QUANTITATIVE COMPARISON OF METEOSAT-BASED THUNDER-STORM DETECTION AND NOWCASTING WITH IN SITU REPORTS IN THE EUROPEAN SEVERE WEATHER DATABASE (ESWD)

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Abstract

Severe thunderstorms constitute a major weather hazard in Europe, with an estimated total damage of € 5-8 billion each year. Yet a pan-European database of severe weather reports in a homogeneous data format has become available only recently: the European Severe Weather Database (ESWD). We demonstrate the large potential of ESWD applications for storm detection and forecast evaluation purposes and complement an earlier case-based study. The analysis of all warm-season (JJA) severe weather days in Europe in 2008 corroborated our earlier findings. There is a good agreement between ESWD reports and Cb-TRAM detected thunderstorms, even though no exact correspondence between ESWD reports and Cb-TRAM cells is required (e.g. due to storm morphology). Correspondingly, a large portion of ESWD reports regarded as misses by our strict in/out-of-Cb-TRAM-polygon criterion were still located close to a Cb-TRAM cell. Quantitatively, only the probability of detection (POD) can be evaluated due to the different characteristics of the two data sources. The POD for storm detection was 0.24 on average, with maximum values up to 0.58. The respective analysis for the 30 and 60 minutes nowcasts yielded average POD values of 0.11 and 0.08, respectively, with maximum values of POD exceeding 0.4 on 3 days for the 30 minutes nowcast and on one day for the 60 minutes nowcast.

1. INTRODUCTION

Severe thunderstorms, with their attendant damaging wind gusts, large hail, flooding, and tornadoes, are common phenomena in many European countries, leading to a total damage estimate of 5 to 8 billion euros per year (source: Munich RE). Extreme events like an F4 tornado in France and an F3 downburst in Austria in 2008 exemplify these damage totals. However, documentation and analysis of European severe convective storms in the scientific literature have been relatively sparse from about 1950-2000, and a pan-European database of actual in situ severe storm reports was unavailable even a few years ago.

Severe thunderstorms require essential ingredients such as the presence of moisture and instability, a source of upward motion and strong vertical wind shear (cf. Doswell, 2001). An important question is which processes lead to the simultaneous occurrence of those ingredients at a certain point. In answering this question for European storms, a particular challenge is posed by the complex terrain and coastlines in Europe. These likely play important roles in creating regionally favourable circumstances for severe thunderstorms, for example by the mesoscale flows that they induce. A better knowledge of European severe thunderstorms could bring new insights into these issues and also foster climatological evaluation and forecasting of severe thunderstorms worldwide.

Accordingly, the European Severe Storms Laboratory (ESSL) was founded in 2002 as an informal network of scientists from all over Europe and formally established in 2006 as a non-profit research organisation (registered association, *eingetragener Verein, e. V.*) with the following primary statutory purposes:

- Basic and applied research on severe weather events;
- Development and quality-control of the European severe weather database, ESWD, which collects detailed and quality-controlled in situ reports of severe weather events all over Europe;
- Coordination of the European Conferences on Severe Storms, ECSS.

Note that neither issuing forecasts nor warnings are among the activities of the ESSL, as these are core duties of the European national meteorological and hydrological services (NMHS). However, in addition to Dotzek and Forster (2008), the present paper will demonstrate that the ESWD data provide many new opportunities to quantitatively evaluate not only thunderstorm detection and forecast products, but in principle also related warnings.

Six NMHS are currently partners of the ESSL: AEMet (Spain), DWD (Germany), FMI (Finland), NIMH (Bulgaria) as well as ZAMG and Austro Control (Austria). DWD and Austro Control are also institutional ESSL members, as well as EUMETSAT. A cooperation agreement with the European Meteorological Society (EMS) was signed in September 2007. Collaboration with additional NMHS or EUMETNET (e.g. with respect to www.meteoalarm.eu), and the ECMWF is desired in establishing the ESSL within the European atmospheric science community.

Recently, Dotzek and Forster (2008) had presented a preliminary comparison study of DLR's cloud tracker Cb-TRAM, an algorithm for the detection and nowcasting of convective storms using METEOSAT data, with data from the ESWD. Five case studies with severe thunderstorms over Europe showed that ESWD reports were consistently correlated to convective clouds detected by Cb-TRAM. Up to 47% corresponded exactly (i.e. report within detected thunderstorm cell), while substantially more reports were located close by these cells. Keeping in mind that no exact correspondence between Cb-TRAM detections and ESWD reports is strictly required, this result was quite encouraging.

Therefore, the present paper extends the study by Dotzek and Forster (2008) to a quantitative analysis of a full thunderstorm season (June, July, and August 2008) over Europe in order to statistically test the robustness of our previous findings. In addition, we also check the correlation of ESWD reports with Cb-TRAM nowcasts up to one hour. Both Dotzek and Forster (2008) as well as the present study aim at demonstrating the potential benefits of coupling satellite-based storm detection and nowcasting algorithms to ESWD ground reports of actual events. In this context, the ESWD database also contributes to ongoing severe weather research projects, like RegioExAKT (Regional Risk of Convective Extreme Weather Events: User-oriented Concepts for Trend Assessment and Adaptation, www.regioexakt.de) in Germany.

2. DATA

2.1 Cb-TRAM

The cloud-tracker Cb-TRAM (Cumulonimbus TRacking And Monitoring, Zinner et al., 2008) is a fully automated multi-channel algorithm for the detection and nowcasting of deep moist convection using Meteosat SEVIRI (Spinning Enhanced Visible and Infra-Red Imager) data. The channels broad-band high-resolution visible (HRV), water vapour (WV) 6.2 μm, and thermal infrared (IR) 10.8 μm are combined to classify three different stages of thunderstorm development, see Fig. 1:

- Strong local development of convective low-level clouds ("convective initiation");
- Rapid cooling of cloud tops by vertical cloud development ("rapid development");
- Mature thunderstorms reaching or even overshooting the tropopause level.

The HRV channel is used to localise regions of enhanced cloud-top structure ("roughness") from reflectivity gradients. In the "mature thunderstorm" identification, also tropopause temperatures from ECMWF (European Centre for Medium Range Weather Forecast) model forecasts are taken into account, thereby implicitly assuming that mature thunderstorm cells level out in the tropopause region.

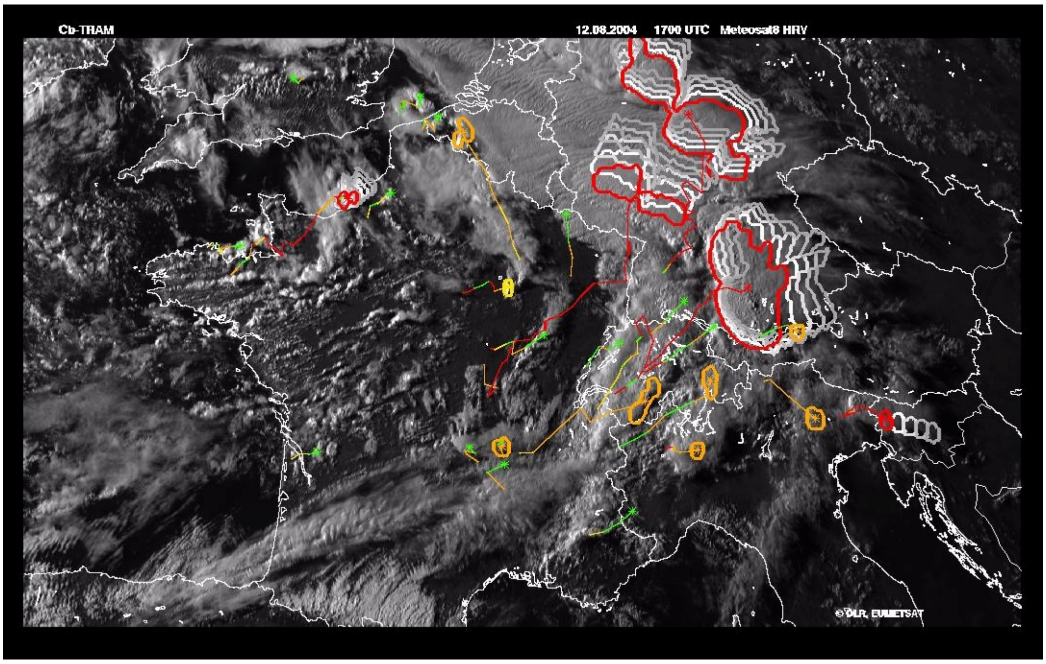

Figure 1: **Cb-TRAM example of 12 August 2004, 1700 UTC. Yellow = onset of convection, orange = rapid development, red = mature thunderstorm. Grey polygons show nowcasts of mature cells for 15, 30, 45, and 60 min, respectively. . Thin coloured lines indicate the tracks of the cells.**

The tracking in Cb-TRAM is based on the geographical overlap between current detections and first-guess patterns of cells detected in preceding time steps. At time *t*, the first-guess patterns are retrieved by using the approximate propagation direction and velocity of a detected cloud pattern at the previous time step *t-1* in combination with an image-matching algorithm (cf. Zinner et al., 2008). This algorithm extracts the general transformation vector field from two consecutive satellite images, thereby describing the cloud motion and local cloud developments. Similar to the first-guess patterns, nowcasting intervals from 15 to 60 minutes (cf. Fig. 1) are generated by extrapolation and exploitation of the pyramidal image-matching algorithm. Additional details as well as application and validation studies of Cb-TRAM were provided by Zinner and Betz (2009), Tafferner et al. (2008) and Forster et al. (2008). Dotzek and Forster (2008) had only focused on the three-level diagnostic detection polygons of Cb-TRAM. In the present study, we also include the verification of the nowcasting steps (30 and 60 minutes ahead in time, respectively).

2.2 European Severe Weather Database ESWD

The main goal of the ESWD (cf. Dotzek et al., 2006, 2009) is to gather and provide detailed and quality-controlled in situ reports of severe convective weather events (e.g., flash floods, hail, straight-line winds, tornadoes) all over Europe using a homogeneous data format and web-based, multi-lingual user-interfaces where both the collaborating NMHS and the public can contribute and retrieve observations. Involving the public via www.essl.org/ESWD/ (or equivalently www.eswd.eu) helps to raise completeness of the ESWD data significantly (Fig. 2). After two years of test operations, 2006 was the first year with operational ESWD service, and the database has been operational since then, undergoing a major software update by the end of 2008. By now, more than 25,000 reports (historic and current) are included in the database (Fig. 2).

ESWD development was based on the fact that severe convective weather events strongly depend on micro- and mesoscale atmospheric conditions, and in spite of the threat they pose to people and property, they usually escape the meshes of existing operational monitoring networks. Besides, such events are often embedded in systems acting on a larger scale, and even if damage is local, severe weather can continue for hours or days and affect more than one European country during its lifespan.

The following types of severe weather are included in the ESWD: Straight-line wind gusts (>25 m s^{-1}), tornadoes, large hail (diameter >2 cm), heavy precipitation, funnel clouds, gustnadoes, and lesser whirlwinds. To extend the range of covered phenomena is among ESSL's objectives, and envisaged by the flexible design of the data format (see www.essl.org/reports/tec/ESSL-tech-rep-2006-01.pdf).

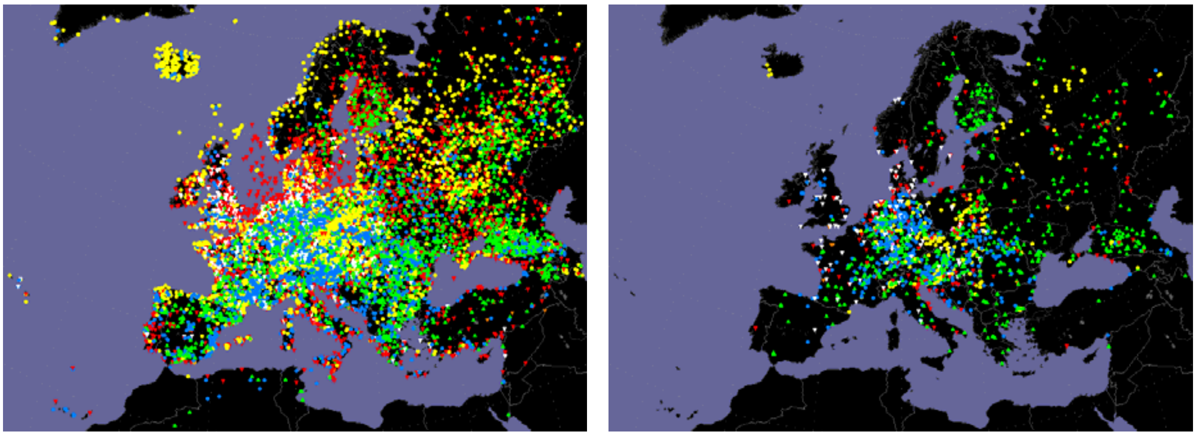

Figure 2: **Left panel: all 25144 ESWD reports (red: tornadoes, yellow: damaging wind, green: large hail, blue: heavy precipitation, white: funnel clouds). Right panel: all 2061 ESWD reports from 1 June to 31 August 2008. Date of ESWD inquiry: 19 November 2009.**

The database is maintained and developed by the ESSL, where also further information on its development is available from the websites www.essl.org as well as www.eswd.eu and www.ecss.eu. Aside from its main public web portal, ESWD development is documented at essl.org/projects/ESWD/ and by Dotzek et al. (2009).

The basic quality-control (QC) procedure foresees that the ESSL is responsible for QC of all ESWD reports coming in via the public interface while the cooperating NMHS are responsible for QC of the severe weather reports in their country, as entered, for instance, through their locally installed ESWD software. Each NMHS partner performs a three-level quality-control on the data gathered at its ESWD installation, while the ESSL is responsible for the three-level QC of the public reports from Europe and those entered by its ESWD maintenance team. Data exchange between the ESSL and the cooperating NMHS takes place in regular intervals, currently usually once a day. Herein, the NMHS partners upload their new or revised data to the ESSL main server, and download the new or updated public reports of severe weather in their respective countries. The three-level QC process specifies that any initial report to the database receives the lowest QC-level QC0 (or QC1 in reports entered by partner NMHS or ESSL if the initial information is already confirmed by several sources). Further verification of the report, including editing and augmenting the information contained therein, can lead to an upgrade to levels QC1 or QC2. The meanings of the three QC-levels in the ESWD are:

- QC0: "as received" (new report, only retained if at least plausibility can be ascertained);
- QC0+: "plausibility checked" (assigned by partner organisation or ESSL);
- QC1: "report confirmed" by reliable sources (assigned by partner organisation or ESSL);
- QC2: "event fully verified" i.e. all information about this event is verified, consistent and comes from reliable sources (assigned by partner NMHS or ESSL).

The ESWD public web portal displays the above terminology for the QC-levels, and highlights the fresh QC0 reports in the tabular list compared to the already checked QC0+ entries. This visual distinction between QC0 and QC0+ reports in the list facilitates the quality-control process during the main severe weather season when many new reports come in, and when it has to be clear at first glance which reports still require at least the initial plausibility check. Ideally, a few days after an extreme weather episode, all QC0 reports should have been either raised at least to QC0+ or deleted.

3. ANALYSIS OF THE 2008 WARM SEASON

3.1 25 June and 29 July 2008

Table 1 and Fig. 3 provide verification examples of convective clouds detected and nowcast by the Cb-TRAM algorithm. Note that the Cb-TRAM contours are corrected by the parallax error resulting from the viewing angle of METEOSAT, so they can be directly compared to the ESWD reports. Our initial study (Dotzek and Forster, 2008) was performed for only five days with warm-season severe convection, of which we show again the results for 29 July 2008 in Table 1.

Case	Number of ESWD reports	Number of ESWD reports within Cb-TRAM object	Percentage of ESWD reports within Cb-TRAM object
29 July 2008	27	11	41%

Table 1: **Number of ESWD reports as well as numbers and percentage of ideal correspondences between Cb-TRAM and ESWD reports, that is, ESWD reports within marked Cb-TRAM areas for 29 July 2008, cf. Dotzek and Forster (2008).**

For this day, 41% of all ESWD reports were falling exactly within the Cb-TRAM polygons, and on two other of the five days studied, this ratio also exceeded 40% (cf. Dotzek and Forster, 2008). Note that the severe weather events need not exclusively occur within Cb-TRAM's detected polygons, but can be shifted laterally or up-/downstream from the storms due to their specific thunderstorm morphology. Besides, the temporal resolution of the satellite pictures is 15 min, so all ESWD reports from 10 min before to 5 min after image time have been compared with the Cb-TRAM contours. Thus, ESWD reports sometimes appeared at a detected cell, but just before or just after a Cb-TRAM detection period. So, in light of the fact that no exact correspondence between Cb-TRAM polygons and ESWD reports is strictly required, the correspondence ratios of more than 40% were encouraging and provided the impetus for the present analysis.

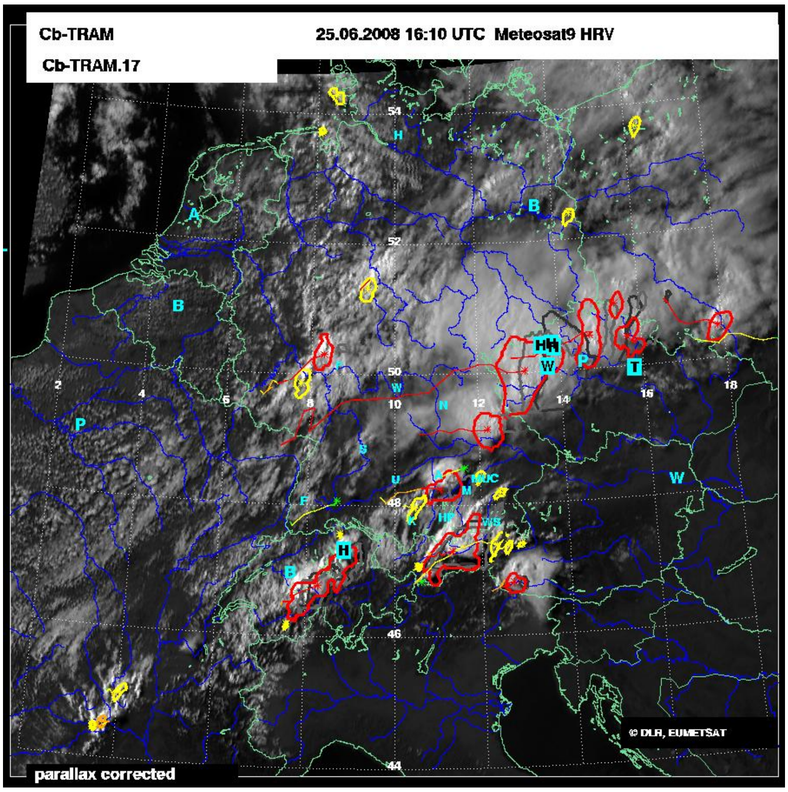

Figure 3: **METEOSAT-9 HRV image on 25 June 2008 at 1610 UTC with thunderstorms detected by Cb-TRAM superimposed as coloured contours (yellow: convective initiation, orange: rapid development, red: mature thunderstorm). Thin coloured lines indicate the tracks of the storms. Also shown are the 15 and 30 minutes nowcasts (grey contours) and ESWD reports (letters on cyan background, H: large hail, W: wind gust, T: tornado, P: heavy precipitation). ESWD reports fall in the timeframe from 10 min before to 5 min after image time.**

The next step was to test the validity of Cb-TRAM nowcasts using ESWD reports. Fig. 3 gives the example of 25 June 2008 at 1610 UTC, showing both a large variety of severe weather reports as well as the detected and nowcast Cb-TRAM objects. The growing completeness of the ESWD over the recent years enables the present study of a large set of warm-season cases with the objective to eventually reveal if, for instance, hail-producing cells have other Cb-TRAM detection or nowcast characteristics than thunderstorms producing damaging winds or heavy precipitation.

Of course, even though ESWD reports of any QC-level have been used here, there may also be cells detected by Cb-TRAM which indeed caused severe weather at the ground, but for which no ESWD report was received. Therefore, the absence of severe weather reports cannot be regarded as proof that a convective storm was not severe. But in any case, the presence of an ESWD report provides strong evidence for the validity of any Cb-TRAM detection polygon assignment.

3.2 Quantitative analysis, warm season (JJA) 2008

For June, July, and August 2008, the probability of detection (POD) that ESWD reports were located within contours of thunderstorm cells detected or nowcast by Cb-TRAM was evaluated. 42 days with less than 10 ESWD reports or zero clouds detected by Cb-TRAM were excluded from the statistical analysis, as these were days with no, only weak, or sparse convective activity which might have been obscured by high-level cloud shields.

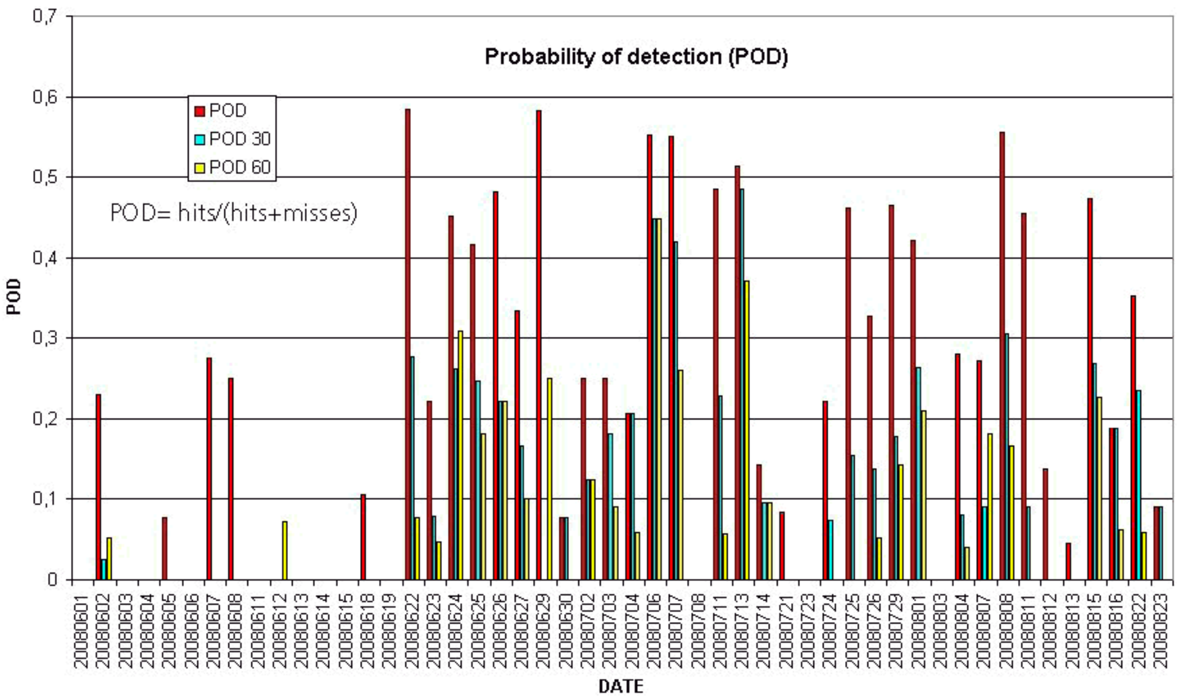

Figure 4: **Statistical evaluation of the ESWD comparison with Cb-TRAM over summer 2008 for days with more than 10 ESWD reports and more than zero clouds detected by Cb-TRAM. Red columns represent the probability of detection (POD) that ESWD reports are within a detected Cb-TRAM cell. The cyan and yellow columns show the POD that ESWD reports correspond with the 30 minutes or 60 minutes Cb-TRAM nowcast, respectively.**

Due to the fact that not all actual severe weather at the ground is reported to the ESWD, and that Cb-TRAM may also detect or nowcast thunderstorms which do not produce severe weather sometime during their lifespan, the comparison between the two data types is complicated. Quantitatively, only the probability of detection

$$POD = \frac{HITS}{HITS + MISSES} \quad (1)$$

can be evaluated. Our analysis revealed that the POD was 0.24 on average. However, 14 days with strong convective activity reached POD-values exceeding 0.4 with a maximum of 0.58 (Fig. 4). Keeping in mind that the severe weather events do not have to occur exclusively within Cb-TRAM's detected polygons, but can be shifted laterally or up-/downstream from the storms due to the specific thunderstorm morphology, the agreement between satellite detected thunderstorms and severe weather reports is rather good. The respective analysis for the 30 and 60 minutes nowcasts yielded average POD values of 0.11 and 0.08, respectively, with maximum PODs exceeding 0.4 on 3 days for the 30 minutes nowcast and on one day for the 60 minutes nowcast, as also illustrated in Fig. 4.

4. CONCLUSIONS

The analysis of the 2008 warm-season thunderstorms presented here underpins the applicability of ESWD ground-truth severe storm reports for verification purposes, in addition to Dotzek and Forster (2008). In principle, any forecast field or nowcasting product (cf. König et al., 2007; Zinner et al., 2008; Dotzek et al., 2009) related to thunderstorm occurrence or to area-based warnings could be evaluated against ESWD reports. This would in turn help to improve these nowcasting techniques or forecast and warning procedures. Our study further showed:

- The results by Dotzek and Forster (2008) could be corroborated. There is a good agreement between ESWD reports and Cb-TRAM detected thunderstorms, even though no exact correspondence between ESWD reports and Cb-TRAM cells is required (e.g. due to storm morphology). Correspondingly, a large portion of ESWD reports regarded as misses by our strict in/out-of-Cb-TRAM-polygon criterion were still located close to a Cb-TRAM cell;
- The POD for storm detection was 0.24 on average, with maximum values up to 0.58;
- If a detected Cb-TRAM cell is not related to an ESWD report, this does not falsify the Cb-TRAM polygon, but the convective storm might simply have not been severe;
- Likewise, absence of Cb-TRAM detections on some days cannot be regarded as proof that there was no severe weather. The ESWD reports on such days might have come from rather short-lived, small or low-topped convective storms, or those developing below cirrus layers.

Ongoing work includes using the ESWD data in the evaluation of total lightning detection and satellite-based convective initiation (CI) detection algorithms.

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