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ORIGINAL ARTICLE

What input data are needed to accurately model electromagnetic fields from mobile phone base stations?

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The increase in mobile communication technology has led to concern about potential health effects of radio frequency electromagnetic fields (RF-EMFs) from mobile phone base stations. Different RF-EMF prediction models have been applied to assess population exposure to RF-EMF. Our study examines what input data are needed to accurately model RF-EMF, as detailed data are not always available for epidemiological studies. We used NISMap, a 3D radio wave propagation model, to test models with various levels of detail in building and antenna input data. The model outcomes were compared with outdoor measurements taken in Amsterdam, the Netherlands. Results showed good agreement between modelled and measured RF-EMF when 3D building data and basic antenna information (location, height, frequency and direction) were used: Spearman correlations were >0.6. Model performance was not sensitive to changes in building damping parameters. Antenna-specific information about down-tilt, type and output power did not significantly improve model performance compared with using average down-tilt and power values, or assuming one standard antenna type. We conclude that 3D radio wave propagation modelling is a feasible approach to predict outdoor RF-EMF levels for ranking exposure levels in epidemiological studies, when 3D building data and information on the antenna height, frequency, location and direction are available.

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INTRODUCTION

Previous observational studies on potential health effects from radio frequency electromagnetic fields (RF-EMFs) from mobile phone base stations have applied several methods to assess exposure. Performing measurements could be perceived as a superior approach to obtain exposure estimates for study participants,[1–4] but is very time intensive and can therefore be prohibitive in large epidemiological studies. Other studies have applied surrogate measures as proxies for exposure, such as average density and power output of antennas per area,[5] or distance to the closest mobile phone base station.[6,7] However, such simple exposure proxies have been shown to correlate poorly with measured exposure levels,[8] which means that study participants are likely to be misclassified hampering the assessment of the presence or absence of health effects.

Alternatives to such simple proxies are geo-spatial models that estimate the RF-EMF for any given geographical location, usually the study participants' place of residence. In such models, information of the geo-spatial environment are combined with antenna characteristics. Even though the physics behind radio wave propagation are well understood, the large number of factors that have an impact on the resultant RF-EMF greatly add to the complexity of the models. Buildings and vegetation can shield, diffract or reflect radio waves, depending on their placement, angles and materials. Ideally, one would have information regarding the exact configuration of the antenna, its location, and the location and properties of any obstructing objects between the antenna and a receptor. Consequently, the exact geometries and materials of objects would have to be available in digital format, which is rarely the case.

Different methods have been applied to model radio wave propagation, with various degrees of accuracy of the input data. Examples are free-space propagation with no building obstruction,[9] or free-space propagation combined with empirically determined transmission factors to account for obstruction by buildings and vegetation,[10,11] or shielding by topography in combination with empirical transmission factors.[12] The most comprehensive model used in epidemiological studies so far, NISMap, applies a 3D modelling environment. NISMap has been used in Basel, Switzerland,[13,14] and in Amsterdam, the Netherlands,[15] and showed a moderately high correlation with measured levels of RF-EMF (Spearman correlation approximately 0.7–0.8). NISMap considers the antennas' radiation patterns, buildings and topography, but the impact of vegetation and reflections are not taken into account.

In general, correlations between modelled and measured RF-EMF seem to improve with increasing level of detail for the input parameters of the models.[10,14] However, it is unclear which characteristics of the input data or radio wave model drive the accuracy of the modelling results. We therefore evaluated the impact of different input data characteristics and model settings on the accuracy of outdoor RF-EMF model predictions in the city of Amsterdam, the Netherlands. The aim of our study is to assess the feasibility of RF-EMF exposure assessment for a range of data

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Table 1. Overview different models to assess RF-EMF exposure.

Model name	*Building*		*Antenna*				*Propagation algorithm*	*DTM*
	3D data	*Damping*	*Location*	*Tilt*	*Type*	*Power*		
(1) Optimal	Yes	Default	Improved	Avail.	Avail.	Avail.	Double powerlaw	Yes
(2) OrigAntLoc	Yes	Default	Original	Avail.	Avail.	Avail.	Double powerlaw	Yes
(3a) FixedTypeTilt	Yes	Default	Improved	Unavail;Fixed	Unavail;Fixed	Avail.	Double powerlaw	Yes
(3b) FixedTypeTiltPow	Yes	Default	Improved	Unavail;Fixed	Unavail;Fixed	Unavail;Fixed	Double powerlaw	Yes
(4a) MinBD	Yes	Minimal	Improved	Avail.	Avail.	Avail.	Double powerlaw	Yes
(4b) MaxBD	Yes	Maximal	Improved	Avail.	Avail.	Avail.	Double powerlaw	Yes
(5) FreeSpaceProp	None	NA	Improved	Avail.	Avail.	Avail.	Free space propagation	No
(6) NearestAnt	None	NA	Original	NA	NA	NA	None	NA

Abbreviations: Avail., available; DTM, digital terrain model; NA, not applicable; RF-EMF, radio frequency electromagnetic field.

and model limitations, as for many epidemiological studies detailed data are not available.

METHODS

Propagation Model Description

We used NISMap for our model tests. NISMap is a deterministic model that accounts for building-obstruction and diffraction with actual 3D building data, instead of empirically derived shielding factors. A more detailed description of NISMap is given in Bürgi et al.[13] For each individual building in the 3D building data set, the damping of the radio waves can be set for the roof, walls and inside. As it was not feasible to determine the individual building damping parameters, we set the damping parameters *a priori* to fixed values. The default roof damping was set to 5 dB, wall damping to 3 dB and inside damping to 0.2 dB/m, based on values from Bürgi et al.[14] We tested two radio wave propagation models. First, a smoothed version of the double power law with breakpoint,[13] derived from principles described in ITU-R P.1411.[16] The double power law is valid for the whole mobile phone frequency range (approximately 300–3000 MHz). Second, we tested free space propagation, which is a simpler wave propagation model that does not consider obstacles between transmitter and receiver.

Study Area and Measurements

Details on the measurement campaign have been described earlier.[15] In brief, a mobile monitoring approach was used to capture the high-spatial variability in RF-EMF. We performed continuous RF-EMF measurements in five areas in Amsterdam along predefined paths of ~2 km length. Each area had different characteristics, ranging from high-rise apartment blocks to low-rise buildings. We repeated measurements 16 times over a 9-month period, at varying days of the week and times of day.

We used two EME-SPY 140 (SATIMO, France) exposure meters to measure the RF-EMF, set to the minimum measurement interval of 4 s. The devices were placed on a plastic bike cart, with which a research assistant walked along the paths. A Garmin Oregon 550 (Garmin, Olathe, KS, USA) GPS-device was used to track the location of the cart.

The two measurement devices were calibrated before the study, and additional accuracy tests were performed prior, during and after the measurement series. These tests showed that the devices were in good working order, except for the GSM1800 band, which suffered from crosstalk (see supporting material Beekhuizen et al.[15]). The accuracy tests were performed with a continuous wave, but the EME SPY uses a combination of physical filtering and a numerical algorithm for band characterization (Martin Röösli, personal communication). When using such a signal (i.e., as encountered in the field), crosstalk is much lower.[17] Here, we therefore also report the results for GSM1800. Including GSM1800 enables us to compute the combined RF-EMF of all downlink mobile phone frequency bands, which will be referred to as the total (downlink) RF-EMF.

Input Data

We obtained antenna data from the Dutch mobile phone antenna operators, containing detailed information (coordinates, height, horizontal direction, vertical tilt, antenna type, frequency, date since in operation and output power) of each antenna in Amsterdam ($N = 3864$). We checked the location, as given in the data from the providers, of all antennas within 200 m of our measurement paths ($N = 132$) by site visits. We found that 81 out of these 132 antennas (61%) were misplaced from their actual location. The average positional error of the misplaced antennas was 14 m, with a maximum error of 65 m. We adjusted the provided locations based on our visual inspection on site.

High-quality 3D building data were acquired from Eurosense (Wemmel, Belgium), with stated vertical accuracy of 0.75 m and dating from 2008. Buildings are digitized as moderately fine resolution box models: houses with inclined roofs will appear as having flat roofs, but larger buildings with several levels, such as churches, will appear as separate boxes.

Last, we obtained a digital terrain model (DTM) to represent the topography of the terrain.

The DTM was extracted from a filtered version of the Dutch elevation model (Actueel Hoogtebestand Nederland), in which objects on top of the terrain (such as trees, buildings and cars) were removed. We interpolated these missing height estimates using the surrounding heights.

Model Tests

We compared the performance of eight different models. The first, our underlying 'default;1' model, was the optimal model (see also Beekhuizen et al.[15]). This model used 3D building data, detailed antenna data (as provided by the mobile phone operators but with corrected locations), a DTM and the double power law propagation algorithm. Subsequently, we varied both the input data as well as the radio wave propagation algorithm, one factor at a time for comparisons (see Table 1). The second model (OrigAntLoc;2) evaluated the effect of using the original, uncorrected antenna locations provided by the antenna operators as correcting all antenna locations would not be feasible in a large epidemiological study. The third model (FixedTypeTilt;3a) was based on a scenario where antenna type and vertical tilt are unknown given that detailed data on the antenna specifications may not always be available. We therefore set all antenna properties to a fixed value based on the central tendency of the values found in our complete data set. The 'FixedTypeTiltPower (3b)' model assumed no knowledge about antenna type, tilt and output power. We set type and tilt to the values used for the 'FixedTypeTilt' model and the output power to the median power level of all Amsterdam' antennas. Fourth, the 'MinBD;4a' and 'MaxBD;4b' models evaluated the effect of building damping parameters for a minimal and maximal building damping, where minimal was 4 dB, 3 dB and 0.0 dB/m, and maximal was 10 dB, 10 dB and 0.8 dB/m for roof, wall and inside damping, respectively. These values were based on potential building damping factors estimated by Berg.[18] Fifth, the 'FreeSpaceProp;5' model, for which we tested the effect of no building obstruction combined with a free space propagation algorithm, and finally, the 'NearestAnt;6' model, in which the distance to the nearest antenna was used as a proxy for exposure. The latter only required knowledge about the location and communication service of the antennas.

Data Treatment and Analysis

We geo-located all measurements gathered over 16 days and grouped the measurements for distinct 5-m segments along the path, which resulted in around 40 measurements per segment. Next, we took the median of the measurement values within the 5-m segment to obtain a robust estimate, yielding 1827 measurement data points. For each model approach, we estimated the RF-EMF every 0.5 m along the measurement paths and subsequently took the median of the 0.5 m values in the corresponding

5 m segment. We refer to the medians per 5-m segment as, respectively, 'measured' and 'modelled' values.

There were few non-detects in our measurements; for GSM900, 0.02% of the individual measurements were below the detection limit, 0.07% for GSM1800 and 8.27% for UMTS. We therefore did not do any imputation; the measurement values below the detection limit were set to the detection limit. The accuracy of each model ($n = 8$) was determined by comparing the modelled and measured values. We computed the bias (the average difference between modelled and measured values), ratio (the mean modelled divided by the mean measured values), precision (the standard deviation of the differences between the modelled and measured values) and the coefficient of variation (CV) as a standardized measure of model fit (precision divided by the mean measured value). All accuracy indicators were computed on the power density (mW/m^2). Last, we computed the Spearman correlation (the rank correlation coefficient between the modelled and measured values). The Spearman rank correlation is a robust indicator of the model's ability to rank exposure in a meaningful way, without the need to define arbitrary thresholds for RF-EMF exposure categories. Furthermore, the Spearman correlation is independent of the unit of choice; contrary to, for example, the Pearson correlation, the same correlations are found when expressing the RF-EMF in electric field strength, power density or in decibel-Watt.

RESULTS

Table 2 shows the performance for each model. Overall, GSM900 was the strongest contributor to the total RF-EMF, followed by GSM1800. On average, the models underestimated the RF-EMF for both GSM frequencies, and overestimated the UMTS RF-EMF. The relative accuracy (i.e., the precision and CV) of the model predictions was low, and similar for the majority of the model runs per frequency band. We set the antenna properties for the 'FixedTypeTilt' model to 65° for the horizontal and 7° for the vertical beam width, and 5° for the down-tilt. The 'FixedTypeTilt-Power' used a fixed output power of 27 dBW. Model performances were similar for the models that considered both building and antenna data, except for the 'FixedTypeTiltPower' model runs and the GSM1800 Spearman correlations for the 'MinBD' (0.64) and 'MaxBD' (0.48) models. When no building obstruction was considered (i.e., the 'FreeSpaceProp' and 'NearestAnt' models), model performance decreased. The 'FreeSpaceProp' model considerably overestimated the RF-EMF, and had a low Spearman correlation of 0.09 for the total RF-EMF. There was an inverse correlation between distance to the nearest antenna and the total measured RF-EMF of −0.50.

Figure 1 shows an example profile plot for area 4 using the 'Optimal', 'FreeSpaceProp' and 'NearestAnt' model, with the measured value as a reference. The figure shows a large overestimation of the RF-EMF using the 'FreeSpaceProp' model, with little contrast, whereas the nearest distance calculation resulted in a larger contrast between observations and a negative correlation with measured values.

DISCUSSION

We found little differences in model performance when including all antenna information in the input data, and when using only basic antenna data (no information on antenna tilt, type and power). An improved location estimate of the antenna did slightly improve model performance. Changing the building damping parameters to very high or very low values had little impact on the results. Conversely, neglecting building obstruction using free space propagation resulted in poor model performance and a large model overestimation. Surprisingly, the simple exposure proxy 'NearestAnt' had a moderate negative correlation with total RF-EMF.

The major strength of this study is the availability of accurate 3D building data and detailed antenna information for the whole city of Amsterdam, enabling us to assess model sensitivity for a wide range of input parameters. A second strength is our measurement methodology. The mobile monitoring approach captured the high-spatial variability in RF-EMF, and we obtained a daytime average RF-EMF by taking the median of 16 repeat measurements at different times of day.

One of the limitations of the study is that we performed all measurements outdoors at street level, in a flat urban environment. As such, one should be careful in extrapolating the results to other environments. For example, in rural areas there might be more variability in antenna type, or typical down-tilt values could be lower. Using unrepresentative fixed values, or fixed values for parameters with high variability, could have a larger effect on model performance than reported in this study. Furthermore, indoor model performance, essential for estimating personal exposure, might be more sensitive to errors in building damping parameters or the spatial accuracy of the 3D building data. Also, at the top floors of buildings, small errors in antenna tilt and type might have a larger effect as higher elevations are typically closer to the main lobe of surrounding antennas. Even though errors in these building and antenna input data parameters could be more detrimental to indoor model accuracy, we do not expect them to invalidate NISMap. A previous indoor validation study showed similar performance for indoor as for outdoor modelling.[14]

We did not check for differences in model performance when using less accurate building data, as might be available in other countries. Another potential source of model error is the DTM. However, as our study area has little elevation differences, lowering the quality of the DTM had no impact on model performance (data not shown). For hilly or mountainous environments, we expect that the quality of the DTM can strongly affect model reliability.

Previous studies differed considerably in the quality and availability of model input data, and the applied radio wave propagation algorithm. Anglesio et al.[9] used a free space propagation algorithm without building obstruction, and their model overestimated the RF-EMF with a factor of 3–10, similar to what we observed in our calculation. The Geomorf model[12] used an empirical transmission factor derived from land cover data, with a Spearman correlation of 0.66 comparing modelled RF-EMF with spot measurements.[19] Bürgi et al.[13] validated NISMap, for both a rural and urban environment, in Switzerland. In the urban environment, detailed 3D building data were available and they found a Pearson correlation of 0.76 for GSM900 and 0.63 for GSM1800 compared with spot measurements. UMTS networks were not yet in steady operation in the urban model evaluation. In the rural environment, 3D building data were not readily available and extracted using 2D building geometry and an approximation of the number of floors per building. The Pearson correlation was 0.86 for GSM900, 0.70 for GSM1800 and 0.66 for UMTS. Bürgi et al.[14] also tested NISMap for an indoor and outdoor (street) measurement data set, using different models and input data quality (varying building damping parameters, radio wave propagation algorithms, antenna duty factor and vertical tilts). They computed the total RF-EMF from all radio services in the frequency range of 87.5 MHz (FM radio) to 2170 MHz (UMTS downlink). The input data included both high-quality antenna data and 3D-building geometry. The Spearman correlations for all models that considered shielding by buildings were stable, between 0.62 and 0.65. When neglecting building damping, the Spearman correlation decreased to 0.50. These results are in line with our finding that changes in building damping, vertical antenna tilt and radio wave propagation model do not have a large impact on the overall correlation, but neglecting building obstruction does.

We obtained a moderate Spearman correlation of −0.50 using the distance to the nearest antenna ('NearestAnt') approach (i.e., the larger the distance the lower the RF-EMF), distinctly better than the free space propagation model ('FreeSpaceProp'). A possible explanation could be that in the urban environment assessed here, it is much more likely to encounter non-line of sight conditions (and thus having a significantly lower RF-EMF) with

Table 2. Overview model performances for each frequency band and the total downlink RF-EMF (unit: mW/m^2).

Model name[a]	*Mean model*[b]	*Mean meas.*[b]	*Ratio*[b]	*Bias*[b]	*Precision*[b]	*CV*[b]	ρ_s[b]
GSM900							
Optimal	0.11	0.21	0.51	− 0.10	0.36	1.68	0.86
OrigAntLoc	0.09	0.21	0.43	− 0.12	0.38	1.77	0.82
FixedTypeTilt	0.11	0.21	0.54	− 0.10	0.35	1.67	0.86
FixedTypeTiltPower	1.01	0.21	4.76	0.80	5.44	25.71	0.79
MinBD	0.12	0.21	0.58	− 0.09	0.35	1.68	0.85
MaxBD	0.10	0.21	0.48	− 0.11	0.36	1.69	0.84
FreeSpaceProp	1.23	0.21	5.80	1.02	0.98	4.62	0.32
NearestAnt							− 0.61
GSM1800							
Optimal	0.06	0.14	0.41	− 0.09	0.29	2.02	0.56
OrigAntLoc	0.07	0.14	0.46	− 0.08	0.32	2.22	0.53
FixedTypeTilt	0.07	0.14	0.49	− 0.07	0.30	2.06	0.60
FixedTypeTiltPower	0.08	0.14	0.59	− 0.06	0.30	2.08	0.60
MinBD	0.08	0.14	0.55	− 0.06	0.29	2.02	0.64
MaxBD	0.05	0.14	0.34	− 0.10	0.30	2.05	0.48
FreeSpaceProp	1.29	0.14	8.91	1.14	0.72	4.99	0.34
NearestAnt							− 0.55
UMTS							
Optimal	0.06	0.04	1.47	0.02	0.11	2.66	0.85
OrigAntLoc	0.06	0.04	1.36	0.02	0.10	2.40	0.83
FixedTypeTilt	0.05	0.04	1.28	0.01	0.10	2.40	0.81
FixedTypeTiltPower	0.04	0.04	0.85	− 0.01	0.07	1.63	0.82
MinBD	0.08	0.04	1.91	0.04	0.12	2.76	0.80
MaxBD	0.05	0.04	1.27	0.01	0.11	2.65	0.81
FreeSpaceProp	0.83	0.04	19.58	0.79	0.66	15.57	0.46
NearestAnt							− 0.68
Total							
Optimal	0.23	0.40	0.58	− 0.17	0.49	1.23	0.69
OrigAntLoc	0.22	0.40	0.54	− 0.18	0.52	1.31	0.61
FixedTypeTilt	0.24	0.40	0.60	− 0.16	0.49	1.23	0.68
FixedTypeTiltPower	1.13	0.40	2.83	0.73	5.43	13.64	0.66
MinBD	0.28	0.40	0.71	− 0.12	0.49	1.24	0.64
MaxBD	0.20	0.40	0.51	− 0.19	0.49	1.24	0.67
FreeSpaceProp	3.34	0.40	8.39	2.94	1.82	4.58	0.09
NearestAnt							− 0.50

Abbreviations: CV, coefficient of variation; RF-EMF, radio frequency electromagnetic field.
[a]Optimal = improved antenna locations, OrigAntLoc = uncorrected locations of antennas, FixedTypeTilt = antennas set to a fixed type and down-tilt, FixedTypeTiltPower = antennas set to a fixed type, down-tilt and power, MinBD = minimum building damping, MaxBD = maximum building damping, FreeSpaceProp = free space propagation radio wave propagation algorithm, NearestAnt = distance to nearest base station as indicator for exposure.
[b]Ratio = mean model/mean measurement, Bias = mean model—mean measurement, precision = standard deviation of the differences between individual measured and modelled values, CV = precision/mean measurement, ρ_s = Spearman's rank correlation.

increasing distance from the antenna. In line with this observation, Bürgi et al.[14] found a Spearman correlation of 0.50 between inverse distance to antenna and outdoor measurements, but the correlation decreased to 0.18 for their indoor measurements at higher elevations, when the chance of being in line of sight conditions at a greater distance of the antenna is larger. We therefore strongly recommend using 3D radio wave propagation modelling, which considers building obstruction, instead of the basic distance proxy.

We found only minor changes in model performance when using fixed antenna types and down-tilt, which could be explained by the small differences between the antenna types (data not shown) and the down-tilt values (median of 5°, interquartile range between 4° and 6°). When using fixed power levels (set to the median of 27 dBW, interquartile range between 25.6 and 29.0 dBW), the Spearman correlation was not strongly affected. We did find a large decrease in precision for GSM900 and subsequently for the total RF-EMF, as changing all power levels to 27 dBW effectively sets microcells (with a power level ~5 dBW) to emit power levels of regular antennas covering larger areas. The results for GSM1800 and UMTS were not affected, as there were no nearby UMTS and GSM1800 microcells in our measurement areas. Thus, when no information on the power level is available, it is feasible to model the exposure if microcells and femtocells can be distinguished from the macro cells.

Interestingly, we found somewhat lower Spearman correlations for GSM1800 (~0.6) than for GSM900/UMTS (>0.8). We suspect that the crosstalk of the measurement devices for the GSM1800 downlink band (Spearman correlation of 0.62 between GSM1800 uplink and downlink bands, and 0.46 between the GSM1800 downlink and DECT band) contributed to this lower correlation. Still, the CV of the optimal model for UMTS was 2.66 and GSM1800 was 2.02, whereas GSM900 had a CV of 1.68. Thus, the relative accuracy of the model predictions to the measurements was actually better for GSM1800 than for UMTS, and best for GSM900. The superior accuracy for GSM900 might be explained by generally larger vertical beam widths for GSM900 antennas. As the vertical beams for GSM1800 and UMTS antennas are typically about half as wide as for GSM900 antennas, the modelled GSM1800 and UMTS RF-EMF are more sensitive to errors in tilt, width and position of the antennas' main beam. Furthermore, interaction of radio waves with obstacles, in particular refraction and reflection, might affect the longer 900 MHz radio waves differently than the shorter GSM1800 and UMTS radio waves. However, this is very difficult to predict given the input data requirements and is therefore not considered in NISMap. The relatively high Spearman correlation for UMTS as compared with GSM1800 can partly be attributed to one measurement area with no nearby UMTS antennas, resulting in an area with only very low modelled and measured RF-EMF. As we

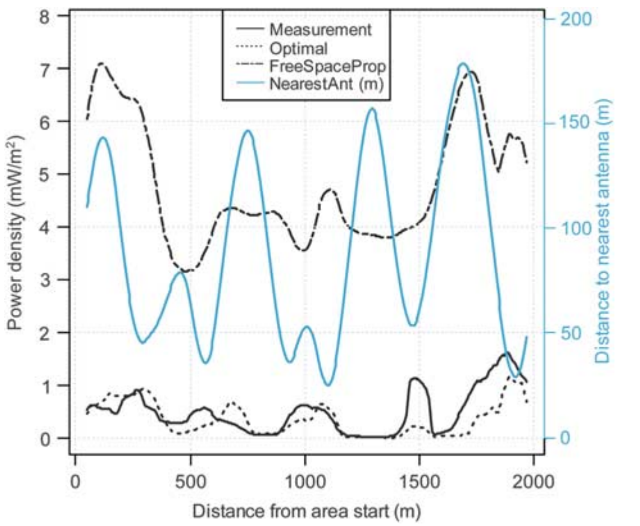

Figure 1. Comparison between the profiles of the total downlink RF-EMF using measurements, optimal model and free space propagation (left *y* axis), and the distance to the nearest antenna (right *y* axis), plotted for area 4. Note that the distance to nearest antenna has an inverse relationship with the measured RF-EMF.

computed the Spearman correlation using the observations over all areas, the observations in the area with no UMTS antenna were easy to rank and increased the contrast, and thereby the correlation. When excluding this measurement area, the UMTS Spearman correlation dropped from 0.85 to 0.72. For these reasons, we suspect that GSM1800 and UMTS model accuracy are more or less similar when using NISMap, and rely in part on the specific antenna and geo-spatial layout.

The results of this study apply to the current network architecture for mobile communication, consisting mainly of macro cells, with high-power base stations mounted on rooftops or separate towers and, depending on the population density and network traffic, covering areas of several acres to a few square kilometres. Future mobile communication networks will use new technologies like LTE (Long Term Evolution) and additional frequency bands (e.g., in the 800 and 2600 MHz range). As network traffic increases, the cell sizes will shrink and additional small cells will be added at hot spots with high traffic. This change will affect the data and model requirements for predicting RF-EMF from mobile networks in the future.

We conclude that 3D radio wave propagation modelling offers a reliable way to rank outdoor RF-EMF exposure levels from mobile phone base stations in epidemiological studies, under the current network architecture. One should be careful in interpreting the absolute values, as the modelled RF-EMF levels can easily be a few factors off from the true value. Detailed information on antenna power, vertical tilt and type are useful, but not a necessity for valid model output when most antennas have similar parameters. The minimum data requirements are information on antenna height, location, direction and frequency, as well as a box model of 3D building data.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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