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Downburst-producing thunderstorms in southern Germany: Radar analysis and predictability

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ABSTRACT

Three days with downburst-producing thunderstorms during the VERTIKATOR intensive observation period in June and July 2002 are studied by means of the C-band polarisation diversity radar POLDIRAD and its network of three bistatic receivers. We present the first wind vector fields from a downburst measured by such a bistatic network. The polarimetric radar data allowed testing the recent hypothesis that a dominant trigger mechanism for wet downbursts might be the cooling due to melting of small hail or graupel in the storm, and we found some evidence for this process in the VERTIKATOR storms. This could be exploited by polarimetric radar nowcasting algorithms for downburst detection. The predictability of the downburst potential was further investigated from proximity soundings and their derived indices WINDEX as well as different formulations of GUSTEX. In particular, a new formulation of GUSTEX is proposed here which shows promising predictive skill for the VERTIKATOR cases and a number of other severe (and non-severe) situations from the same region in southern Germany.

1. Introduction

Downbursts as a special class of straight-line wind events present a considerable hazard not only to property and human lives, but in particular to aircraft during take-off and landing (cf. Fujita, 1981, 1985; Fujita and McCarthy, 1990; Doswell, 2001). Due to their higher frequency of occurrence, they easily outweigh the threat posed by tornadoes, even though that exists in Europe as well (e. g., Roach and Findlater, 1983; Bech et al., 2007).

The common terminology classifies downbursts into the sub-categories microburst and macroburst, where the latter term is used if the areal extent of the wind damage exceeds 4 km (the threshold between misoscale and mesoscale, Fujita, 1981). Yet, throughout this paper which analyses both micro- and macroburst cases, we will mainly use the generic term "downburst". A further phenomenological distinction is made between dry downbursts (e. g., Wakimoto, 2001) and wet downbursts (e. g., Fujita, 1985). Wet downbursts are characterised by heavy precipitation at the ground, either rain or hail. Dry downbursts only require light precipitation at the level of downdraft initiation which quickly evaporates during descent of the air mass, such that usually no precipitation reaches the ground. This makes early detection of dry downbursts using Doppler radars and eye observations quite difficult and enhances the threat that they pose to low-flying aircraft. However, dry downbursts are apparently very rare events in Central Europe, as they require the presence of very deep and nearly adiabatic subcloud layers which are seldom present in this region. To the authors' knowledge, dry downburst reports in Europe are currently anecdotal, at best.

Wet downbursts, like the cases we present here, are easier to detect both by radar and by eye due to their dense precipitation core. Nevertheless, the distinction between a rain shaft with or without high winds strongly depends on the thermodynamic stratification of the air mass and on the presence of a layer with

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high horizontal momentum near the level of downdraft initiation. Relying solely on the visual or radar appearance of an intense thunderstorm does not easily allow for a decision if high winds have to be expected from it. This may lead to warnings being issued too late (or not at all) and consequently to damage at the ground which could have been avoided or mitigated in principle. Faust (1948) describes a significant wet downburst on 13 July 1941, affecting what is nowadays Frankfurt international airport with little prior warning and leading to the destruction of 40 aircraft at the ground.

In general, downbursts of a given intensity occur more frequently and their damage swaths also tend to affect larger areas than those of equally intense tornadoes. For this reason, it is important to study the life-cycles of downburst-producing thunderstorms over both flat and complex terrain to detect possible differences and to investigate their predictability from routinely available observations like radiosonde ascents and weather radar observations.

Polarimetric Doppler radar is ideally suited for the analysis of the life-cycles and for the development of nowcasting methods. A special opportunity to study downburst events was provided by the VERTIKATOR project (www.vertikator-afo2000.de), which aimed at an improved understanding of initiation and development of shallow and deep convection over mountainous terrain. Interaction of synoptic scale settings with local effects like the heat low over mountain ranges or valley flows on convective transport was a major focus. During the VERTIKATOR intensive observation period (IOP) in summer 2002, one investigation area was located in the northern Alpine Foreland between Munich, Germany, and Innsbruck, Austria (cf. www.pa.op.dlr.de/vertikator/). A great variety of observations were made, involving several aircraft, radars, lidars, sodars, and a surface mesonet. In addition, routine observations from radiosondes, satellites and cloud-to-ground (CG) lightning data from the BLIDS network (with sensors similar to the NLDN in the USA, cf. Cummins et al., 1998) are available.

During the VERTIKATOR IOP in June and July 2002, several wet downbursts were observed in the northern Alpine foreland within about 50 km radius from the polarisation diversity radar POLDIRAD operated by the German Aerospace Centre DLR. This is a region of Germany with a high frequency of thunderstorms (30 to 35 thunderstorm days per year, see Bissolli et al., 2007), often accompanied by hail or straight-line winds (Koschmieder, 1944; Meischner et al., 1991; Höller, 1994; Höller et al., 1994), for which the infamous Munich hailstorm of 12 July 1984 (Heimann and Kurz, 1985; Höller and Reinhardt, 1986) is an example with a total damage close to 1 billion EUR. In this paper, we will analyse (bistatic) polarimetric Doppler radar data from the VERTIKATOR IOP events and use the observations to test recent findings by Atlas et al. (2004) emphasizing the role of melting small hail for initial downdraft formation.

Another aspect in studying severe local storms is to investigate their predictability using radar-based nowcasting tools or numerical simulations. Potential impacts by global climate change on the frequency, size and intensity of these events are also being studied extensively. As a contribution to the ongoing project RegioExAKT (www.regioexakt.de) — aside from the radar nowcasting aspect — we will investigate in the second part of this study the predictability of the VERTIKATOR downbursts (and related cases) based on different formulations of the WINDEX (McCann, 1994) and GUSTEX (Geerts, 2001) indices. Our motivation to use these was that both parameters can be derived with little computational effort from operational atmospheric soundings and thus can be routinely made available shortly after completion of a sounding. A further motivation to test parameters like these is that they can also be derived from reanalysis data (cf. Brooks et al., 2003, 2007) or regional climate model runs for climate change scenarios. This will allow for a statistical comparison between the “index climatology” now and in the future scenario.

Our paper is organised as follows: Section 2 provides the necessary background information on downburst climatology and formation mechanisms. Three downburst-producing thunderstorms are exemplarily analysed in Section 3, while Section 4 investigates the predictability of the downbursts events and compares the VERTIKATOR events to other case studies, either in the same region (Dotzek et al., 2001; Fehr et al., 2005; Dotzek et al., 2007) or even affecting larger parts of Germany (Gatzen, 2004). Sections 5 and 6 present discussion and conclusions.

2. Downburst climatology and formation mechanisms

2.1. Downburst climatology in Germany

In order to assess how representative the present downburst cases are, it is necessary to review the German downburst climatology first. This will show if the 2002 downbursts were typical events or more exceptional, and provides a basis for comparison to the German tornado climatology recently investigated by Dotzek et al. (2000) and Dotzek (2001, 2003). Fig. 1 shows the German downburst climatology using all TorDACH storm reports up to 2005 (version 1.6). An earlier version of that database was analysed by Dotzek et al. (2007, their Fig. 1) and can be compared to the augmented data used here. By now, the TorDACH data have been included in the European Severe Weather Database (ESWD, www.essl.org/ESWD/, cf. Dotzek et al., 2009-this volume). Since 2006, severe storm events from Germany are only recorded in the ESWD.

Downbursts in Germany are almost exclusively of the wet downburst type. Fig. 1a illustrates the evolution of downburst reporting in Germany. Their recording mainly began around 1880, in context of the work leading to the monograph by Wegener (1917). Until 1940, the reporting ranged between 30 to 60 reports per decade. This level was later only exceeded in the 1950s and 1980s. Recently both the activity of the TorDACH network and the widespread availability of online news, weather fora as well as renewed interest in severe convective storms research in Europe (see Snow, 2001, 2003; Dessens and Sanchez, 2007) led to a boost in reports to nearly 80 per year since 2000. The total number of wind reports in the final TorDACH data is 1019, of which 705 date from the period 1950–2005.

The diurnal cycle is given in Fig. 1b. Peak activity is limited to the afternoon and evening hours, with some further activity during the night, resembling the thunderstorm daily cycle (cf. Wegener, 1917). The downbursts during VERTIKATOR occurred in the afternoon or evening, so with this respect, the present cases are quite typical. The annual cycle of downbursts is given in Fig. 1c for each month. A dominant July maximum of downburst activity is obvious. Generally, from