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A Derecho in Europe: Berlin, 10 July 2002

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Abstract

The European windstorm that affected parts of Germany on 10 July 2002 is classified as a derecho. With respect to the synoptic situation, it was identified as a dynamic or strongly–forced derecho. Examining different observational data, this case shows many similiarities to those investigated in the United States, giving evidence that derechos do occur in Europe as well: A well–defined surface convergence line and a thermal boundary aloft marked the derecho's path that was associated with a strong upper–level jet streak as well as a low–level jet at the leading edge of the storm.

1 Introduction

On 10 July 2002, during the VERTIKATOR field experiment (*Vertikaler Austausch und Orographie*, vertical transport and orography) in southern Germany, a line of severe convection crossed the northeastern part of Germany, producing widespread wind gusts. The line reached Germany's capital, Berlin, at 1815 UTC, at which time a maximum gust of 42 $\mathrm{m\,s^{-1}}$ was observed. The Berlin Tegel airport had to be closed, and highways and railroads were blocked by overturned trees. The weather services as well as the public were not well prepared. In Berlin, 4 residents died and 39 were injured. Within the city's periphery, four additional fatalities occurred. Most of them were hit by uprooted trees, as in the most tragic case, where two children died at a youth camp organized by Berlin's fire department in Berlin–Wannsee. All over the city, thousands of trees broke off or were uprooted; about 30 000 trees had to be felled in the following weeks. The present paper gives an analysis of this event, classifying it as a derecho using the definition of Johns and Hirt (1987), who developed four criteria to identify derecho events:

- There must be a concentrated area of reports consisting of convectively-induced wind damage or convective gusts of more than 26 $\mathrm{m\,s^{-1}}$ (50 kt). This area must have a major axis length of at least 400 km.
- The reports within this area must also exhibit a nonrandom pattern of occurrence. That is, the reports must show a pattern of chronological progression, either as a singular swath (progressive) or as a series of swaths (serial).
- Within the area there must be at least three reports, separated by 64 km or more, of either F1 damage or convective gusts of 33 $\mathrm{m\,s^{-1}}$ (65 kt) or greater.
- No more than 3 h can elapse between successive wind damage (gust) events.

This nomenclature has not been used in Germany before, least of all there is no climatology that deals with such events, although previous convective windstorms probably reached the criteria. The 21 July 1992 CLEOPATRA squall line (*www.pa.op.dlr.de/cleocd/start.htm*) may be one example of a widespread convectively–induced windstorm that occurred over Germany in the past (Haase–Straub et al., 1997; Meischner et al., 1993). However, the experience from those cases was ignored on 10 July, when background knowledge of organized convection itself was not used to improve the forecasts. Accordingly, German meteorologists were surprised at the storm's size and strength. In fact, gusts up to 25 $\mathrm{m\,s^{-1}}$ had been expected due to the relatively large synoptic–scale pressure gradient along the cold front that was predicted by operational model runs.

This paper is structured as follows: section 2 gives an overview of the synoptic situation, while section 3 treats the evolution of the convective system. In section 4, the analysis of observed wind gusts is used to classify this severe convective event as a derecho. Section 5 presents the conclusions of this case study.

2 Synoptic Overview

In the second week of July, the upper and mid tropospheric flow over Europe was dominated by an intense trough across the northwestern part of the continent, yielding a deep southwesterly flow over the western regions (Fig. 1a). Over south–central Europe, the flow was split into two branches, a northern branch which stretched from France and Benelux to the North Sea, and a second branch, which deviated towards the central Mediterranean, where it formed a weak ridge. Along the periphery of the northwestern main trough, several vorticity maxima affected western Europe.

In association with an intense short–wave trough, another vorticity maximum travelled around the main trough reaching the northern border of the Iberian Peninsula late in the day of 9 July. At 1500 UTC on 10 July, the axis of this negatively tilted short–wave trough extended from southern Great Britain into southern central Germany. At the 300 hPa level, the maximum wind speed reached more than 50 $\mathrm{m\,s^{-1}}$ over France. The synoptic–scale forcing associated with such intense jet streaks can be quite strong, helping convection to develop. Derechos that occur under those synoptic conditions are called dynamic (Johns and Hirt, 1987) or strongly–forced derechos (Evans and Doswell, 2001).

At the 850 hPa level, an air mass characterized by high equivalent potential temperature (θ_e) up to 340 K was advected from southeastern Central Europe into eastern Germany (Fig. 1b). In contrast, intense cooling due to cold air advection and evaporation of stratiform rain took place west of an eastward moving cold front in western Central Europe. By the afternoon, the 850 hPa θ_e–gradient reached 30 K over a distance of 500 km.

3 Derecho Evolution

The locations of orographic features mentioned in the text are shown in Fig. 2. The satellite image (Fig. 3a) indicates the front's position at 1449 UTC, three and a half hours before the derecho hit Berlin. A persistent line of thunderstorms can be seen advancing eastward over southern Germany. Stratiform precipitation was observed west of the front underneath the broad cloud shield over western Germany. East of the cold front, new thunderstorms are visible that formed rapidly parallel to the Böhmer Wald Mountains, Oberpfälzer Wald Mountains, and Thüringer Wald Mountains between 1400 and 1500 UTC. As the cold front's convection dissipated during the next hour, the new line of convective cells merged into a MCS that is portrayed at 1628 UTC in Fig. 3b. Downstream of this feature, the northeastern part of Germany was partly clear. At the surface, winds were weak with a northerly direction to the west of Berlin, and southerly to easterly directions east of it (see Fig. 4). A convergence line reaching from the Baltic Sea east of Rügen Island to the western Erzgebirge Mountains separated both wind regimes and marked the path of the derecho. Just above this surface convergence line, the operational 850 hPa θ_e–fields of the Bologna Limited Area Model (BOLAM, Buzzi et al., 2003) indicated a thermal boundary at the leading edge of the southern Central Europe warm air advection regime (Fig. 1b). Observational studies in the United States point out that such pre–existing, line–normal thermal boundaries can play a role in the formation and propagation of bow echoes. Along those boundaries, enhanced low–level convergence could lead to more intense convection and associated wind gusts (Davis et al., 2001).

Over eastern Germany, this thermal boundary is well portrayed by the surface observations of the German weather service: East of this boundary, temperatures were about 3–6 K higher, while the dewpoints were about 3–7 K lower. This indicates that the boundary layer was more turbulently mixed east of the convergence line than west of it, which is confirmed by a 1800 UTC sounding from Lindenberg about 40 km southeast of Berlin (Fig. 5). This sounding, being a proximity sounding in terms of the definition given by Evans and Doswell (2001), shows more properties of the pre–storm environment. Relatively dry air near the ground and steep lapse rates up to 750 hPa were present which enhanced the potential for strong downdraft gusts and cold pool formation due to evaporation inside the downdrafts. For the same reason, the mid–level dry airmass above 700 hPa that was also detected by soundings west and south of Berlin could had been important for the cold pool formation. Another point that should be discussed is the instability of the pre–storm environment. At Lindenberg, a 50 hPa mean–layer CAPE of around 1000 J/kg was observed. However, this observation did not reflect the CAPE–values west of the convergence line, where shallow low–level moisture was observed that was not reproduced by available numerical models. Finally, the vertical wind profile did not indicate very strong low level shear by the time the rawinsonde was started at 1645 UTC. But 1290 MHz wind profiler and sodar measurements at the same place show the development of low–level shear over Lindenberg during the next hours (Fig. 6) with increasing low–level southeasterly winds. In the range of the 850 hPa level, the wind changed from about 10 $\mathrm{m\,s^{-1}}$ southeast to more than 20 $\mathrm{m\,s^{-1}}$ south–southeast between 1600 and 1900 UTC. The operational 1200 UTC run of the Local Model (LM, Doms and Schaettler , 1999) of the German weather service showed this low–level jet, just downstream of the negatively tilted 850 hPa trough axis extending to the north with Berlin at its western flank. At 300 hPa, LM output suggests that the strong Central European jet streak had reached southeastern Germany, while its left exit region affected northeastern Germany. This regional relationship of upper–level and low–level flow can also be identified from the operational BOLAM 0000 UTC + 15 h forecast fields in Fig. 1a and 1b (cf. *www.cmirl.ge.infn.it/map/bolam/bolamin.htm*).

The observed low–level jet may have formed as a result of the indirect thermal circulation underneath the exit region of this jet streak (Uccellini and Johnson, 1979). Accordingly, isallobaric surface analysis (not shown) indicates a synoptic–scale increase of the surface pressure of 4 hPa within 3 h over the Czech Republic and southeastern Germany and a decrease of 3 hPa within 3h over northeastern Germany. The low–level jet was directed along this isallobaric gradient.

The convective line reached Berlin at 1815 UTC. The C–band Doppler radar at Berlin Tempelhof airport documented the mesoscale structure of the convective line (Fig. 7). The reflectivity over Berlin at 1845 UTC shows signatures described in conjunction with high wind events in the United States (Cannon et al., 1998). Over northern Berlin, a bow–shaped segment of the propagating derecho is visible. This feature originated from an intense convective cell that merged with the convective line, and most likely produced the strong wind gusts observed between 1815 and 1845 UTC. New pre-storm convective cells are detected to the northeast of the city that merged with the MCS later on. By this means, a couple of bow–shaped segments developed along the leading edge of the convective line as it moved northward, classifying the derecho as a serial one. South of the bow echo that is displayed in Fig. 7, the southwestern part of Berlin is covered by a weak reflectivity region known as a rear inflow notch (RIN, Przybylinski and Gery, 1983; Burgess and Smull, 1990). Descending air originating from the rear inflow jet and evaporation is thought to lead to this weak radar reflectivity (Burke and Schultz, 2003). The rear–inflow jet points from the rear of the convective system to the leading edge of the bow echo. It transports relatively dry air into the downdraft, enhancing evaporation and associated cooling (Weisman, 2001). In this case, the rear inflow jet reached the ground only close to the bow echo, whereas it was elevated some kilometers behind it, as indicated by wind profiler data from Lindenberg southeast of Berlin (see Fig. 6). It should be noted that Lindenberg was not hit by the derecho that passed the location to the northwest. Nonetheless, a strong westerly flow was measured 300 meters above Lindenberg after 1900 UTC that remained during the following hours.

Without losing intensity, the derecho reached the northeastern coast of Germany shortly after 2000 UTC, producing wind gusts up to 35 $\mathrm{m\,s^{-1}}$ at Rügen Island, and then decayed over the Baltic Sea.

4 Analysis of observed wind gusts

Fig. 8 shows observed wind gusts of the derecho, and its position, as indicated by the wind shift detected by two ground-observation networks, one of the German weather service , the other of Meteomedia, a private weather company. Combining these two networks, more than 100 surface wind observations denote the position of the wind shift of the cold front and associated derecho over northeastern Germany, which is displayed by solid and dashed lines. As the 1200 and 1500 UTC data indicate, the cold front propagation was restricted to southern and central Germany while it was stalling over northern Germany. At this time, broad convection that marked the cold front position was observable on satellite images (Fig. 3a). To the east, a new line of convection was forming, leading to a new outflow boundary at 1600 UTC that is displayed by a dashed line in Fig. 8. The new convective line reached its mature stage between 1600 and 1700 UTC as indicated by the satellite image in Fig. 3b and the subjective analysis in Fig. 4: Just between the leading edge of the outflow boundary and the remaining surface trough of the cold front a sharp mesoscale ridge was analysed, yielding to the assumption that a cold pool had formed increasing the pressure gradient as well as the isallobaric gradient to the south of Berlin. Rasmussen and Rutledge (1993) found that the propagation speed of convective lines increased by the time of the transition between the intensifying and mature stage; this was also observed on 10 July over eastern Germany, when the convective line suddenly accelerated after 1600 UTC. This was associated with a strenghtening of observed wind gusts, as depicted by crosses, dots and grey circles, marking where wind gusts of more than 22, 26, and 34 $\mathrm{m\,s^{-1}}$ occured, respectively (see Fig. 8).

Over southern Germany, no gusts of more than 26 $\mathrm{m\,s^{-1}}$ were observed except on mountains. In contrast, widespread maximum wind gusts up to 34 $\mathrm{m\,s^{-1}}$ did occur over broad parts of northeastern Germany, where front propagation was fastest. Nearly two-thirds of all observed gusts of more than 26 $\mathrm{m\,s^{-1}}$ occurred within a strip extending from the western Erzgebirge Mountains to Berlin and further to the Baltic Sea near Rügen Island. The path of strongest wind gusts was about 500 kilometers long and 100 kilometers wide. Inside this region, five measured wind gusts exceeded 34 $\mathrm{m\,s^{-1}}$, six more observations attained 33 $\mathrm{m\,s^{-1}}$. Four of the gust reports of more than 34 $\mathrm{m\,s^{-1}}$ were separated by at least 100 kilometers. Therefore, the windstorm under consideration satisfied the criteria for a derecho proposed by Johns and Hirt (1987).

5 Conclusions

This case study of a derecho over Germany shows that severe convection can attain a size and intensity comparable to that in the United States. Even though the European land mass is smaller and more heterogeneous, organized severe convection over Central Europe has shown to be an appreciable hazard to life and property. More precisely, the Berlin derecho of 10 July 2002 shared some well established synoptic- and mesoscale features of derechos in the United States:

- The synoptic–scale flow pattern was characterized by an intense negatively tilted upper short–wave trough associated with a strong upper–level jet streak. A thermally indirect circulation may have provided a low–level jet, enhancing warm air advection and moisture pooling just below the left exit region of the upper–level jet.

- Along the leading edge of the low–level jet, a pre–existing frontal boundary marked the derecho path over northeastern Germany. At the surface, it was possible to analyze a well–defined pre–existing convergence line.

- The increase in the speed of observed wind gusts over eastern Germany was associated with an acceleration of the leading edge propagation of a convective line after it had reached its mature stage.
- Radar reflectivity images show signatures often described in conjunction with high wind events, including bow echoes, rear inflow notches and cell mergers at the leading edge of the line of convection.
- Wind profiler data from Lindenberg indicate strong low–level wind shear ahead of the derecho and suggest the presence of an elevated rear inflow jet.

Not only small–scale, but also large–scale severe convection over Europe bears many similarities to convective phenomena in the United States. As a consequence of the Berlin derecho, the German weather service and Meteomedia have developed new concepts for severe weather warnings. In addition, the "European Storm Forecast Experiment" (www.estofex.org) was initiated by a group of European meteorologists to forecast severe convection over Europe.

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Figure captions

Figure 1: Operational BOLAM forecast for 10 July, 1500 UTC. (a) 300 hPa geopotential (gpm) and wind speed ($\mathrm{m\,s^{-1}}$). Geopotential heights are shown by black lines, wind speed is indicated by gray shading. (b) 850 hPa θ_e–field in K and wind vectors scaled by the 10 $\mathrm{m\,s^{-1}}$ vector at the bottom of the figure.

Figure 2: Orographic map of the affected region. Terrain heights are shaded in greyscale.

Figure 3: NOAA satellite visible channel images of Germany at 1449 (a) and 1628 UTC (b).

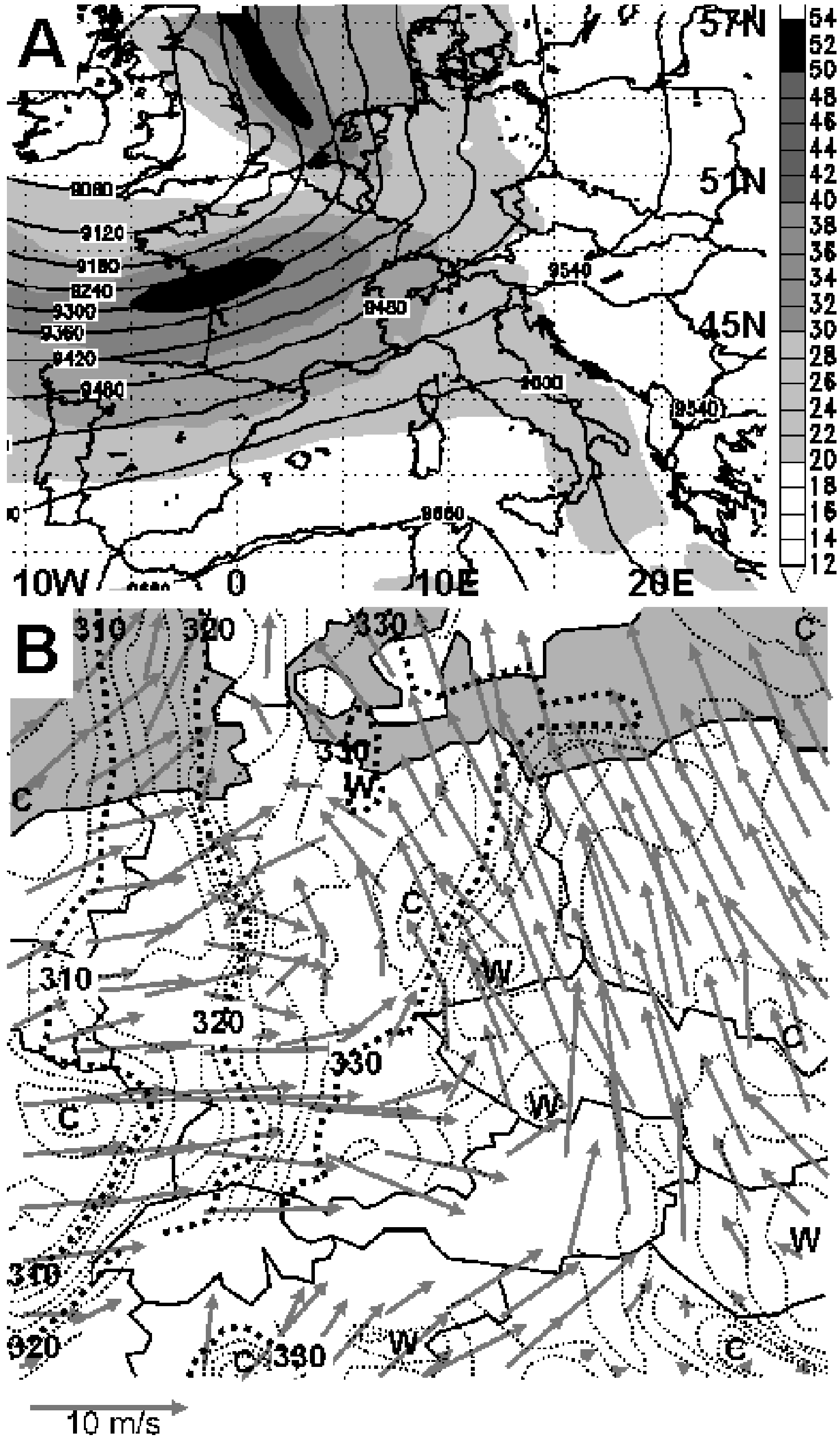
Figure 4: Subjective analysis of surface pressure field at 1700 UTC based on observations by the German weather service. Temperatures and dewpoints in ° C, wind barbs in kt.

Figure 5: 10 July, 1800 UTC sounding at Lindenberg in the pre–storm environment 40 km southeast of Berlin. Wind barbs are given in knots.

Figure 6: Wind profiler and sodar data from the German weather service at Lindenberg. Wind barbs are given in knots.

Figure 7: Radar reflectivity in the Berlin region at 1845 UTC. Arrows point at the rear inflow notch south of the bow echo over Berlin and developing pre–storm convection.

Figure 8: Measured maximum wind gusts (symbols) and cold front position (lines) over Germany. Wind gusts above 22 $\mathrm{m\,s^{-1}}$ are depicted by crosses, above 26 $\mathrm{m\,s^{-1}}$ by dots, and above 34 $\mathrm{m\,s^{-1}}$ by grey circles. The UTC time of cold front position is shown at the end of each line. Solid lines are plotted every three hours, with dashed lines of hourly intervals.



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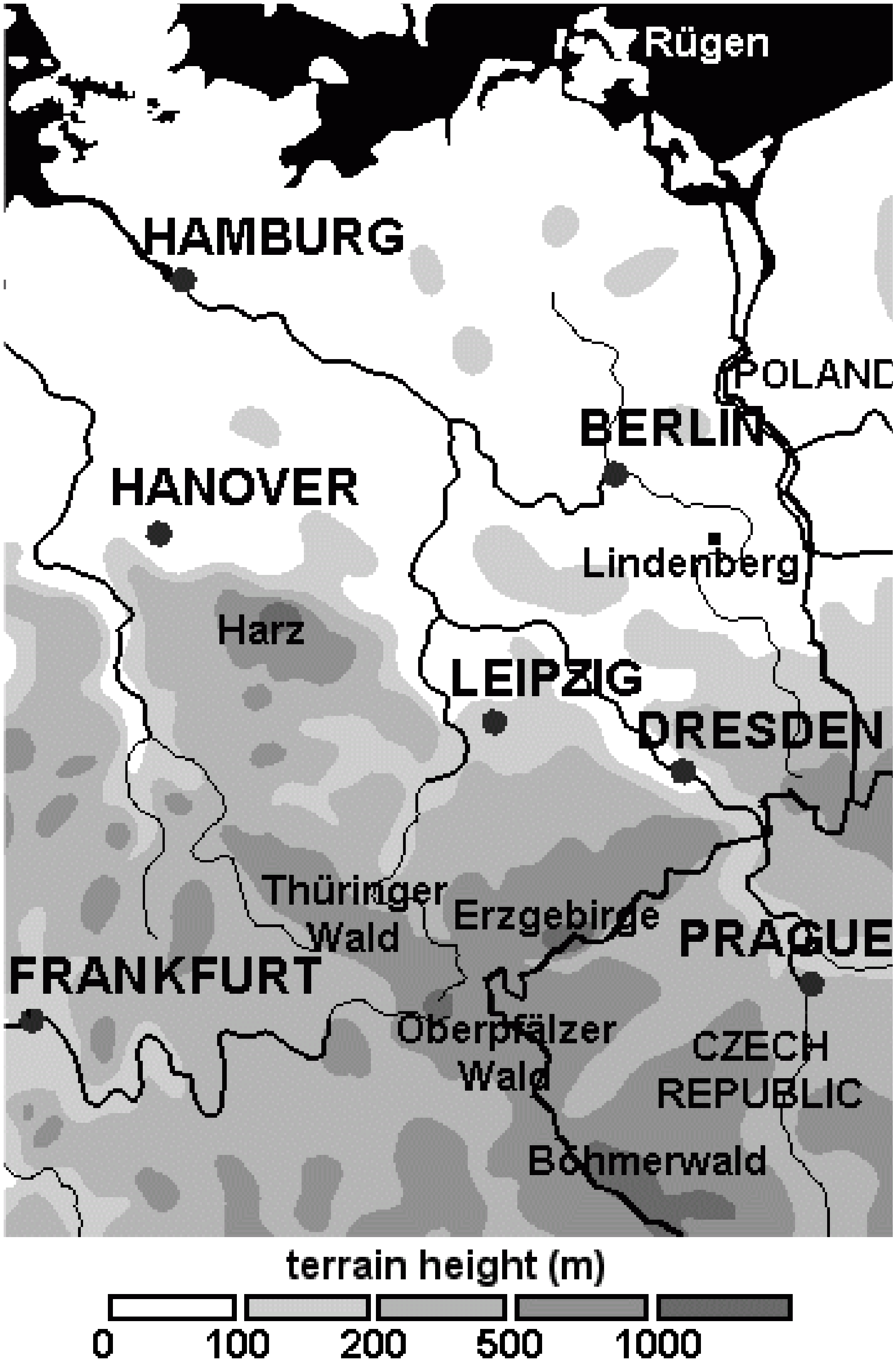

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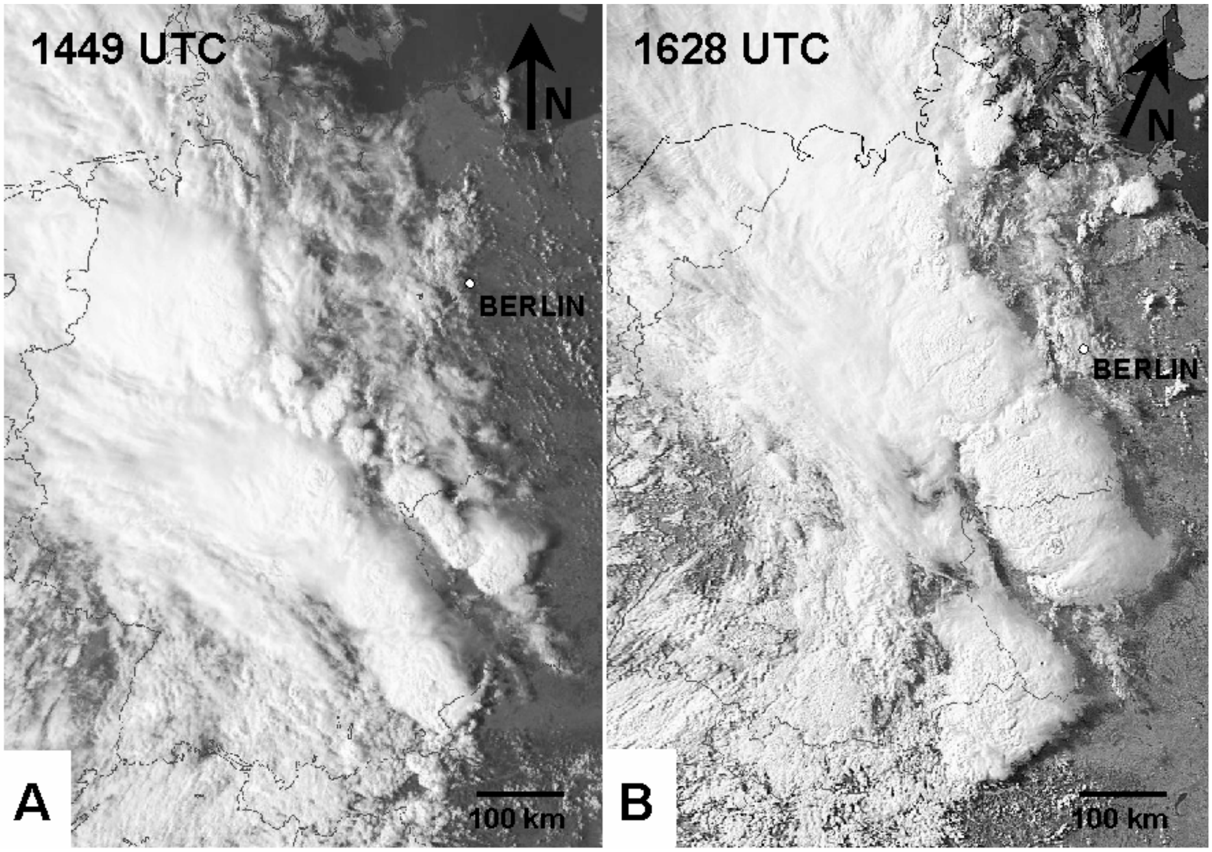

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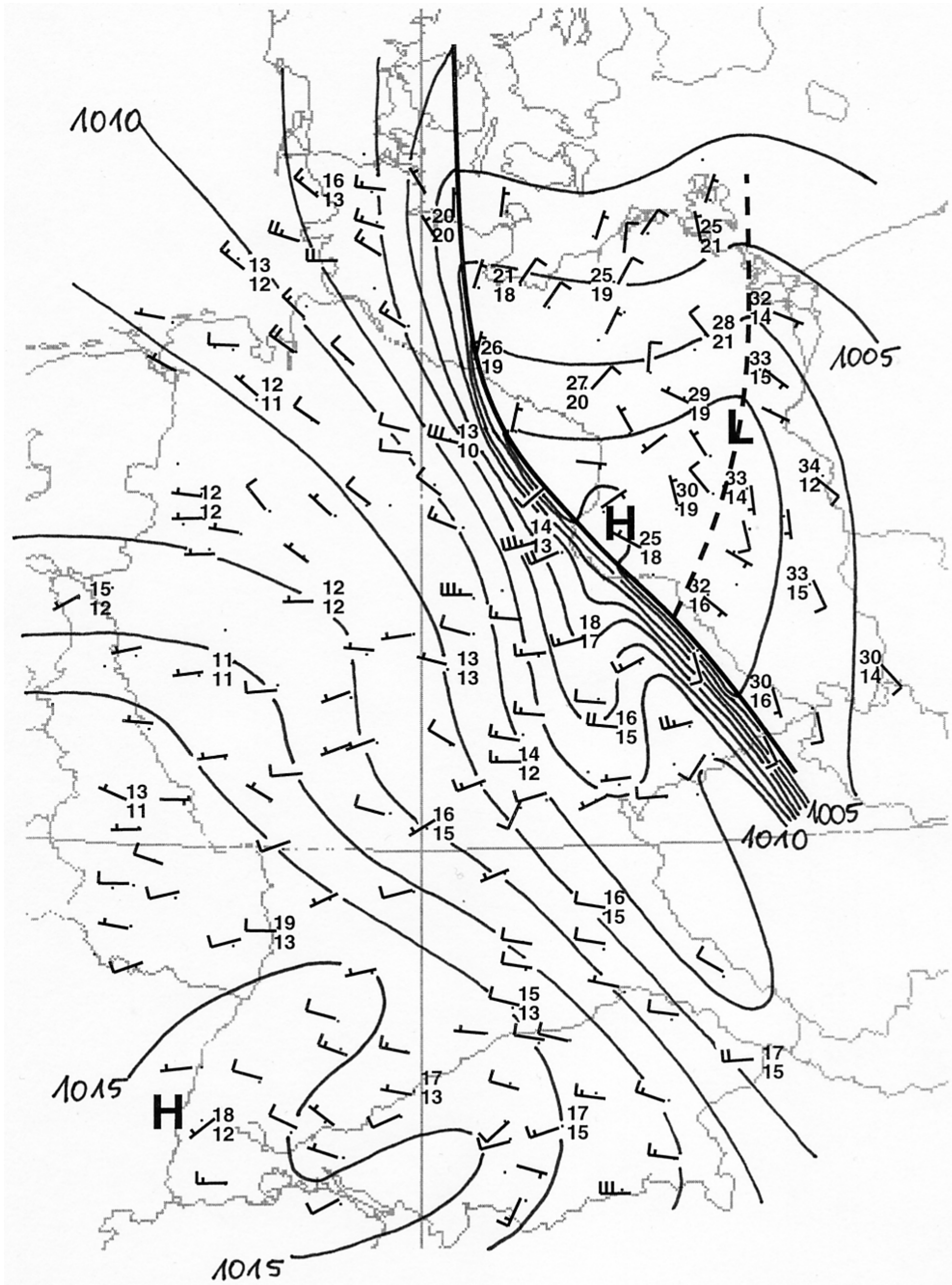

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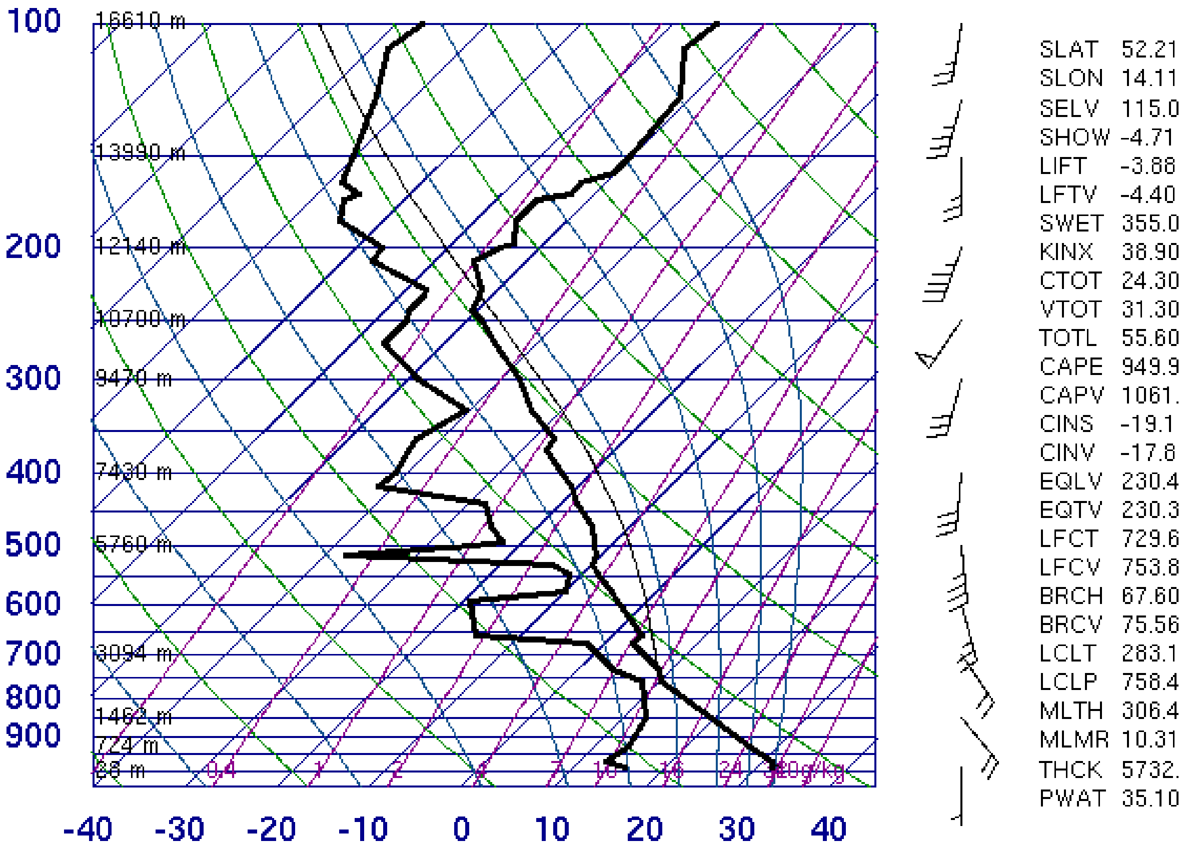

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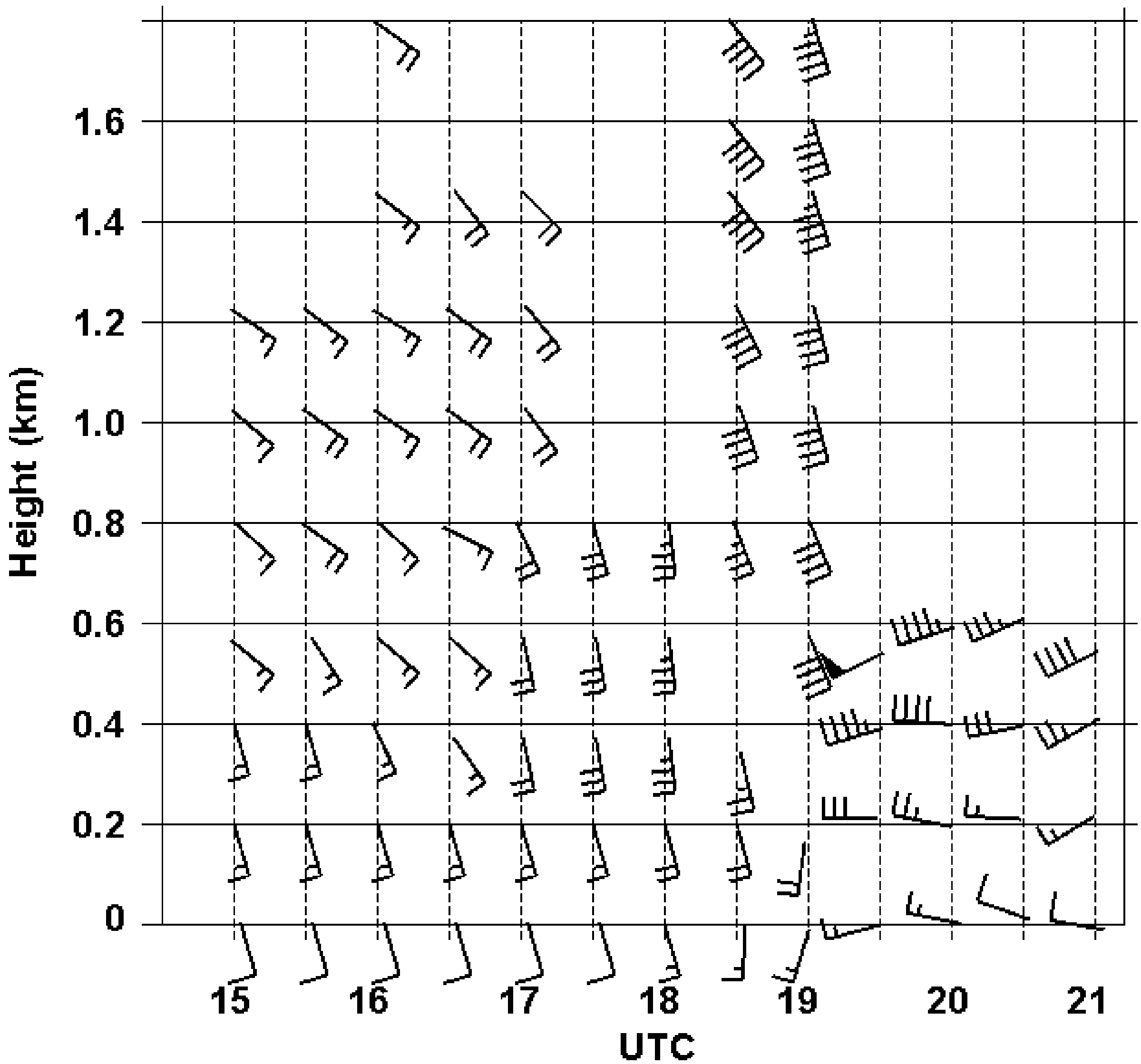

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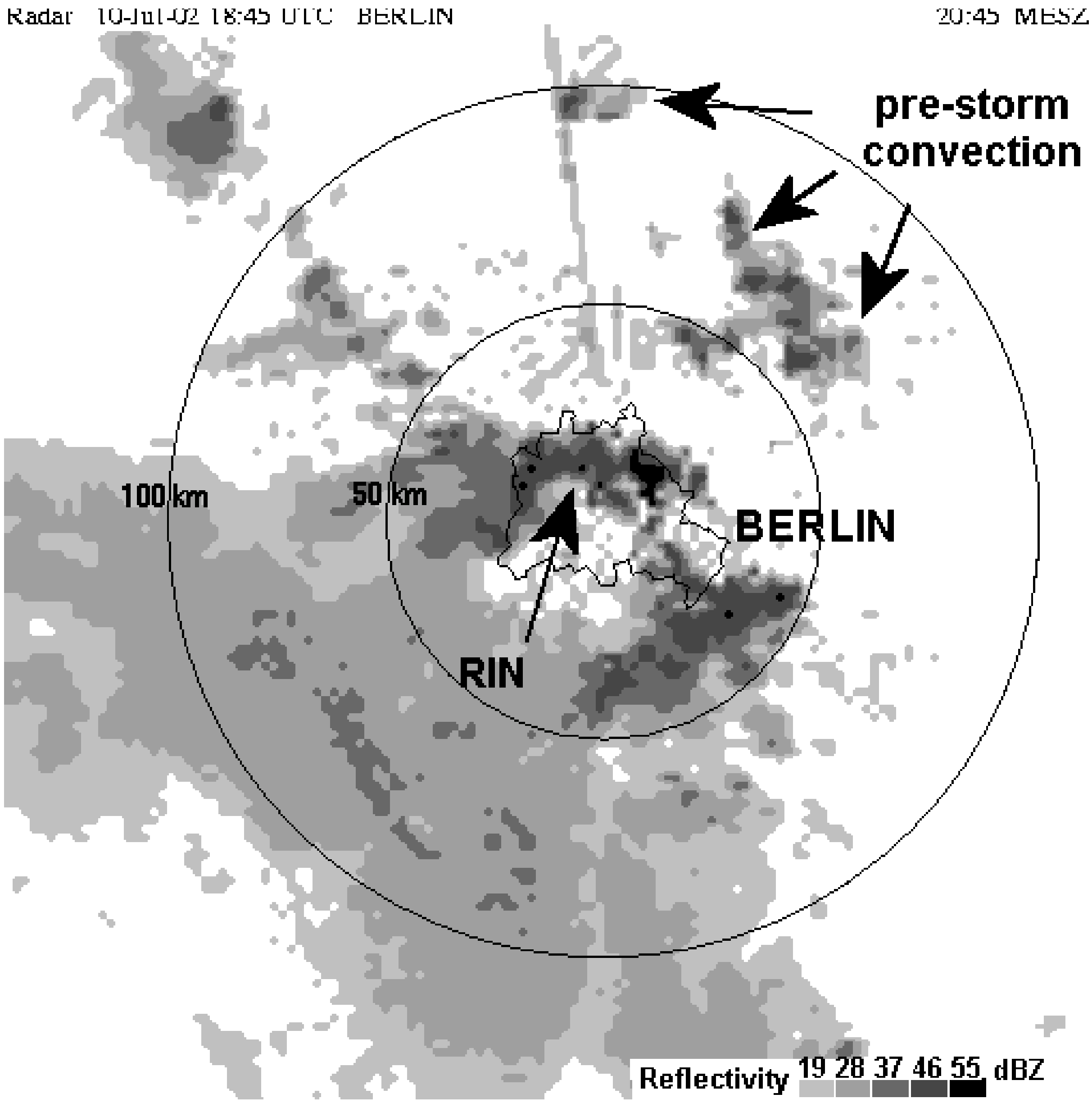

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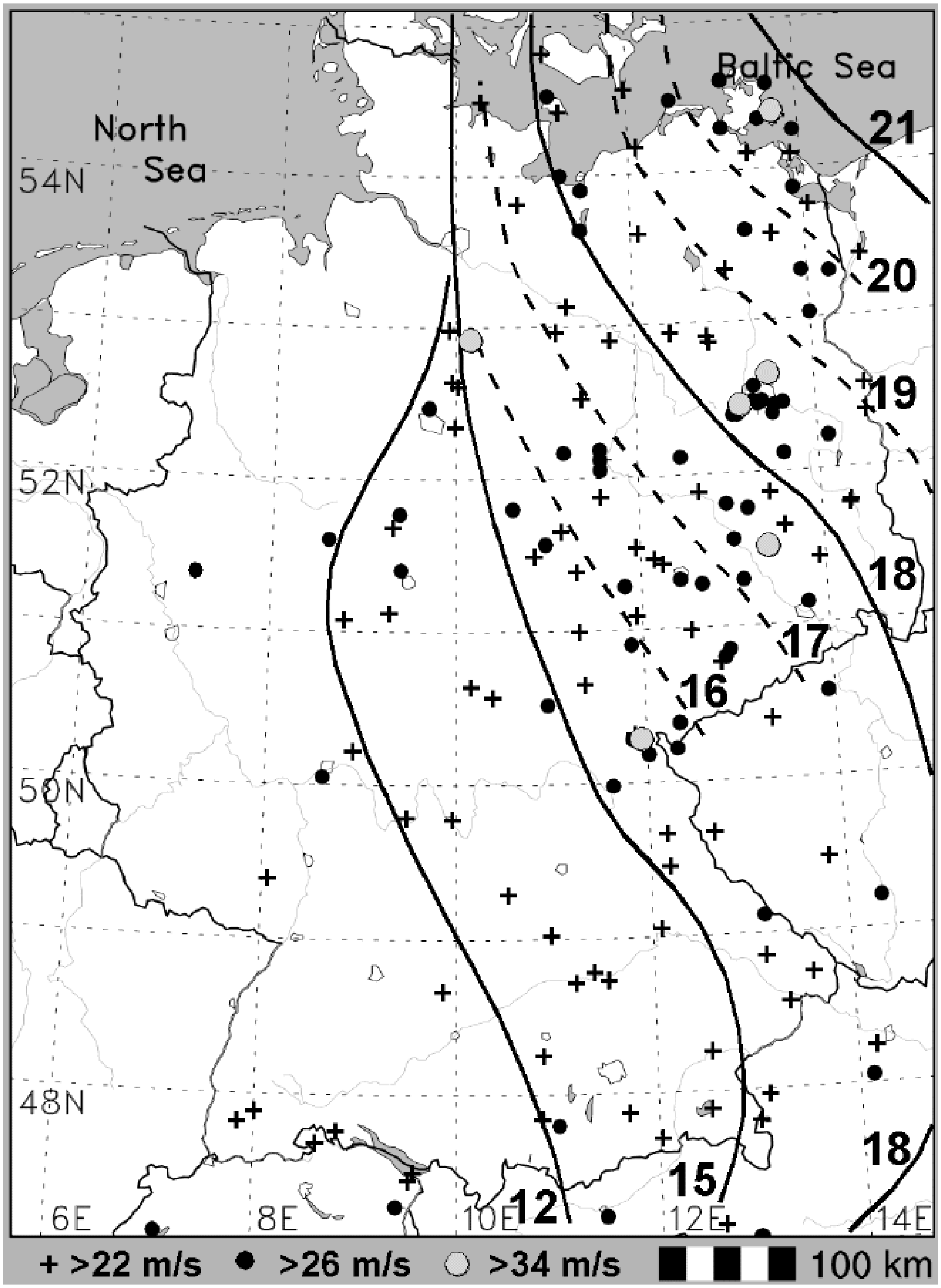

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