# *Validation of emf calculation models by measurements*

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# Requirements of software models for EMF evaluations (ARPA activities)

- Calculating time suitable for the number of evaluation required (hundreds a month)
- Possibility to perform evaluations at different heigths from the ground, onto planes or surfaces following orography
- Possibility to lay evaluations upon cartography

# Types of models tested

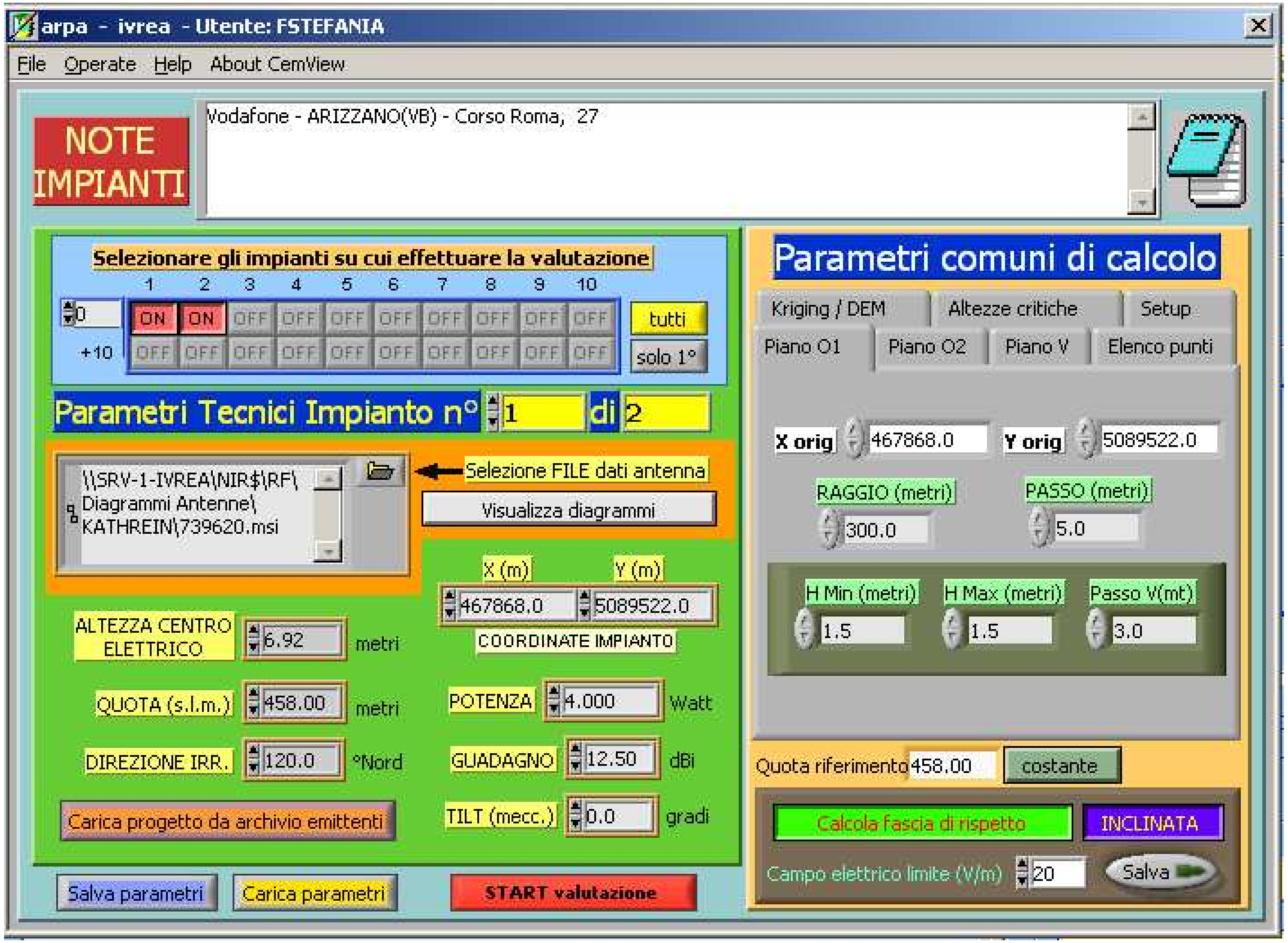
1. Far field – free space (CEMView – ARPA Piemonte; Vigila – Telecom, Nfa2k – Aldena, SuperNec)

2. Far field – presence of reflecting obstacles (buildings) (ray tracing: Vigila)

3. Near field – free space (SuperNec)

# *Far field – free space developed by Arpa Piemonte: CEMVIEW*

*(*National Instrument Labview*)*

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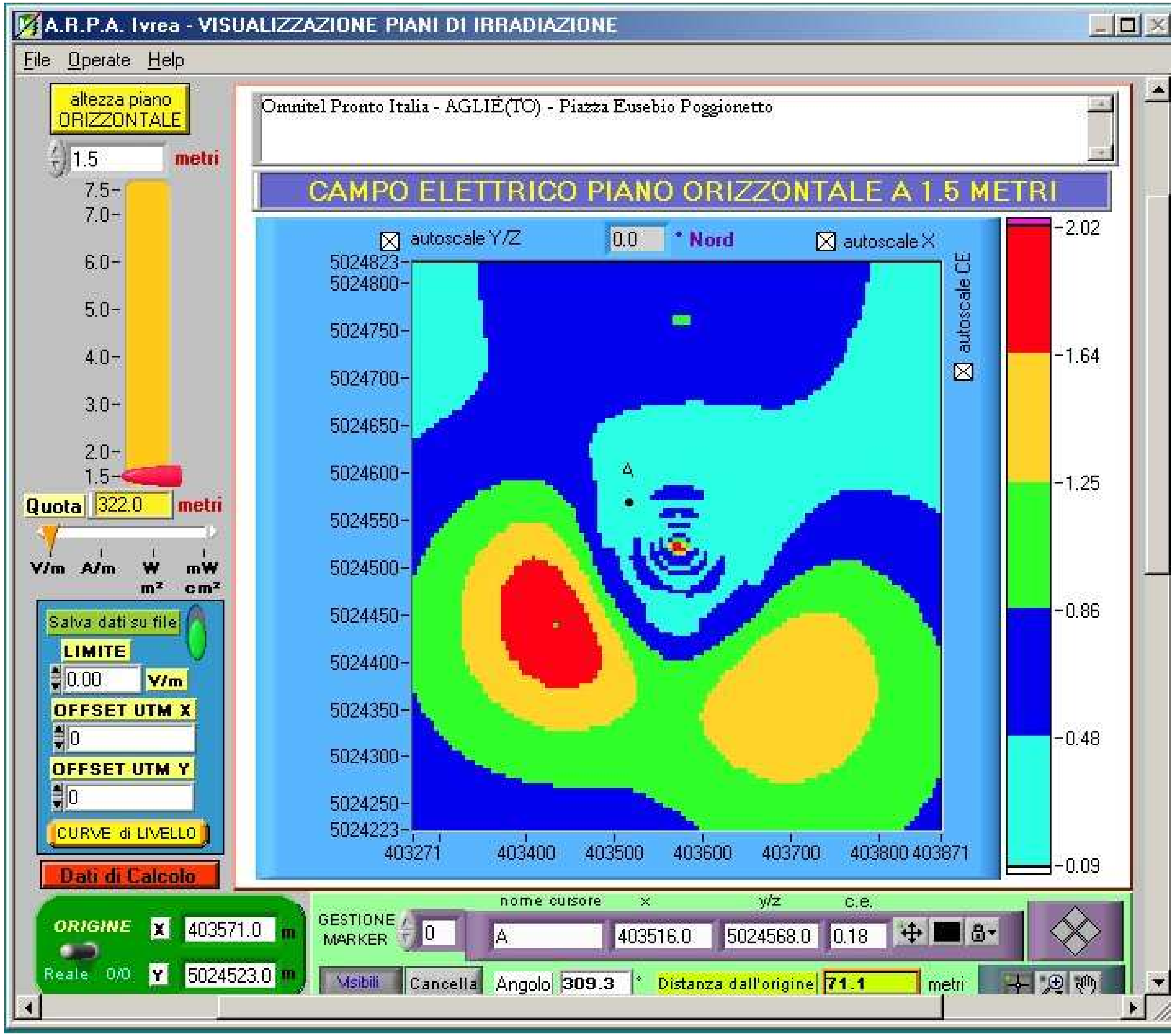
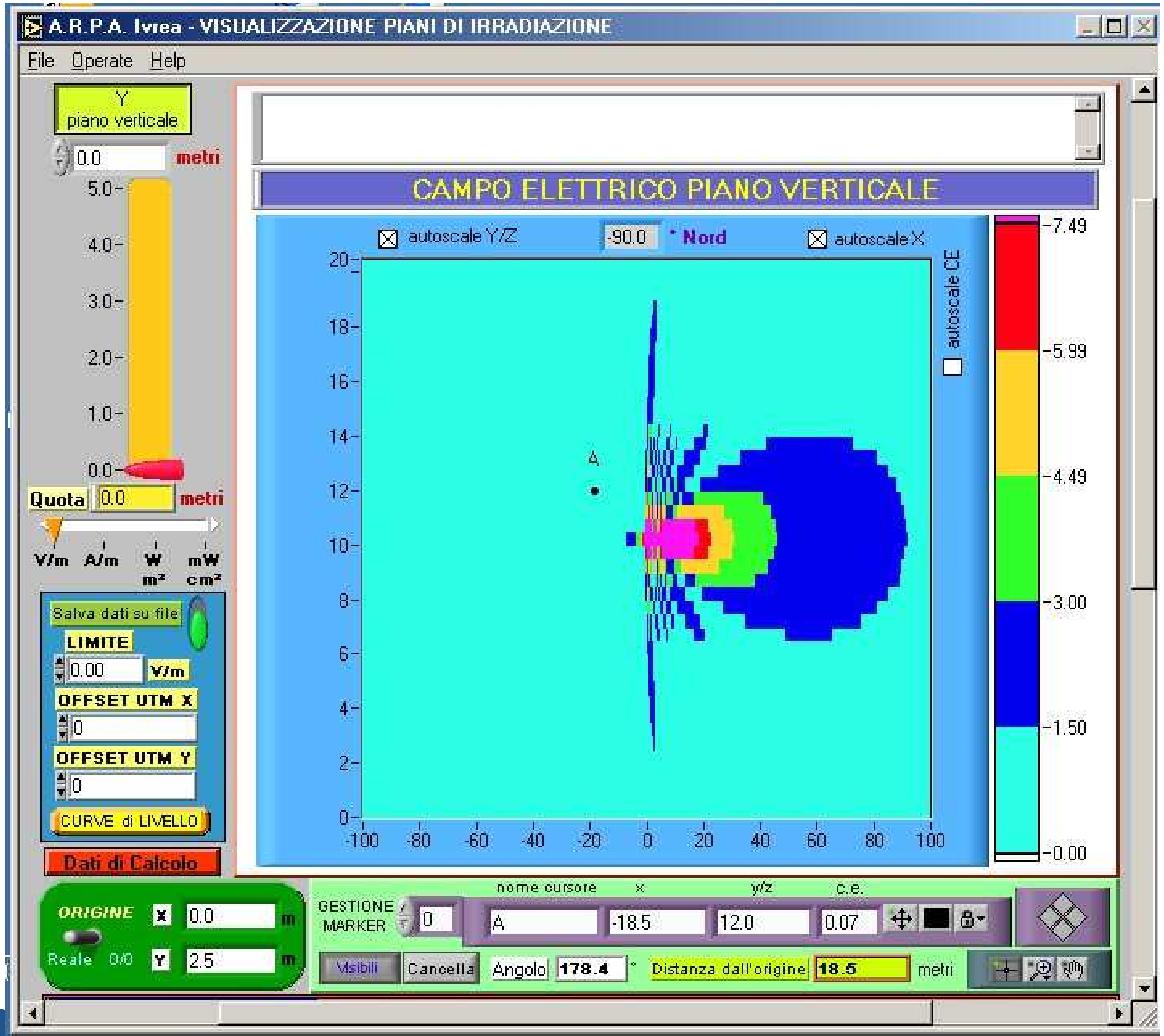
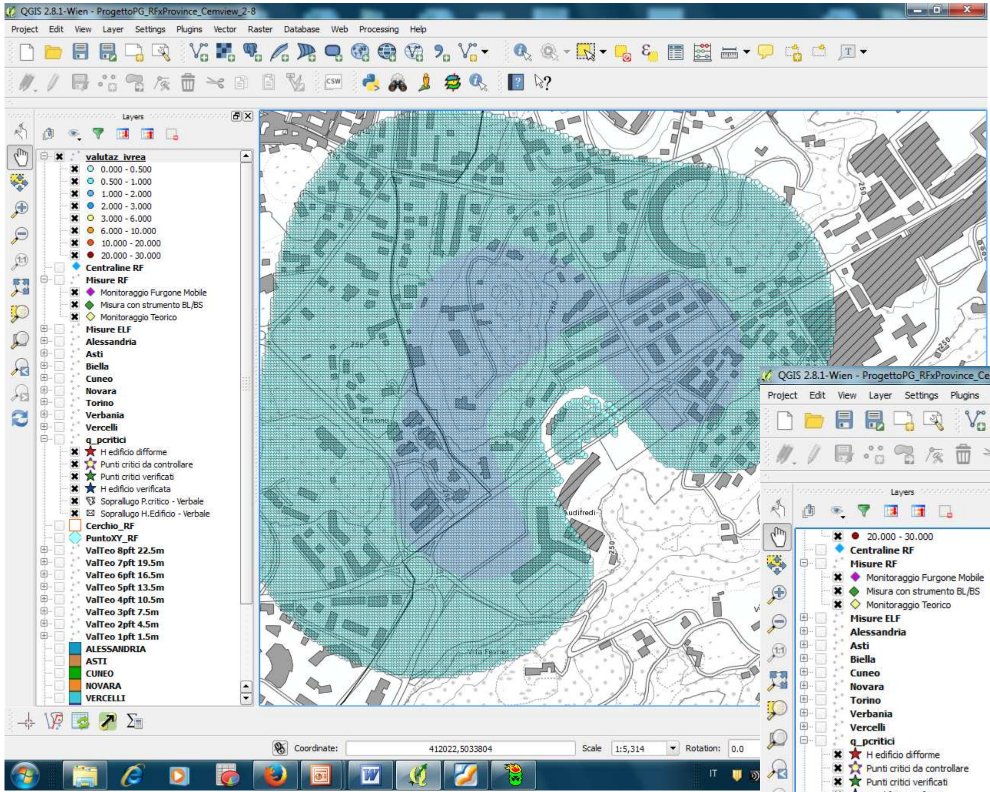
# OUTPUT EXAMPLE

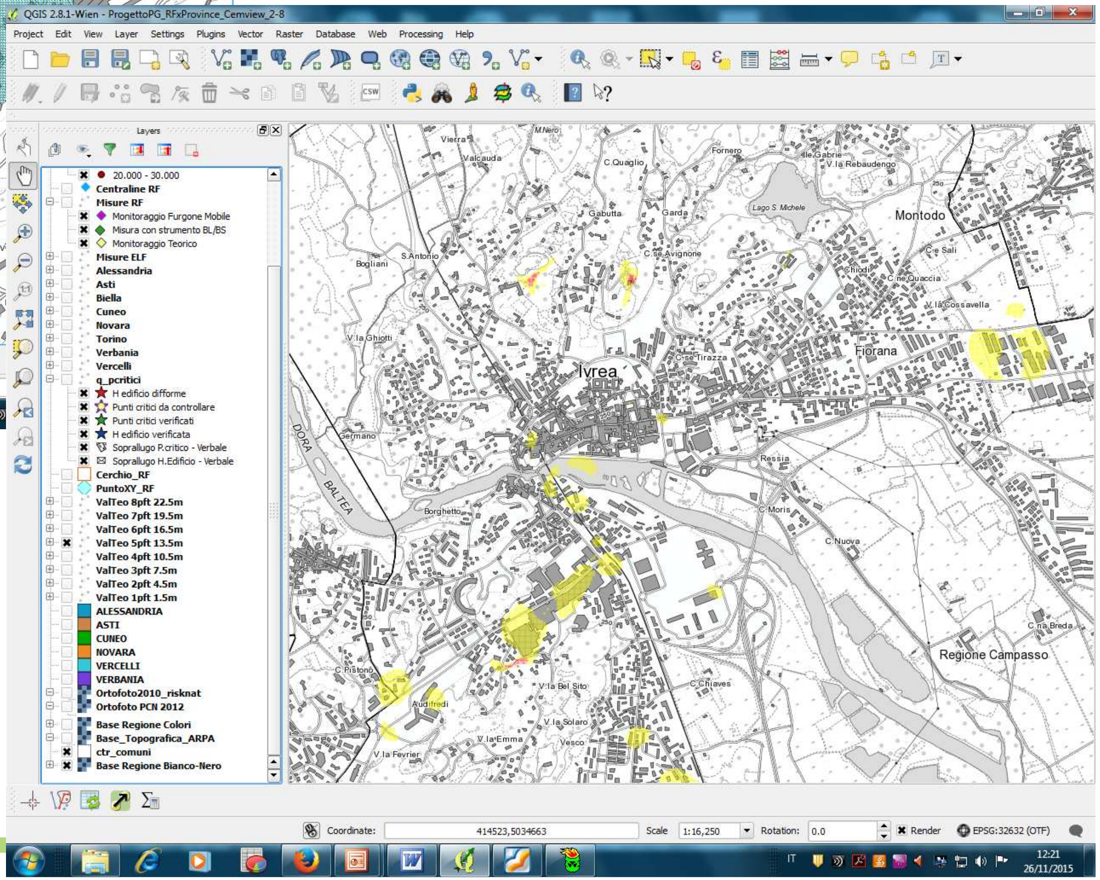


# OUTPUT EXAMPLE



# Cemiew georeferred maps

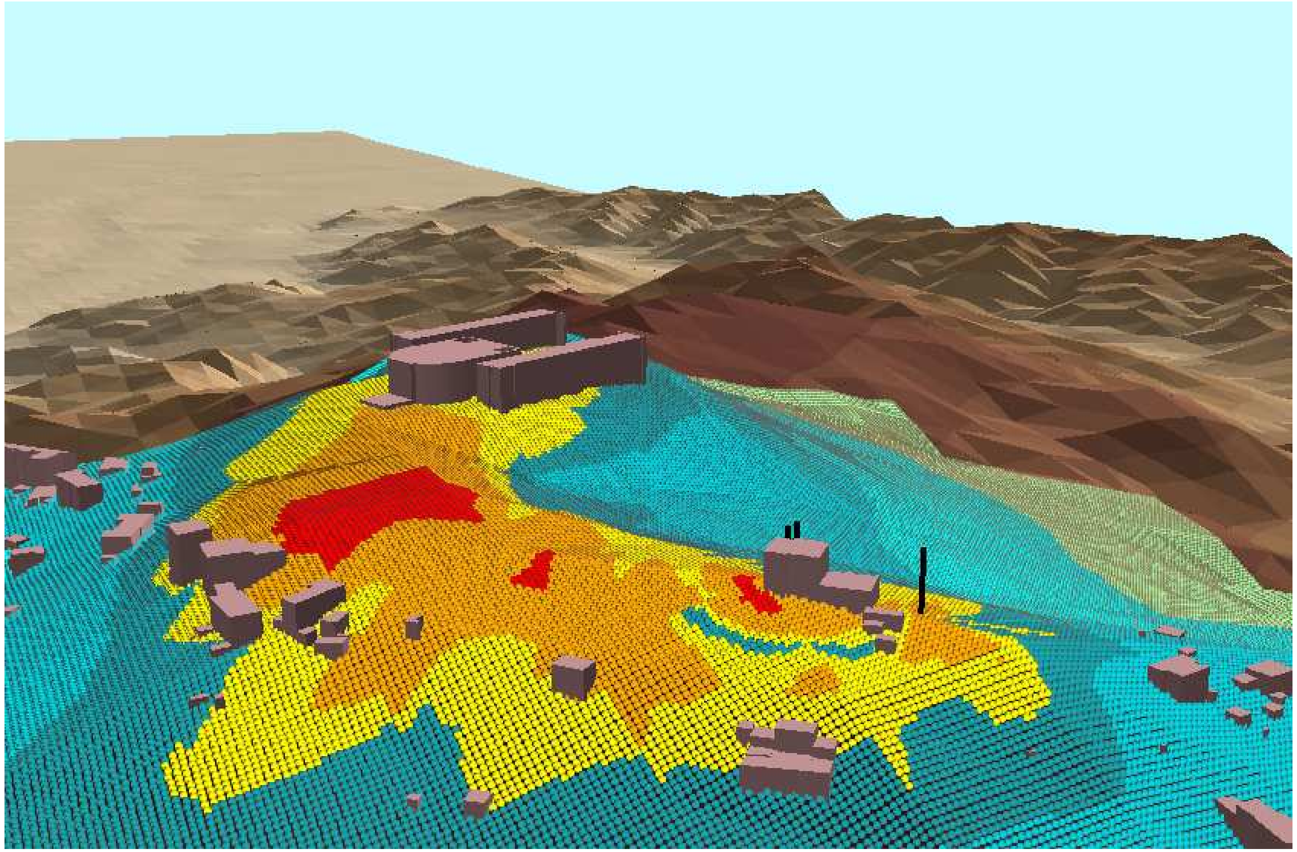




THEORETICAL ESTIMATION

Far field and Free Space approximation

Sum of emissions from more sources



Digital Terrain Model (DTM) cartography

## Far field and Free Space approximation

$$E = \frac{\sqrt{P \times G(\theta, \varphi) \times 30}}{d}$$

E – Electric field strength in a certain point (V/m);

P – antenna supply power

d – distance of the P point from the transmitting antenna (m);

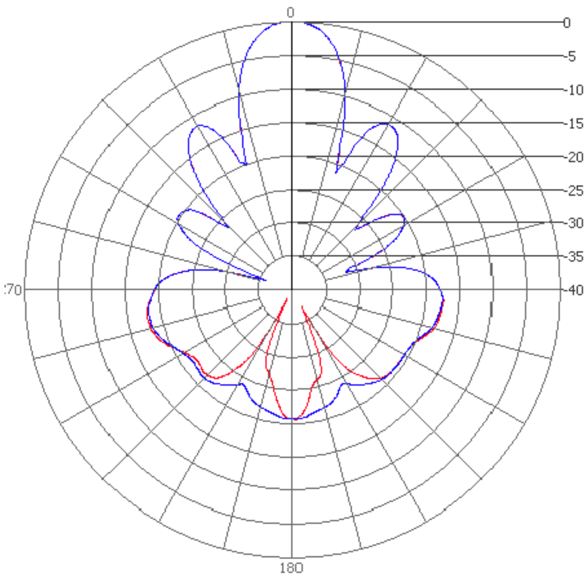
$G(\theta,\varphi) = G \cdot f(\theta,\varphi)$ where G is the antenna gain and $f(\theta,\varphi)$ is antenna directivity function.

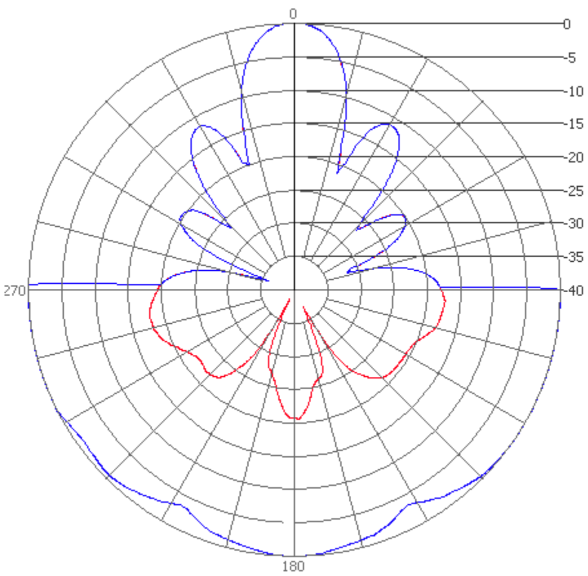
***The different models use the same calculation algorithm, but they differ by the 3D radiation pattern building procedure.***

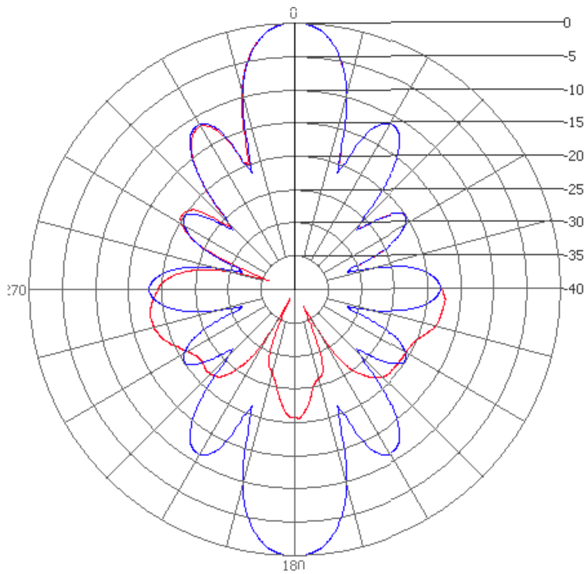
# Building 3D radiation pattern

Methods implemented in CemView:

1. SUM : builds 3D pattern on the hypothesis of simmetry of the vertical pattern in front of and behind the antenna. This method sums for each direction attenuation values corresponding to angles φ (horizontal pattern) e θ (vertical pattern). So the vertical pattern behind the antenna is obtained by overturning the frontal one and summing attenuations. It is based on an hypothesis that can affect significantly the global pattern, buta can be used in some specific cases.




CEMVIEW - SOMMA

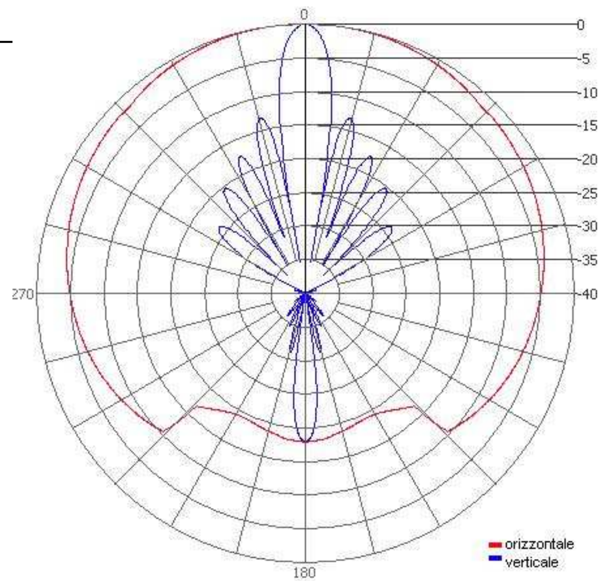
2. REVOLUTION: builds the 3D pattern basing on 2 hypothesis:

- The shape of the solid pattern is determined by the transformation of vertical pattern during its revolution from 0° to 180° azimut
- The attenuation values for a certain azimut angle are proportional to the trend of the horizontal pattern.

So the 3D pattern is obtained by turning the vertical pattern on the horizontal one, varying attenuations according to the horizontal attenuation. In a certain direction θ attenuations of vertical pattern will be a function of attenuation of the horizontal pattern in that direction.

The vertical pattern, from Er (0 °, φ) to Er (180 °, φ), is subject to a change linearly dependent on θ:

$$Er_{lin}(\vartheta,\varphi) = Er(0°,\varphi) - \frac{Er(0°,\varphi) - Er(180°,\varphi)}{180} \cdot \vartheta$$



This has to be adapted, in the horizontal plane φ = 0, to the effective radiation pattern.
A correction factor K(θ) is then defined, which expresses the relative deviation of the "linear pattern" compared to the real one:

$$K(\vartheta) = \frac{Er(\vartheta, 0°)}{1 - \frac{Er(0°,0°) - Er(180°,0°)}{180} \cdot \vartheta}$$

This correction factor must also vary with φ. In the one corresponding to φ = 90° there must be no deformation of the solid, that is, K (θ, 90°) = 1. The trend chosen is of elliptical type, with coefficient variable according to whether K (θ,0°) is> or <= 1, in order to combine the trend of vertical planes with any θ.

K(θ,φ) is then defined by the following:

K(θ, 0°) >1

$$K(\vartheta,\varphi)=\frac{1}{1-(1-\frac{1}{K(\vartheta)^2})\cdot\cos^2\varphi}$$

K(θ, 0°) <=1

$$K(\vartheta,\varphi)=\frac{K(\vartheta)^2}{1-(1-K(\vartheta)^2)\cdot\cos^2(90-\varphi)}$$

The generic value Er(θ,φ) will be calculated as follows :

$Er(\theta,\varphi)=K(\theta,\varphi)\ Er_{lin}(\theta,\varphi)$

Comparison among methods for building 3D diagrams in 3 softwares:

VIGILA

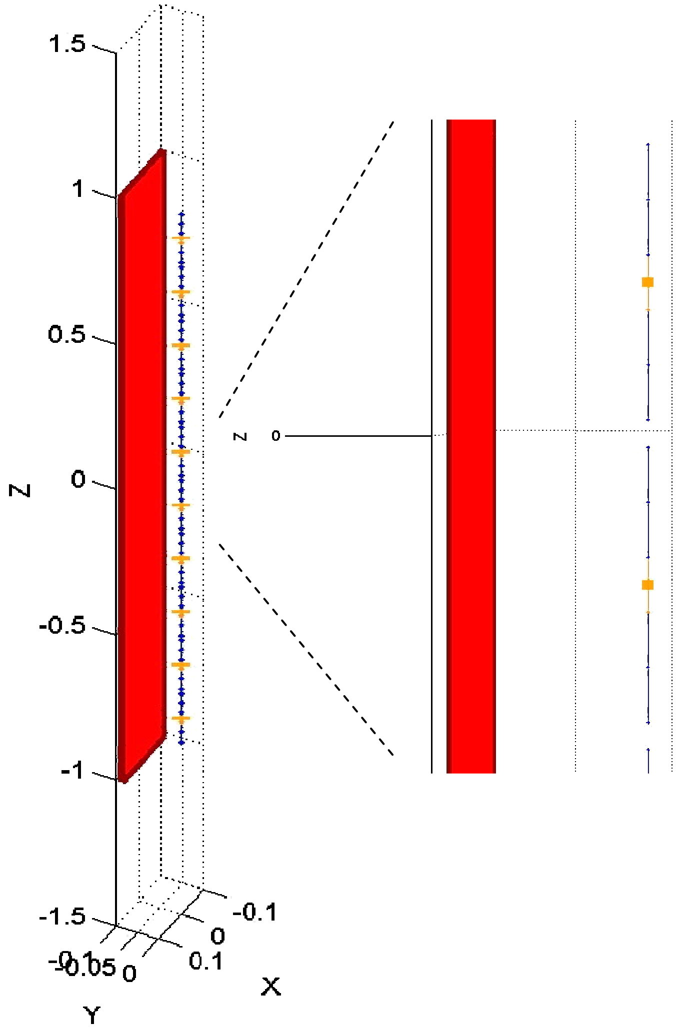
CemView (Revolution)

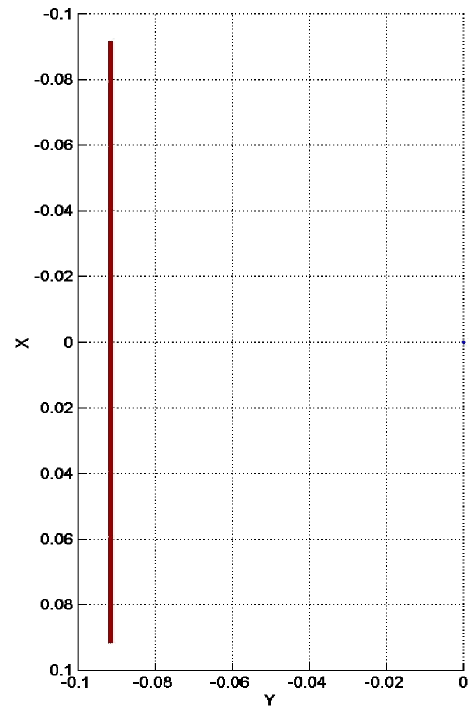
ALDENA

Each software uses a different building algorithm.

The obtained values of attenuation, on vertical patterns($\theta$=30°, $\theta$=60°, $\theta$=90° ) were compared to the cuts of the exact 3D diagram calculated by MOM (SUPERNEC).

# Antenna :10 vertical dipoles with a reflecting plane behind

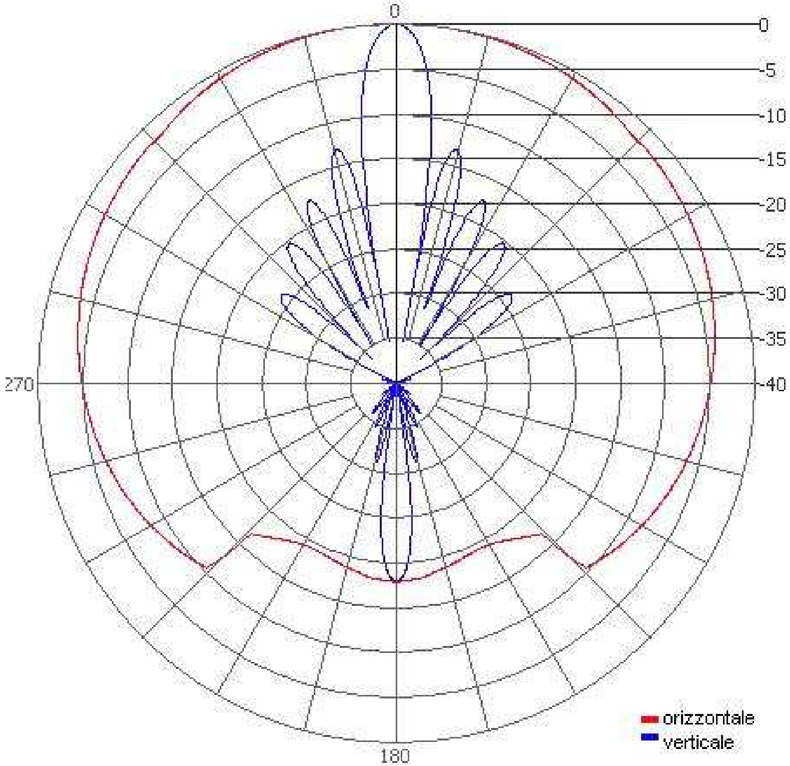



TOP

RIGHT

# Horizontal and vertical patterns of the simulated antenna

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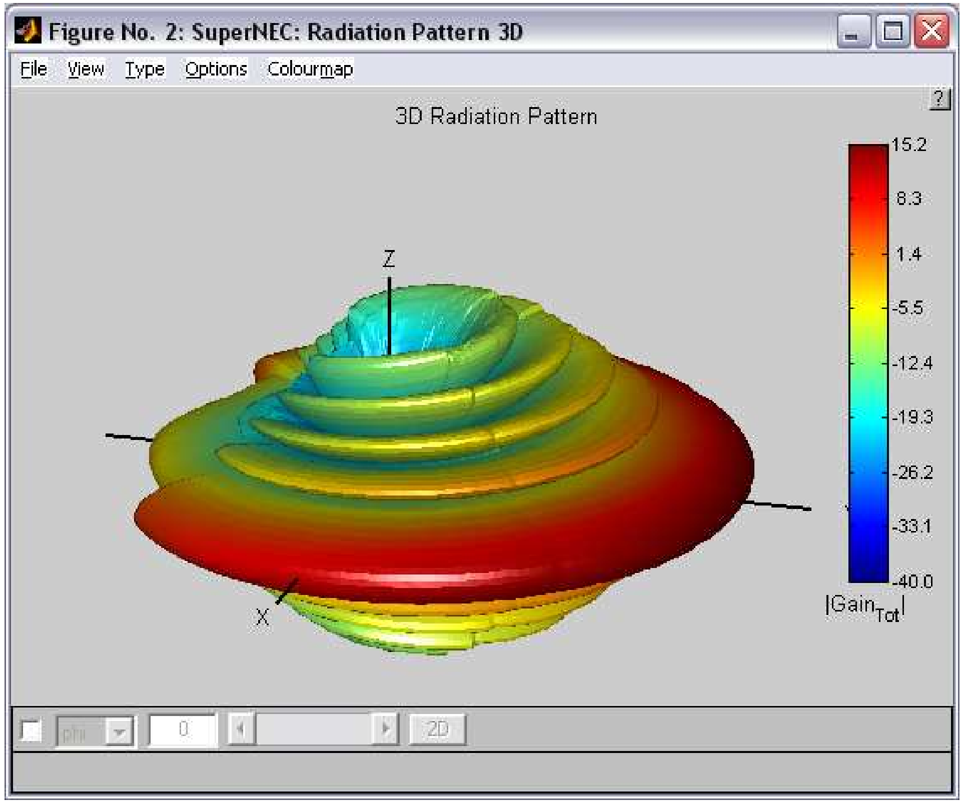
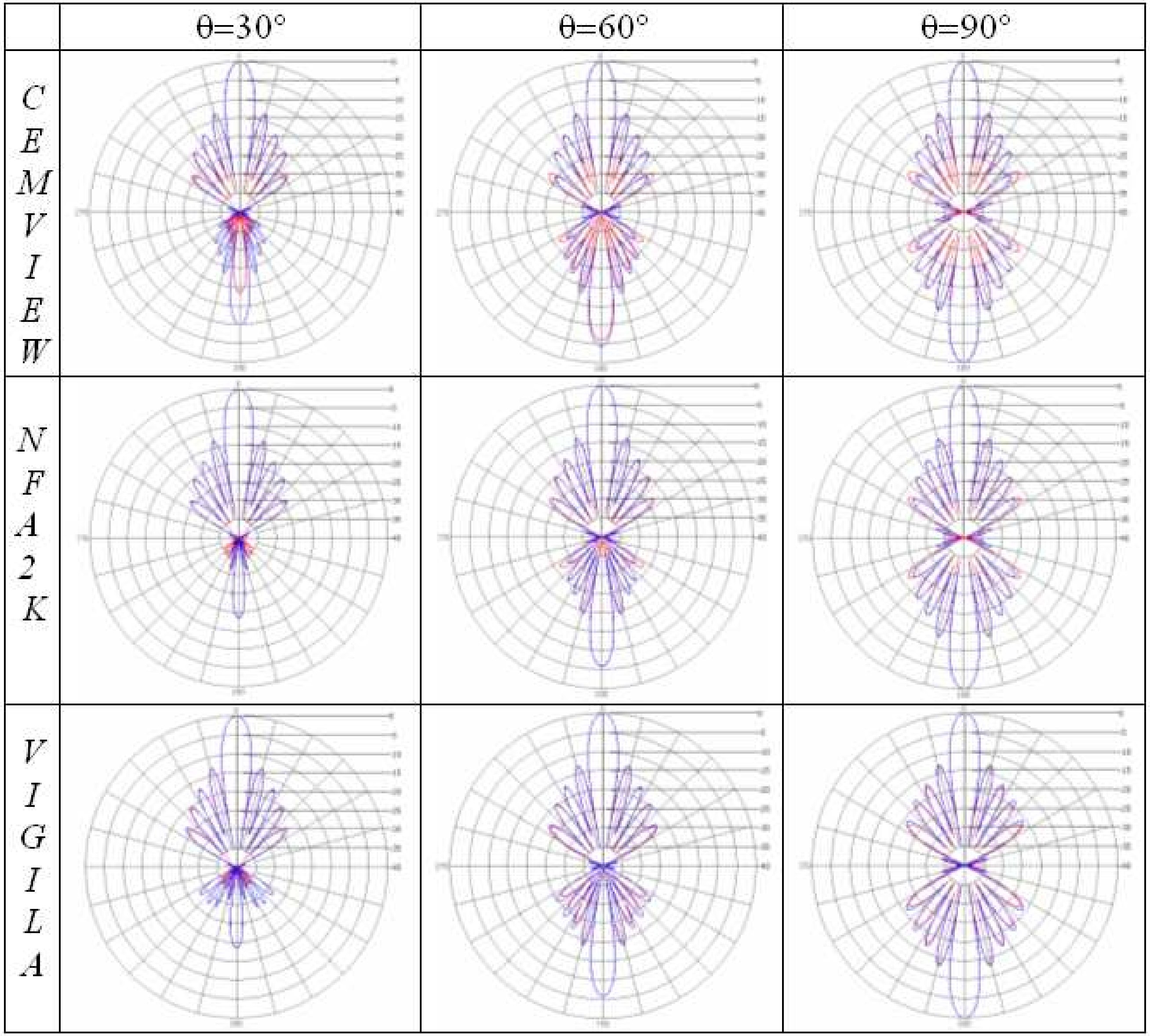
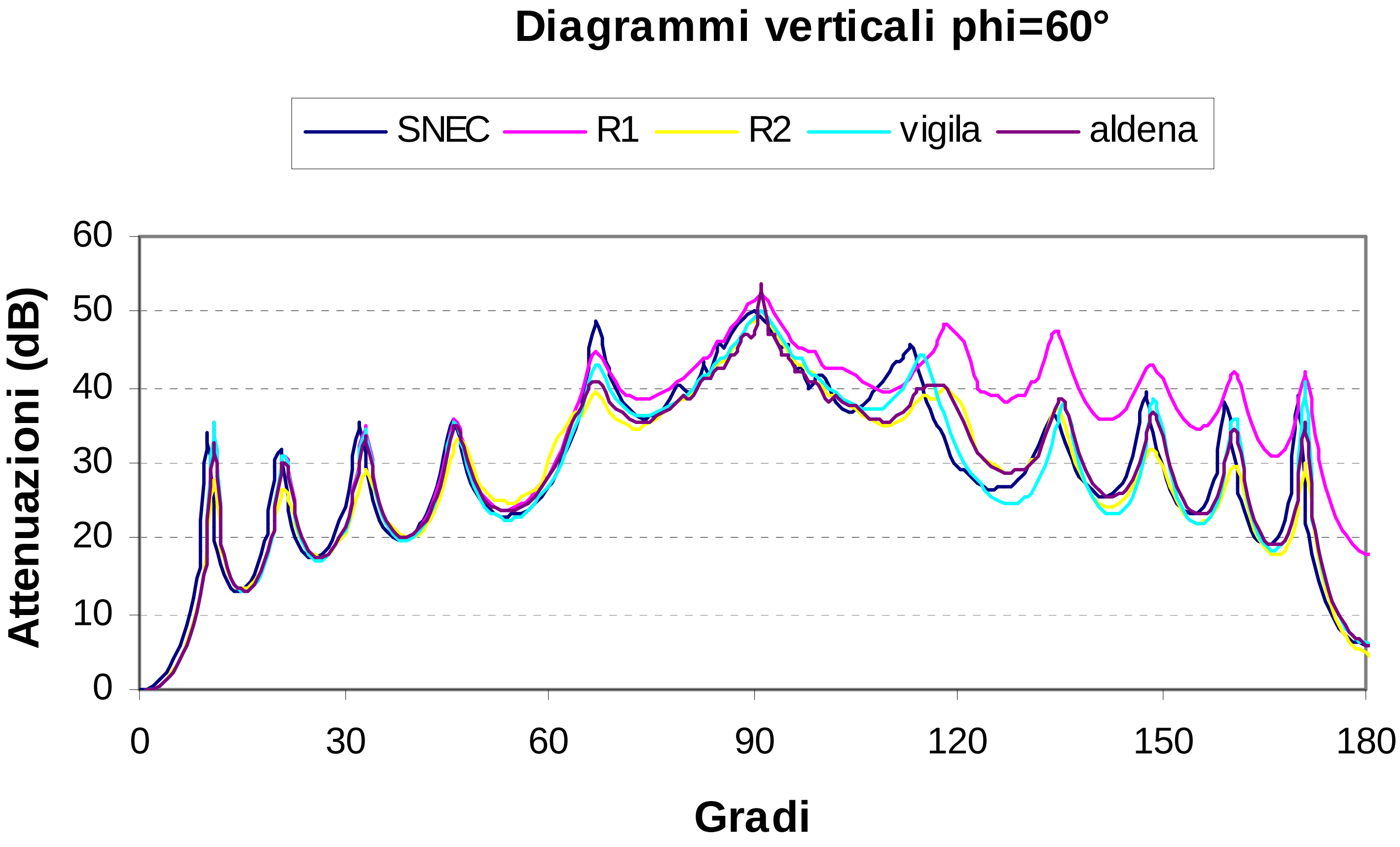
# 3D pattern calculated by SuperNec






SuperNec: red ; Other softwares: blue

**For all the tested softwares, the pattern obtained is more correct in front of the antenna, whereas behind it there are bigger differences among each software and SuperNec.** In general, the three tested softwares under-estimate attenuation values behind the antenna and between lobes (resulting in over-estimate of the calculated electric field), but in some directions there can also be over-estimate of the attenuation (minor lobes behind the antenna)



## Comparison between measurements and model results in complex **radio-tv sites**

### Site 1

| SIGNAL | E (V/m) Measured |
|---|---|
| Radio 1 | 7.44 ± 1.49 |
| Radio 2 | 0.03 ± 0.01 |
| Radio 3 | 0.76 ± 0.15 |
| TV 1 | 0.24 ± 0.05 |
| TV 2 | 0.22 ± 0.04 |
| TOTAL (Measuremed) C.E. (V/m) = 7.48 ± 1.5 | |

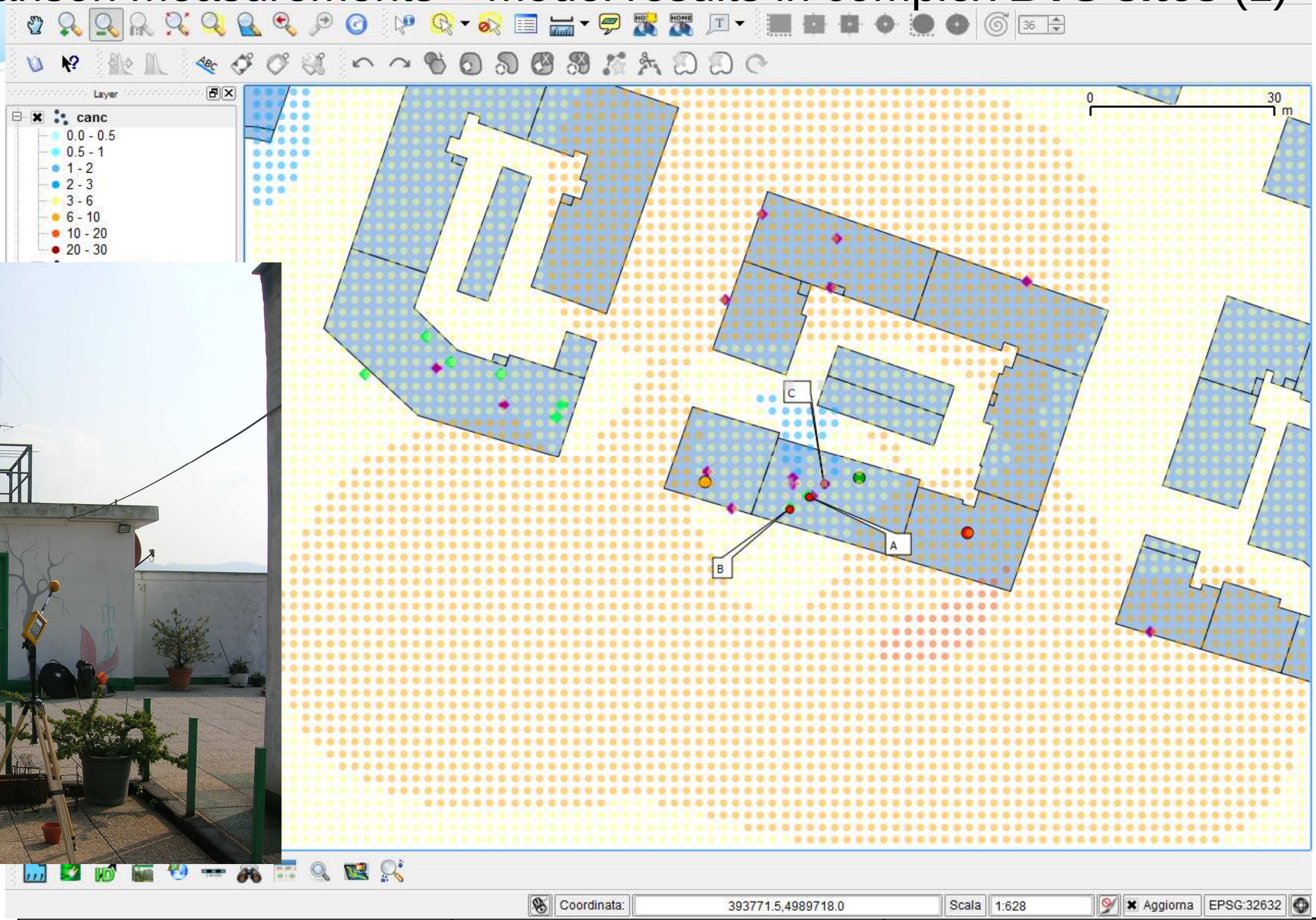
| SIGNAL |
|---|
| Radio 1 (7.68) |
| Radio 2 (1.26) |
| Radio 3 (0.96) |
| TV 1 (0.02) |
| TV 2 (0.14) |
| TOTAL (Calculated) C.E. (V/m) = 7.84 |

### Site 2

| SIGNAL | E (V/m) Measured |
|---|---|
| Radio A | 2.90 ± 0.58 |
| Radio B | 7.70 ± 1.54 |
| Radio C | 3.45 ± 0.69 |
| Radio D | 2.67 ± 0.53 |
| Radio E | 1.89 ± 0.38 |
| TV A | 0.06 ± 0.01 |
| TV B | 0.07 ± 0.01 |
| TV C | 0.05 ± 0.01 |
| TV D | 0.05 ± 0.01 |
| TV E | 2.04 ± 0.41 |
| TOTAL (Measured) C.E. (V/m) = 9.72 ± 1.94 | |

| SIGNAL |
|---|
| Radio A (2.37) |
| Radio B (5.88) |
| Radio C (4.95) |
| Radio D (3.11) |
| Radio E (3.44) |
| TV A (0.01) |
| TV B (0.01) |
| TV C (0.01) |
| TV D (0.01) |
| TV E (3.16) |
| TOTAL (Calculated) C.E. (V/m) = 9.81 |

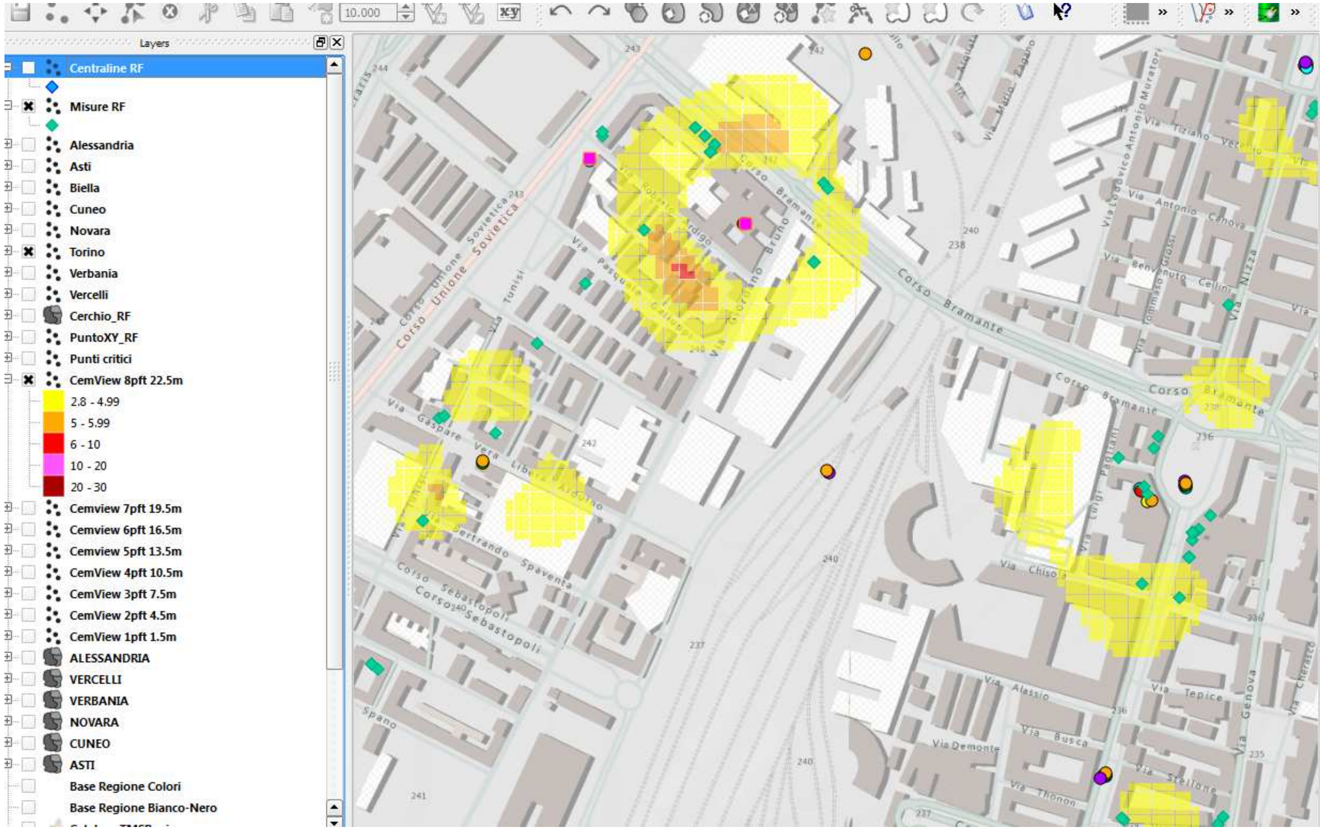
# Comparison measurements – model results in complex **BTS sites** (1)




| Corso adriatico 24 | Electric field (V/m) measured | Electric field (V/m) calculated H=37.5m |
|---|---|---|
| A | 3.82 | 3.59 |
| B | 3.68 | 3.7 |
| C | 4.12 | 3.93 |

# Comparison measurements – model results in complex **BTS sites** (2)

Calculations using BTS parameters of measurement day




| *Gestore* | *Valore di campo elettrico massimo valutato teoricamente nel punto di misura* ([a]) | Livello di campo elettrico misurato ([b]) |
|---|---|---|
| H3G | 1,48 | 1,37 |
| Telecom Italia | 2,92 | 2,38 |
| WIND | 4,59 | 4,1 |
| Vodafone | 1,68 | 1,07 |
| **Totale** | **5,88** | **5,05** |

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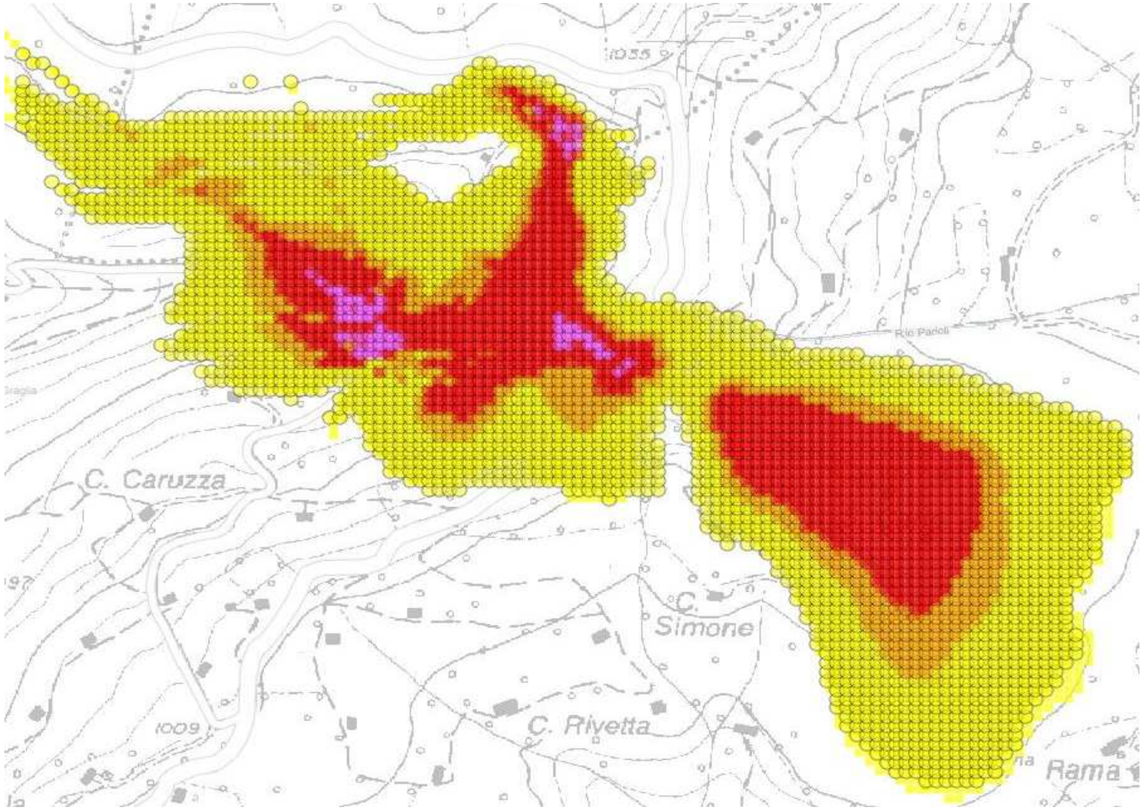
# AUTOMATIC COMPUTING SYSTEM

- Subdivision of land in a grid with step 10m
- Subdivision of the digital terrain model in smaller portions (about 10km side) to speed up the calculation model
- Automation of the calculation model: reception of all input parameters by XML/TXT files and storage of the output directly to text file (.TXT)
- Definition of the specific parameters for the calculation of the electric field: horizontal step 10m, 8 floors evaluation (1.5m - 22.5m), in an area of side variable according to the total radiated power, taking into account the digital terrain model
- Approximation of the coordinates of the calculated values according to the grid and storage of evaluations for each plant in a database, by applying a threshold (1V/m) to ensure good performance to the system
- Quadratic sum of the electric field values produced by different plants in the same point of the grid and storage in database, applying a threshold (2.8V/m) to lighten the system
- Creation of a QGIS project connected to the database, with option to enable the evaluation at the floor of interest and to overlay different base maps and other themes (buildings, plants positions, measurements)
- Exposure of a database view containing the theoretical evaluations on ARPA Geoportal (http://webgis.arpa.piemonte.it/campi_elettromagnetici_webapp/)
- Automatic execution of the system on the server for processing daily updates (new plants). Execution can also be activated from local PC on request.

# Comparison between authomatic system results (1) and traditional model (Cemview) results (2)

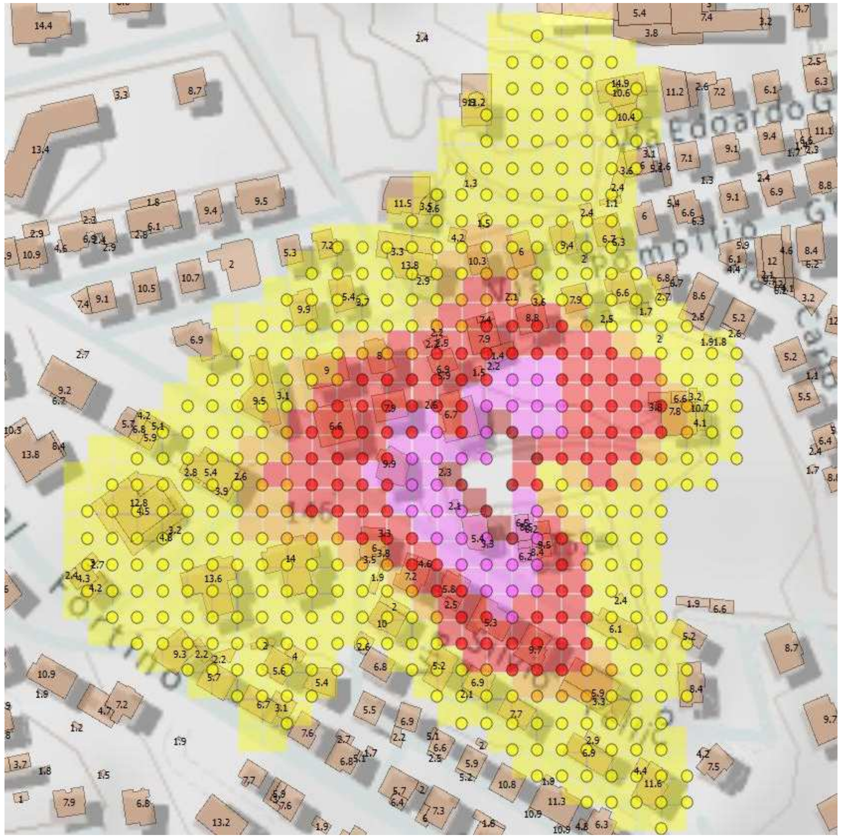
(1)Square points in the image
(2)Round points in the image

## Radio/TV site, mountain environment

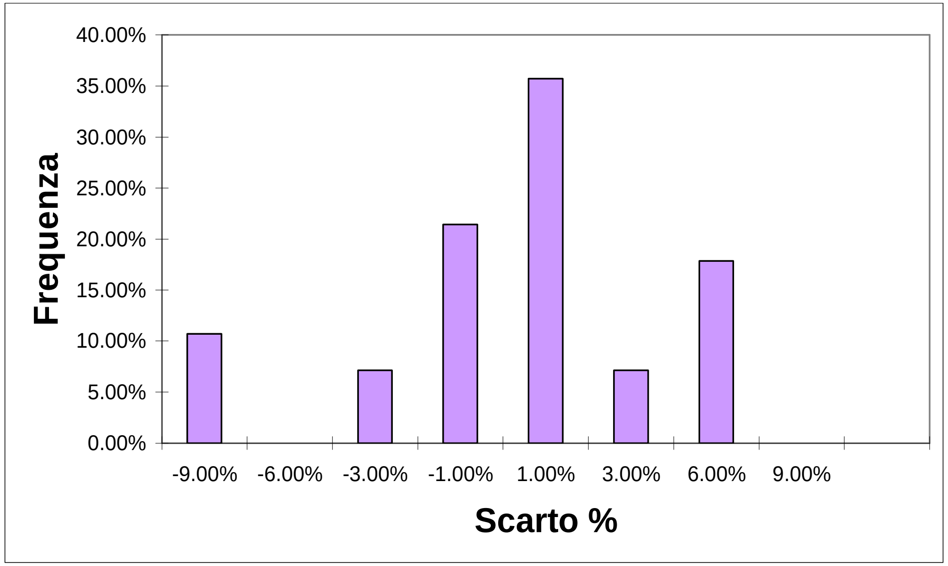



| Intervalli di campo elettrico (V/m) | Scarto % tra i valori medi ricavati dalle due valutazioni |
|---|---|
| 2.8 - 4.99 | -2.1% |
| 5 - 5.99 | -0.1% |
| 6 - 9.99 | 0.4% |
| 10 - 19.99 | 6.7% |

# BTS urban sites



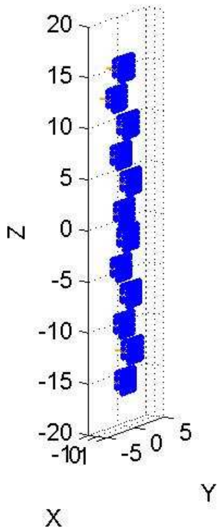
| Intervalli di campo elettrico (V/m) | Scarto % tra i valori medi ricavati dalle due valutazioni |
|---|---|
| 2.8 - 4.99 | -4.15% |
| 5 - 5.99 | 0.15% |
| 6 - 9.99 | -0.75% |
| 10 - 19.99 | 6.0% |

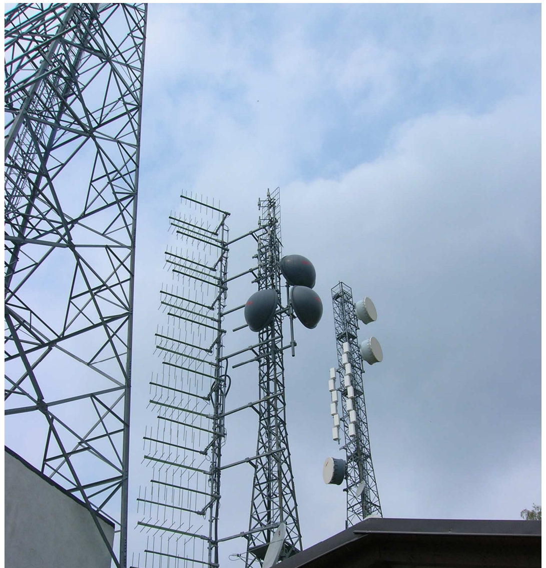



Distribution of variances among fields values obtained by the two models in 100 points (different sites).

## What if far field approximation is not valid?

Numeric model for the simulation of a real radio site with 2 antenna systems ► software Supernec (MoM).



Plant B (f= 107.1MHz): H=19.5m

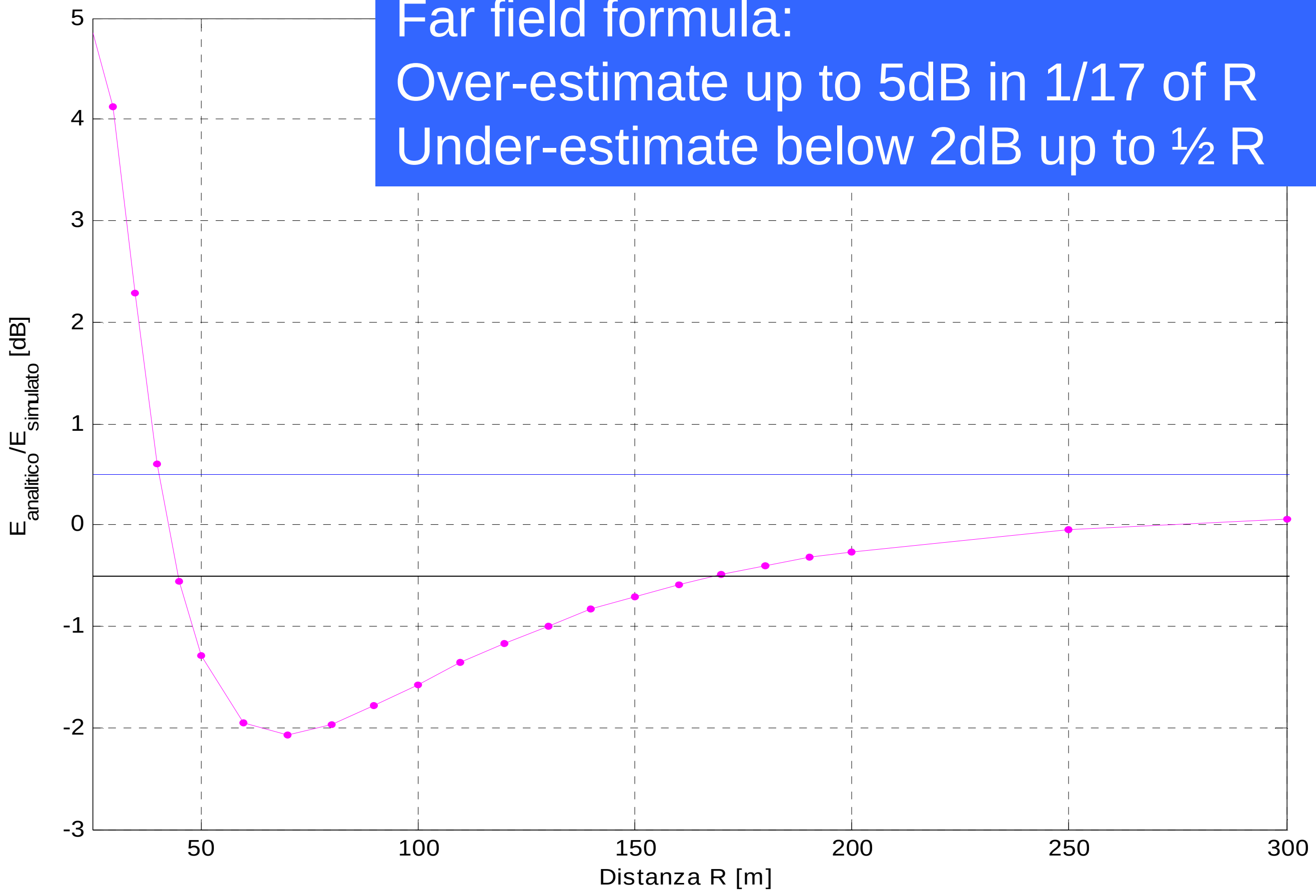
Plant A (f=102.5MHz): H=30m

Evaluation of far field/near field ratio along two directions (maximum radiation and a secondary lobe) and on horizontal and vertical planes (angular trend):

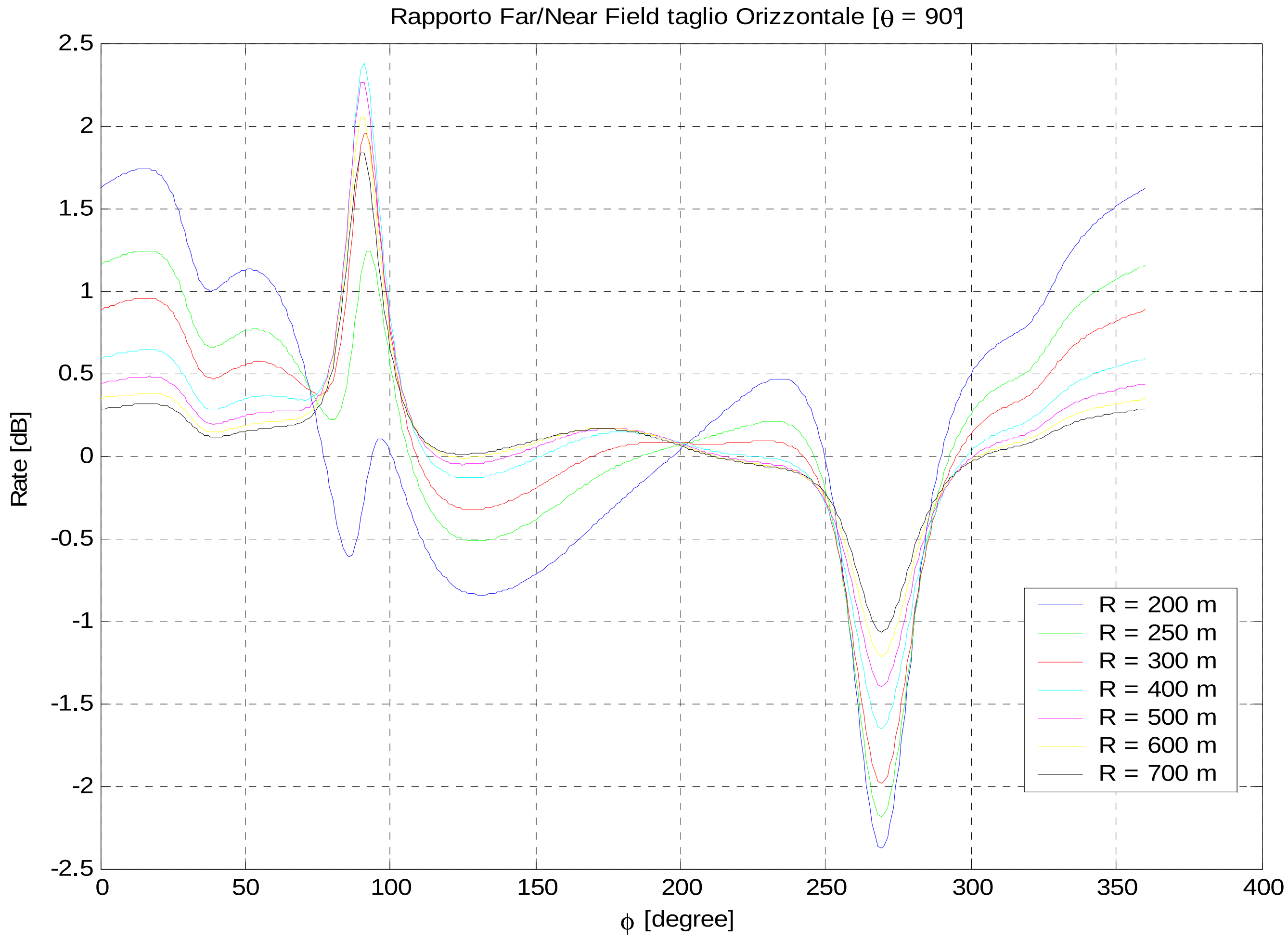
-For single antenna systems
-For overall system (A+B)

# Plant A: far field/near field ratio along maximum radiation direction (170°N - far field distance: R=615m).

Far field formula:
Over-estimate up to 5dB in 1/17 of R
Under-estimate below 2dB up to ½ R



# Plant A: angular trend of far field/near field ratio at different distances from the plant (horizontal plane)

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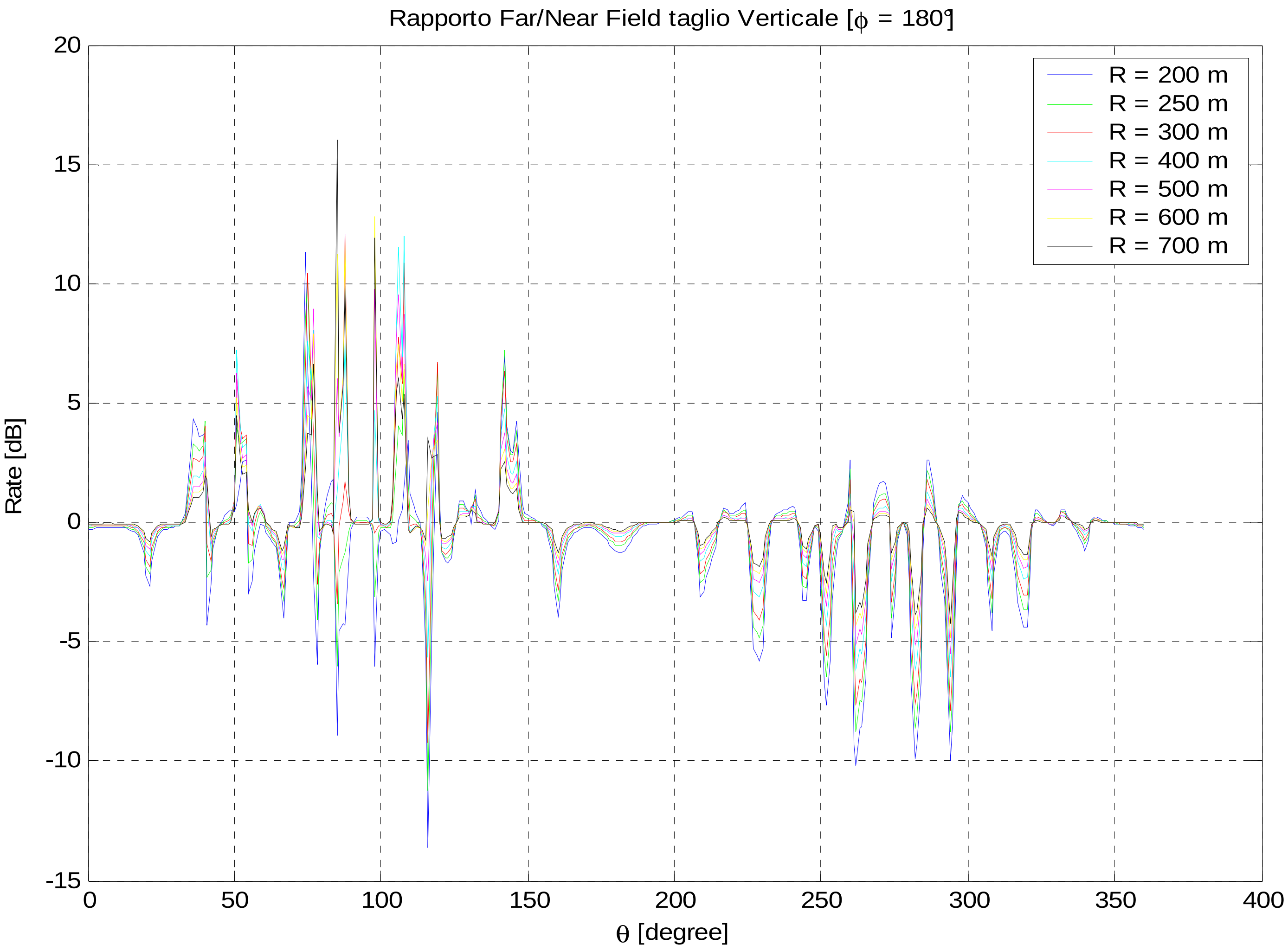
# Plant A: angular trend of far field/near field ratio at different distances from the plant (vertical plane)

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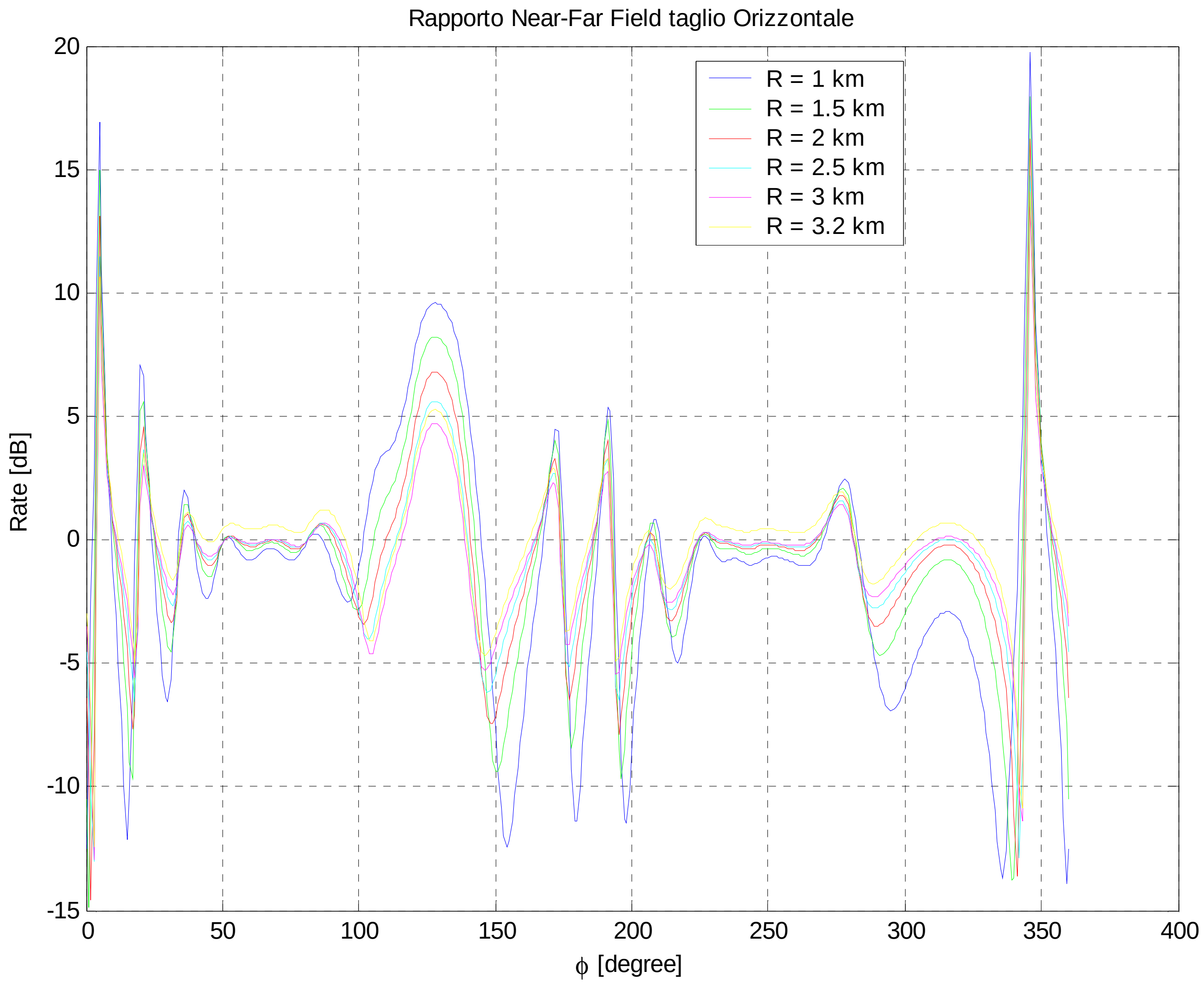
System A+B : far field/near field ratio on horizontal plane (far field distance R=3911m).

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Using far field formula in near field region can lead to:

-Under-estimate of electric field level (up to 2.5 dB on main radiation lobe – below 0.5 dB from R/4 – and up to 10 dB on secondary lobes)
-Over-estimate of electric field level (up to 5 dB on main lobe in 1/17 of R, up to 15dB on secondary lobes)

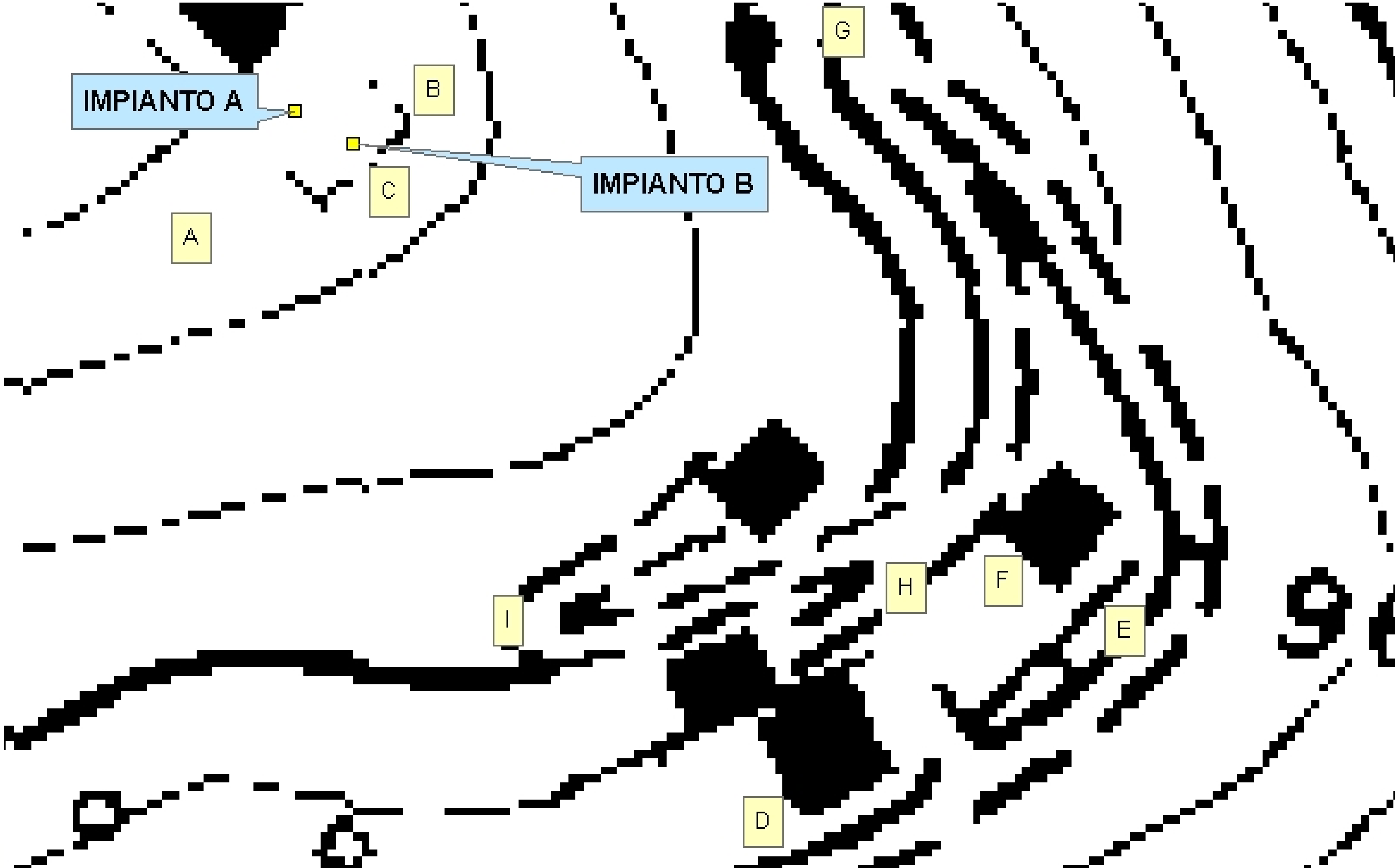
# Validation of the Mom model by comparison to measurements

*Narrowband measurements: CEI 211-7 guide*

**INSTRUMENTAL CHAIN:**

- **Spectrum analyzer Rohde & Schwarz FSP 3 (9kHz ÷ 3GHz)**
- **Conic dipole antenna Clampco EMSAP 2000 (50MHz ÷ 2500MHz)**
- **Cable 20m Suhner (18 GHz)**
- **Shielded mobile lab**

# Measurement points



# Comparison calculations (VAL) – measurements (MIS)

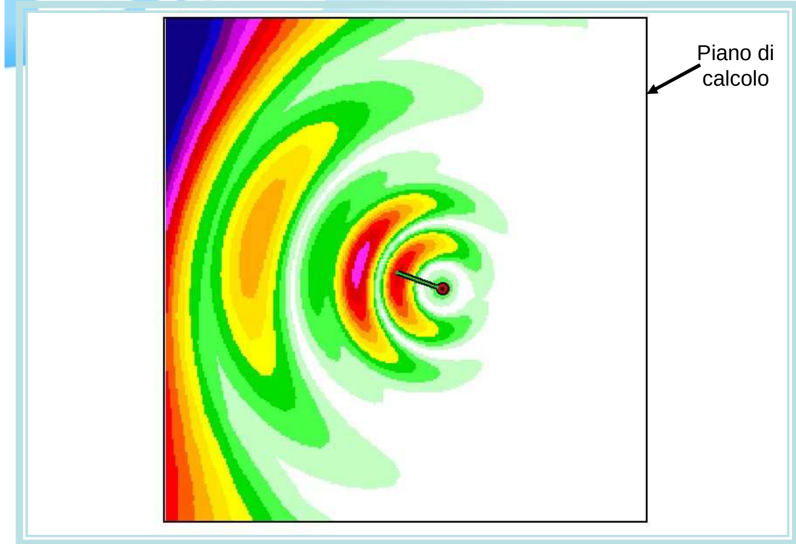
| PUNTO DI MISURA | IMPIANTO A | | IMPIANTO B | |
|---|---|---|---|---|
| | VAL | MIS | VAL | MIS |
| A | 3.5 | 4.01 ± 1.00 | 1.4 | 1.54 ± 0.39 |
| B | 1.3 | 2.85 ± 0.71 | 1.2 | 1.31 ± 0.33 |
| C | 2.7 | 3.85 ± 0.96 | 0.6 | 0.44 ± 0.11 |
| D | 1.1 | 1.31 ± 0.33 | 2.3 | 2.13 ± 0.53 |
| E | 0.7 | 0.92 ± 0.23 | 5.7 | 6.22 ± 1.56 |
| F | 1.0 | 1.06 ± 0.27 | 2.2 | 2.46 ± 0.62 |
| G | 0.2 | 1.27 ± 0.32 | 1.0 | 1.27 ± 0.32 |
| H | 1.6 | 1.44 ± 0.36 | 2.2 | 1.52 ± 0.38 |
| I | 2.0 | 2.15 ± 0.54 | 4.8 | 3.49 ± 0.87 |

NOT LOS

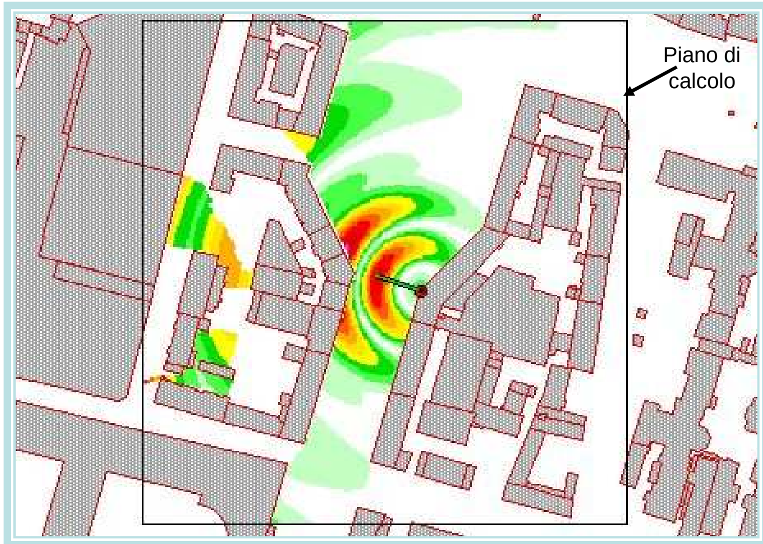
Percentage of cases with comparable levels (difference below measurement uncertainty): 67%

Mean variance: 20%

# Ray tracing model (Vigila)



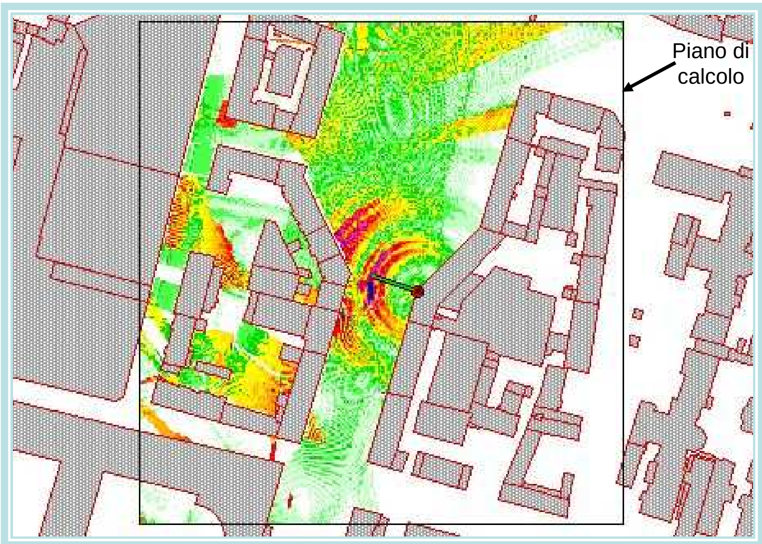

*Free space*



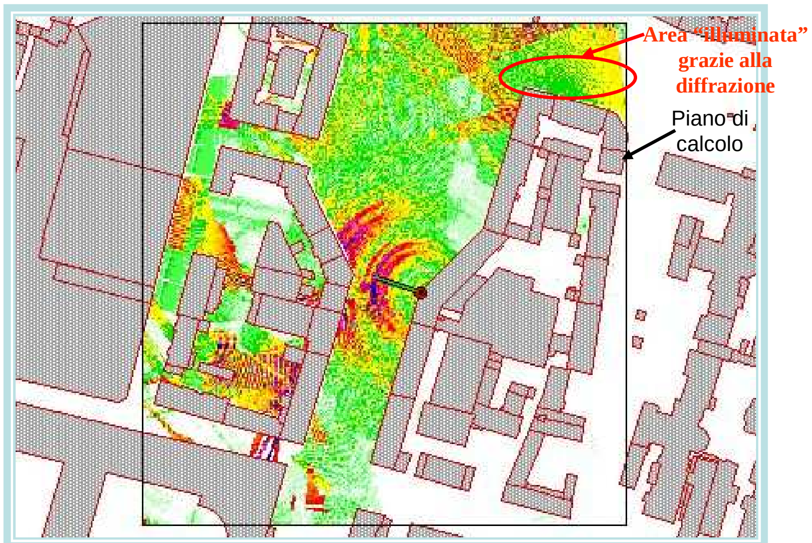

LOS

**Valori teorici di campo ele**
**(V/m)**

- 0.05 – 0.10
- 0.10 – 0.15
- 0.15 – 0.20
- 0.20 – 0.25
- 0.25 – 0.30
- 0.30 – 0.35
- 0.35 – 0.40
- 0.40 – 0.45
- 0.45 – 0.50
- 0.50 – 0.55
- 0.55 – 0.60
- 0.60 – 0.65
- 0.65 – 0.70
- > 0.70




1st order contributions (reflections and diffractions)




2nd order contributions (double reflections, diffraction-reflection)

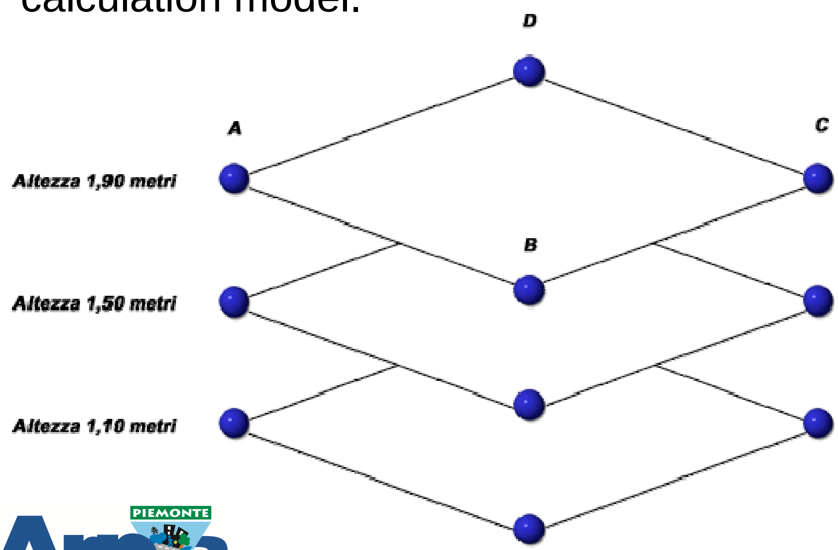
# Ray tracing model validation

Validation was made through a measurement campaign, choosing measurement points in order to test different propagation environments and analysing BCCH channels through narrow-band measures

The tested software (VIGILA TM 3.0), which was developed by the TiLab laboratories, implements a backward ray-tracing technique, considering the 1st and 2nd order contributions, for 6 possible configurations (direct path, single reflection, double reflection, single diffraction, diffraction-reflection and reflection-diffraction). The software uses as input a vector database containing 3D cartographic information and, for each building, the building material. On the basis of these data, the software calculates the visibility array and thus the possible optical paths between the source and the reception points.

# Experimental validation

The ray-tracing model was validated through several measurements carried out in some areas of the city of Turin, chosen according to the following criteria: the availability of particularly detailed and up-to-date vector cartography, the type of urban environment and the presence of significant electric field levels with respect to the urban background. To select the areas with higher field levels the distribution of the electromagnetic field generated by radio base stations has been assessed, on the whole of the municipal territory, by means of a simplified far-field calculation model.




Choice of areas with electric field levels between 1.5 V/m and 3.0 V/m

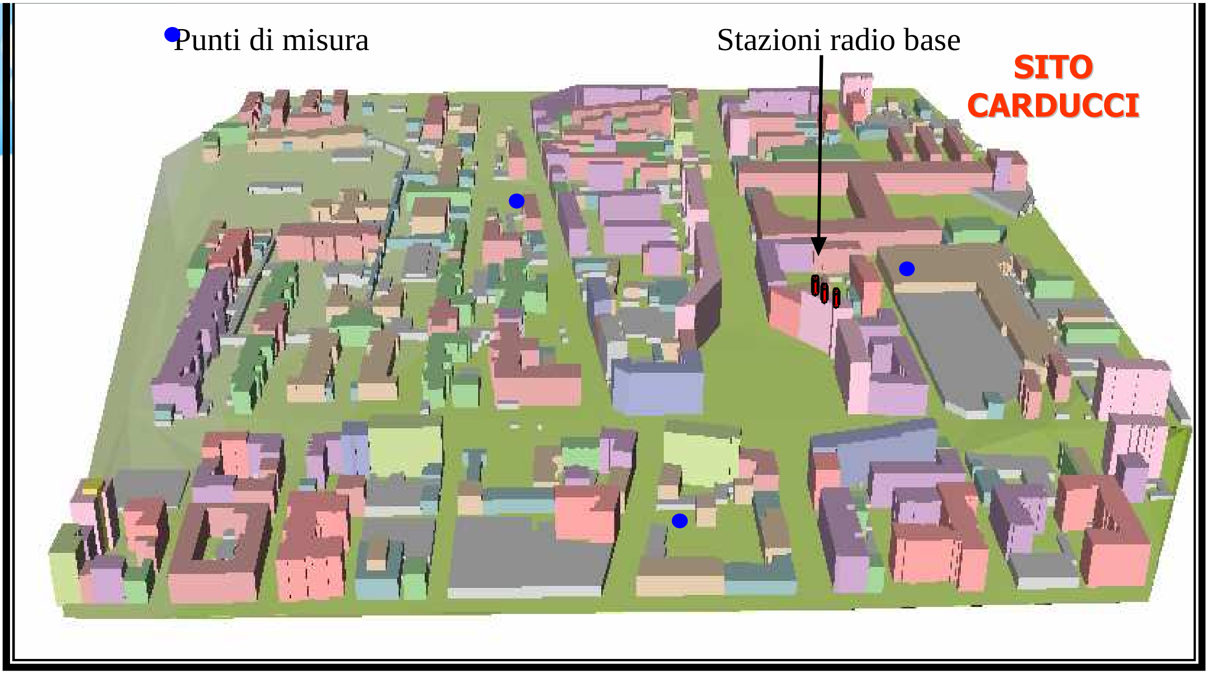
↓

Site 1 (Carducci) → Measurements in far field regions, different visibility conditions

Site 2 (Adriatico) → Measurements between near and far field region (3 BTS)

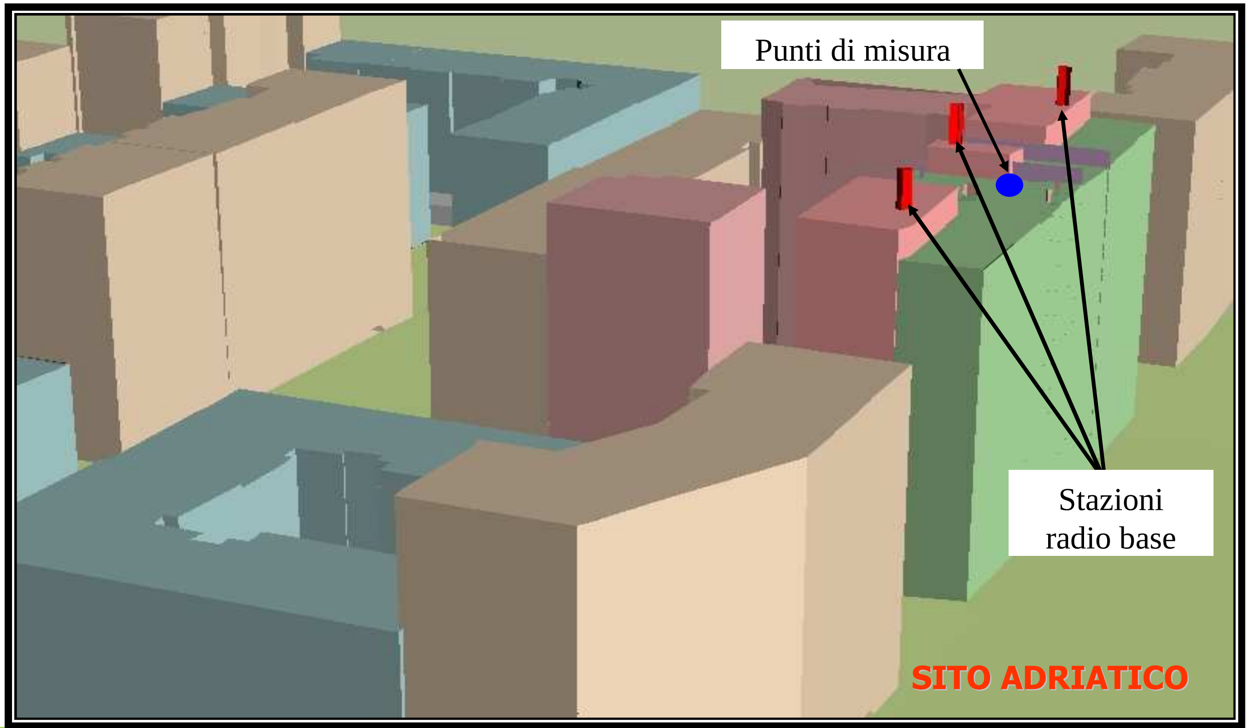
↓

For each site, measurements of electric field (BCCH of GSM signals) were performed in points on the edges of a square (1m side) at three different heights from the ground (12 total points). The measurements mean on these 12 points was then compared to the calculation results .

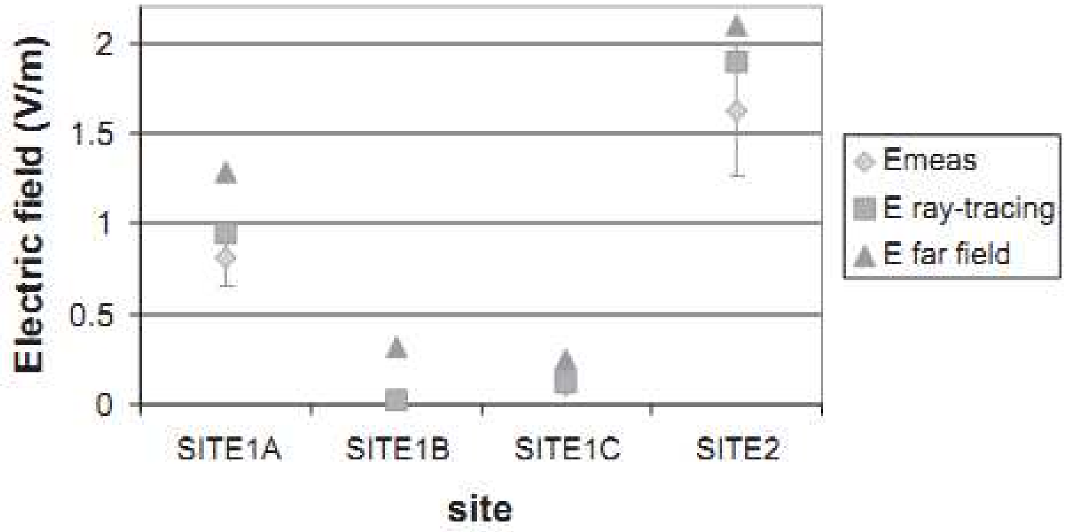

Punti di misura
Stazioni radio base
SITO CARDUCCI

Site 1

Site 2


Punti di misura
Stazioni radio base
SITO ADRIATICO

| Measurement site | Emeas (V/m) | Ecalc (V/m) | $S_{Ecalc}$ | Δ (%) |
|---|---|---|---|---|
| SITE 1A | 0.810±0.158 | 0.952 | 0.032 | 17.5 |
| SITE 1B | 0.025±0.005 | 0.023 | 0.001 | -8.0 |
| SITE 1C | 0.100±0.021 | 0.127 | 0.006 | 27.0 |
| SITE 2 | 1.623±0.358 | 1.895 | 0.022 | 16.8 |




The uncertainty associated to each measured value was obtained summing the instrumental uncertainty to the standard deviation of the distribution of the values measured on the considered volume, which is related to the uncertainty due to antenna positioning. The standard deviation of calculated values (σ/√(n-1)) in the volume considered for each measurement site was assessed to estimate the uncertainty for the average calculated field level [SEcalc].

感谢您的关注