GIS ANALYSIS OF AUSTRIAN-BAVARIAN CLOUD-TO-GROUND LIGHTNING DATA[I]

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I. INTRODUCTION

Based on lightning records provided by the *Austrian Lightning Detection and Information System* (ALDIS), the cloud-to-ground (CG) lightning structure was analyzed. The cross-border study site covers an area of 40,000 square kilometres encompassing the Austrian Federal province of Salzburg and south-east Bavaria, Germany. From 1998 to 2009 about 1 million CG lightning flashes occurred in the area populated by roughly 1.3 million inhabitants.

In order to analyze CG lightning activity fine-grain concerning the spatiotemporal distribution of lightning occurrence and the coherence between lightning activity and topographic properties, a geographic information system (GIS) was used. Furthermore, a cross-border approach for the derivation of hazard zones as an indicator for the optimization of preventive measures was developed. Consequently, the results of this study can be used as a decision support for lightning prevention, risk management, spatial planning and civil protection.

II. METHODOLOGY

One major focus was the analysis of the spatiotemporal behaviour of cloud-to-ground lightning in the study area. To visualize and compare spatial patterns, lightning flash densities were modelled using an 1 square km grid. This lightning flash density can be defined as the number of flashes of a specific lightning type occurring on or over unit area in unit time (Kuleshov et al., 2009).

For the calculation of the flash density in the study area, well-known GIS technologies were used to count cloud-to-ground flashes per grid cell for certain time intervals. This procedure allowed the derivation of the so-called *local flash density* (LFD), which represents the number of flashes per square kilometre. In order to smooth statistical outliers occurring on the LFD-surface a 3x3 moving window was used to calculate a focal mean for each grid cell (see FIG. 1; left). This arithmetically averaged *focal flash density* (FFD) is commonly used to describe lightning activity and to assess the lightning strike risk for buildings (e.g. EN62305-2: Kern, Landers and Diendorfer, 2008).

In addition to these conventional approaches, a third method named *probabilistic flash density* (PFD) was developed. For the derivation of the PFD, a more complex calculus following the conception of Campos and Pinto (2007) was used. In contrast to the LFD and FFD, probability ellipses, which are available for each detected lightning flash, were aggregated instead of discrete flash points. In order to enable the grid aggregation, the probability ellipses were divided into 10% probability slices. Thus, the PFD could be calculated by means of the summation of all probability-slice-values per grid cell depending on their grid overlap area (see FIG. 1; right).

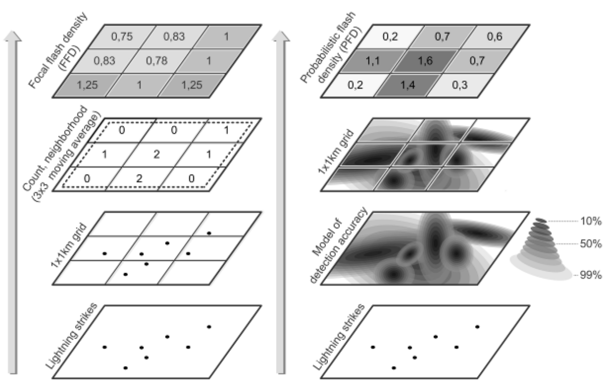

FIG. 1: Estimation of the focal flash density (left) and the probabilistic flash density (right)

By means of these density models it was possible to derive lightning “Hot Spots” and “Cold Spots” by delimitating grid cells with an above or below average lightning activity in each year. In this context, areas with high lightning activity in each year can be thought of as hazard zones.

Besides, the spatial coherence between lightning activity and topographic properties was calculated on a cell by cell basis using a linear ordinary least square regression model. This makes it possible to apply a spatially distributed regression not only to the whole study area, but also to arbitrary sub-territories. For this purpose, the 1,000x1,000m lightning-grid is supplemented with further spatial information such as height above sea level, surface curvature, land cover and settlement structure, et cetera.

In the following section, the results of the study are presented in conjunction with some generic lightning statistics.

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III. RESULTS

From 1998 to 2009, the lightning detection network EUCLID registered roughly 1 million CG lightning flashes in the study area. The mean annual density was 2.24 flashes per km^2 in the whole study area, 2.35 in Salzburg and 2.06 in south-east Bavaria respectively (see TABLE 1).

	CG Flashes (1998-2009)	Annual density (Flashes per km^2)
Study Area	1,076,151	2.24
Salzburg	201,750	2.35
South-East Bavaria	129,104	2.06

TABLE 1: Key figures for the lightning activity in the study area

The lightning density maps show a high CG density variance due to varying thunderstorm activity and tracks. It has to be mentioned, however, that the variance strongly depends on the applied calculation method. Using the local flash density (LFD) method, mean annual densities from 0.25 to 26.00 lightning flashes per km^2 occurred. In contrast, the calculation of the focal flash density (FFD) led to more realistic values, whereas the probabilistic flash density (PFD) exhibited statistical outliers similar to the results obtained with the local flash density method (see TABLE 2).

	Minimum	Maximum
LFD	0.25	26.00
FFD	0.73	6.37
PFD	0.57	22.53

TABLE 2: Minimum and maximum densities for the various density calculation methods

Because of the reliability and the widespread use of the FFD, this method was chosen for the further spatial analyses and the visualization of the perennial lightning activity in the study area (see FIG. 2).

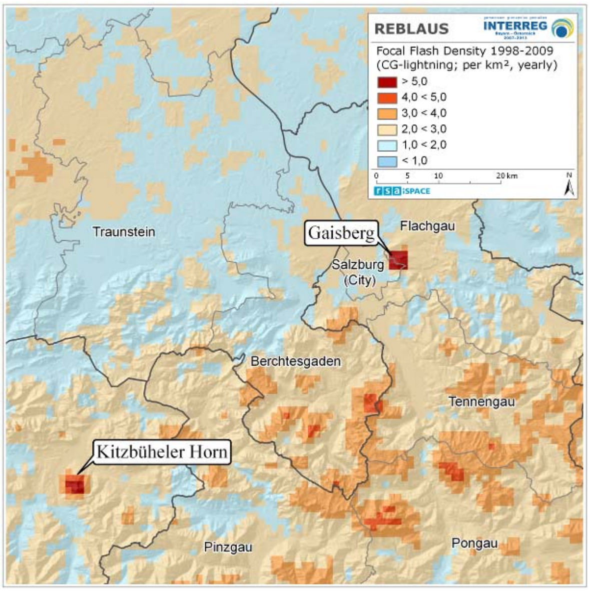

FIG. 2: Focal flash density map of the border area between Salzburg and south-east Bavaria (mean annual lightning activity 1998-2009)

Areas with extraordinary high lightning activity were observed on two mountaintop towers: One near Salzburg City (Gaisberg) and another nearby Kitzbühel (Kitzbüheler Horn). At these two locations, upward initiated lightning plays an important role. Further areas of high lightning activity are located across the northern edge of the Alps between the districts Pinzgau and Tennengau.

To quantify regional lightning "Hot Spots" and "Cold Spots" respectively, grid cells with an above or below average lightning activity in each year between 1998 and 2009 were extracted. FIG. 3 shows the spatial distribution of these clusters within the study area. Thereby, "Hot Spots" mainly occur in the southern and south-eastern part of the considered area, whereas "Cold Spots" primarily occur in the north and west with an extended "Cold Spot" spanning the border area between Salzburg and Tyrol. It should be mentioned in this context, that the majority of the areas with pronounced lightning activity are located along unsettled mountain ridges. The settled area exhibits a relatively low mean focal flash density of about 2 flashes per km^2. To evaluate the effects of lightning on the infrastructure in the region, a comprehensive analysis with respect to damages caused by lightning flashes is underway.

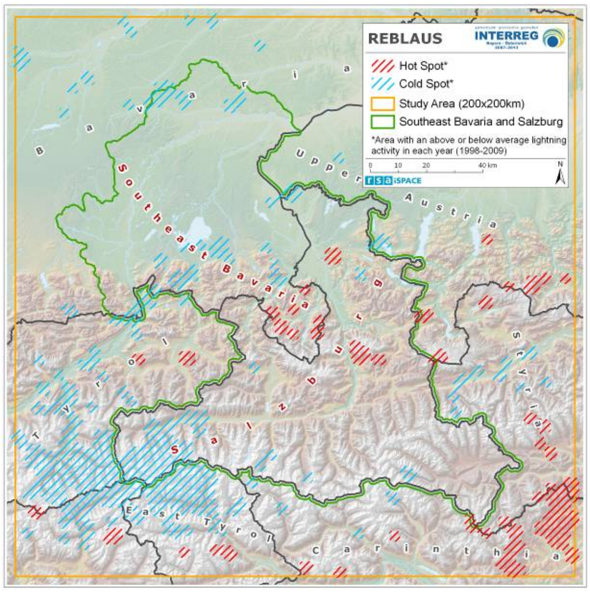

FIG. 3: Lightning "Hot Spots" and "Cold Spots" in the study area

Because of the lightning patterns visualized and the generally large difference in altitude (250 to 3,400m.s.l.), it seemed to be likely that the lightning activity exhibits a certain height dependency. FIG. 4 shows a surface diagram indicating height and daytime distribution of the lightning activity in the study area. Whereas the effects of daytime on the lightning activity are very clear, height dependency is not linear in this representation. An increase in altitude leads to a higher activity until the culmination point (around 1,800m.s.l.) is reached.

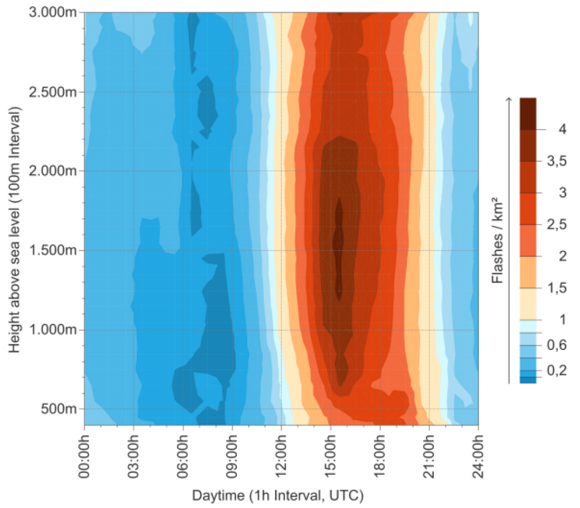

FIG. 4: Height and daytime dependency of the lightning activity

As already mentioned above, the coherence between lightning activity and altitude was quantified based on an ordinary least square regression. The assumption of a strong positive effect (higher lightning activity with increasing altitude) could be confirmed for the districts Flachgau, Berchtesgaden and Tennengau (see also FIG. 2), which exhibited a squared Pearson coefficient (R^2) of about 0.5. In contrast, no significant effect was found regarding the whole study area (R^2=0.096). A possible explanation could be that the relief characteristics strongly vary across the study area. Regions with a relatively low difference in altitude such as the alpine foothills in the northern part of the study area didn't show any height dependency.

A higher correlation occurred when using a relative altitude variable, which is an indicator for the surface curvature of the relief. In order to derive the relative altitude, each grid cell was normalized by the height of the surrounding cells. In this case, the regression showed a correlation of about R^2=0.14 for the whole study area. Smaller spatial units such as the federal province of Salzburg exhibited a Pearson coefficient of R^2=0.32.

In addition, the correlation between lightning activity and land cover was analysed. However, no clear coherences were detected. Moreover, no sign for regional CG clustering due to water bodies was observed.

IV. CONCLUSION

One main outcome of the study was an up-to-date knowledge base about regional lightning hazards as well as associated risk such as thunderstorm and hail. Thereby, the derived density maps made it possible to capture lightning "Hot Spots", which can be considered as hazard zones. Extensive "Hot Spots" were found along the northern edge of the Alps and the south eastern part of the examined area, whereas "Cold Spots" mainly occurred in the west. It has to be mentioned, however, that these zones don't represent a sharp delimitation. Because of the spatially and temporally discontinuous characteristic of this process, heavy thunderstorms can also appear at locations which exhibited low lightning activity within the twelve years considered in this study. Nevertheless, a web-based implementation as a decision support for spatial planning and risk management purposes can be envisaged. In this context, the spatially disaggregated database enables policymakers to assess hazard probabilities and react to them in an appropriate manner.

Moreover, based on the density maps, various calculations regarding the coherence between lightning activity and the highly diverse topography in the study area could be made. Thereby, height dependencies were found in the districts Flachgau, Tennengau and Berchtesgaden. However, the correlations strongly depended on the relief of the considered region. Areas with a relatively small difference in altitude, such as the foothills in the north, showed no dependency. There was also no recognizable sign for coherences between lightning activity and the prevailing land cover patterns.

The GIS technologies used to aggregate and analyse the detected CG lightning flashes provide powerful tools for handling spatial data. By means of the calculation and comparison of different density aggregation methods, valuable insights regarding their implementation with geographic information systems could be gained. One major advantage of the PFD is the consideration of detection inaccuracies, which enables a more realistic estimation of lightning densities. In order to use this innovative method for large-scale risk analyses, however, further research with respect to the validation of the model will be necessary.

V. REFERENCES

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