Abstract

The warm-season moist deep convection is frequently accompanied by hazardous weather such as lightning, strong winds, heavy precipitation, and flash floods. It follows that accurate weather forecasts contribute to the safety of public, property, and transportation systems. Nowadays, numerical weather prediction (NWP) can forecast severe convective weather in a few-hours advance. In the absence of strong synoptic or topographic forcings, the NWP models are prone to errors because convection initiation may be missed due to unresolved boundary layer processes or insufficient weather observations for data assimilation.

This study initially focuses on the 21 August 2007 severe convective system (SCS) that developed over Masurian Lake District (Masurian LD) and brought high public attention in Poland. Then, the study investigates capabilities of a convection-permitting NWP model in hindcasting of that SCS. The discussed SCS induced surface wind gusts up to 35 m s^{-1} and significant waves on the lakes that caused extensive damage and loss of life. At that time, operational NWP systems at the Institute of Meteorology and Water Management – National Research Institute (IMGW-PIB) were not sufficiently advanced to explicitly forecast severe convective processes. Even today, the SCS represents a challenge for convection-permitting NWP because of a poor availability of surface and free-troposphere observations over the Central-Eastern Europe that can be assimilated into an NWP system.

Meteorological data available for the 21 August 2007 are collected and analyzed in this study, including the pre-storm synoptic and mesoscale conditions. This analysis shows that the SCS developed within a subtropical air mass, with no synoptic-scale forcing and in the presence of a mesoscale cold pool outflow from earlier scattered deep convection. Downwind from the scattered convection, a moist plume was observed in the surface layer. It was elongated in the NNW direction and featured dewpoint temperatures exceeding 20°C. The low-to-mid tropospheric SSE winds over Masurian LD likely overlapped the plume as suggested by model simulations. All those factors created favorable conditions for the development and fast propagation of deep convection that organized itself into a bow echo system.

The analyzed bow echo system represents a complex NWP case because it developed in response to transient favorable surface conditions, low-to-mid tropospheric winds, and a small-scale mechanical destabilization. The COSMO NWP model is used for the SCS convection-permitting modeling and two global datasets were tried to provide large-scale environment for limited-area simulations over Poland. The ERA-5 reanalysis was assessed superior and it was used as a source of initial and boundary conditions. Initial NWP simulations indicated that several modifications were necessary to obtain a reliable representation of the pre-storm conditions over Masurian LD. Those included assimilation of the pre-storm soil, surface, and upper-air weather observations collected up to the noon of 21 August 2007.

As the model misses to timely initiate a bow echo system, the setup was expanded to include either a deterministic or a stochastic idealized convection initiation scheme. The stochastic scheme was assessed as the superior for the kilometer-scale convection-permitting COSMO NWP simulations because its application led to the realistic representation of the bow echo system. That also denotes that the COSMO NWP model is capable to reconstruct the development of the bow echo system under the condition that the model data are realistic and the model is fitted with an effective convection initiation scheme. The setup with the stochastic scheme was subsequently used for additional model testing, focusing on the sensitivity of the bow echo representation to the refined horizontal resolution and cloud microphysics. The discussion of NWP simulations included an assessment of the influence of the modifications on the systems dynamics and consequent changes in the structure and magnitude of simulated surface wind gusts.

Overall, analyses of available observations and completed numerical simulations highlight a complex environment and difficult to predict chain of events that lead to the development of the bow-echo system. This dissertation documents the COSMO NWP model capabilities in modeling of that convective system. This research is classifed within the discipline of environmental engineering.

Key words: deep convection, convection-permitting modeling, bow echo system, stochastic convection initiation