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Evolution and structure of ozone mini-holes: a mesoscale integrated modeling case study

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Variability of stratospheric ozone distribution on different spatial and temporal scales is attributed to several factors of chemical and dynamical origin. In particular, prevalence of chemistry or dynamics in evolution of ozone anomalies is universally recognized to be stipulated by their size.

Local ozone anomalies, i.e. positive or negative (mini-holes) synoptic-scale deviations in total ozone column (TOC), have been the subject of theoretical and observational studies over the last decades. Having characteristic lifetime of about a few weeks, they are regarded as purely dynamical formations.

Numerical modeling of formation, evolution and decay of local ozone anomalies is of significant interest both from fundamental and practical point of view. Local anomalies constitute an important short-term component of stratospheric ozone variations, and their dynamical formation is a manifestation of stratosphere-troposphere interactions. In the past two decades modeling studies of local ozone anomalies involved various approaches, from idealized simulations of atmospheric dynamics with ozone as a passive tracer to global chemistry-climate models. Still, there is a lack of fine-scale modeling studies of dynamical processes related to formation and evolution of ozone anomalies.

In the present study, local ozone anomalies are investigated by means of a mesoscale online-coupled meteorology-chemistry modeling system, based on a modified version of the Weather Research and Forecasting Model with Chemistry (WRF-Chem).

WRF-Chem represents state-of-the-art in integrated meteorological and atmospheric chemical transport models. It is intended for use in such applications as air quality research and simulates chemical transport and photochemical reactions typical for troposphere. For the present study, the WRF-Chem system has been adapted to simulate stratospheric dynamics and transport of ozone as an active tracer. Parameterization of radiative transfer has been modified to allow for dynamical variations in distribution of stratospheric ozone, thereby simulating two-way interaction between radiation transfer and ozone transport. Model is integrated with upper limit of 1 mb.

Modeling results are presented for several cases of formation, evolution and decay of both negative and positive anomalies over the territory of Europe. Of particular interest is the case of negative anomaly over Central and Eastern Europe in December 1997 – January 1998. This ozone mini-hole is characterized by a minimum TOC value of 160 Dobson units, which is comparable to values in Antarctic ozone hole. It is the deepest anomaly for the whole period of instrumental observation in Belarus. Results for more recent anomalies with different trajectories of motion are also presented. As a primary data source for initial and boundary conditions, the ERA-Interim reanalysis from the European Center for Medium-Range Weather Forecasting (ECMWF) is used. Modeling results are compared with reanalysis data, satellite and ground-based observations, including the Minsk Ozonometric Station.

Simulation reveals structure of ozone mini-holes with predominant ozone depletion in the lower stratosphere just above the tropopause. Comparison of modeling results obtained with different combinations of parameterization schemes and role of feedback between radiation and ozone dynamics is given. Influence of mesoscale weather processes and synoptic-scale phenomena on formation and evolution of anomalies is analyzed.