Forecasting Weather Related Fire Brigade Operations on the Basis of Nowcasting Data

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Abstract. A statistical model to assess probabilities for the occurrence of fire brigade operations is presented. The model takes into account data from a nowcast system, operationally run at the German weather service (DWD), and information describing the local exposure by publicly available OpenStreetMap data. It is demonstrated, that the model is capable of providing spatial information on the likelihood of fire brigade operations occurrences. While water related operations (e.g. due to flooded basements) are found to be modelled rather well, tree related operations (e.g. the removal of wind throw) are more difficult to model. It is concluded that this is due to the fact that tree related operations can be caused by either severe precipitation or severe gusts. While precipitation is well captured by the nowcast data used to model the meteorological hazard, this is not the case for severe gusts.

Keywords. Thunderstorm, weather impacts, disaster-risks, risk-based warnings

1 Introduction

It has been stated in the Sendai Framework for Disaster Risk Reduction 2015-2030 by the United Nations [01] that the implementation of effective disaster risk reduction measures should be based on an understanding of disaster risks, including all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment. On local and national levels, this requires to systematically evaluate, record, share and publicly account for disaster losses to gain understanding of the impacts in the context of event-specific hazard, exposure and vulnerability information.

Severe convective events, accompanied by strong wind gusts, high intensity precipitation and hail often cause large impacts on society [02]. Particularly in large metropolitan areas these events can pose enormous challenges to civil protection agencies such as fire brigades. In order to maintain an effective management of fire brigade operations in advance as well as during such events it would certainly be of great value to be able to predict possible impacts on high spatial resolution, such as urban district scale or higher. However predictability of local impacts is strongly limited due to a lack of predictive skill for severe weather conditions on such small scales, particularly for lead times of hours and more. Secondly, impacts strongly depend on non-meteorological factors such as the local exposure to specific hazards as well as the vulnerability of exposed assets.

This study aims to develop a high-resolved impact model for operations of the Berlin fire brigade for convective thunderstorm events, mainly focusing on impacts related to heavy precipitation and hail. Based on weather related operation records of the Berlin fire brigade this study investigates in how far data from state of the art nowcasting systems could potentially be used to predict local weather impacts on very short lead times.

In particular, two severe convective events [03] are analyzed in greater detail, demonstrating the applicability of the model and pointing out how such approach could be used as the basis for the design of future warning systems based on impact- and risk- forecasts.

The remainder of this paper is structured as follows. In Chapter 2 details are specified on the data sets used in this study. In Chapter 3 a brief description of the methodological steps used to model and "forecast" local weather impacts on the basis of meteorological nowcasting data. Results are presented in Chapter 4 followed by conclusions and an outlook in Chapter 5.

2 Data

2.1 Fire-Brigade Operation Data

A dataset provided by the Berlin Fire Brigade is analyzed, comprising weather related fire brigade operations for the period 2002-2011. Total counts of weather related fire brigade operations in the period 2002-2011 accounted to slightly above 10.000 per year. This corresponds to about 27% of all operations of the Berlin fire brigade, which (according to the annual reports of the Berlin Fire Brigade [04]) accounted to about 37.000 operations per year in the same period. In comparison, fire extinction operations (about 7.500 per year) accounted for about 20% of all operations. Note that ambulance call outs (~245.000 per year) and false alarms (~31.000 per year) have been disregarded here.

Besides location and time of the alerts, the data base contains keywords associated to each operation. Based on a keyword analysis it can be found, that most weather related operations are due to water damages (33%), traffic obstruction (25%) or to tree related incidents (17%). Operations related to construction elements accounted for about 14% and Ice and snow related operations for 2%, which naturally occur exclusively in winter. Some other keywords (individually accounting for 1% or less each) have been used which sum up to about 8% of all weather related operations. For the study presented in this paper, both water related as well as tree related operations are considered. While water related impacts might be directly linked to severe precipitation associated with the convective events, tree related incidents might be due to either hail or severe wind gusts associated with the events.

(a) (b)

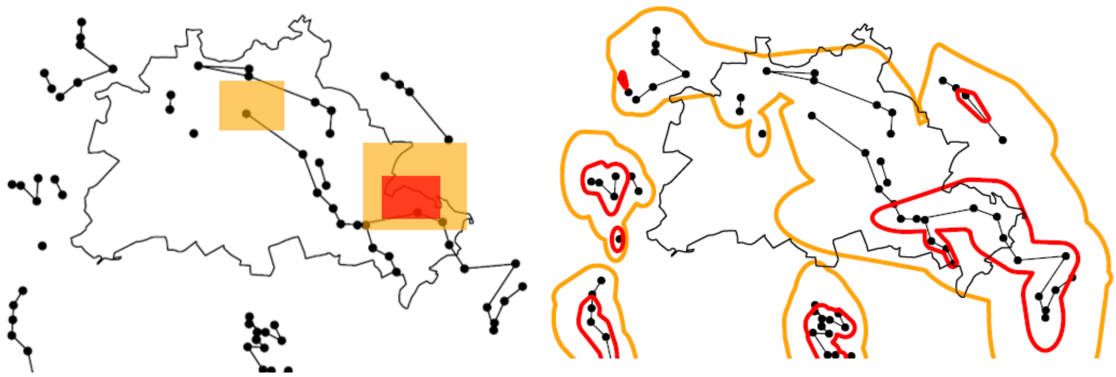

Fig. 1. Derivation of information on the local strength of the meteorological hazard for an example situation, the 6th of June 2011. (a) Original data from KONRAD analyses. Cell locations are shown as black dots. Information about the extent of areas with radar reflectivity >46dBZ (yellow) and >55dBZ (red) are shown exemplarily for 2 cells. (b) Derived polygons representing the envelope of the areas affected by >46dBZ (yellow) and >55dBZ (red).

2.2 Nowcasting Data

To assess local precipitation intensities of a convective event we analyze data from an automated cell detection algorithm (KONRAD, KONvektionsentwicklung in RADarprodukten). KONRAD is an operational Nowcast system at the German Weather Service (DWD) and is used to detect and describe convection evolution in radar products [05,06]. Based on 2D radar reflectivity data it is run operationally every 5 minutes. As a threshold for the detection of convective cell, over an area of more than 15km² the radar reflectivity must exceed 46dBZ. Besides cell location, additional cell information are available from KONRAD such as the movement speed as well as the direction of movement of a cell. Moreover information on the cell's size are available, namely specifying the size of the area for which the reflectivity exceeded 46dBZ as well as the area for which reflectivity exceeded 55dBZ. Also, minimum and maximum longitudinal as well as latitudinal extend are specified. For an example situation (6th of June 2011) resulting cell tracks consisting of the cell locations at successive time steps are shown in Fig. 1 (a).

From the KONRAD analyses comprising detailed data on detected convective cells, the local strength of the meteorological hazard is extracted. This is done by assuming ellipsoidal shaped cells which are characterized by means of minimum/maximum longitudinal and latitudinal extent. Furthermore using the size ratio for the cell areas exceeding 46dBZ and 55dBZ, a second ellipsoid is constructed for the higher intensity threshold. In a second step, the envelope area of the ellipsoids for both reflectivity thresholds are calculated. For this ellipsoids are shifted (and increased or decreased in size) from the cell's location at time t to the cell's location at time t+5min. Resulting envelope polygons are shown in Fig. 1 (b). In a third step, these envelope polygons are used to derive a gridded "footprint" of the convective cell. This is done by assigning the corresponding intensity category to each grid point which lies within either one of the two polygons. For the resulting "footprint" (shown in Fig. 2) containing the local cell intensity for each grid cell a regular 1x1km grid is chosen.
KONRAD data is analyzed for the period of 2007-2012, comprising a set of 180 convective events which hit the area of Berlin. For each of these events the start and end time are assessed by using the first and last time-step for which a convective cell was detected.

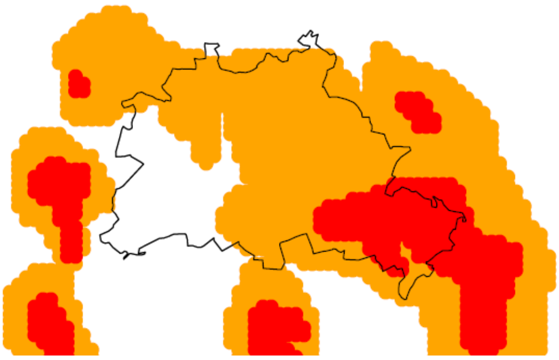

Fig. 2. Derived "footprint" for the 6th of June 2011 comprising the local hazard strength on a regular 1x1km grid.

2.2 OpenStreetMap data

Data from the open source project OpenStreetMap (OSM, www.openstreetmap.org) are used to derive local building densities. The data base contains georeferenced information on the locations as well as the size of individual houses. For this study we derived building densities in two ways. The first method is simply calculating the number of building counted within a cell of a predefined regular 1x1km grid. The second method calculates the sum of the size of all houses within a grid cell (which equals the total area covered by buildings). Normalizing this area by the area of the grid cell results in a building coverage (in %). Resulting building density (number of building per km²) and building coverage (area coverage in %) are comparable in terms of their spatial distributions. However locally considerable differences occur. An analysis of the spatial correlation showed that the long term density of fire brigade operations correlates much better to the building coverage (correlation coefficient of 0.71) compared to the building density (correlation coefficient of 0.24). In the following we thus use the building coverage (in %) as a predictor for the exposure to water related fire brigade operations. Spatial building coverage as derived from OpenStreetMap is shown in Fig. 3.

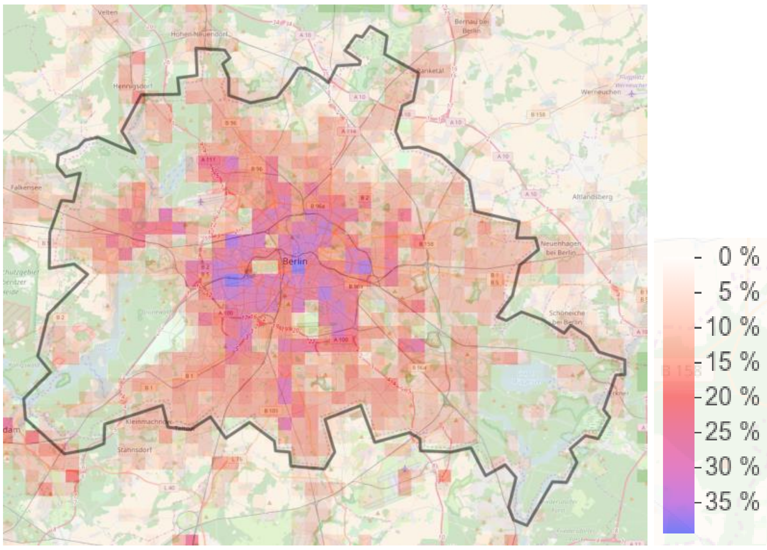

Fig. 3. Derived gridded building density information from OpenStreetMap data (www.openstreetmap.org). The building coverage is calculated on a regular 1x1km grid as the fraction of a grid cell covered by buildings (specified in %).

3 Methodology

To model the risks related to convective events in the urban area of Berlin, we follow an approach describing potential weather impacts by the combination of 3 components, namely *hazard*, *exposure* and *vulnerability*. For an impact to be realized, vulnerable values (e.g. houses, individuals, trees) need to be *exposed* to a *hazard* of a certain strength. Since no impact is realized if either of the three components is zero, the symbolical model could be formulated by a product of those components

$$\textit{potential impact} = \textit{hazard} \times \textit{exposure} \times \textit{vulnerability} \qquad \textbf{(1)}$$

Practically, the relation specified in Eqn. 1 needs to be based on a statistical model, relating information on weather impacts to predictors for the local hazard strength, exposure and vulnerability, since only in very few cases, all 3 components can be described in an analytical fashion. This might be the case when describing potential impacts of single assets, for which both the value at risk as well as analytical vulnerability curves could be derived, which are based on physical-technical (e.g. in case of an individual building) or physiological (e.g. in case of human health risk) properties. In these cases a microscopic damage function might be derived in an analytical or semi-analytical manner.
However in most cases, exposure and vulnerability need to be described for a portfolio (e.g. a portfolio of houses or people) within a certain region, leading to empirical macroscopic damage functions [07].

In our study we use the building coverage as a predictor for the exposure. This can be justified by the fact that the most probable causes of water damages are flooded basements or local flooding due to insufficient drainage capabilities. Additionally this can be justified by our finding that a high correlation of 0.71 is found when calculating the spatial correlation between the long term occurrence of water related fire brigade operations and the building coverage calculated as described in Section 2.2. As a predictor for the local hazard strength, the radar reflectivity derived as described in Section 2.1 is used. Since no information on housing vulnerability is available we aim to derive so called vulnerability curves. These vulnerability curves then describe the missing information on vulnerability by relating the two predictors for hazard and exposure to the observed impacts.

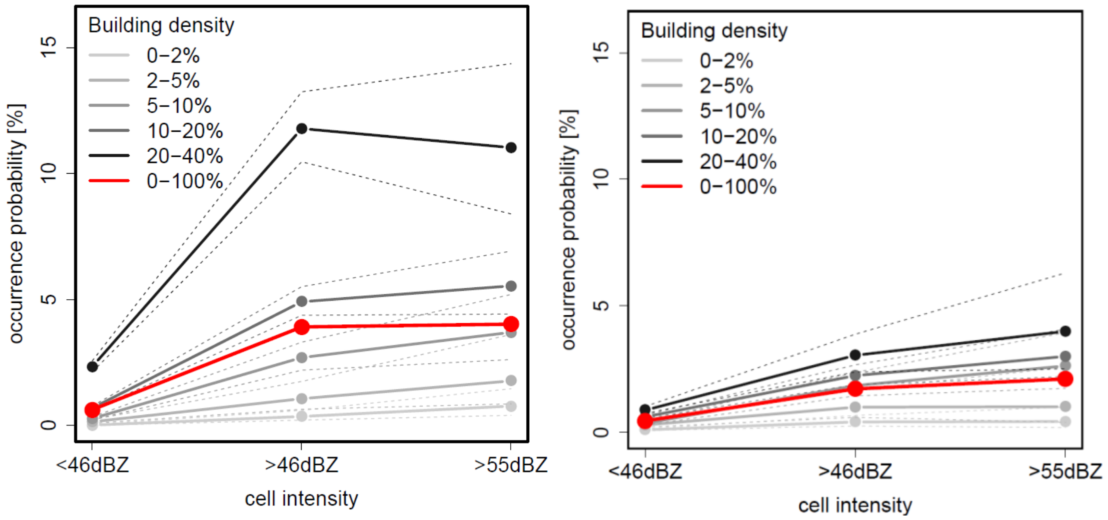

Fig. 4. Empirically found dependence of water related (left) and tree related (right) fire brigade occurrence probability from local cell intensity and building density.

4 Results

In a first step an analysis is performed relating the local hazard strength -calculated on a 1x1km grid- to the occurrence of fire brigade occurrences within a grid cell. For this we analyze all detected convective situations which hit the area of Berlin (180 events). For each event, we calculated the local intensity at each grid cell which can be either no convective cell, i.e. no reflectivity above the threshold of 46dBZ (a), a convective cell with a reflectivity exceeding 46dBZ (b) or a reflectivity exceeding 55dBZ (c).

We then assess the local occurrences of water related fire-brigade operations on the same 1x1km grid. For each grid cell, we can identify whether an operation occurred within the time the convective situation occurred. Since in many cases the alert for an operation is made after the convective event occurred we also check for operations occurring up to 6 hours after the convective event ended (the last time step in which the KONRAD system detected a convective cell). The resulting observed occurrence probability (i.e. the relative number of cases in which an operation occurred within 6 hours after the event) is shown as red circles in Fig. 4 (left). It is found, that in less than one percent of all cases for which no convective event affected a grid cell an operation occurred. If the radar reflectivity for an event exceeded 46dBZ, this occurrence probability raises to about 4% and raises only slightly if the radar reflectivity exceeded 55dBZ.

Similarly the analysis can be performed for tree-related fire brigade operations as shown in Fig. 4 (right). While the general dependence is similar, occurrence probabilities are considerably lower. If the radar reflectivity for an event exceeded 46dBZ, this occurrence probability is found to be about 2% and again raises slightly if the radar reflectivity exceeded 55dBZ.

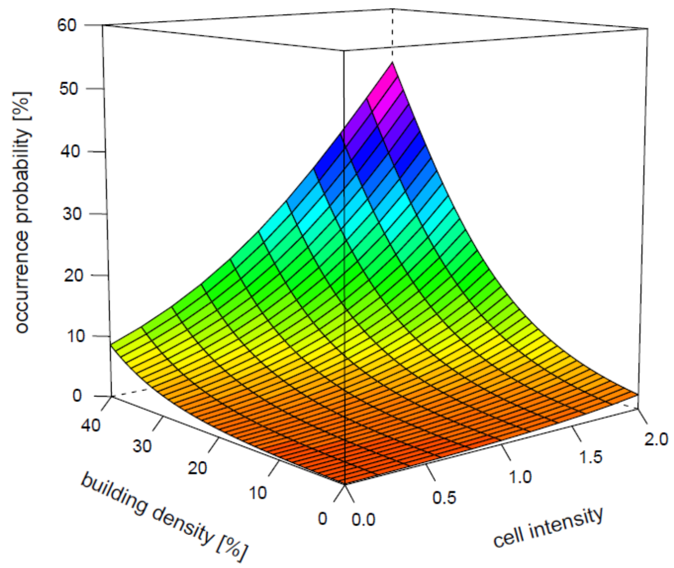

Fig. 5. Results of logistic regression model for the occurrence probability for water-related operations within a grid cell. Cell intensity of 0 corresponds to a radar reflectivity below 46dBZ, cell intensity of 1 corresponds to an exceedance of 46dBZ and cell intensity of 2 corresponds to an exceedance of 55dBZ.

In a second step this increase in fire brigade occurrence probability is stratified by the predictor for the exposure, namely the building coverage. For this, the building coverage is categorized into five classes, namely very low (0-2%), low (2-5%), medium (5-10%), high (10-20%) and very high (20-40%). For each category, the relation between cell intensity and occurrence probability is now assessed separately. Resulting vulnerability curves considering water related fire brigade operations are shown in Fig. 4 (left) in different shades of grey. It can be found, that the occurrence probability strongly depends on the building coverage. While in areas of very low building coverage the occurrence probability is only 0.4% (0.8%) in case the local radar reflectivity exceeds 46dBZ (55dBZ). On the contrary, the occurrence probability raises above 12% in areas of very high building coverage. Evaluating the intermediate categories shows a continuous increase in occurrence probability for increasing building coverage.

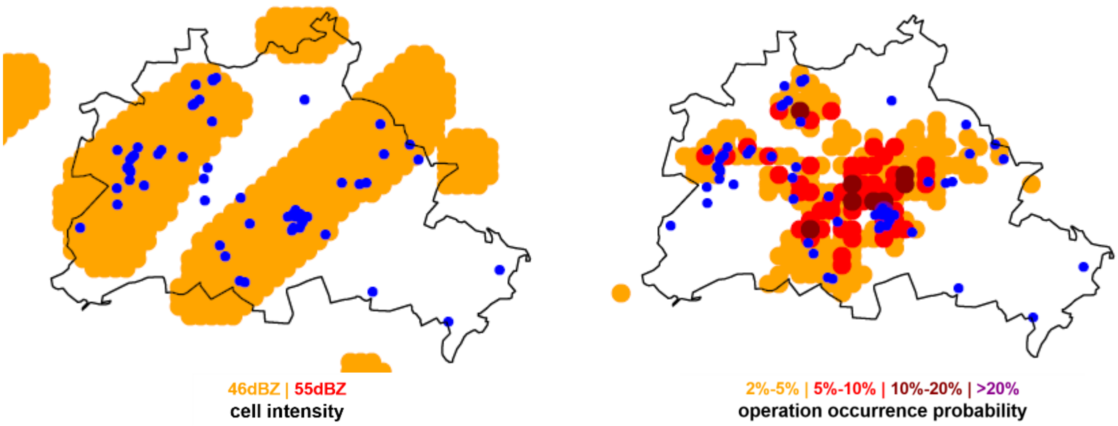

Fig. 6. Case study 22nd of June 2011. Spatial "footprint" of the event as derived from KONRAD (left). Modelled operation occurrence probability (right). Blue circles indicate individual water-related fire-brigade operations.

The analysis on the basis of tree related operations (compare Fig. 4, right) shows, that also in this case, building density clearly influences the occurrence probabilities. However, the dependence is much weaker. While for areas with very low building coverage, resulting occurrence probabilities for tree related operations are similar to the probabilities in case of water related operations. However in areas of very high building coverage, occurrence probabilities for tree related operations do not raise above 4 %. This can be due to the fact that for tree related incidents the building coverage does not serve as an equally good predictor than in the case of water related incidents. This is confirmed when considering the spatial correlation of the building density to the long term density of operation occurrence, which is 0.71 in case water related operations and only 0.62 in case of tree related operations.

In a third step, the dependence on cell intensity and building coverage is addressed by means of a bivariate logistic regression analysis. Results from this bivariate model fit are shown in Fig. 5 (right). It is confirmed that for low building coverage the occurrence probability only slightly raises, even in the presence of a convective cell of high intensity (cell intensity 2). In the absence of a convective cell (cell intensity 0) however, the probability raises up to several percent in areas of very high building coverage. If an intense convective cell strikes an area of very high building coverage, occurrence probabilities strongly increase. They can reach up to 50% for a building coverage of 40% and a local radar reflectivity exceeding 55dBZ (cell intensity 2).

To demonstrate the potential use of the model presented above, two case studies are considered in the following. The first case study consists of a frontal passage over Germany crossing Berlin at around 18:00 UTC of the 22nd of June 2011. Several convective cells formed in vicinity of the front crossing Berlin with rather high cell movement speed in a north-westerly direction. The second case study consists of a weakly forced convective situation over Germany on 6th of June 2011. Numerous convective cells were formed over large parts of Germany with rather low cell movement. Particularly one intense convective cell crossed the area of Berlin entering from south-east towards the center of Berlin. Details to the case studies analyzed here can be found in [03].

The derived "footprint" for the 22nd of June 2011 is shown in Fig. 6 (left). Two cells are identified crossing Berlin. Both cells did exceeded the threshold of 46dBZ over considerable areas of Berlin. However the cell intensity did not reach 55dBZ. The first cell within the investigated area occurred at 16:50 UTC, the last cell was detected at 17:35 UTC. Fire brigade operations within the time period 16:50 UTC – 23:35 UTC (6 hours after the end of the event) are shown in Fig. 6 (left) as blue circles. A rather good correspondence can be found between the areas which have been affected by a cell. However also few operations occurred at locations at which no convective cell was detected, meaning that radar-reflectivity did not reach the first threshold of 46dBZ. However slightly lower reflectivity, indicating less intense precipitation may have occurred in those regions. Using the vulnerability curves derived above, the information on the cells' intensity can be transformed in a "forecast" of the operation occurrence probability (Fig. 6, right) taking into account also the information about the local building coverage. Fig. 6 (right) shows, that particularly in the central parts of Berlin high operation probabilities are calculated, matching much better the pattern of observed operations.

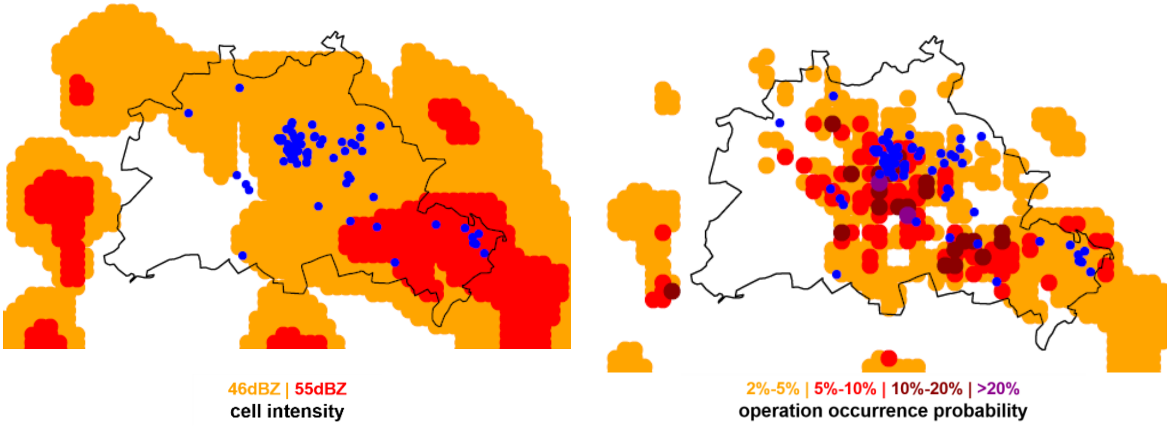

Fig. 7. Case study 6th of June 2011. Spatial "footprint" of the event as derived from KONRAD (left). Modelled operation occurrence probability (right). Blue circles indicate individual water-related fire-brigade operations.

Similar findings can be made considering the second case study (6th of June 2011) shown in Fig. 7. Again the event "footprint" which describes the pure meteorological hazard strength shows that large parts of Berlin were affected by the event (Fig. 7, left). Particularly in the south-east of Berlin a cell of high intensity was detected with radar-reflectivity exceeding 55dBZ. Considering the observed fire-brigade operations (blue circles in Fig. 7, left) shows that a region of high operation density is found in central-northern regions of Berlin, a region in which the identified cells already weakened, with radar-reflectivity below 55dBZ. Again, considering the modelled occurrence probabilities as shown in Fig. 7 (right) a rather good correspondence to the pattern of observed fire-brigade operations can be found.

Additionally for both case studies, modelled occurrence probabilities and observed operations can be compared when considering tree related operations. In Fig. 8 (left) this is shown for the 22nd of June and in Fig. 8 (right) for the 6th of June. Since modelled probabilities are considerably lower, the scale has been modified accordingly. Resulting spatial patterns however are rather similar. Particularly in case of the frontal passage (22nd of June), the observed operations (green circles) show much more widespread impacts which is captured rather poorly by the model. As noted above, for tree related incidents the building density can be found to be a worse predictor and may thus not suffice to adequately describe the exposure.

Also, tree related operations may be due to both precipitation induced incidents or may be wind related. For the latter case of wind related impacts, the radar-reflectivity which is used to characterize the local hazard strength and is an indicator for the local precipitation certainly does not sufficiently describe the local occurrence of gusts. Since the cell movement speed was high in the case of the frontal passage on the 22nd of June, (compare Fig. 4 in [03]), occurred wind speeds can also be assumed to be high in this case. It is thus likely that a large fraction of tree related incidents on this day was due to the occurrence of severe gusts. For the 6th of June (Fig. 8, right) however, the occurrence probabilities match rather well to the observed occurrences of tree related operations. Compared to the 22nd of June, the cells were moving rather slowly, it can thus be assumed that in this case local wind gusts were not as high. Tree related incidents on the 6th of June can thus be assumed to be mostly due to severe precipitation. Thus modelling results in this case are found to be considerably better.

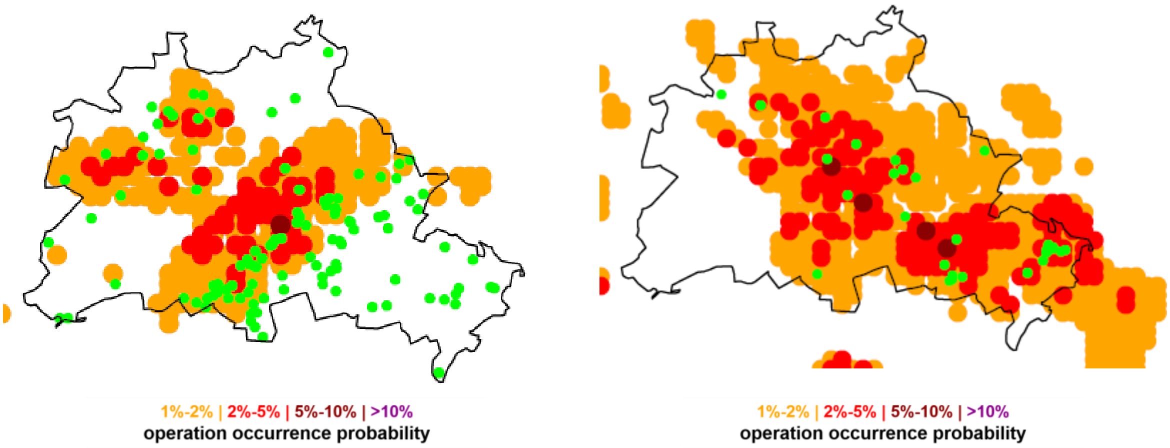

Fig. 8. Modelled occurrence probabilities for tree related fire-brigade operations for the 22nd of June 2011 (left) and for the 6th of June 2011 (right). Green circles indicate the occurred tree-related fire-brigade operations.

5 Summary and Conclusions

This study investigated the possibility to use meteorological data from a nowcasting system to model local impacts due to convective events. As impact data we used a data set provided by the Berlin fire-brigade, comprising georeferenced information on weather related operations. On a high resolution of 1 km, a statistical model was developed relating the local hazard strength -as derived from the nowcasting data- to the local occurrence probability of fire brigade operations.

Besides the dependence from the local hazard strength (i.e. precipitation intensity described through radar-reflectivity) the influence of the exposure is modelled by taking into account local building coverage derived from the open source project OpenStreetMap. The building coverage as predictor for the local exposure is found to strongly influence the occurrence probability, particularly if water related fire brigade operations are considered. For tree related operations, the relationship is found to be less distinct, due to the fact that the building coverage does not serve as an adequate predictor in this case.

In two case studies, the capabilities of such impact model were tested. It has been demonstrated that by applying the developed model to the nowcast data enables us to better describe where fire brigade operations are likely to occur, particularly in the case of water related operations. In case of tree related operations, results are found to be dependent on the specific meteorological event. In case of the first case study, severe local wind gusts played an important role. By means of radar-reflectivity the hazard in this case is only insufficiently described. In the second case study, wind gusts were most likely considerably lower and thus did not play a significant role. Thus most tree related incidents in this case were most likely also due to severe precipitation. Thus the model is able to capture the observed operation occurrences rather well.

The study demonstrates, that based on a combined assessment of meteorological (forecast) data and information on the local exposure can be used for the implementation of appropriate impact or risk based warnings. This is in line with what has been stated within the Sendai framework for disaster risk reduction, namely that the implementation of effective disaster risk reduction measures should be based on an understanding of disaster risks, including all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment. Using such model to develop forecast systems for the expected number of operations and their spatial distribution may help fire brigades to use appropriate preparation measures in case of severe weather situations ahead. In highly populated metropolitan areas this may be of particular interest, since exposure to severe weather situations may be extremely high in these regions.

As seen in the case of tree related weather impacts, future work should broaden this type of analysis to a wider range of available data to model the exposure towards severe weather. This might include information on land usage, information on infrastructure (roads and railways) or orographic features derived from digital elevation models. Similarly, future analyses should consider a broader set of meteorological variables to sufficiently describe local hazard strength.

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