Convection Initiation in COPS: Radar Climatology and 6 August 2007 Case Study

Tammy M. Weckwerth*, Lindsay J. Bennett2, James W. Wilson1, Joël Van Baelen3, Martin Hagen4, Tracy J. Emerson1 and Leslie Grebe4

1National Center for Atmospheric Research, Boulder, CO, USA, *tammy@ucar.edu
2School of Earth and Environment, University of Leeds, Leeds, UK
3CNRS and Université Blaise Pascal, Clermont-Ferrand, France
4Deutsches Zentrum für Luft- und Raumfahrt, Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany

Abstract

A climatology of convection initiation (CI) events has been developed using radar reflectivity data in southwestern Germany and eastern France over the period of May-August of 2000-2008. The nine-year summertime climatology results are compared with the results from the summer of 2007, during which the Convective and Orographically-induced Precipitation Study (COPS) field campaign was conducted. A detailed case study of a COPS day, on 6 August 2007, using two Doppler on Wheels (DOW; Wurman et al. 1997) mobile radar systems, GPS tomography water vapor fields and WRF mesoscale modeling simulations, will also be presented to illustrate potential mechanisms affecting CI on that day.

The radar climatology study region included the Vosges Mountains of France, the Rhine Valley which straddles France and Germany, the Black Forest Mountains and the Swabian Mountains of Germany. Convection occurred frequently during the summer months throughout the study region. The CI density illustrates preferential storm development in the mountainous regions. There is a strong mid-day peak of the CI events suggesting that diurnal heating is critical for CI in the region.

COPS was conducted with the objective of obtaining improved understanding of convective processes and short-term quantitative precipitation forecasting (QPF) in low-mountain regions (Wulfmeyer et al. 2008). The COPS summer exhibited preferential CI density (CI events per area) in the mountainous regions but not as pronounced as the climatology. Compared with the frequency of daytime, locally-forced CI occurrences during the climatology, the COPS summer appeared to exhibit more synoptically-forced CI.

The 6 August 2007 case study illustrates daytime CI along the slopes of the Vosges Mountains. The storms strengthen and merge as they propagate across the Rhine Valley, produce an outflow boundary and cause further CI events in the valley. Preliminary results of this case study will be presented.

1. Motivation

A small number of relevant CI studies have been performed in the COPS region. Aoshima et al. (2008) performed a Meteosat rapid scan high-resolution CI satellite climatology during the COPS Intensive Operations Periods (IOPs) of June-August 2007. They found that the CI density was three times greater in the Vosges and Black Forest mountains compared to the Rhine Valley. There was a pronounced maximum (18% of all CI events) at 13-14 UTC suggesting that the convection was driven by the daytime heating of the planetary boundary layer. Case studies showed that a combination of diurnal heating and mesoscale convergence zones led to CI despite limited thermodynamic support (i.e., low CAPE and relatively high CIN; Kalthoff et al. 2009). Hagen et al. (2011) compared two CI days during COPS and noted that the Rhine Valley is densely populated with strong industrial activity; therefore they suggested that the heat island effect could supply enough buoyancy to overcome the CIN and allow for thunderstorm development.

This paper will extend the previous work by providing a comprehensive radar climatology of the region, showing the preferred initiation locations and timing. Additionally preliminary results of a COPS CI case study will be presented in which low-level high-resolution dual-Doppler winds are combined with GPS moisture retrievals, surface stations, soundings and WRF simulations. The goal of this case study is to provide detailed observations of the processes leading to CI.
2. Radar climatology and case study methodology

The dataset used for the radar climatology was the German Weather Service (DWD: Deutscher Wetterdienst) C-band radar reflectivity composite with 4x4-km spatial and 15-min temporal resolution during May-August of 2000-2008. During the summers of 2005-2006, the DWD mosaic radar data was missing approximately half of the time, therefore the MeteoSwiss C-band radar composite dataset (2 km/5 min resolution) was used to fill in the gaps for those two summers. The study area encompassed >25,000 km² with 52% (48%) of the area covering mountainous (Rhine Valley) regions. For this study, the three mountain ranges and the Rhine Valley were divided into north and south sections (oddly-shaped white lines in Fig. 1) to assess the variations in statistics between the different regions.

Convection initiation was defined when a radar image illustrated new convection with radar reflectivities at or above the moderate threshold (defined as 28-36.5 dBZ). This reflectivity threshold is consistent with previous work defining CI when radar reflectivity values exceeded 35 dBZ (e.g., Wilson and Schreiber 1986; Mecikalski and Bedka 2006) since that value correlates well with the development of lightning within mature cumulonimbus clouds (Roberts and Rutledge 2003). There were 3190 CI events identified for the nine-year summertime climatology.

The 6 August 2007 case study was performed using synchronized scans from the two DOWs, positioned 31 km apart. They collected pre-convective observations of the clear-air wind field through to the development and decay of the storms. The data were interpolated onto a Cartesian grid and using mass continuity, were synthesized into a three-dimensional wind field. Tomographic retrievals were obtained from GPS stations in the region (e.g., Van Baelen and Penide 2009). These observations will be combined with soundings, surface stations and other COPS instrumentation to assess the processes leading to CI on this day. Simulations with high-resolution WRF (Weather Research and Forecasting; e.g., Skamarock et al. 2005) model were performed to address the generality of the 6 August 2007 observational results. The model configuration consisted of three domains at grid sizes of 6.3 km, 2.1 km and 0.7 km, with two-way nesting, initialized with 1 degree GFS analyses. Thompson microphysics and the MYJ boundary layer scheme were chosen to be run with the Noah land surface model. Explicit convection was utilized for the inner two domains while the Betts-Miller-Janjic parameterization scheme was used for the outer domain.

FIG. 1. Map of southwestern Germany/eastern France showing the COPS domain used in this radar climatology study (white circular region). Elevation is shown in m MSL. Radar locations used in this study are shown by the radar symbols. Mountain peaks for the three COPS mountain ranges are shown as triangles. Oddly-shaped contours indicate different regions used in this study and used in Table 1.
3. Radar climatology of the COPS region

Due to previous research (e.g., Banta and Schaaf 1987), it was expected that there would be a concentration of CI events near the mountain peaks. Figure 2 shows the location of CI events for the summertime period 2000-2008 (Fig. 2a) as well as 2007 alone; the COPS year (Fig. 2b). There is not an obvious clustering of points over the higher peaks. CI locations are distributed throughout the entire study area, with a slight visual appearance of an increase in density over the southern Black Forest and in the western Swabian Mountains (Fig. 2a). There are minor variations in the year-by-year maps but the widespread occurrences of CI events are observed every summer, including the COPS summer (Fig. 2b).

FIG. 2. Convection initiation locations within the COPS domain for summer months of a) 2000-2008 and b) 2007. The number of CI events for each time period is shown in parentheses.

In order to quantify the preferred locations for CI, the number of events per area for each region was calculated. For the different regions illustrated in Fig. 1, the annual-average densities (events per 1000 km²/yr) of CI events for both the nine-year climatology period and for 2007 alone are shown in Table 1. During the entire climatological period, the mountain regions (average of 13.4 CI events/1000 km²/yr) had the highest density of initiations while the Rhine Valley produced approximately one-half as many CI events (average of 7.1 CI events/1000 km²/yr). Table 1 shows that the greatest density of CI events occurred in the western Swabian Mountains (15.7 CI events/1000
km²/yr) and the southern Black Forest Mountains (14.4 CI events/1000 km²/yr). In contrast the southern Rhine Valley produced only 7.4 CI events/1000 km²/yr. This preference for mountain CI suggests that orographic lifting and convergence associated with diurnal heating and slope flows play an important role in CI in the COPS region.

In 2007 alone the maximum density of CI events, as shown in the parentheses of Table 1, occurred in the northern Vosges and eastern Swabian Mountains (13.8 CI events/1000 km²). The average CI density of the mountain regions was 13.0 CI events/1000 km² while the average CI density in the Rhine Valley was 8.6 CI events/1000 km². In contrast to the satellite climatology results by Aoshima (2008) who found the ratio of mountain to valley CI events was 3, this study found that the ratio was much less (1.5). This difference could be due to different datasets (satellite vs. radar) and due to the fact that the satellite data was analyzed only for a subset of the COPS days, i.e., the IOP days. The ratio of mountain to valley CI was less in the COPS summer (1.5) than in the climatological data (1.9), suggesting that different forcing mechanisms were dominant in 2007 compared with the 2000-2008 climatology.

Table 1 additionally shows densities of the CI events of different regions separated into different categories for maximum strength and size attained, duration of the storm and time of CI. There are 2-3 times greater density of CI events that become strong, large and long-lived storms that initiate in the mountains than those storms that initiate in the Rhine Valley. For example, the average density of CI events that developed into intense storms >55 dBZ in the mountains was 3.3 CI events/1000 km²/yr compared with only 1.1 CI events/1000 km²/yr in the Rhine Valley. Similarly the largest and longest duration storms had higher average densities in the mountains (2.8 and 7.6 CI events/1000 km²/yr, respectively) that were two times greater than the average densities in the Rhine Valley (1.2 and 3.3 CI events/1000 km²/yr, respectively). For the weaker, smaller and short-lived storms, there was a more uniform distribution of CI density across the region with on the order of only 50% more CI events occurring in the mountains than in the valley. For example, the storms that reached only 36 dBZ had a highest density occurrence in the western Swabian Mountains (1.7 CI events/1000 km²/yr) while the density in the southern Rhine Valley was 1.1 CI events/1000 km²/yr. Similar results were obtained during the COPS summer (density values shown in parentheses in Table 1). Thus the stronger, larger and long-lived storms had a 2-3 times greater density occurrence in the mountains than in the Rhine Valley while the weaker, smaller and short-lived storms were more evenly distributed between the mountains and the Rhine Valley (ratio of 1.5).

![FIG. 3. Percent of CI events within the COPS region vs. date for 2000-2008 (gray) and COPS summer of 2007 (black). Each vertical bar corresponds to three days.](image)

There was a relatively consistent frequency of CI events throughout the summertime days of 2000-2008 (Fig. 3). CI events were identified on 61.8% of the summertime days in the nine-year period. The highest percentages of CI events occurred in mid-May, early June and late July-early August (gray bars of Fig. 3). CI events occurred on 70.7% of the summertime COPS days (black bars of Fig. 3). While the percentages of COPS CI days were similar to climatology, the character, timing and distribution of the convection was somewhat different. For the COPS summer, the highest percentage of CI events occurred in late May and early-mid June. July and August had far fewer CI events than climatology with the exception of a few days. Rather than the climatological pattern of CI events on most days, the COPS summer exhibited a higher percentage of CI events on fewer days. This was particularly true early in the summer.
There was a clear diurnal peak at 1000-1030 UTC for CI events during the 2000-2008 period (Fig. 4). This time corresponds to a steep increase in solar heating (local noon is at 1130 UTC) and suggests a strong relationship with surface heating and associated surface forcing mechanisms. This is earlier than previous CI studies, including Aoshima et al. (2008) who observed a maximum of satellite-observed CI at 1300-1400 UTC. Those differences might be attributed to only a subset of COPS IOP data analyzed by Aoshima et al. (2008) and/or radar detections of CI occurring earlier than Meteosat detections. It also appears the COPS summer (black bars of Fig. 4) depicts a broader daytime peak than the climatology which may be more consistent with the Aoshima et al. (2008) results.

![Fig. 4](image_url)

**Fig. 4.** Percentage of convection initiation events vs. time of day (UTC) in 2000-2008 (gray bars) and the COPS summer (black bars). Histogram bars are 30-min intervals.

**Table 1.** Annual summertime average density of convective events (events/1000 km²/yr) for various regions of Fig. 1. The COPS summer densities are shown in parentheses. The CI events are separated according to maximum reflectivity, size and duration of the storm.

<table>
<thead>
<tr>
<th>Region</th>
<th>CI</th>
<th>Maximum reflectivity (dBZ)</th>
<th>Size (km²)</th>
<th>Duration (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>36</td>
<td>45</td>
<td>54</td>
</tr>
<tr>
<td>S. Vosges</td>
<td>12.6</td>
<td>0.9 (1.2)</td>
<td>3.1 (3.2)</td>
<td>5.2 (3.7)</td>
</tr>
<tr>
<td>N. Vosges</td>
<td>13.7</td>
<td>1.3 (2.3)</td>
<td>4.0 (3.1)</td>
<td>5.7 (6.2)</td>
</tr>
<tr>
<td>S. Rhine Valley</td>
<td>7.4 (7.3)</td>
<td>1.1 (0.9)</td>
<td>1.8 (1.3)</td>
<td>3.0 (3.4)</td>
</tr>
<tr>
<td>N. Rhine Valley</td>
<td>6.7 (9.9)</td>
<td>1.1 (2.1)</td>
<td>2.4 (3.2)</td>
<td>2.5 (3.7)</td>
</tr>
<tr>
<td>S. Black Forest</td>
<td>14.4 (13.0)</td>
<td>0.7 (0.6)</td>
<td>2.7 (2.9)</td>
<td>5.9 (4.9)</td>
</tr>
<tr>
<td>N. Black Forest</td>
<td>12.3 (13.1)</td>
<td>1.3 (2.3)</td>
<td>3.2 (0.9)</td>
<td>5.0 (6.8)</td>
</tr>
<tr>
<td>W. Swabian</td>
<td>15.7 (12.7)</td>
<td>1.7 (0.9)</td>
<td>3.7 (4.5)</td>
<td>6.3 (5.0)</td>
</tr>
<tr>
<td>E. Swabian</td>
<td>12.2 (13.8)</td>
<td>1.1 (0.5)</td>
<td>2.9 (1.4)</td>
<td>6.2 (10.0)</td>
</tr>
</tbody>
</table>
4. 6 August 2007 case study

On 6 August 2007 a frontal system approached the COPS low-mountain region from the west. In advance of the front, convection initiated along the eastern slope of the Vosges Mountains. The storms propagated eastward into the Rhine Valley and produced an outflow boundary that supported secondary initiation.

Dual-Doppler observations were obtained from the Doppler on Wheels (DOW) mobile radars. These systems provided clear-air measurements prior to convection forming in the Vosges Mountains (Fig. 5). At 1330 UTC the low-level winds were south-southwesterly throughout the Rhine Valley with an upslope component generating low-level convergence along the slope of the Vosges Mountains. By 1430 UTC two cells formed along the eastern slope of the Vosges (Fig. 6). The storms propagated across the Rhine Valley, produced an outflow boundary and caused further initiation in the valley (not shown). The goals of this case study are to better understand the causes of the location and timing of the first convective cells.

FIG. 5. DOW wind syntheses overlaid on topography at 1330 UTC on 6 August 2007. The DOW locations are shown as red x’s.

Additional information about the pre-convective environment will be assessed with the use of surface stations, soundings and GPS moisture retrievals. Initial WRF results of the inner 0.7-km-resolution grid show that the south-southwesterly and upslope flows were generally well represented at 1330 UTC (Fig. 7). By 1430 UTC small and weak cells formed in a similar location to those observed (Fig. 8). Numerous sensitivity studies were performed by varying the input analyses and the parameterization schemes. These simulations all produced similar wind, cloud and rain fields but will be thoroughly compared with synoptic and profiling data, as well as with the DOW data, to gain confidence on their representativeness of this case study. Further simulations may include removing the mountains to assess the importance of the Rhine Valley and the Vosges Mountains in convective development and evolution on this day.

5. Summary and conclusions

Results of a nine-year European radar data climatology from the COPS region of southwestern Germany and eastern France are presented from the summer months (May-August) of 2000-2008. The DWD and MeteoSwiss composite radar data show numerous CI events in the low-mountain regions of the COPS domain. Numerous storms occurred throughout the region, including in the Rhine Valley. The frequency of storms in the region was high, with more than 61% of the summertime days having CI events. During the COPS summer of 2007, 71% of the summertime days had CI events.
The CI densities of the climatology showed preferred development locations; CI density was nearly twice as pronounced in the mountain regions compared to the Rhine Valley. The mountain/valley CI ratio in the COPS summer was only 1.5. This suggests that mountain-forced CI caused by differential heating along the slopes and/or upslope flow was less in the COPS summer than in the climatology.

Most of the CI events over the nine-year period occurred at mid-day suggesting a strong relationship with diurnal heating and associated slope flows and convergence lines produced by differential heating. The climatological CI peak occurred at 1000-1030 UTC which was earlier than previous CI studies showed. The COPS summer exhibited a different distribution with more CI events occurring at various times of the day and more nocturnal storms, further supporting the suggestion of stronger synoptic-scale forcing during the summer of 2007.

When the storms were stratified by intensity, size and duration, it was apparent that the strongest, largest and long-lived storms initiated most frequently in the mountains (mountain to Rhine Valley ratio of 2-3) while the weaker, smaller and short-lived storms were more evenly distributed between the mountains and Rhine Valley (mountain to Rhine Valley ratio of 1.5).

Even though the mountain CI and densities were higher than the Rhine Valley, it was interesting to observe the high frequency of events in the Rhine Valley. One possible reason for CI in the Rhine Valley may be the common occurrence of boundary layer convergence zones. Hagen et al. (2011) frequently observed CI in the Rhine Valley on days with strong southwesterly winds. They attributed the origin of CI to convergence zones caused by flow around the Vosges at the southern and northern ends and flow through the west-east oriented gaps and valleys of the Vosges. Low-level boundaries were also shown to be important for CI in the COPS region by Kottmeier et al. (2008). Such boundaries were often observed by the DOW mobile radars, typically positioned in the Rhine Valley during COPS. Some of those boundaries occurred at distinct angles to the mountains and valleys. Thus the causes of the boundaries could be slope flows, valley flows and channeling and blockage by the various mountain ranges. Such boundaries and their relationships with convection will be analyzed in future studies with a combination of DOW data, extensive and diverse COPS datasets and numerical modeling studies.

One such case study currently underway is on 6 August 2007. Preliminary results show convection initiation on the slopes of the Vosges Mountains along a region of ow-level convergence in the wind field. WRF simulations showed a similar wind structure prior to convective development. A combination of DOW wind syntheses, surface stations, soundings, GPS tomography and WRF simulations will be used to assess the causes and timing of CI during this case study. Preliminary results will be presented at the conference.

FIG. 6. Same as Fig. 5 except for 1430 UTC.
**FIG. 7.** WRF high-resolution simulation of wind field, topography (shaded) and precipitation (blue shading) at 1330 UTC on 6 August 2007. Black dots indicate locations of DOW radars. Black nearly north-south line is France/Germany border.

**FIG. 8.** Same as Fig. 7 but for 1430 UTC.
Acknowledgments

The German Weather Service (DWD) is gratefully acknowledged for providing the PI radar data used for this study. Katja Friedrich (CU) provided two summers of MeteoSwiss radar data used to fill in the gaps in the DWD data. Niles Oien (NCAR/RAL) was critical for translating the data and setting up the European CIDD display for analysis at NCAR. Janine Goldstein (NCAR/EOL), Jean Hurst (NCAR/EOL) and Bruce Morley (NCAR/EOL) assisted in various parts of the convection initiation identifications. Discussions with Jay Miller (NCAR/EOL), James Pinto (NCAR/RAL) and Wiebke Deierling (NCAR/RAL) were insightful and very helpful. The NCAR Short-Term Explicit Prediction (STEP) Program is gratefully acknowledged for supporting a portion of this research. The DOWs in COPS were funded through the German Research Foundation (DFG) and the Ministry of Science in Baden-Württemberg. NCAR is sponsored by the National Science Foundation.

References


