospheric content of gas impurities to the thunderstorm production of nitrogen oxides. [Yoshida. 2009] In each model experiment, meteorological quantities and chemical gaseous components were calculated for two cases: taking into account thunderstorm activity and, accordingly, excluding thunderstorm flashes. The calculations were carried out up to a drop of 10 hPa, but special attention was paid to the analysis of the high-altitude region UTLS. The experiments were carried out for the summer period of 2013. To calculate the lightning production of nitrogen oxides at each node of the grid, the (Price and Rind.1997) parameterization (PR92, PR94) was used for neutral stratification (Barthe, 2008)

3- Description of the model used

The numerical model WRF-Chem was adapted for central Europe and the North-West of the Russian Federation, as shown in Fig. 3. The used version of the WRF-Chem model covers the altitude range from the earth's surface to a level of 10 hPa. The space step is fixed (dx = dy = 15 km, 5 km). The vertical step is variable: at the surface ≈ 60 m, from 1–3 km it ranges from 200–400 m, and for 5–13 km it is estimated to be 500– 600 m. The model resolution is 180 × 180. The meteorological boundary conditions are based on the NCEP GFS FNL reanalysis data, with a space step of 0.5 ° × 0.5 ° (≈ 55.5 km).



4- Model calculations results

Numerical experiments were carried out for the period from June 1 to August 30 (57 days with thunderstorms were selected). For each experiment, the model was run twice (without taking into account the LNOx parameterization and taking into account this parameterization). Figures 3–6 demonstrate some of the results obtained, which demonstrate the importance of nitrogen oxides of the horizon and their significant influence on the regional climate and atmospheric composition.

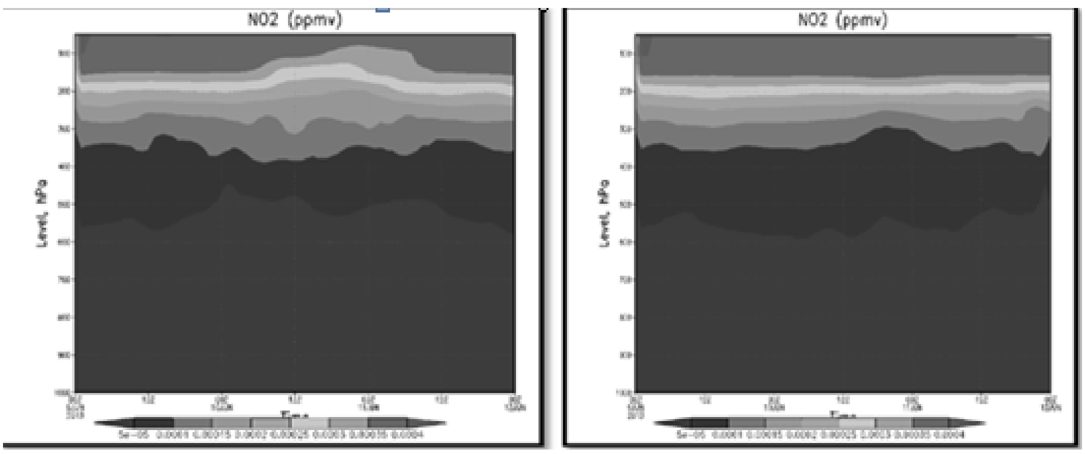


Figure 3. High-altitude daily distribution of NO2 (ppmv) 06/09/2013-Mar 12, 2013 Continental zone (left) 420 NN 240v.d, coastal zone (right): 420. n, 400v.d

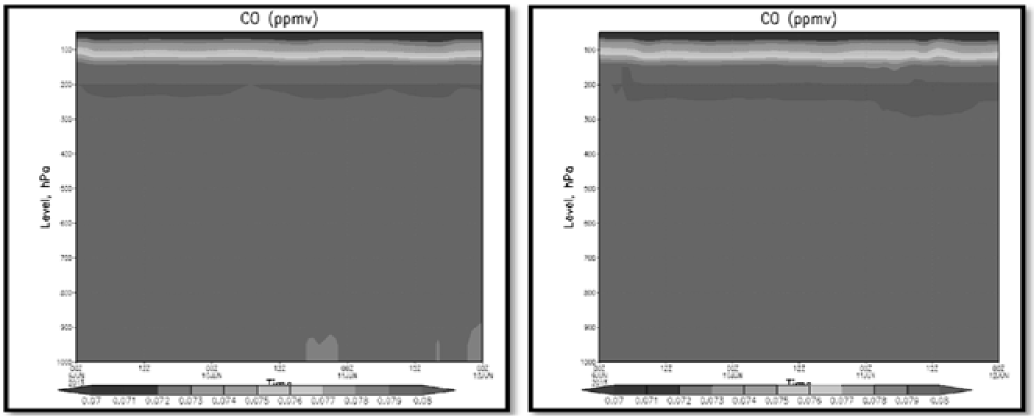


Figure 4. the altitudinal daily distribution of the CO (ppmv) 06/09/2013–12.03.2013 continental zone (left) 420 NN 240v.d, coastal zone (right) 420. n., 400v.d.

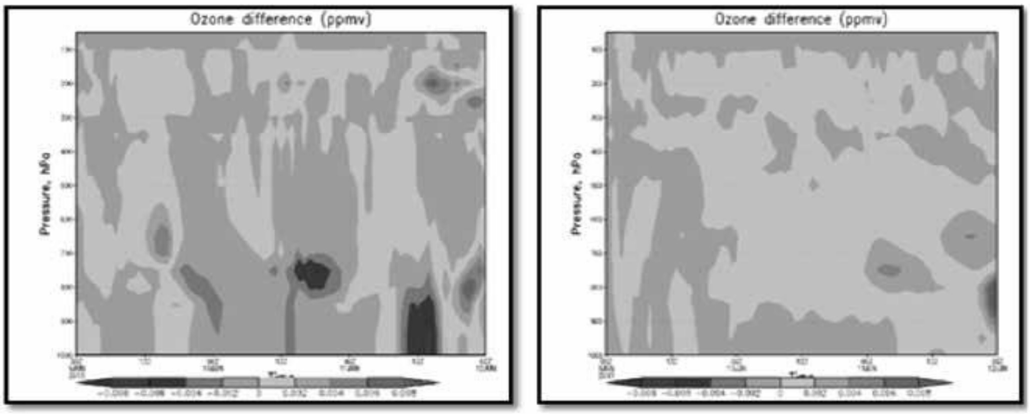


Figure 5. WRF-Chem O3 vertical distribution of concentration difference with / without lightning source LNOx (ppmv) 09-12.06.2013 continental zone (left) 420 n. 240v.d, coastal zone (right): 420. n., 400v.d.

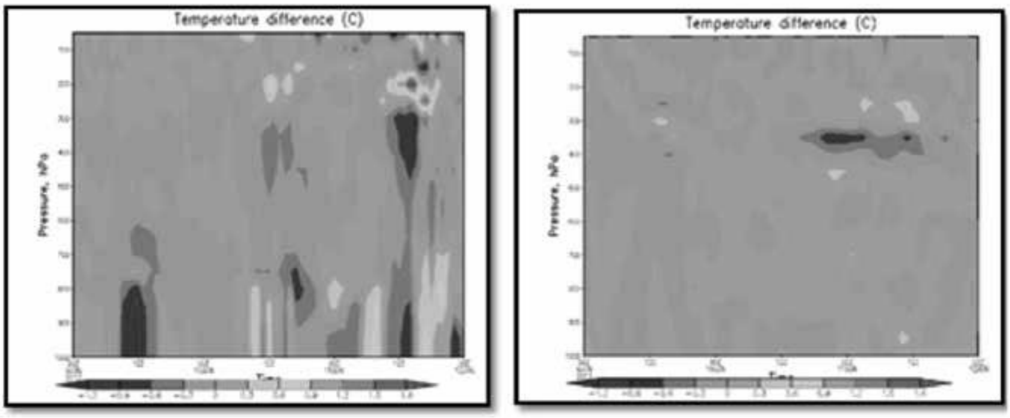


Figure 6. WRF-Chem vertical distribution of the temperature difference with / without lightning source LNOx (ppmv) 09-12.06.2013 continental zone (left) 420 N lat. 240v.d, coastal zone (right): 420. n., 400v.d.

Conclusions

In the present work, we calculated the sensitivity of the WRF-Chem model to thunderstorm activity. It was found that within the mesoscale model, the best choice of the duration of the experiment is 72 hours. The concentrations of atmospheric gases, the temperature of the upper troposphere and the lower stratosphere were analyzed with the inclusion in the model of the parameterization of nitrogen oxides generated by lightning flashes. The estimates have shown that, as a result of the variability of thunderstorm production of nitrogen oxides, their concentration in the upper troposphere and lower stratosphere can vary over a wide range. This, in turn, creates the potential for variability in the gas composition of the atmosphere. The calculation of ozone concentration also reflects high sensitivity to changes in the total NO concentration at different altitudes of the atmosphere. It is important that when the additional emissions of NO generated by lightning are included in the model, a positive trend in ozone is observed. Changes in temperature fields at a level of 10–12 km with an additional source of LNOx emphasize the presence of feedback between the concentration of nitrogen oxides and convection. A noticeable increase in temperature at the level of 200-150 hPa is explained by the removal of thunder flashes from the surface of the earth. The calculations performed to demonstrate the relevance of thunderstorm nitrogen oxides for the balance of such gases as ozone and hydroxyl radicals. In this regard, the use of theoretical parameterizations is a reasonable and important method for determining the rate of formation of nitrogen oxides, their concentrations and the effect on changes in weather and climate.

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