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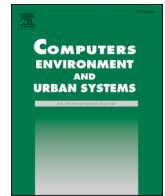
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Spatial (in)accuracy of cell broadcast alerts in urban context: Feedback from the April 2023 Cannes tsunami trial

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ABSTRACT

Since June 2022, France is equipped with cell broadcast technology which alerts individuals within a predefined area. Despite the proven effectiveness of this technology, few studies take a spatial view of cell broadcast alert at a local level. Trials carried out in France were assessed only on their technical success, without verifying the rate of reception of the message by individuals in the official alert area, or the gap between the official alert area and the actual broadcast area. This study focuses on a trial conducted in April 2023 in Cannes (France). Using a geo-located survey method and spatial analysis tools, we show how cell broadcasting is more imprecise than one might think at the local level. Reception rates depend on the telephone operators and a large and ragged edge effect is measured, which means that the message is broadcast far beyond the area defined by the authorities. A second approach was to check the reception of three cell broadcast messages sent within a 20-min interval at fixed points, which revealed the fluctuation of the broadcast area over time, making its spatial extent complex to predict. Similar works should be carried out in other urban and rural areas.

1. Introduction

1.1. The European rise of location-based alerts

Since the 2010s, there has been a progressive modernisation of national alerting systems in the world. Traditional siren-based systems are being replaced with more sophisticated mobile phone-based systems that take into account the location of individuals in real time. These systems called location-based alert systems (LBAS) (Aloudat et al., 2007), allow broadcasting of alert messages to all mobile phones located in the target area (Bean, 2019). Compared to traditional tools (sirens, telephone calls, door to door, etc.), the benefits of LBAS are obvious: they issue massive alerts over a large area in a short time; the message is sent to a predefined target area; the spread of mobile phones makes alerting effective; alerts are activated within a single system allowing coordination of alert operations, redundancy of dissemination and evolution over time of message content (Aloudat et al., 2007; Bopp, 2021; Chang et al., 2018; ETSI, 2010).

Several countries have adopted LBAS since a few years: Japan (since 2007), Australia, Chile, the USA, Netherland (2012), South Korea (2014), Belgium (2017), Island (2019), among others (Douvinet et al., 2022a). In 2022, a decree obliges EU Member States to have an alert system based on the location of individuals. This regulation marks a turning point in the European warning system. Nine European countries choose to develop the cell broadcast (CB) solution, which is one of the emblematic tools for alerting people in predefined target area. Other LBAS exists: 10 European countries choose the location-based SMS (LB-SMS) solution and 4 a smartphone application. In addition, 5 countries including France, have chosen to develop a hybrid CB-LB-SMS platform.

1.2. Technical functioning of the cell broadcast and research gap

Cell Broadcast (CB) consists of broadcasting a notification to mobile terminals in a predefined area called the “cell broadcast zone” (ETSI, 2010). This technology has been operational since 1997, and does not require prior knowledge of the target phone numbers (Aloudat et al.,

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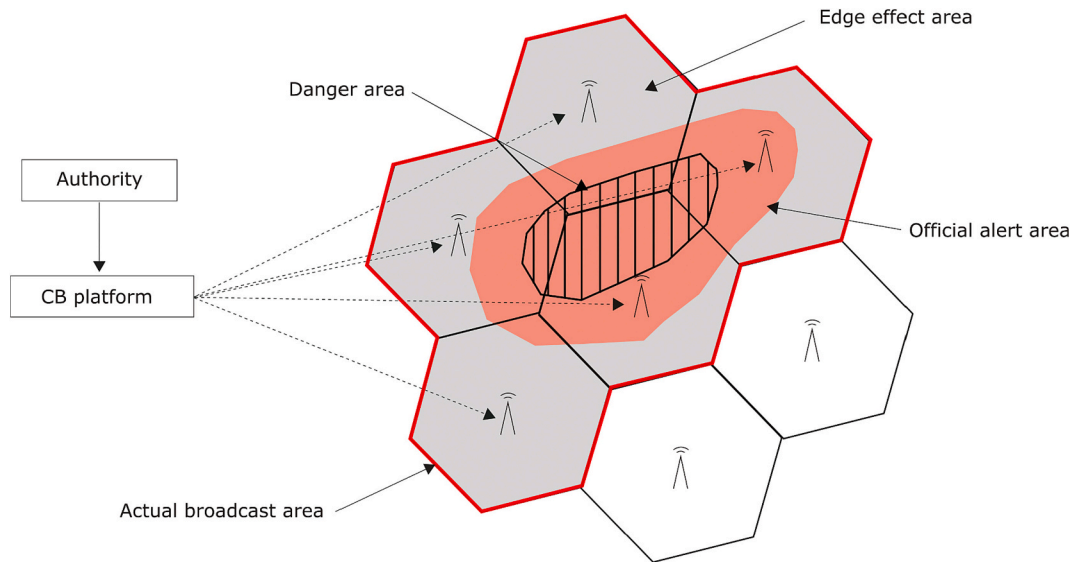


Fig. 1. Spatial functioning of cell broadcast.

2007). The message passes through telecommunication antennas in the form of radio waves using dedicated CB equipment. Then, the message is broadcast to all mobiles located in the cell. This is known as a point-to-area broadcast mode (Jagtman, 2010; Sillem & Wiersma, 2006). The message is broadcast for a period of time during which any individuals with a cell phone moving into the alert area will receive the message. CB spectrum has a capacity of about 64,000 different channels, with the possibility of dedicating a channel to each type of message (Chochliouros et al., 2009). Therefore, CB is not subject to the risk of congestion as messages broadcast over traditional telecommunication channels can be. Since 2012, all iOS, Android and Windows phones support the CB technology.

Research on CB has highlighted its technical efficiency (Al-dalahmeh et al., 2018; Bean, 2019) and its ability to effectively disseminate information to individuals (Smith et al., 2022; Wood et al., 2015). In the US, initial feedback suggests that the technology is likely to play a role in reducing Covid-19-related deaths in states that have used CB (Bean et al., 2021). From a social perspective, the perception of CB by individuals has been explored highlighting its ability to mobilise people to protect themselves (Bean et al., 2016; Kim et al., 2019; Perreault et al., 2014). Other studies have focused on the typical content of messages (Douvinet et al., 2022b; Smith et al., 2022; Sutton et al., 2015). From an organisational perspective, work has been done on how to integrate LBAS into national warning system (Bielski et al., 2017; Chang et al., 2018; Kuller et al., 2021; Sutton & Kuligowski, 2019). Several studies stress the need to focus on more than just technical advances made possible by LBAS, but also to consider the social, spatial and organisational dimensions, as part of a holistic approach (Bopp et al., 2021; Sutton & Kuligowski, 2019).

The spatial properties of CB have been little studied in the scientific literature, even though it is one of the most important technical advances. On a large scale, the modeling of a spatial indicator of alertability has made it possible to estimate the rate of alertable individuals in France by CB (81,3%), while highlighting spatial inequalities to the detriment of rural areas where the habitat is scattered (Bopp & Douvinet, 2020). On a smaller scale, Gonzales et al. (2016) estimated the population that could be alerted by CB in a territory affected by a tornado outbreak in 2011 in Alabama, highlighting the challenge posed by the spatial imprecision of alerts, which results in the alerting of unconcerned people, thereby undermining the credibility of the alerts. Parker et al. (2015) simulated the performance of LBAS using a multi-agent system in a fictitious territory and showed how spatial over-estimation of the alerting area may have dramatic consequences on

evacuation.

Edge effects are one of the disadvantages of the CB, especially as they are underestimated by authorities who have little experience in the use of LBAS, as is the case in Europe (Bopp, 2021). The smallest possible grid for CB alert is the telecommunication cell (ETSI, 2010). All telecommunication cells intersecting the official alert area are activated to spread the message. Thus, the message is broadcast beyond the area designed by the authorities: we call this area the actual broadcast area (Fig. 1). The size of the telecommunication cells varies (and is generally negatively correlated with the resident population), so the size of the edge effect varies. In France, no study has investigated the spatial effectiveness of CB alerts on fine scales and the quantification of this edge effect. The question of the variability of this edge effect during the broadcast time also remains unexplored. The challenge is to improve the spatial accuracy of alerts and to reduce over-alerting of unaffected individuals.

1.3. Research objectives

Since June 2022, France has carried out >30 trials on parts of its territory, without having any spatial information on the success of these trials: how many individuals have actually received the alert in the target population? In relation to the alert area, how far were the messages sent? How many people outside the alert area received the message? The answers to these questions are important in assessing the effectiveness of the CB. Based on a tsunami alerting exercise that took place in an urban context (French city of Cannes, 75,000 inhabitants), this article attempts to answer these questions by modeling the effective area of alert dissemination using post-exercise questionnaires. Four main objectives are raised: 1) to observe whether the reception of the alert in the official alerting area depends on the individual's telephone operator or on the type of mobile phone; 2) to estimate by modeling and spatial analysis methods the actual broadcasting area of the CB alert; 3) to check whether the actual broadcast area is constant over time; 4) to explore whether the measured edge effects correspond to a spatial logic, considering the geographical context (telecommunication antenna localisation, relief).

2. Background to the 13th Cannes exercise

2.1. Study site

Cannes is a medium French city located on the Mediterranean coast

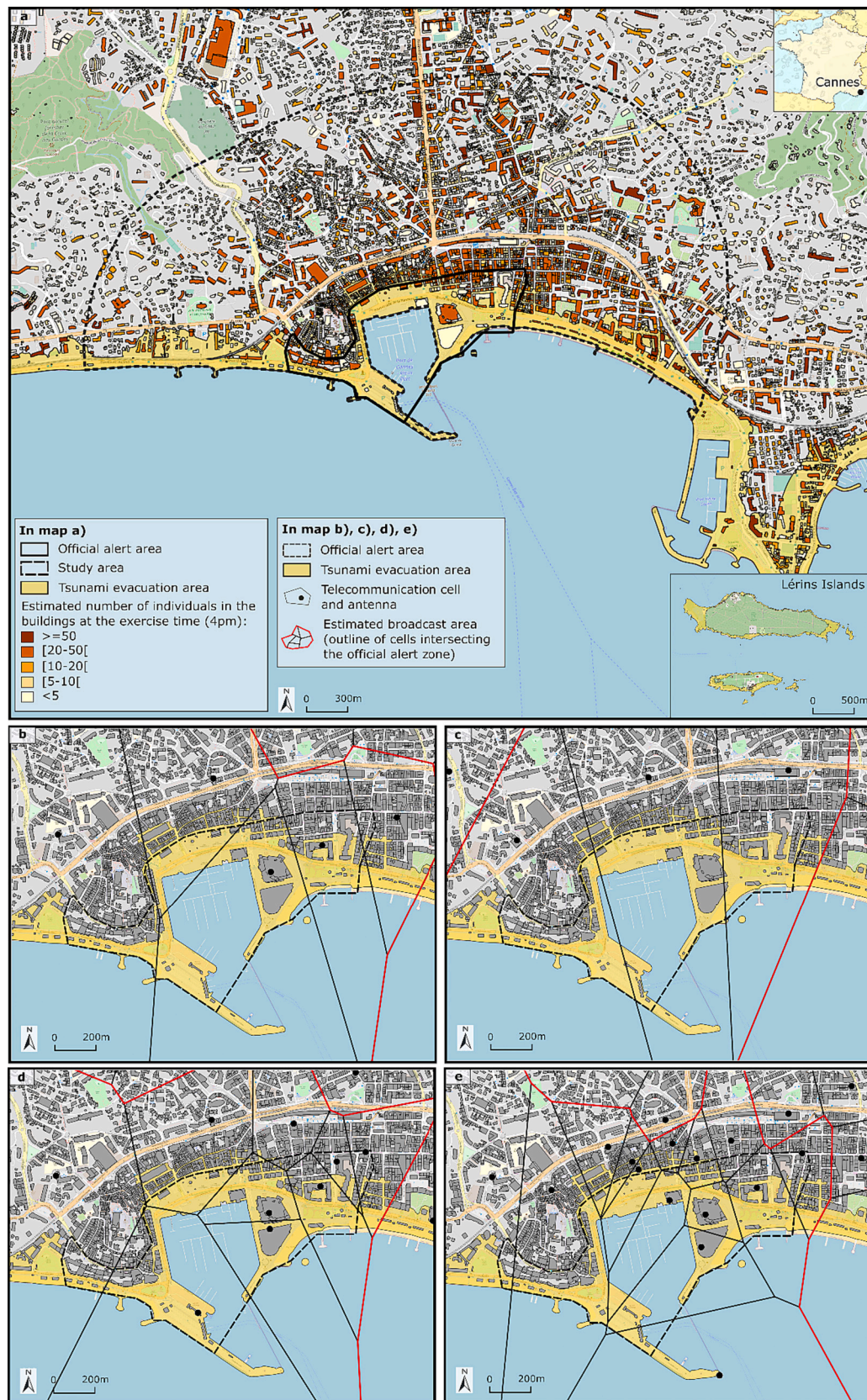


Fig. 2. Presentation of the study site: a) global map of the city of Cannes and the tsunami risk zone; b-c-d-e) Voronoï cellular networks in the alert area (b: Bouygues®; c: Free®; d: Orange®; e: SFR®).

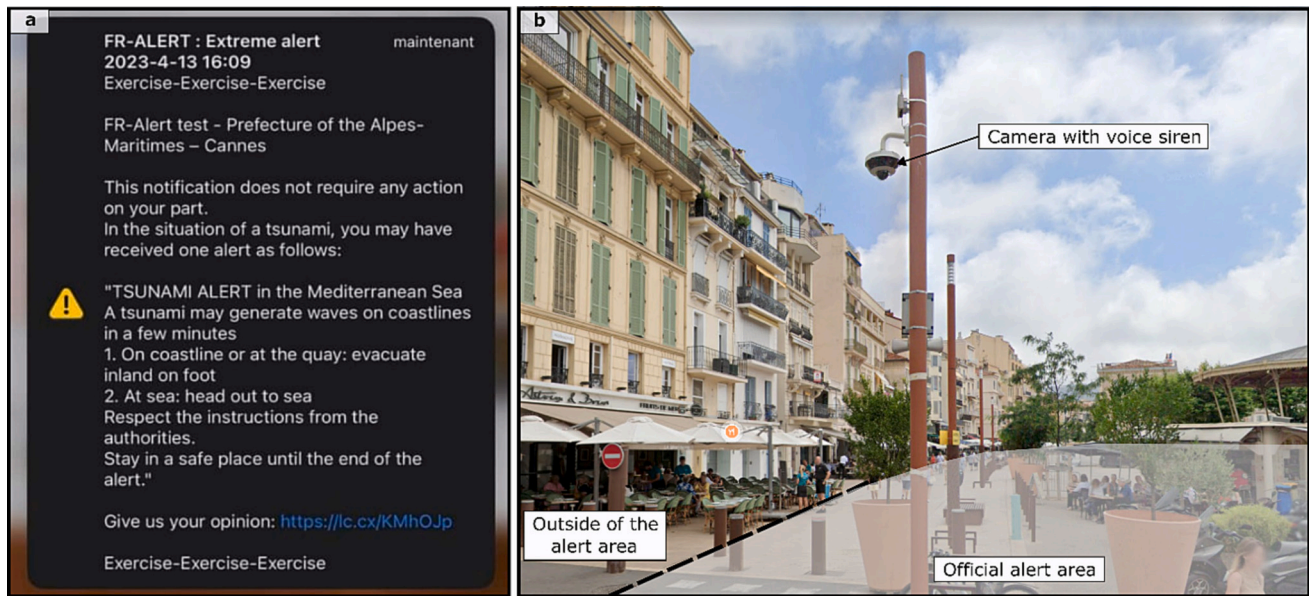


Fig. 3. a. English version of the CB notification broadcast during the exercise (initial message and repetition); b. Screenshot from Google Street View® of one of the boundaries of the official alert area, at the intersection of Félix Faure Street and Louis Blanc Street.

(Alpes-Maritimes department) with a population of 75,000. Cannes is categorised by INSEE as a dense city belonging to the urban unit of Nice of which it is a suburb (Cannes is located 25 km to the east). Cannes is a city characterised by seaside tourism. The city is densely built up with a city centre that spreads out along the sea. It is backed by hills culminating at 270 m to the northeast and 165 m to the northwest where the habitat is more scattered. Cannes has a port and two islands (Lérins Islands) located 3.5 km and 5 km from the port.

French part of the Mediterranean Sea and so the city of Cannes are exposed to the risk of Tsunami. Two scenarios are considered: 1) in the case of a strong magnitude earthquake ($M_w > 6.9$) occurring in the Ligurian Sea, the simulations show run-ups of about 1 m, with waves arriving in 7 min on the coast of Cannes; 2) if a regional earthquake of higher magnitude ($M_w > 7.5$) occurs in North Algeria, the simulations indicate run-ups of 2 m to 3 m, arriving within about 1 h30 (Carles et al., 2023; Filippini et al., 2020). Cannes is a seaside tourist town that can generate large crowds on the coast. As part of two PhD projects at the Avignon University, an aerial survey estimated the number of individuals visiting the Cannes beaches in the high season at 14,500. In order to reduce its vulnerability, the city is in the process of raising awareness of the tsunami risk and has financed the installation of markers in the area to be evacuated (evacuation route and refuge sites).

We estimate that there were 2983 individuals in the official alert area at the exercise time, but 11,196 individuals if we consider those located in a telecommunication cell that intersect the official alert area, i.e., a potential overall alert of 375% (3.7 times the target population). We estimated this number based on the working population, rather than the residential population (the exercise took place at 4 p.m.). We used the same dasymetric approach as Bopp and Douvinet (2022), crossing the databases of INSEE (typology of workers and inactive people by municipality) and IGN (typology of buildings). We divided the individuals according to their type of employment, in proportion to the number of buildings dedicated to this type of employment: managers, employees and craftsmen were located in the trade and service buildings, workers in the industrial buildings, farmers in the agricultural buildings and the inactive (unemployed, retired and students) in the residential buildings. The tourist population was estimated at a maximum of 2000 people on the beaches near the alert area, using a fixed count method and transects, calibrated over a week (Carles et al., 2023).

The spatial configuration of the telecommunications network is

uneven depending on the operators (Fig. 2.b-c-d-e). In particular, the number of cells intersecting the official alert area varies from 3 (Free®) to 14 (SFR®). As a result, the average cell size varies by a factor of 4.5 between Free® (0.72 km²) and SFR® (0.16 km²).

2.2. Features of the 13th of October tsunami trial

The tsunami alert was issued by the Alpes-Maritimes Prefecture. The FR-Alert platform was activated to broadcast a cell broadcast alert in two zones: one concentrated on the port of Cannes (Fig. 2.a) and the other on the Boca District. The Boca area was not studied in this paper because it is far enough away from the port area and too small. In parallel, loudspeakers (Fig. 3.b) were activated to broadcast an alert message in French and English 5 min after the first cell broadcast alert was sent. The cell broadcast message was also displayed in French or English (Fig. 3.a) depending on the nationality of the SIM card.

The cell broadcast started at 4.05 p.m. on Thursday 13th April and remained active until 4.45 p.m. when an end-alert message was sent. At 4.25 p.m., the same alert message was sent back by the prefecture. In the field, individuals were therefore able to receive up to 3 cell broadcast notifications (the initial message, its repetition and the end-alert message). Sending three messages every 20 min within the same alert area allows us to test the spatial variability of the broadcast area between t_0 (initial message), $t + 20$ (repetition), and $t + 40$ (end-alert message).

3. Methods and data

3.1. Data collection

Fast geolocation surveys were conducted to maximise the number of responses within a constrained time frame ($n = 375$). The surveys were carried out mainly face-to-face by a team of students, PhD students and postdoctoral fellows, immediately after the first alert notification ($n = 295$) and then completed by telephone calls the following days ($n = 80$). In each case, three questions were asked: 1) "Did you receive an alert message on the main screen of your mobile phone around 4.05p.m.?" 2) Is your phone an Android or iOS? 3) What is your telephone operator? In order to avoid interpretation bias, the investigators may explain how the CB worked to respondents who appeared confused. In some cases, a confirmation question was asked: "Did your phone make a

continuous sound around 4.05 p.m.”. The precise location of the respondent was also collected in order to constitute points patterns and to estimate the effective area of dissemination. The question refers only to the initial message and not to the others, as the challenge was to interview individuals quickly after receiving the first alert. Although some individuals mentioned having received the notification several times, only the receipt of the initial message was considered.

In order to avoid location bias due to the movement of individuals, the surveys were initially focused on individuals moving within the official alert area within 10 min of receiving the first notification. Individuals were asked for details of their precise location when they received the alert. After this time, the surveys targeted only shopkeepers and office workers, ensuring that they were located at their place of work at 4.05 p.m., when the first notification was issued. This explains the concentration of points patterns collected in commercial areas to the detriment of more residential areas: the dispersion index ranging from 1 (maximum concentration) to >2 (high dispersion) is $R = 1.36$. Questionnaires were administered along a centre-periphery gradient, starting in the official alert area and extending until 1.1 km beyond its boundaries (visible as “study area” in Fig. 2.a). The survey teams took different trajectories in order to spread the collected responses as widely as possible in space. The responses were randomly located within the building. Efforts were made to have a homogeneous number of responses along the centre-periphery gradient.

A second set of data was collected by the Cannes City Hall. It concerns the reception of the alert by public administration agents in their workplace at Cannes ($n = 191$). Each agent indicated whether or not they received the alert on their phone for each of the three notifications sent (the initial, the repeat, the end of alert). Phone specifications and operators were not requested for this sample.

3.2. Data analysis

The data analysis was carried out in three stages to meet the different research objectives. The first analysis focused on a reference area, which corresponds to the official alert area, to which we added a 25 m band. This is the area where we are certain that the message has been broadcast. The 25 m around the official area was added in order to increase the statistical weight of reference (from 79 responses to 112) and because a first modeling of the edge effect (using Voronoi polygons from the spatial data of the antennas) reveals that this area is entirely covered by telecommunication cells which intersect the official alert area. In this reference area, data from the Cannes city hall ($n = 50$) was discarded because it does not indicate the type of telephone nor the operator. Descriptive and inferential statistics were used to find out whether the reception of the alert is dependent on the type of phone or the phone operator.

Secondly, a logistic regression was used to observe how the linear distance to the official alert area affects the CB reception. The regression was restricted to responses outside the official alert area ($n = 297$). A GIS was used to calculate the linear distances between the response and the boundary of the official alert area. The maximum distance is 1070 m. Three responses collected on the Lerins Islands (>3 km) were discarded because the spatial coverage of telephone antennas at sea does not have the same granularity as on land.

Thirdly, we perform an interpolation method (linear kriging) on the entire points pattern ($n = 375$) in order to estimate a spatial probability of CB notification broadcast. To do this, we used the results of steps 1 and 2 to estimate, for each point that did not receive the alert and was located outside the official alert area, the probability that the non-reception of the notification was due to a technical problem rather than a spatial logic (distance to the official alert area). Thus, knowing that 1) the rate of reception varies significantly by operators (step 1) and 2) distance has a significantly negative effect on the receipt of the CB notification (step 2), the formula estimating the probability of being in the broadcast area PBA is:

Table 1

CB notification reception rate according to the nature of the telephone in the reference area (the percentage given in the first line correspond to the French market share of each operating system).

Notification receipt	Android (59.7%)	iOS (39.0%)	Mean	Chi ² result
N	55	55	/	$\chi^2 = 0.33$
Yes	61.8%	54.5%	58.2%	ddl = 1
No	38.2%	45.5%	41.8%	$p = 0.56$ n.s.

$$PBA(x) = \frac{OS(x)}{(OS(x) + LR(x))}$$

With:

- $OS(x)$: the success rate [0–1] of the x operator in the official alert area (which is 0.80 for Bouygues Telecom®, 0.76 for SFR®, 0.42 for Orange®, 0.11 for Free®, and 0.58 for the others);
- $LR(x)$: the result of the logistic regression for x which is $f(x) = \frac{e^x}{(1+e^x)}$ with the exponent $x = 0.75 - 0.004 \cdot D$, with D the distance to the official alert area.

The PBA value obtained is between 0 and 1. The closer the value is to 0, the higher the probability of non-receipt of the CB notification is due to the distance from the official alert area. The closer the value is to 1, the higher the probability of non-receipt of the notification is due to a technical issue related to the telephone operator. The points corresponding to individuals having received the alert and/or being located in the official alert area have a value of 1. The kriging was then modeled based on the PBA values of the surveyed points. Further, inferential and exploratory statistics were used to analyse the variability of the distance between several probability isolines drawn from kriging (0.30, 0.40, 0.50, 0.60, 0.70) and the official alert area. Rank test was used because the data are nonparametric (Lilliefors-test, $p < 0.001^{***}$). The data collected by the Cannes City Hall has been subjected to descriptive statistical analysis to verify the temporal variability of the actual broadcast area.

4. Results

4.1. Significant differences of CB reception rate between operators

The reception rate in the reference area is 58.2% which can be considered as low since in this area non-reception can't be related to a spatial problem. Receiving the CB notification in the reference area is not significantly dependent on whether the phone is an Android or iOS ($p = 0.56$) (Table 1). On the other hand, the reception of CB notification in the reference area is significantly dependent on the phone operator during this exercise ($p < 0.001^{***}$) (Table 2). Large differences are observed (69.5% between Bouygues® and Free®).

4.2. The weak but significative role of distance

Logistic regression of CB notification receipt as a function of distance from the official alert area shows a small but significant negative relationship ($p < 0.001^{***}$). The intercept value is 0.75, and the odds ratio is 0.996 ± 0.001 . The logistic function for predicting y (which corresponds to the probability of receiving the CB notification) is given in Fig. 4. At 100 m, the probability of receiving the notification independently of the operator is 61%, while it is 27% at 500 m and 6% at 1000 m. Although distance does have a significant effect on reducing the reception probability, the regression coefficient suggests the existence of a significant edge effect.

Table 2
CB notification reception rate according to the telephone operator in the reference area (the percentage given in the first line correspond to each operator's share of the French market).

Notification receipt	Bouygues Telecom ® (19.1%)	Free® (13.6%)	Orange® (35.5%)	SFR® (22.2%)	Mean	Chi² result
N	20	19	26	28	/	$\chi^2 = 28.4$
Yes	80.0%	10.5%	42.3%	75.7%	58.2%	ddl = 3
No	20.0%	89.5%	57.7%	24.3%	41.8%	$p < 0.001^{***}$

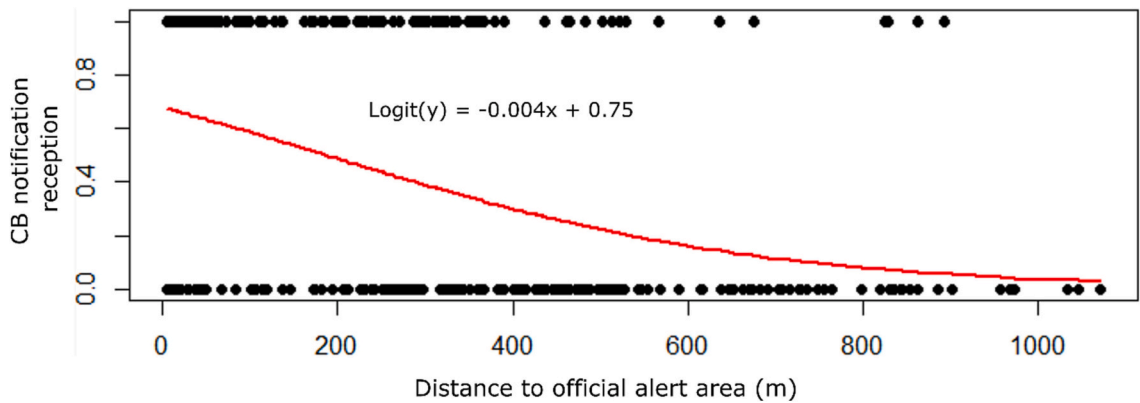


Fig. 4. Logistic regression of reception as a function of distance from the official alert area.

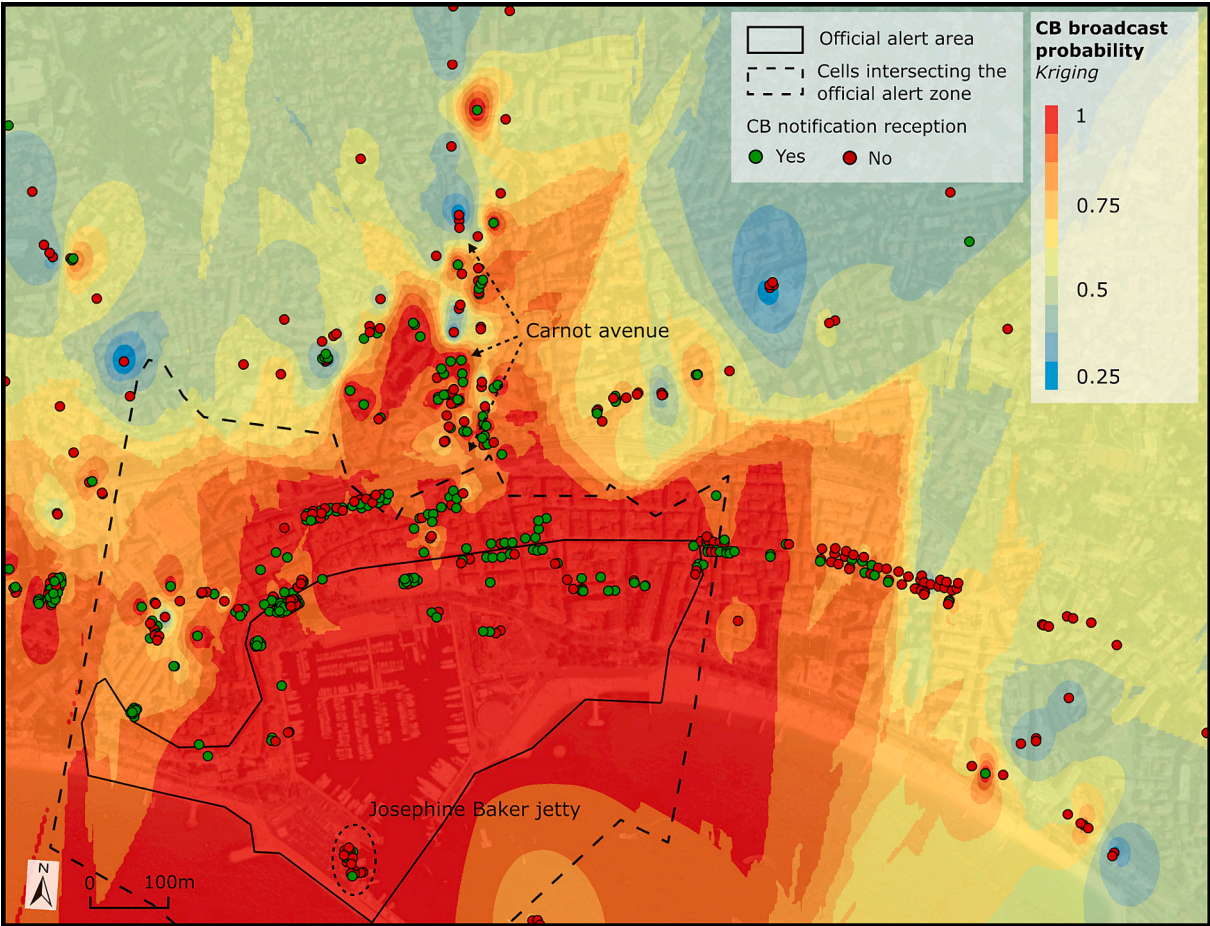


Fig. 5. Kriging interpolation of the probability that the non-reception of CB notification is due to a problem with the telephone operator. The lower the value, the higher the probability of being outside the real broadcast area.

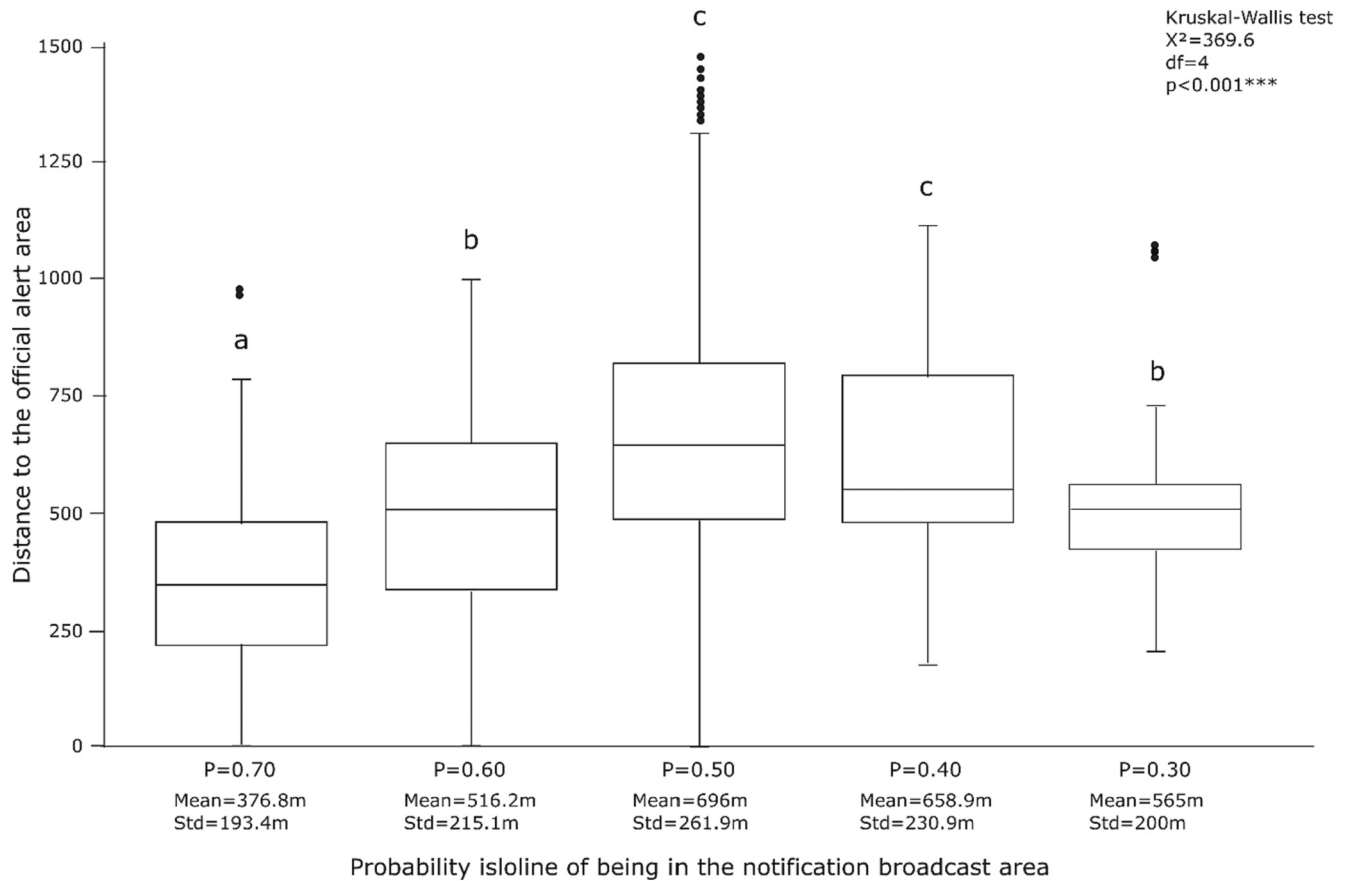


Fig. 6. Boxplot of measured distances to the official alert area by isolines of probability of being in the notification broadcast area. Two isolines of probability sharing the same letter ($P = 0.60/P = 0.30$ and $P = 0.50/P = 0.40$) are not significantly different according to the pairwise comparison from the Kruskal-Wallis test (adjusting method = BH (Benjamini & Hochberg, 1995)).

4.3. A consistent and irregular edge effect

The linear kriging interpolation confirms the existence of an edge effect during the Cannes April 13th alert exercise (Fig. 5). The maximum distance to the official alert area for an individual who has received the CB notification is 892 m. This edge effect even exceeds the edge effect estimated by Voronoi polygon modeling of the telecommunications cells intersecting the official alert area (dotted line in Fig. 5). The zonings of the CB notification broadcast probabilities are ragged (Fig. 5). Although this may be due to bias related to the lack of data dispersion, we observe that the edge effect was particularly large north of the official alert area, along Carnot Avenue, while in the northeast and northwest, the edge effect is more attenuated. The visual analysis of the kriging allows us to observe spatial discontinuities: we can identify “bubbles” of high probability in a neighborhood of low probability (to the north, northeast and northwest) and conversely, “bubbles” of low probability in areas of high probability (north and west).

The intercept value calculated in logistic regression is higher than the reception rate (set between 0 and 1) in the official alert area (+0.17). This raises the question of the data calibration in the official alert area. One area in particular stands out negatively in the reception statistics: to the south, along the Josephine Baker jetty from where the boats leave for the Lérins Islands. This area is well within the official alert area, yet only 6 of the 21 individuals surveyed said they had received the alert. In this area, it is possible that the operators Free® (5 out of 5 individuals did not receive the notification) and almost certain the operator Orange® (6 out of 6 individuals did not receive the notification) did not broadcast the alert, whereas the operators Bouygues® and SFR® had rather expected reception rates. The probability that the operator Free® did not

broadcast the notification in this part of the official alert area is $P_{Free} = 0.426$ (based on the failure rate of Free® in the reference area and the number of individuals in the studied area: $P_{Free} = 0.895^5$). For the Orange® operator, this probability amounts to $P_{Orange} = 0.994$ (0.423^6). Thus, it is very likely that even in the official alert area, there are grey areas, i.e., areas where the notification has not been broadcast.

We also analysed the spatial variability in the probability of CB notification broadcast. In a GIS, we formed a dot line spaced 20 m apart along the 0.7, 0.6, 0.5, 0.4 and 0.3 kriging probability isoline. We calculated the distance between each dot and the official alert area. The statistical results show a high variability in the observed distances between each of the probability limits and the official alert area (Fig. 6). The results show that, above $P = 0.5$, the shorter the distance to the official alert area, the greater the probability P of being in the notification broadcast area (Kruskal-Wallis test, $p < 0.001***$). This result is quite logical, but below probability $P = 0.5$, the distance does not increase significantly when the probability of being in the notification broadcast area decreases (BH pairwise test, $p = 0.25$ between 0.4 and 0.5 isoline probability and $p = 0.33$ between 0.3 and 0.6 isoline probability).

The dispersion indicators show a strong dispersion of the distance values to the official alert area for the isolines of probabilities 0.4 to 0.7 (Fig. 6). This dispersion is less important for the isoline of probability 0.3, in particular because this isoline is not very extensive spatially (unlike the other more extensive isolines, the isoline 0.3 surrounds some points of low probability). On the 0.4–0.7 isolines, the interquartile range is on average ± 31.9 m. These features highlight the strong spatial variability of the edge effect compared to the official alert area.

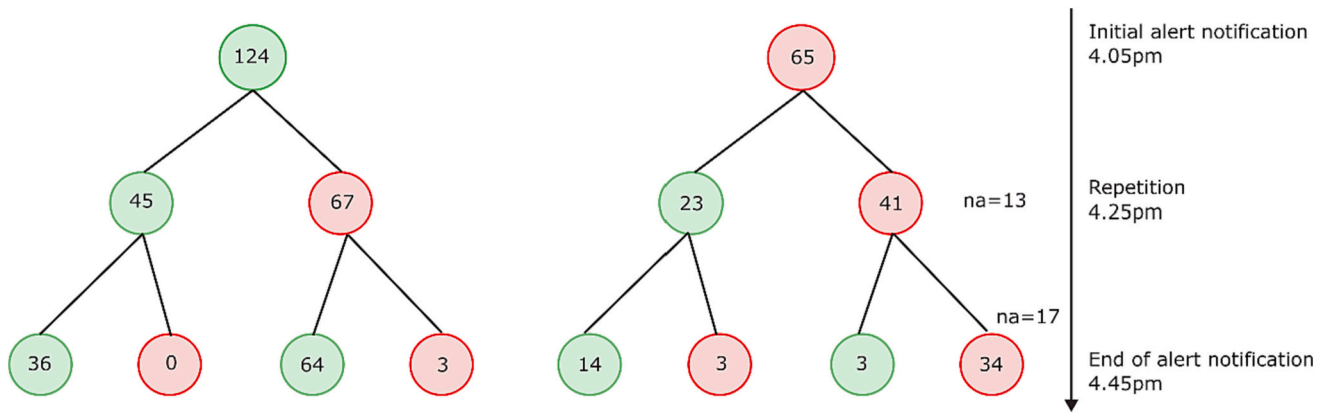


Fig. 7. Classification of agents according to the reception of the 3 notifications sent during the exercise of April 13th in Cannes (green = yes; red = no). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

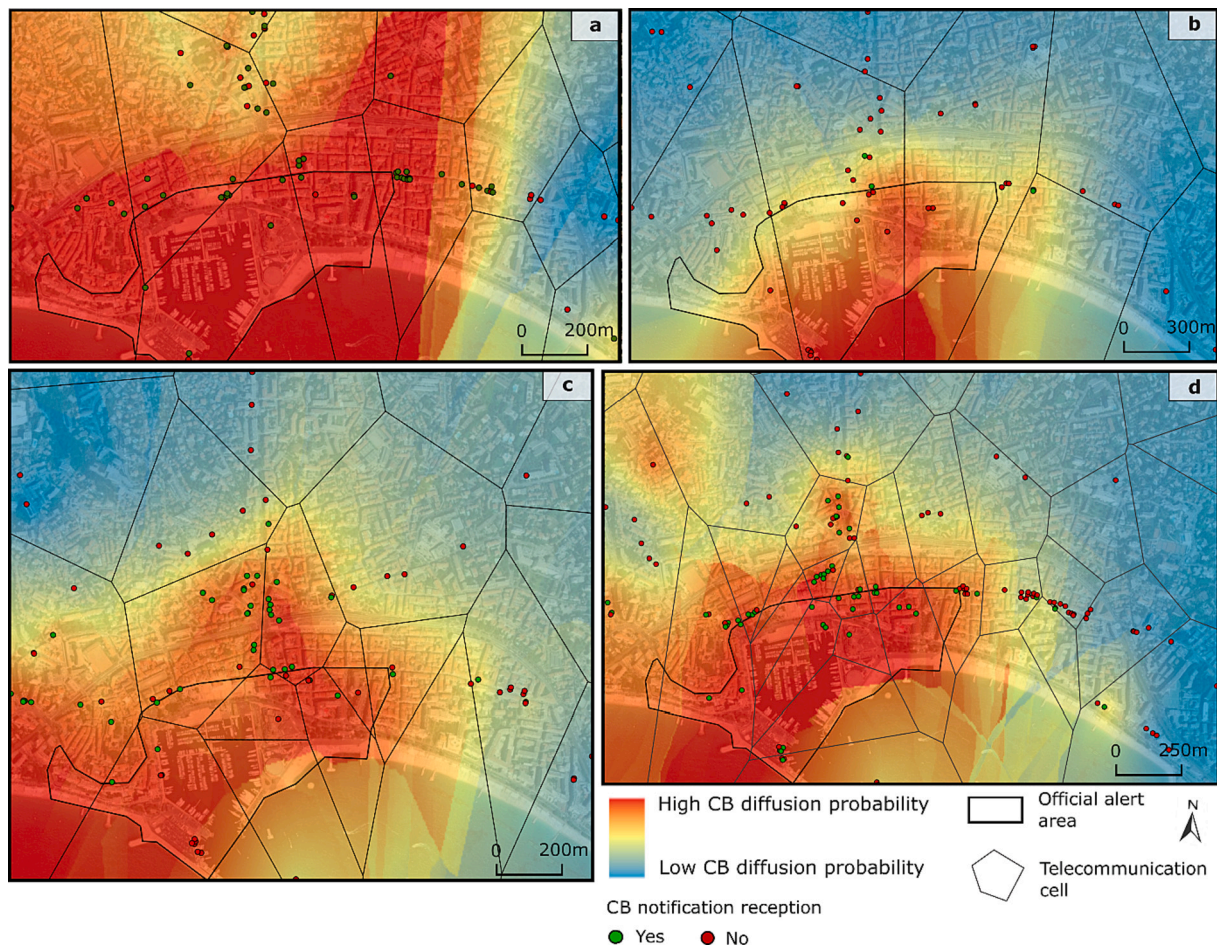


Fig. 8. Kriging interpolation of the probability of CB notification broadcast for each operator (a: Bouygues®; b: Free®; c: Orange®; d: SFR®).

4.4. Instability of the broadcast area over time

The analysis of the data provided by the City Hall of Cannes reveals an instability of the notification broadcasting area between the initial alert, its repetition and the end-alert message. If the broadcast area were timely stable, 100% of the agents should have either received all three messages, or received none of the three messages. Instead, 22.9% of the agents ($n = 36$) received the three messages and 21.7% ($n = 34$) did not receive any. Thus, 55.4% of the agents ($n = 87$) have received, and not received at least one of the three messages. Fig. 7 tells us that the

majority of agents who received the first notification received the third, but that a significant portion of these individuals (59.8%) did not receive the repeat. For agents who did not receive the initial notification, the reception of the second notification (for 37.5% of agents) seems to condition the reception of the end of alert notification.

There is a gap of 7.4% between the success rate of our sample in the official alert area (58.2%) and the City Hall sample (65.6%). This gap may be resulted from the use of telephone services linked to the same operator for municipal agents. The data provided by the City Hall reveals highly positive or negative rates of reception within the same

buildings (same services).

5. Discussion

5.1. Dealing with unreliability and spatial inaccuracy of CB notification

The results highlight both the unreliability of the CB notification at the official alert area scale and the inaccuracy of the broadcast area, which large-scale studies may not be able to detect. >41% of the individuals located in the alert area did not receive the alert notification, knowing that all respondents had a cell phone. If the reception rates of the operators Bouygues Telecom® and SFR® are high, the operators Orange® and especially Free® seem to have technical issues that need to be understood and resolved. When questioned, the operators did not mention any technical problem during the Cannes tsunami test. However, starting from the vectorized file of the official alert area, each operator has their own method and tools to identify the cells to be activated for CB broadcasting. Yet, these methods have not been clarified but could explain the different success rate of CB notification according to the operators. Future studies will have to confirm if these issues are related to the exercise of Cannes or if they are observed in other situations.

Phone settings are also a factor in the failure rate in the official alert area (Gojmerac et al., 2016). For some phones, it is up to the user to authorise the reception of emergency alerts in the settings of his phone. Without this authorisation, the alert notifications are not delivered. Communication campaigns should advise and guide individuals to activate this feature. Also, owning a dual SIM phone increases the risk of missing CB messages due to overlapping paging schedules (reception time) of the two SIM cards, causing a higher collision rate (Dandga et al., 2012). In France, 13.2% of people owned a multi-SIM phone in 2015 (87th in the world).¹ In Cannes, only 5 individuals said they had a dual-SIM, without being explicitly asked this question.

The spatial accuracy of CB notifications is undermined by three outcomes: 1) clearly observable edge effects well beyond the boundaries of the official area; 2) spatial variability of this edge effect, with discontinuities; 3) temporal variability of the notification broadcasting area. The spatial and time variation of the edge effect makes it difficult to estimate it upstream. Reading the kriging map gives clues to the likely spatial discontinuity of the broadcast area because there seem to be islands of variable size in which the notification was broadcast. Based on the estimate of the number of individuals per building at 4.05 p.m. on April 13th (see 2.1), we estimated the total number of individuals located in the dissemination area. In a GIS, we multiplied the number of individuals present in each building by the broadcast probability coefficient taken from the kriging map [0–1] read at the coordinates (x,y) of the centroids of the buildings. With this estimate, 26,090 individuals would have been in the CB notification broadcast area, while the target population (in the official alert area) is 2983 individuals: >8 times the target population.

The correlation between the kriging raster and a 5 m Digital Surface Model (DSM) is significantly negative (Spearman's rho = -0.63, $p < 0.001^{***}$). However, we cannot say that altitude acts as an obstacle to CB broadcast. Firstly, because the official alert area is located on the coast and the further away you are, the higher the altitude. Secondly, because there is no masking effect from topographic obstacles (hill, ridge line) when comparing the kriging raster with the DSM. However, the spatial inaccuracy of CB notifications is probably related to the size of the telecommunication cells and the technical operation of the antennas. A kriging analysis carried out for each operator highlights the variability of the broadcasting area depending on the operator (Fig. 8).

¹ Study of the OpenSignal company: <https://docs.google.com/spreadsheets/d/1Ihh1CqLBoVYu8tVXO7h1sPudhJBkExCAALJQZtAMFY/edit#gid=1744995906>

This variability is undoubtedly linked to the mesh of telecommunication cells that are specific to each operator.

Figure 8 also shows a spatial mismatch between the notification broadcast probability and the telecommunication cells modeled by the Voronoï tessellation method. First, Voronoï tessellation is not the most appropriate method to represent cell boundaries. Researchers observed that 60% of the devices attached to an antenna were located outside the antenna's Voronoï polygon (Ogulenko et al., 2022). Also, 95% of the monthly calls received by an antenna are spatialised over more than twice the size of the antenna Voronoï polygon (Ogulenko et al., 2021). These results highlight the underestimation of cells by the Voronoï model. Studies suggest a Bayesian probabilistic approach to better estimate the cell to which a device is attached (Ogulenko et al., 2021; Tennekes & Gootzen, 2022). Second, models based on clear boundaries between cells are wrong because cells overlap (Ogulenko et al., 2021; Tennekes & Gootzen, 2022). A device located close to an antenna A could be attached to a more distant antenna B (Ogulenko et al., 2021). Thus, because there are no clear boundaries between the telecommunication cells, the CB notification broadcast area is difficult to predict. Having characteristics on the antennas (beam direction, elevation angle, height) would improve the estimation of the CB notification area.

The protocol carried out in this article must be extended to other territories, and particularly in rural areas, knowing that the cell size varies negatively with an urbanity gradient (Lee et al., 2014). For example, there are 49.7 antennas/km² in Cannes, compared with 0.32 in the Alpes-de-Haute-Provence department (a rural department with the density of 24 inhabitants/km²). An even more significant edge effect is therefore expected in rural areas.

In some situations where the spatial boundaries of hazards are blurred, the accuracy of alert is not an issue (heavy rainfall, heat wave episode, storm, earthquake, etc.). But in other situations, the spatial accuracy of the alert is a key issue of crisis management operations (industrial risk, wildfire, flood, tsunamis, volcanic eruption, etc.), especially when issuing evacuation instructions. Unwanted flows of people can complicate rescue operations (network saturation, massive influx of people into refuge sites, movement of individuals to the danger area, etc.). In Cannes, individuals who were located in the Suquet District (east of the official alert area) at 35 m altitude (therefore not exposed to the tsunami risk) received the alert and said they hesitated to evacuate their building.

5.2. Individuals' perception of the Cannes tsunami CB notification

A link to an online questionnaire was distributed at the end of the alert messages during the Cannes exercise, which made it possible to obtain additional results ($n = 814$). Being in a building has no effect on the non-reception of the alert: 65% of the individuals having answered the questionnaire declared to be in a building when they receive the notification while they are 19.8% to declare being on the move (car or public transport) and 15.3% outside. Beyond the purely technical and spatial aspects, the feedback is rather positive and encouraging: only 17.4% of individuals were annoyed by receiving the notification and 83.6% found it curious. Some individuals were scared (42.5%) or stressed (50.3%). The instructions broadcast in the message were understandable for 81.2% and the location of the event was easily identifiable for 70.3% of individuals. Also, 69.2% of individuals said they would have known how to react if the alert had been real. Lastly, we observed in the field a significant number of people who tried to clear the message very quickly, without reading it. We suspect that these individuals were bothered by the sound of the notification received in public. Following this observation, we modified the perception questionnaires distributed at the end of the alert messages for each exercise that included a CB notification in France (Douvinet et al., 2022b). We found that 25% of respondents said that they had tried to mute the telephone sound by acknowledging the message before reading it. The authorities and the scientific community should consider this issue.

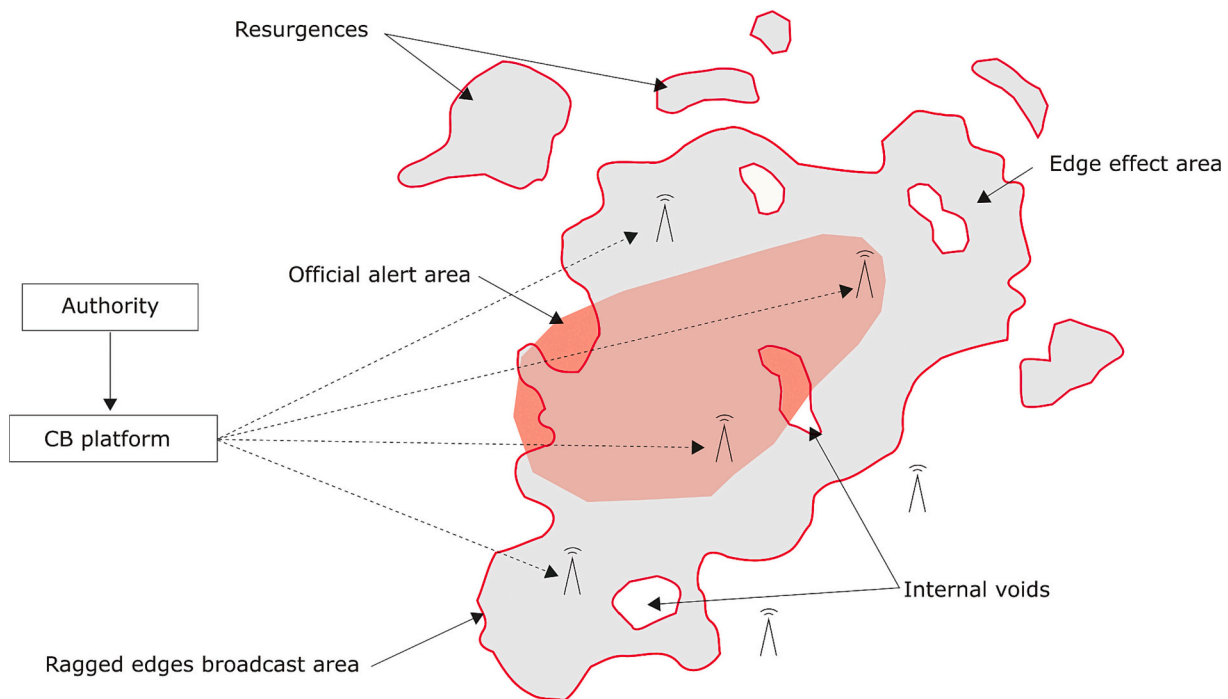


Fig. 9. Schematisation of the spatial issues of cell broadcast at a local level.

5.3. Suggestions for the authorities

This work reveals how difficult it is to predict the spatial envelope of the actual alert broadcast area in urban context (Fig. 9). In this regard, we would like to draw the attention of the authorities to several points. First, it is pointless to model extremely precise contours of official alert areas, as the edge effect will destroy the spatial accuracy of the upstream modeled area. For example, as part of an attack alert exercise, the prefecture of Seine-Maritime (in the northwest of France) has modeled an alert area surrounding the Zénith (large meeting room) by a few hundred metres, but excluding the building from the alert area so that the terrorist inside the building does not receive the alert message. In view of the results obtained at the Cannes exercise, it is obvious that such a level of finesse in the modeling of the alert area is useless and that the individuals located within the Zenith enclosure also received the notification.

Working on the content of alert messages, knowing that it will be read by individuals located outside the danger zone, seems an interesting option. Textual elements specifying the location of the danger can be written (Douvinet et al., 2022). The distribution of a map within the alert message is also a way of contextualising the danger in space (Cain et al., 2021). The message should be sent to the host country language and then in English in order to be understood by the maximum number of people. The multiplication of alert tools to warn of the danger remains necessary, especially as we found that there are internal voids within the CB broadcast area (Fig. 9). Other tools must be activated in the event of an alert: sirens, voice sirens, digital social networks, variable message signs, SMS notification, etc. (Bopp et al., 2021). The prevention of populations remains a central element of risk management policies and having a new alert technology should not prevent efforts in this area. Funding publicity campaigns to make French citizens aware of the FR-Alert system is a good thing, as is the organisation of regular exercises for individuals to receive CB notifications.

All these elements should not prevent FR-Alert from being used by the authorities. To date (September 2023), 11 events have been the subject of CB activation in France: forest fire in Gironde, a cyclone and a volcanic eruption in Reunion (Indian Ocean), storm and flood in the northeast, etc. This is too few in comparison with other events that have

not been the subject of a CB alert (storm in Corsica, industrial accident in Seine-Maritime, avalanche in the Alps, forest fire in Pyrénées-Orientales, etc.) (Grancher et al., 2023). European cooperation should be set up to identify the issues for the effective use of location-based alerts.

6. Conclusion

Using spatial analysis and statistics methods, this article reveals the inaccuracy of CB notification during the Cannes Tsunami trial: (1) reception depends on telephone operators; (2) a significant edge effect results in alerting individuals located outside the official alert area; (3) the edge effect is difficult to predict because there is a spatial variability of the isolines of reception equiprobability as well as a temporal variability of the broadcast area limits during the alert time; (4) there are grey areas (internal voids) in the official broadcast area where the alert was probably not broadcast by some operators. These results counterbalanced the spatial accuracy of the cell broadcast notification in an urban context, and it is expected that this inaccuracy increases with the degree of rurality of the territories. The authorities should consider this spatial inaccuracy when modeling alert areas and drafting messages. The issue is to prevent people outside the danger zone from disrupting crisis management. The method used in this article must be replicated in other territories (densely urban, moderately urban, rural, mountainous), in order to better calibrate this edge effect and fully take it into account in the cell broadcast activation procedures in France and Europe.

Declaration of Competing Interest

The authors have no competing interests to declare.

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