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Sounding-derived parameters associated with tornado occurrence in Poland and Universal Tornadic Index

M. Taszarek *, L. Kolendowicz

Department of Climatology, Institute of Physical Geography and Environmental Planning, Adam Mickiewicz University, Dzięgielowa 27, 61-680 Poznań, Poland

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ABSTRACT

This study is mainly devoted to operational meteorology, to improve tornado forecast in Poland and create a Universal Tornadic Index formula. A study is focusing on climatology of sounding-derived parameters associated with tornadoes in Poland and their potential value for tornado forecasting. The data was collected from soundings made in 10 stations in and around Poland which were closely in time and space connected with tornado occurrence. The main aim of the study was to analyze the thermodynamic and kinematic parameters derived from soundings and formulate an index. The information about tornado incidents was taken from media reports and the European Severe Weather Database for the years 1977–2012. Total of 97 tornado cases were divided according to their strength for significant (F2/F3), weak (F0/F1) and unrated cases, and also according to their environmental surface temperature, for warm (>18 °C) and cold (<18 °C) tornadoes. As it turned out, depending on the temperature, tornadoes tended to present different environmental conditions for tornadogenesis. In warm cases, the most important factor was instability while for cold cases it was dynamic wind field. It was also proven that significant tornadoes in Poland occur in conditions accompanied by high moisture content, moderate instability and high wind shear conditions. The results of this study were used to create a Universal Tornadic Index designed to forecast activity in warm and cold, and weak and strong tornadic environments. The quality of this index was tested for the period with increased tornado activity in Poland from 2008 to 2010.

1. Introduction

Present synoptic meteorology is mostly based on numerical weather models which are a set of mathematical equations using basic physical principles and simulating how weather will change in the following hours or days. The input for the numerical models is partly data taken from atmospheric soundings which give information about the temperature, moisture content and wind strength in the vertical profile of the troposphere, therefore the better we will understand soundings connected with particular severe weather the better we will be able to predict them.

Thermodynamic and kinematic parameters which may be derived and calculated from the atmospheric soundings can be good predictors of severe weather phenomena. Many studies have been made on creating various types of parameters such as storm indicators, instability indexes, water content parameters, wind parameters and others. Simple ones use ambient temperature and dew point at different heights. Examples are the convective potential k-index (KI; George, 1960) and storm strength total totals (TT; Miller, 1967). More complicated parameters use parcel theory which is based on parcel lifting and takes into account adiabatic transformations. Examples of such parameters are convective available potential energy (CAPE; Miller, 1967), lifted index (LI; Galway, 1956) and Showalter index (SI; Showalter, 1953). More complex composite parameters such as significant tornado parameter (STP; Thompson et al., 2003), energy helicity index (EHI; Davies, 1993) or significant severe parameter (SSP; Craven and Brooks, 2004) are composed

* Corresponding author. Tel.: +48 504 437 574.
E-mail address: tornado@amu.edu.pl (M. Taszarek).

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from several other parameters and were created for forecasting specific phenomena such as a tornado, hail or a supercell (Browning, 1964).

In addition to these parameters, a number of studies have been devoted to compare soundings data and severe weather occurrence. Grünwald and Brooks (2011) compared sounding parameters from reanalysis data and the strength of tornadoes in Europe and the U.S. and revealed differences in lifted condensation level (LCL) and CAPE distribution, suggesting that in the U.S. tornadoes are formed in higher CAPE and lower LCL environments. Studies of Rasmussen and Blanchard (1998), Craven et al. (2002) and Brooks et al. (2003) found that CAPE with high wind shear is a good discriminator between severe thunderstorms with tornadoes and nontornadic thunderstorms. Craven and Brooks (2004) have analyzed vertical lapse rates, CAPE, downdraft CAPE (DCAPE), LCL and vertical wind shear on the example of U.S. tornadoes, thunderstorms and hailstorms and proposed a strong tornado parameter. The skill of various forecast parameters as predictors of severe weather in Europe has been recently studied by Haklander and van Delden (2003), Groenemeijer and van Delden (2007) and Kaltenböck et al. (2009). Groenemeijer and van Delden (2007) and Kaltenböck et al. (2009) found that LCL is not as good a tornadic environment discriminator as in the U.S. but high values of 0–1 km wind shear and 0–1 km storm relative helicity (SRH; Droegemeier et al., 1993), can indicate tornado hazard. In Poland not many studies have been devoted to analyzing tornado environments.

As Rasmussen and Blanchard (1998) state, baseline climatology of forecast parameters is needed to support forecasters in qualifications whether for example SRH or CAPE is "marginal" or "large". Without known climatology of sounding parameters dedicated for various regions it is difficult to state which values of parameters are conductive for tornado risk.

In this study, we will analyze wind shear, SRH, CAPE and moisture content parameters derived from 97 proximity soundings connected with tornado reports in Poland from 1977–2012 for unrated, weak (F0/F1), significant (F2/F3), cold (sounding surface T $<18°C$) and warm (sounding surface T $>18°C$) tornado cases (damage ratings estimated in F-scale, Fujita, 1971). The goal is to determine operational tornado climatology of these parameters and establish how they can affect tornado strength and how they are dependent on temperature. We are also interested in examining conditions for unrated cases which will confirm Grünwald and Brooks (2011) that cases that have not been assigned damage ratings are likely to be weak (F0/F1). Two different patterns of environmental conditions for "cold" and "warm" tornadoes will be discussed.

The obtained database will help to create a Universal Tornadic Index (UTI) dedicated for forecasting weak, significant, cold and warm central European tornadic environments. The quality of the index will be tested on 1097 proximity soundings days for years 2008–2010. Parameters obtained from these soundings will also be used to compare with previously analyzed tornadic soundings. The motivation for this study was to better understand the environment in which tornadoes occur in Poland and improve their forecasting by creating an index which will be used in mesoscale model by the Polish Institute of Meteorology and Water Management. We also drew a hypothesis that, depending on the surface temperature, the combination of instability and wind shear parameters in tornado cases changes. This allows us to distinguish two different environments in which tornadoes are formed (Fig. 5.3.1).

2. Theory

The subject of this study is the analysis of sounding-derived parameters in the relationship to the occurrence of tornadoes in Poland. In order to better select and understand analyzed parameters it is worthwhile to briefly introduce mechanism of tornadogenesis. Generally tornadogenesis requires that large vertical vorticity arises at the ground (Markowski and Richardson, 2009). Referring to the mechanisms which are responsible for tornado creation we can distinguish few sources for causing rotation. Davies-Jones et al. (2001) distinguished two main types, non-mesocyclonic tornadoes that are formed with pre-existing vertical vorticity and mesocyclonic tornadoes that are formed with deep rotating updraft below supercells.

2.1. Non-mesocyclonic tornadoes

These tornadoes are relatively weak and are formed within preexisting vertical vorticity (Davies-Jones et al., 2001). They develop early in the storm lifecycle (Burgess et al., 1993). Waterspouts and landspouts (Bluestein, 1985) are initiated when a developing convective updraft is stretching shallow vertical vortices above the surface. They start to be formed when convergence boundaries such as outflow boundaries, fronts and wind-shift lines are present, and form vertical "rolls" which initiate vorticity. They consist of updrafts sufficiently strong to stretch up vortex and form a tornado.

Doppler radar studies show that landspout and waterspout pre-existing vorticity is a result of horizontal shearing instability in convergence boundaries, where winds blow from various directions and cause air turbulence (Wakimoto and Wilson, 1989; Wilczak et al., 1992). Multicellular structures, such as clusters and lines, work in the same way in spawning weak tornadoes but have a tendency to collide convergence boundaries, merging and strengthening pre-existing vorticity (Holle and Maier, 1980). In this mechanism, near the ground convergence resulting in vertical vorticity collides and under the action of updraft, stretches vortex to tornado size (Markowski and Richardson, 2009). Climatologically these type of tornadoes are characterized by increased instability in the lowest part of the troposphere, updraft sufficient to stretch up vortex (presence of low level steep lapse rates and high CAPE released below 3 km AGL) and presence of wind-shift boundaries to initiate surface veering (Caruso and Davies, 2005; Davies, 2006).

2.2. Mesocyclonic tornadoes

Mesocyclonic tornadoes are connected with strong rotating updraft which is present in supercells. Supercells are responsible for the vast majority of strong and violent tornadoes (Doswell and Burgess, 1993). Most researchers assume that tornadoes greater than F2 are mostly produced by supercells, which are connected with deep moist convection (Doswell, 2001). These tornadoes are more likely to have contact with the surface for several minutes or even for hours. Much research has been devoted to analyzing the environment of supercells. Many