Atmospheric Research 158–159 (2015) 231–244

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

Thunderstorm occurrence and characteristics in Central Europe under different synoptic conditions

Kathrin Wapler [a,b,*], Paul James [b]

[a] Hans-Ertel-Centre for Weather Research, Atmospheric Dynamics and Predictability Branch, Germany
[b] Deutscher Wetterdienst, Offenbach, Germany

ARTICLE INFO

Article history:
Received 1 November 2013
Received in revised form 4 July 2014
Accepted 11 July 2014
Available online 21 July 2014

Keywords:
Thunderstorm
Synoptic conditions
Climatology
Automatic classification

ABSTRACT

The occurrence and characteristics of thunderstorms in Central Europe are examined in relation to the predominant synoptic conditions as derived from an automatic classification of synoptic patterns. Lightning strokes measured by a lightning detection network, human thunderstorm observations at weather stations and convective cells derived from radar reflectivity are used. The analysis reveals conditions favourable for thunderstorm development and highlights regions affected under different flow regimes. Additionally, the cell-based analysis shows that different synoptic conditions are typically associated with specific cell characteristics, such as the direction and speed of movement or cell sizes and severity. These relationships can be explained meaningfully via a description of the synoptic-meteorological characteristics of each of the standard weather patterns. As such these results may support a better understanding of thunderstorm formation as well as improve forecasters' situational awareness.

1. Introduction

Severe weather associated with thunderstorms poses a significant threat to life, property and economy. Hence, detailed knowledge of the occurrence of thunderstorms and their characteristics is important. A better understanding of the underlying thermodynamical process of thunderstorm development may improve forecasting skill of such events. The formation of convective weather events depends on a variety of processes. While fast processes on the mesoscale are generally associated with the impact itself, it is the synoptic situation, associated with slow processes, that create the environment for such events.

The general distribution of thunderstorms in various parts of Europe is well known (Wapler, 2013; Tuomi and Makela, 2008; Sonnadara et al., 2006; Enno, 2011; Schulz et al., 2005; Novak and Kyznarova, 2005; Antonescu and Bucea, 2010; Santos et al., 2012; Soriano et al., 2005). However there is still much to learn about the frequency and intensity of thunderstorms and their temporal and spatial occurrence under variant atmospheric conditions. A weather regime dependent thunderstorm climatology may help to support the estimation of predictability of such events, the development of nowcasting and forecasting systems as well as the forecasters' situational awareness.

Several analysis of the occurrence of convective systems dependent on favourable environmental parameters or convective indices have been performed (Brooks et al., 2003; Romero et al., 2007; Groenemeijer and van Delden, 2007). Some studies investigated various deep convective events in specific regions and performed principal component or cluster analysis to study predominant synoptic conditions. These include hail storms in regions of Spain (Garcia-Ortega et al., 2011; Aran et al., 2011) and southwestern France (Merino et al., 2014), long-lasting deep convective systems in the Mediterranean basin (Melani et al., 2013), waterspouts in the Eastern Adriatic bain, intense precipitation in the Spanish Mediterranean area (Martin et al., 2014), and extreme precipitation events in the Czech Republic (Kaspar and Mueller, 2014). Fewer studies analysed predefined synoptic patterns associated with deep convection,

---

* Corresponding author at: Deutscher Wetterdienst, Frankfurterstrasse 135, 63065 Offenbach, Germany.
E-mail address: kathrin.wapler@dwd.de (K. Wapler).

http://dx.doi.org/10.1016/j.atmosres.2014.07.011
0169-8095/

e.g. Kolendowicz, 2012 for Poland, Lewis and Gray, 2010 for the UK and Kunz et al., 2009 for parts of southern Germany.

Kunz et al. (2009) studied the frequency of thunderstorms and hailstorms in southwest Germany using insurance data. They found BM (Zonal Ridge across Central Europe), SWz (Cyclonic South-Westerly) and SWa (Anticyclonic South-Westerly) as the three large-scale circulation and weather patterns that were most frequently associated with hail days (see Table 1). However, they focused only on a small domain and did not study other characteristics of thunderstorms.

Insurance data and data collected by the European Severe Weather Database (ESWD; Dotzek et al., 2009; Dotzek and Groenemeijer, 2009; Groenemeijer et al., 2009) provides very useful data for various phenomena. However, it has to be considered that the observations only provide information on “positive events”, i.e. no entry in the data base does not mean that no severe weather event occurred. The same applies for weather stations. A severe weather event might have happened just outside of the range covered by human observations. Thus climatologies of (severe) convective weather events are difficult due to the inhomogeneous and not standardised data. However, lightning detection networks (and radar networks) allow for more continuous spatial climatologies.

Wapler (2013) presented a detailed climatology of lightning characteristics for Central Europe. This data set was included in the current study. Furthermore, a cell-based thunderstorm analysis is conducted in the present study. The analysis of thunderstorm distribution and characteristics in relation to synoptical conditions uses an automated classification based broadly on James (2007), which provides an objective multi-parameter classification of synoptic patterns and is also used to support medium range forecasts. Medium range forecasts of thunderstorm activity may be improved if a clear relationship between the well-known and widely used synoptic patterns and thunderstorm distribution and characteristics can be shown.

The focus of the study presented here is Germany and its surroundings, thus covering different geographical areas including low and high mountain regions as well as flat land and coastal areas (see Fig. 1 for a map of the analysis domain).

The remainder of this paper is organised as follows. Section 2 presents the data and methods used in this study. Section 3 shows the analysis of cell characteristics in Section 3.1 and the spatial thunderstorm distribution in Section 3.2 under different synoptic conditions. This is followed by a discussion of four individual synoptic patterns in Section 4. Finally, Section 5 provides a summary and some concluding remarks.

2. Data and methods

2.1. Thunderstorm observations

The lightning data used in this study are obtained from the VLF/LF (very low frequency/low frequency) LIghtning detection NETwork LINET (Betz et al., 2009). The network consists of 30 antennas in Germany (and many more elsewhere in Europe) and is considered to have a very high detection efficiency with a quasi continuous spatial and temporal resolution. The distance between neighbouring sensors within the area of interest is around 200 km or less. The receivers detect the magnetic flux of the lightning signal by means of two orthogonal loops. The time-of arrival (TOA) technique is employed to locate the strokes. According to comparisons with measurements on

Table 1
Classification of Grosswetterlagen.

No.	Abbr.	Name	2007–2012	1961–2012
1	Wa	Westlage, antizyklonal (*Anticyclonic Westerly*)	31	379
2	Wz	Westlage, zyklonal (*Cyclonic Westerly*)	77	561
3	Ws	Südliche Westlage (*South-Shifted Cyclonic Westerly*)	46	284
4	Ww	Winkelförmige Westlage (*Maritime Westerly* (*Block E. Europe*))	56	391
5	SWa	Südwestlage, antizyklonal (*Anticyclonic South-Westerly*)	35	489
6	SWz	Südwestlage, zyklonal (*Cyclonic South-Westerly*)	85	398
7	NWa	Nordwestlage, antizyklonal (*Anticyclonic North-Westerly*)	44	389
8	NWz	Nordwestlage, zyklonal (*Cyclonic North-Westerly*)	56	421
9	HM	Hoch Mitteleuropa (*High over Central Europe*)	21	244
10	BM	Brücke Mitteleuropa (*Zonal Ridge across Central Europe*)	40	365
11	TM	Tief Mitteleuropa (*Low over Central Europe*)	49	271
12	Na	Nordlage, antizyklonal (*Anticyclonic Northerly*)	21	299
13	Nz	Nordlage, zyklonal (*Cyclonic Northerly*)	8	244
14	HNa	Hoch Nordmeer, antizyklonal (*High Norwegian Sea, Ridge C. Europe*)	21	225
15	HNz	Hoch Nordmeer, zyklonal (*High Norwegian Sea, Trough C. Europe*)	44	458
16	HB	Hoch Britische Inseln (*High over the British Isles*)	27	269
17	TrM	Trog Mitteleuropa (*Trough over Central Europe*)	62	435
18	NEa	Nordostlage, antizyklonal (*Anticyclonic North-Easterly*)	26	143
19	NEz	Nordostlage, zyklonal (*Cyclonic North-Easterly*)	38	266
20	HFa	Hoch Fennoskandien, antizyklonal (*Scandinavian High, Ridge C. Europe*)	25	232
21	HFz	Hoch Fennoskandien, zyklonal (*Scandinavian High, Trough C. Europe*)	23	341
22	HNFa	Hoch Nordmeer-Fennoskandien, antiz. (*High Norw. Sea to Finland, Ridge C. E.*)	22	194
23	HNFz	Hoch Nordmeer-Fennoskandien, zykl. (*High Norw. Sea to Finland, Trough C. E.*)	28	310
24	SEa	Südostlage, antizyklonal (*Anticyclonic South-Easterly*)	49	426
25	SEz	Südostlage, zyklonal (*Cyclonic South-Easterly*)	7	194
26	Sa	Südlage, antizyklonal (*Anticyclonic Southerly*)	28	289
27	Sz	Südlage, zyklonal (*Cyclonic Southerly*)	31	301
28	TB	Tief Britische Inseln (*Low over the British Isles*)	39	291
29	TrW	Trog Westeuropa (*Trough over Western Europe*)	59	407