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Title: Nuclear EMP simulation for large-scale urban environments. FDTD for electrically large problems.

Author(s):
Smith, William S.
Bull, Jeffrey S.
Wilcox, Trevor
Bos, Randall J.
Shao, Xuan-Min
Goorley, John T.
Costigan, Keeley R.

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Nuclear EMP simulation for large-scale urban environments.

FDTD for electrically large problems.

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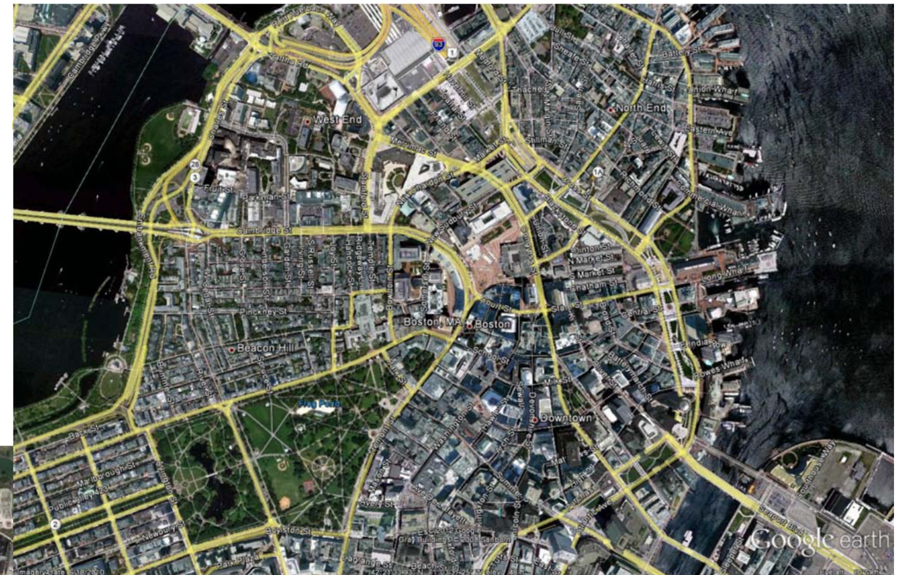
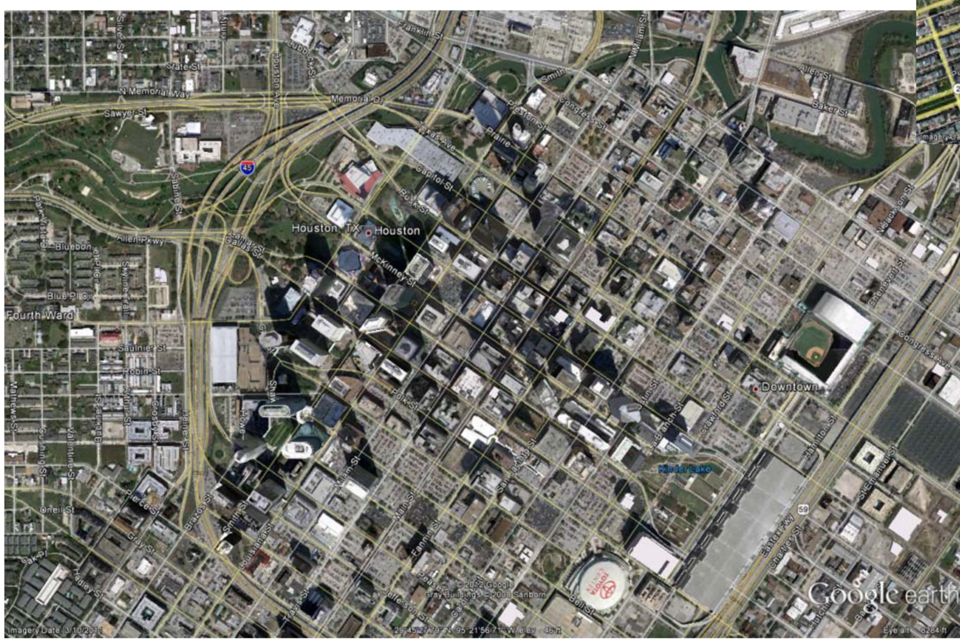




Scott Smith[2], Jeff Bull[3], Trevor Wilcox[1], Randy Bos[5],Xuan-Min Shao[4], Tim Goorley[3], Keeley Costigan[2]

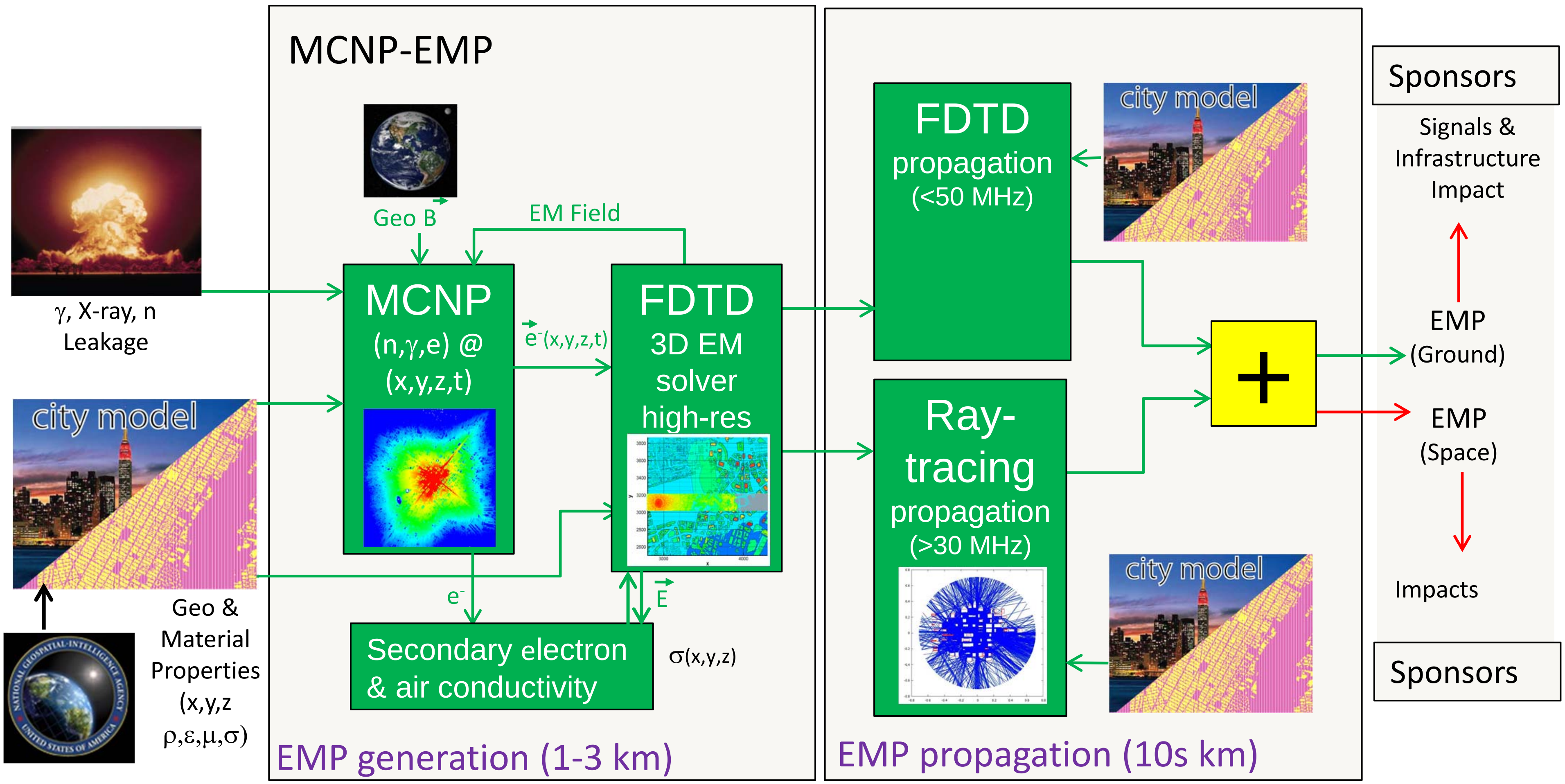
[1]NEN-5 Nuclear Design and Risk Analysis
[2]EES-16 Computational Earth Science
[3] XCP-3 Monte Carlo Codes
[4]ISR-2 Space and Remote Sensing
[5]XCP-4: Methods and Algorithms

Los Alamos National Laboratory
wss@lanl.gov
JOWOG 43, Aug 2012, Los Alamos National Laboratory

Case for Coupled MCNP/FDTD for urban EMP

- **In case of a terrorist nuclear attack in a metropolitan area, EMP measurement could provide**
  - a prompt confirmation of the nature of the explosion (chemical or nuclear) for emergency response
  - and characterization parameters of the device (reaction history, yield) for technical forensics
- **However, urban environment could affect the fidelity of the prompt EMP measurement (as well as all other types of prompt measurement)**
  - Nuclear EMP wavefront would no longer be coherent, due to incoherent production, attenuation, and propagation of gamma and electrons
  - EMP propagation from source region outward would undergo complicated transmission, reflection, and diffraction processes
- **EMP simulation for electrically-large urban environment**
  - Coupled MCNP/FDTD (Finite-difference time domain Maxwell solver) approach
  - FDTD tends to be limited to problems that are not "too" large compared to the wavelengths of interest because of numerical dispersion and anisotropy. We use a higher-order low-dispersion, isotropic FDTD algorithm for EMP propagation.

NEMP4d Capability:
E & B (x,y,z,t) in Urban Environments



Progress on initial self-consistent code suite, early results for Houston and Boston, V&V still needed.

Urban EMP efforts

- Developed two new high-order, isotropic algorithms for electrically large problems.
  - Smith et al., “A hierarchy of explicit low-dispersion FDTD methods for electrically large problems, IEEE trans. Antenna propagat., 2012 (in print)
- Corrected air chemistry package
  - compared to EM propagation from HEMPV
- Continuing work on high-order FDTD algorithms for discrete dielectric interfaces and objects:
  - Discrete boundaries
  - Thin planes, slits
  - Thin wire
  - Vent holes
- MCNP integration with MCNP(Simple tests show the integration is working)
  - Electrons with/without magnetic field
  - Gamma induced Compton currents with magnetic field in MCNP
  - Compton current city model
- Implementation of Houston and Boston studies

Corrected air chemistry with inputs from MCNP
Time/space varying current and air conductivity
(Δx, Δy, Δz=1m, Δt=1.7 ns)

Secondary electron – ion package based on existing legacy (Unimax, HEMPV) code:

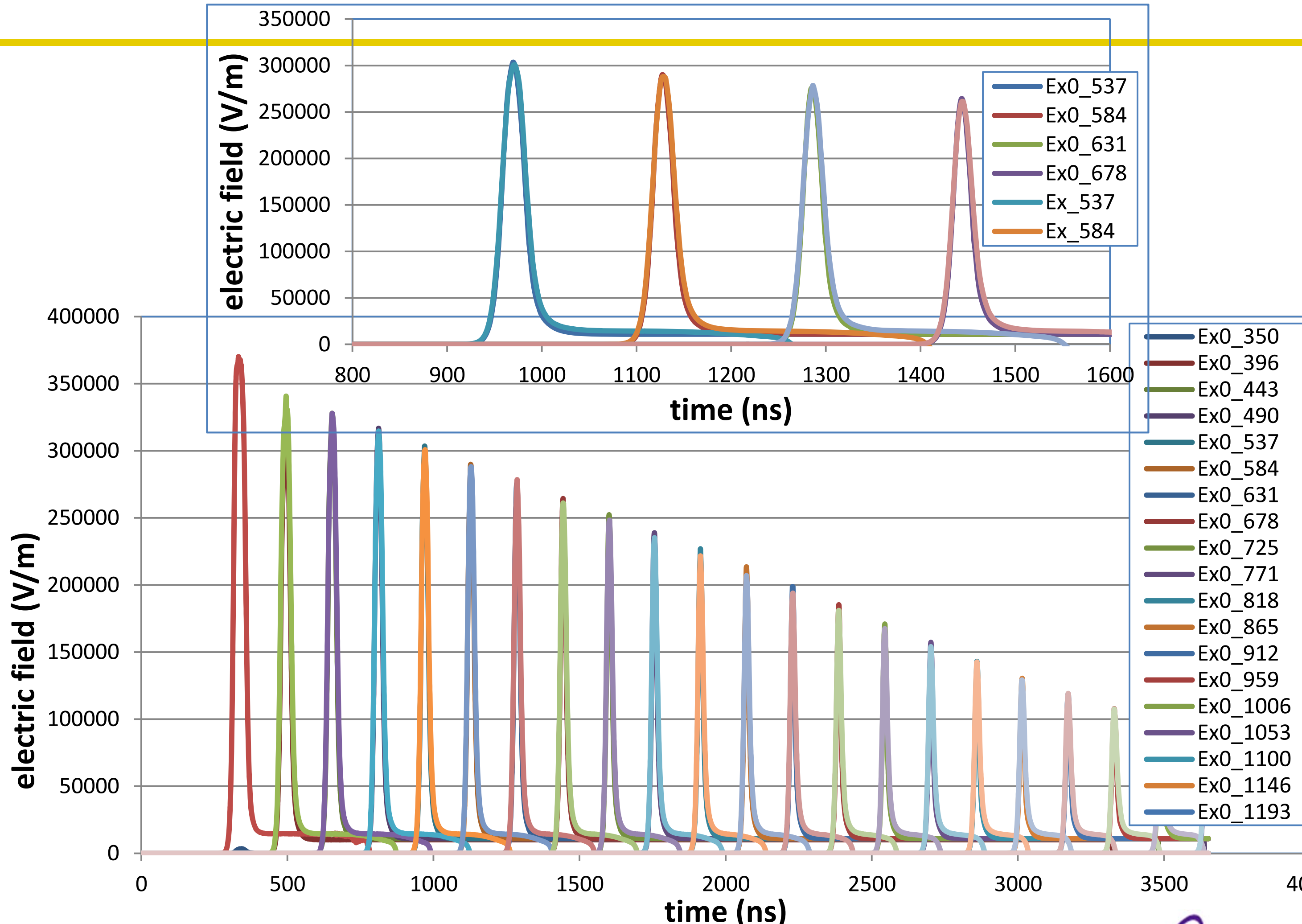
- secondary electron production
- Electron avalanche
- 2,3-body attachment
- Electron-ion
- ion-ion recombination

$$\frac{\partial n_s}{\partial t} = r_s n_p + r_v n_s - \alpha n_s - \alpha_r n_s n_+$$

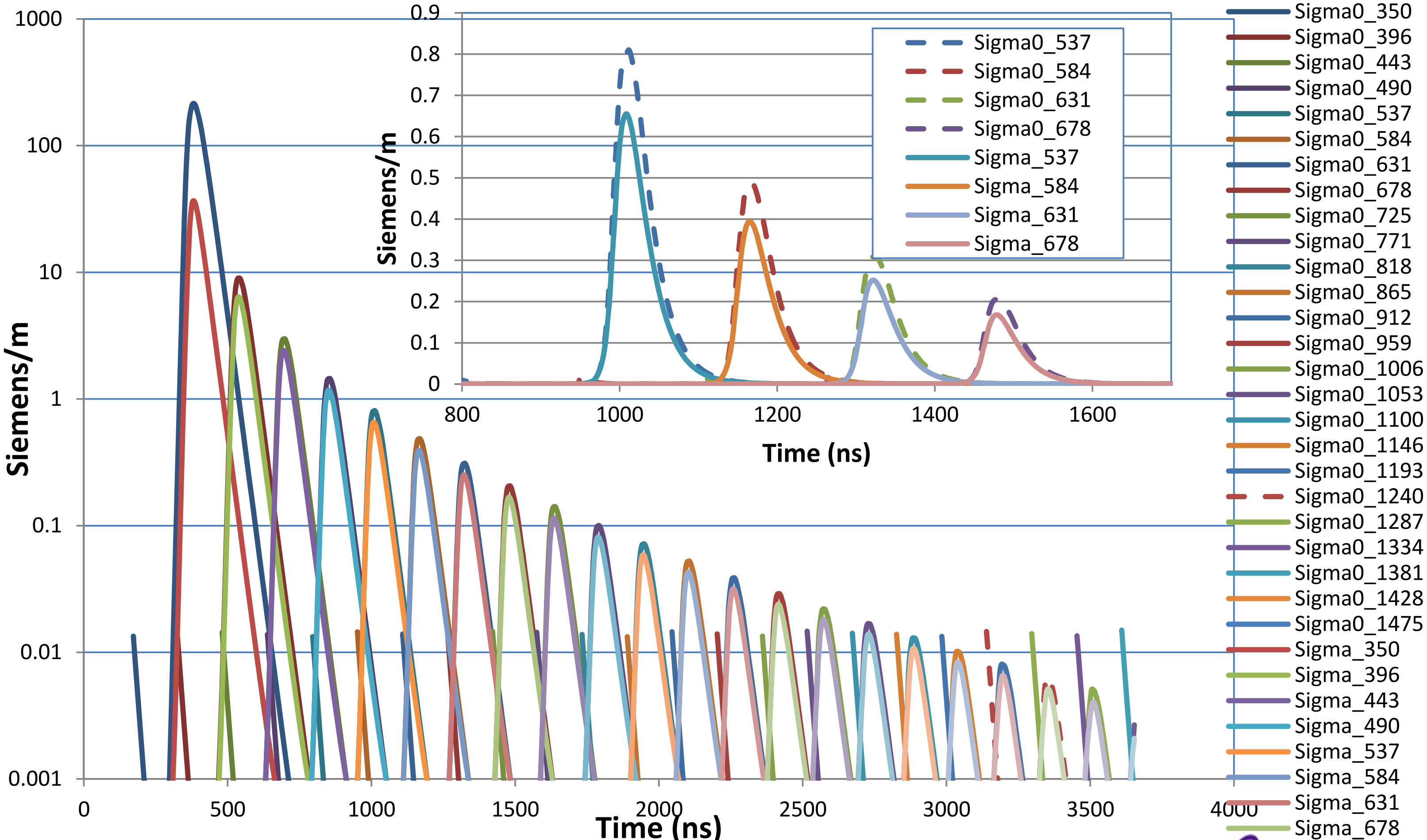
$$\frac{\partial n_+}{\partial t} = r_p n_p + r_s n_p + r_v n_s - \alpha_r n_s n_+ - \alpha_i n_+ n_-$$

$$\frac{\partial n_-}{\partial t} = \alpha n_s - \alpha_i n_+ n_-$$

Ex: HEMPV vs FDTD with air chemistry



Conductivity: HEMPV vs FDTD with air chemistry



Two new High-order isotropic algorithms for FDTD

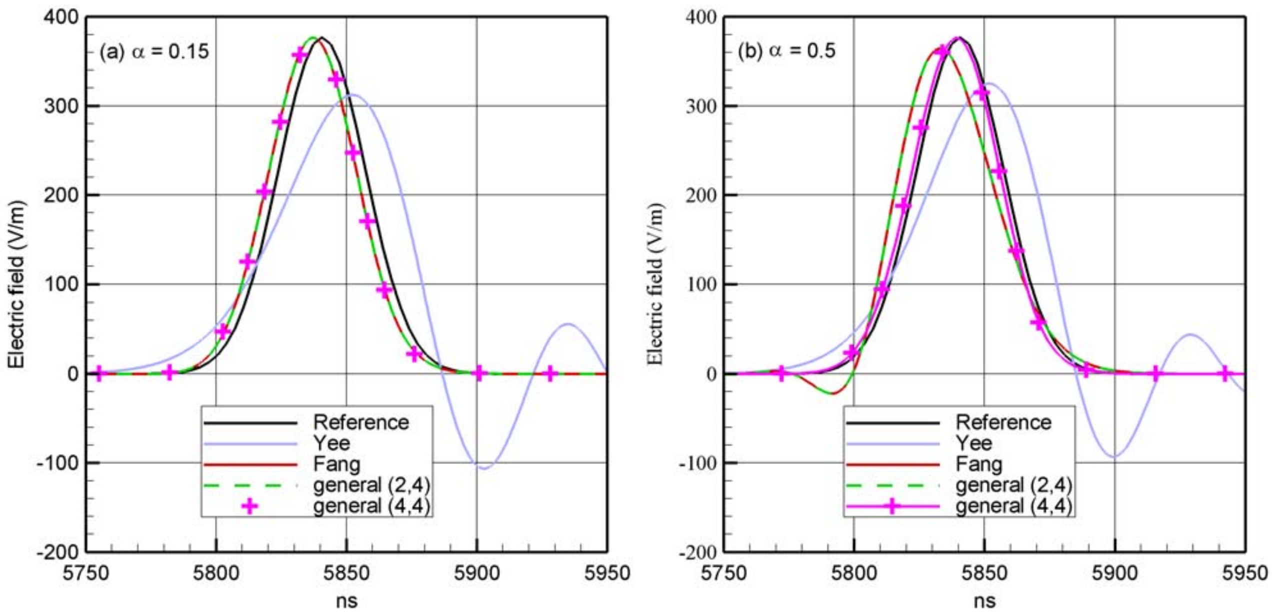


Fig. 1. Propagation of planewave gaussian waveform. Yee (2,2), Fang (2,4), general (2,4), and general (4,4) algorithms are compared to the original Gaussian waveform (yeeref in the legend) at 1780m from source. The x-axis is nano-seconds and the y-axis is z-component of the electric field in V m^{-1}. (a) Gaussian pulse propagated with α=0.15. All of the schemes with 4^{th} order spatial accuracy retain the pulse shape compared to the reference Gaussian pulse. (b) Same, but α=0.5. The Fang and general (2,4) schemes exhibit similar dispersion compared to the reference Gaussian. The general (4,4) pulse shape remains un-degraded compared to the reference Gaussian.

High-order isotropic algorithm for FDTD

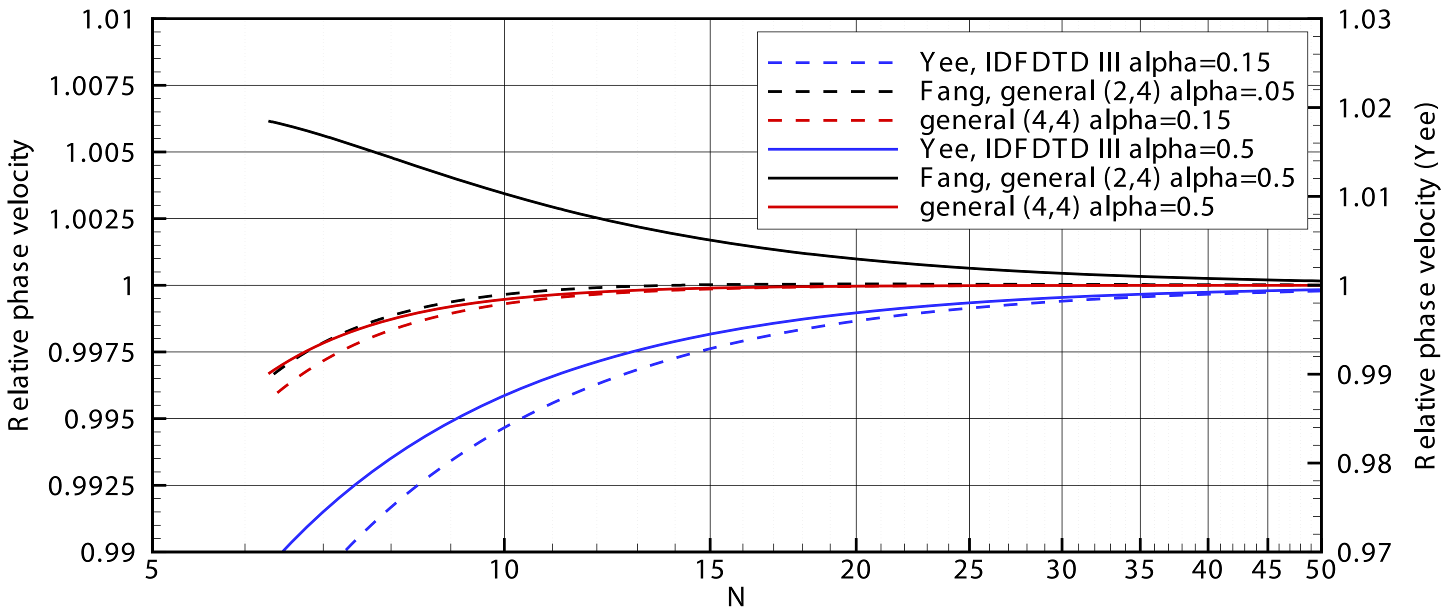
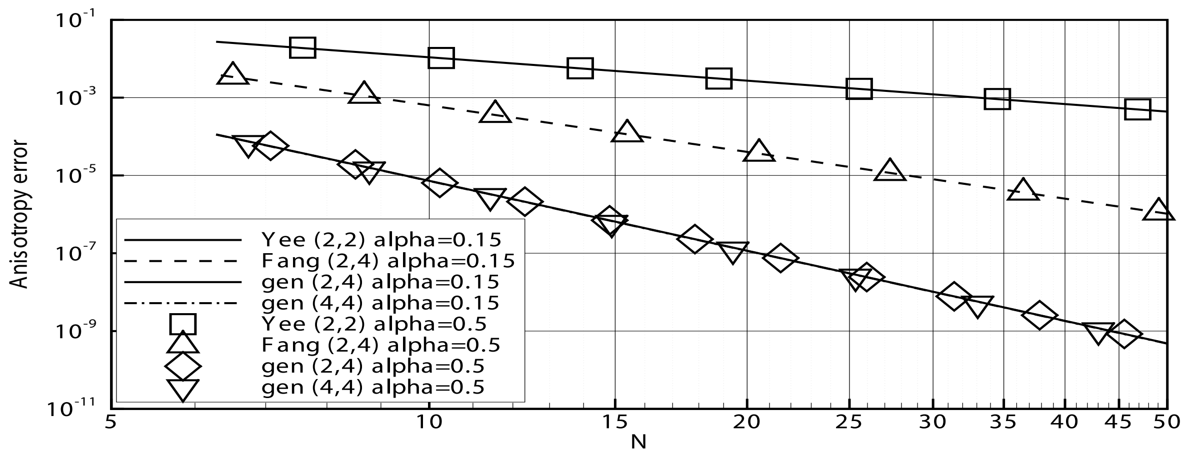
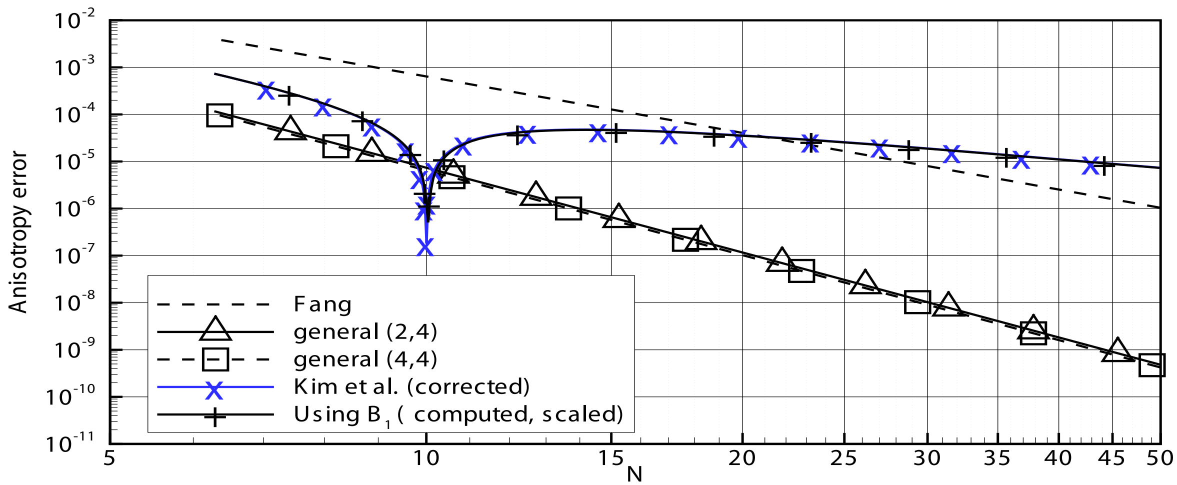


Fig. 1. Relative phase velocity for wave propagation along the x-axis. Yee, IDFDTD-III, Fang, general (2,4), and general (4,4) schemes are shown. Computations were done at α=0.5 (solid lines) and α=0.15 (dashed lines). The Yee scheme and the IDFDTD III scheme exhibit essentially identical dispersion. The general (2,4) scheme and the Fang (2,4) scheme have essentially identical dispersion behavior. The general (4,4) scheme shows only weak dependence on α.

Anisotropy error
Yee, Fang, ID-FDTD and LANL schemes





Anisotropy error defined as:

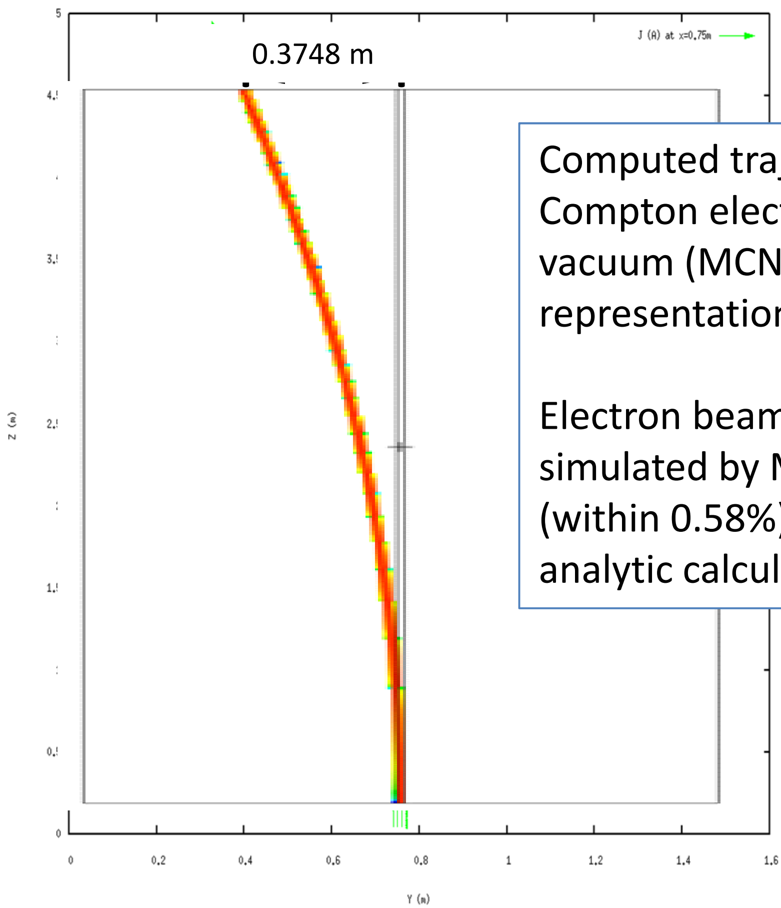
$$\left[\max(\upsilon_p') - \min(\upsilon_p')\right] / \min(\upsilon_p')$$

MCNP/FDTD Integration Progress

- FDTD integration into MCNP6 build system (Completed)
- FDTD interface being fine tuned
- FDTD model depend variables moved to interface and input deck
- MCNP – FDTD simple test cases being developed
- Direct access of MCNP current tally by FDTD (Completed)
- Magnetic field mesh in MCNP (Completed)
- Updating MCNP magnetic field from FDTD under testing
- Time stepping in MCNP under testing

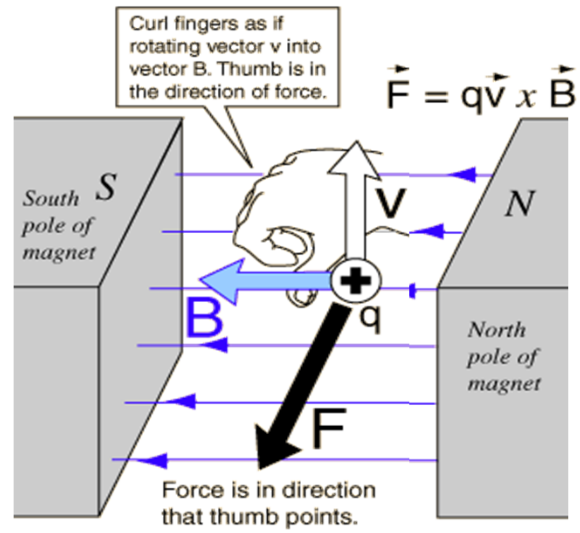
MCNP magnetic field integration test

20MeV electron beam in 0.0025T magnetic field



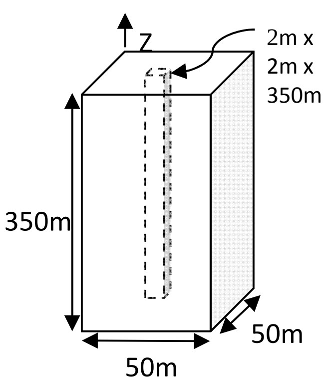
Computed trajectory of Compton electron beam in vacuum (MCNP and FDTD representations shown).

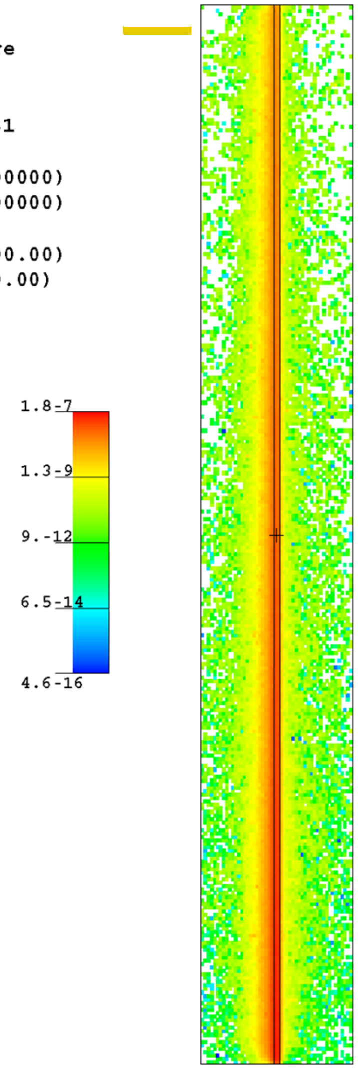
Electron beam deflection simulated by MCNP is correct (within 0.58%) compared to analytic calculation



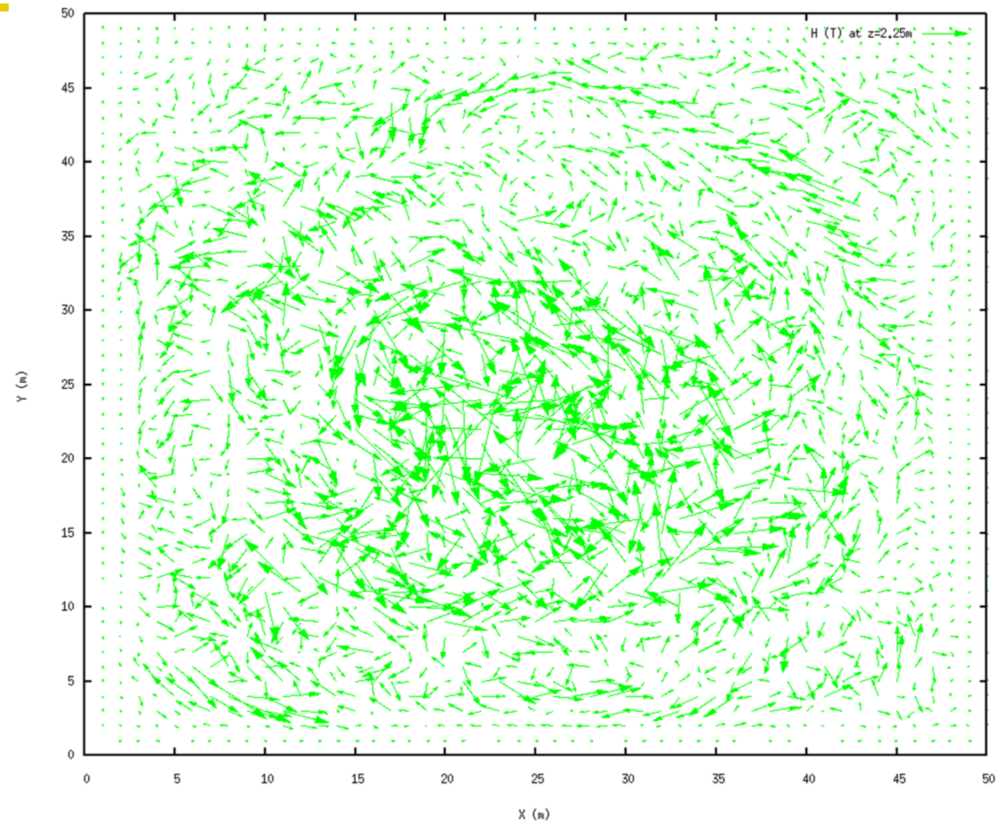
MCNP gamma simulation with 0.0025 T magnetic field in x-direction

```
 03/07/12 13:12:21
simulate current along wire
 (void) in mag field

probid =  03/07/12 12:41:31
basis:    YZ
( 0.000000, 1.000000, 0.000000)
( 0.000000, 0.000000, 1.000000)
origin:
(  2500.00,  2500.00, 17500.00)
extent = ( 17500.00, 17500.00)

Mesh Tally      104
nps          1000000
runtpe = jnkr
dump               2
```



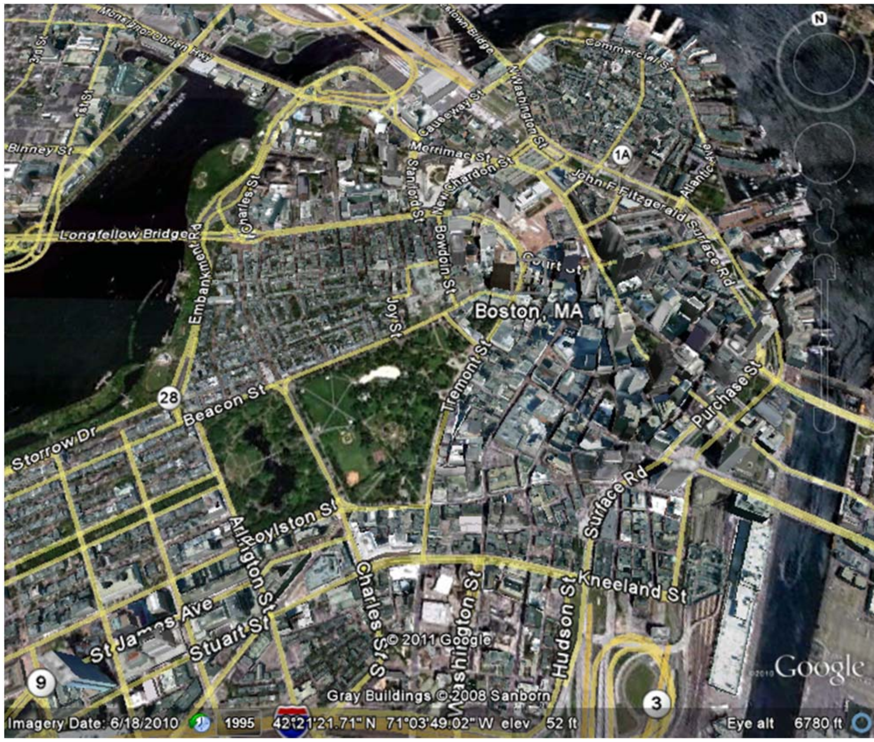


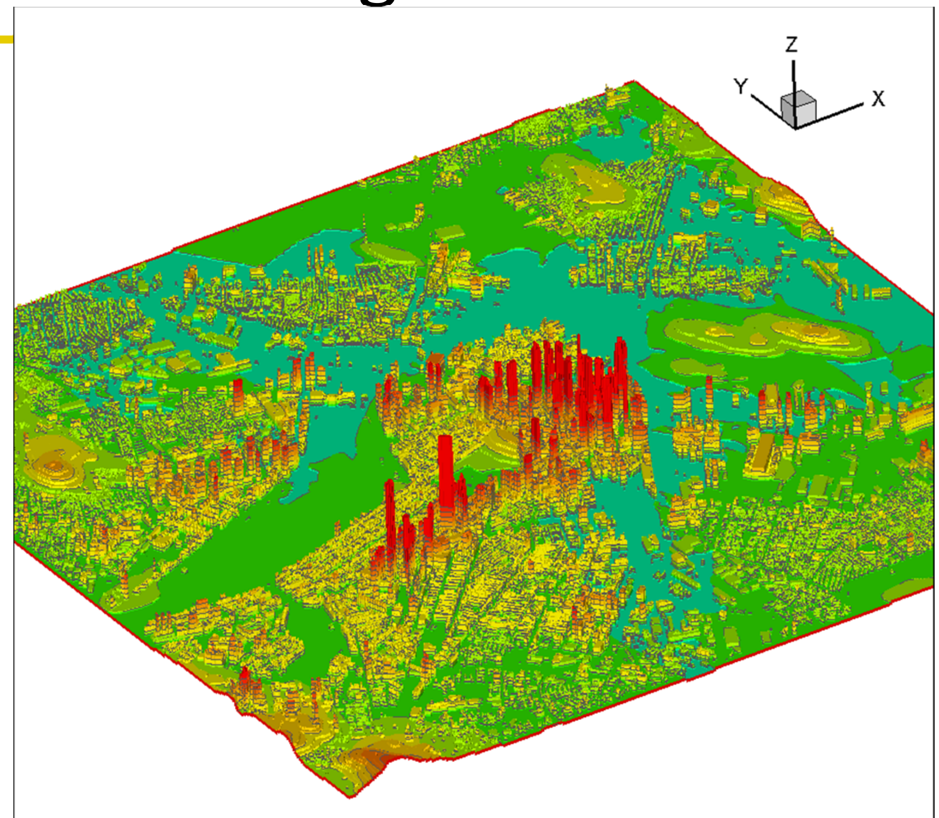
Compton electron current



FDTD H-field in x-y plane at z=175 m

MCNP/FDTD coupled EMP simulation Boston area and model grid

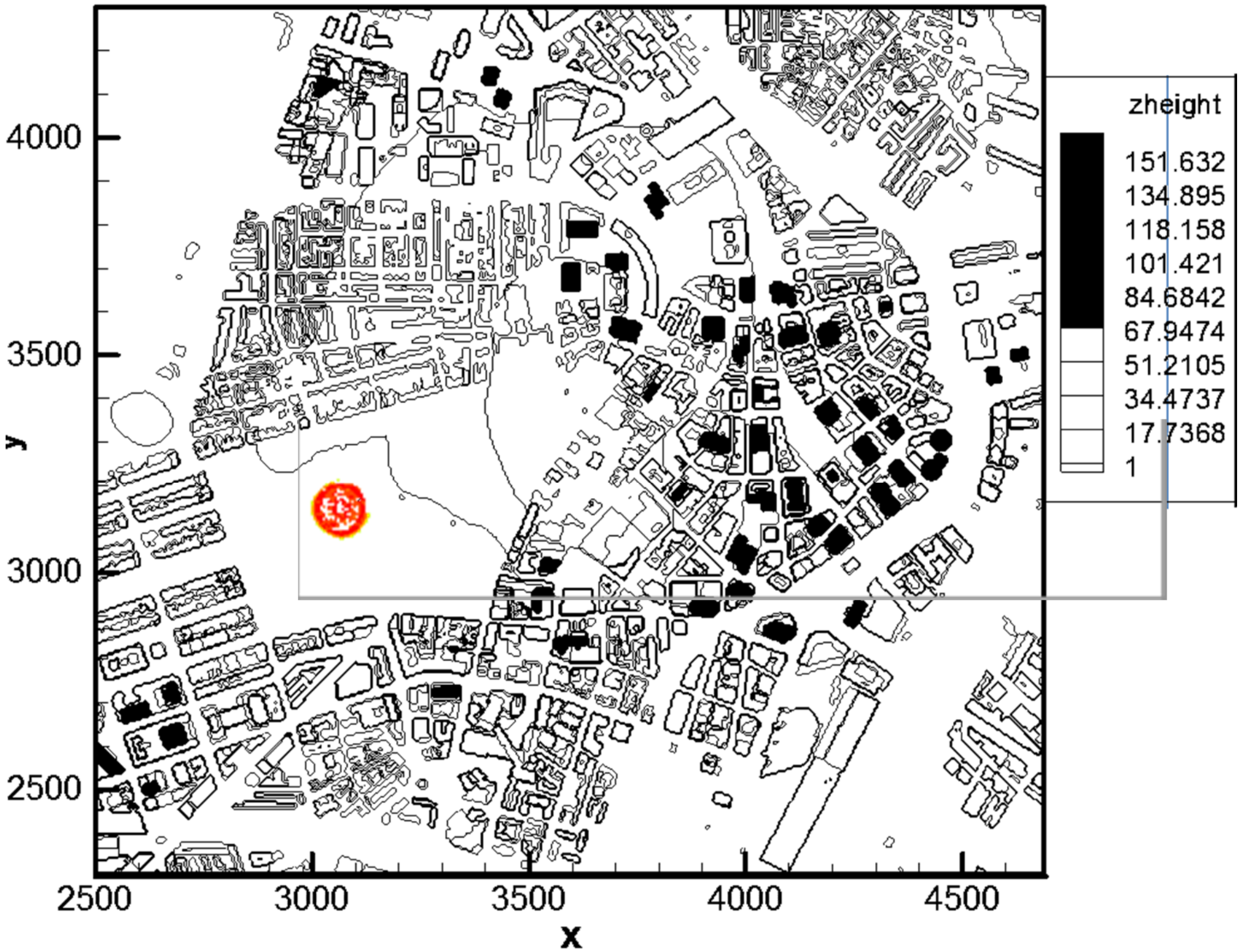




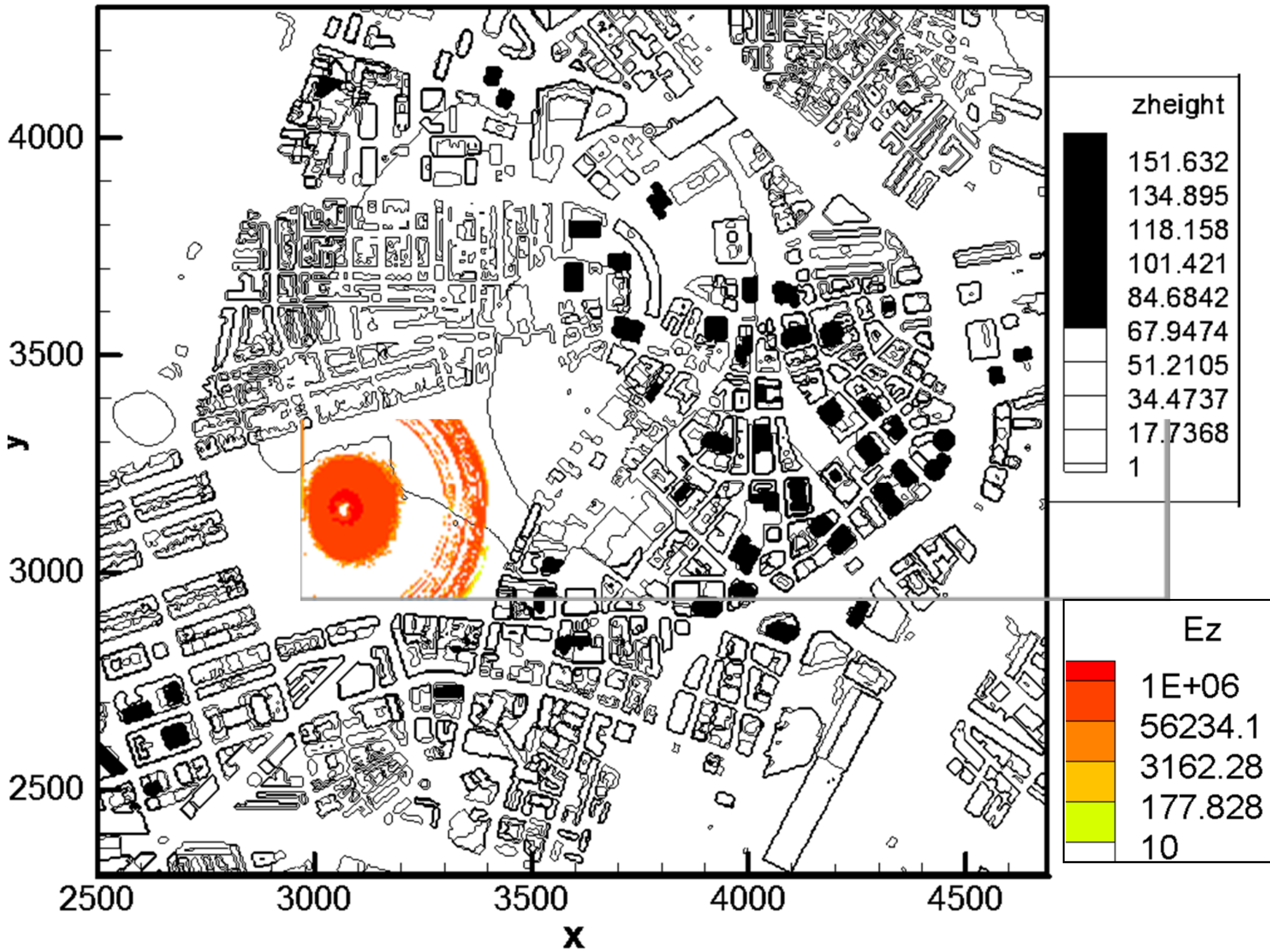
Boston commons detonation (generic fatman) γ
Time/space varying current densities from MCNP
FDTD 6400x400x200, 1m resolution (N=10 for 30MHz)
160 processors, 12hrs

Do trees affect and electron distribution?

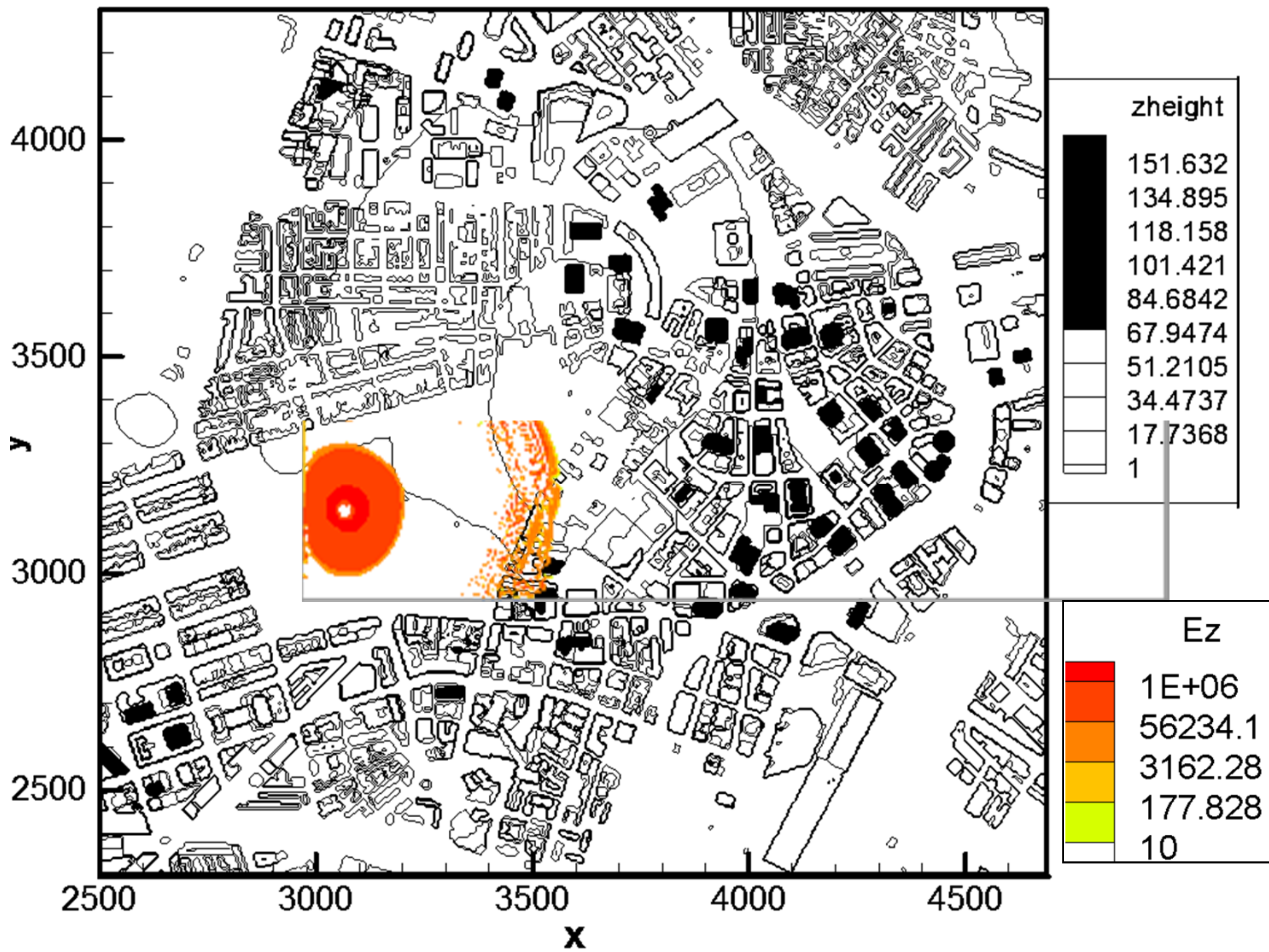
Ez magnitude from NUDET



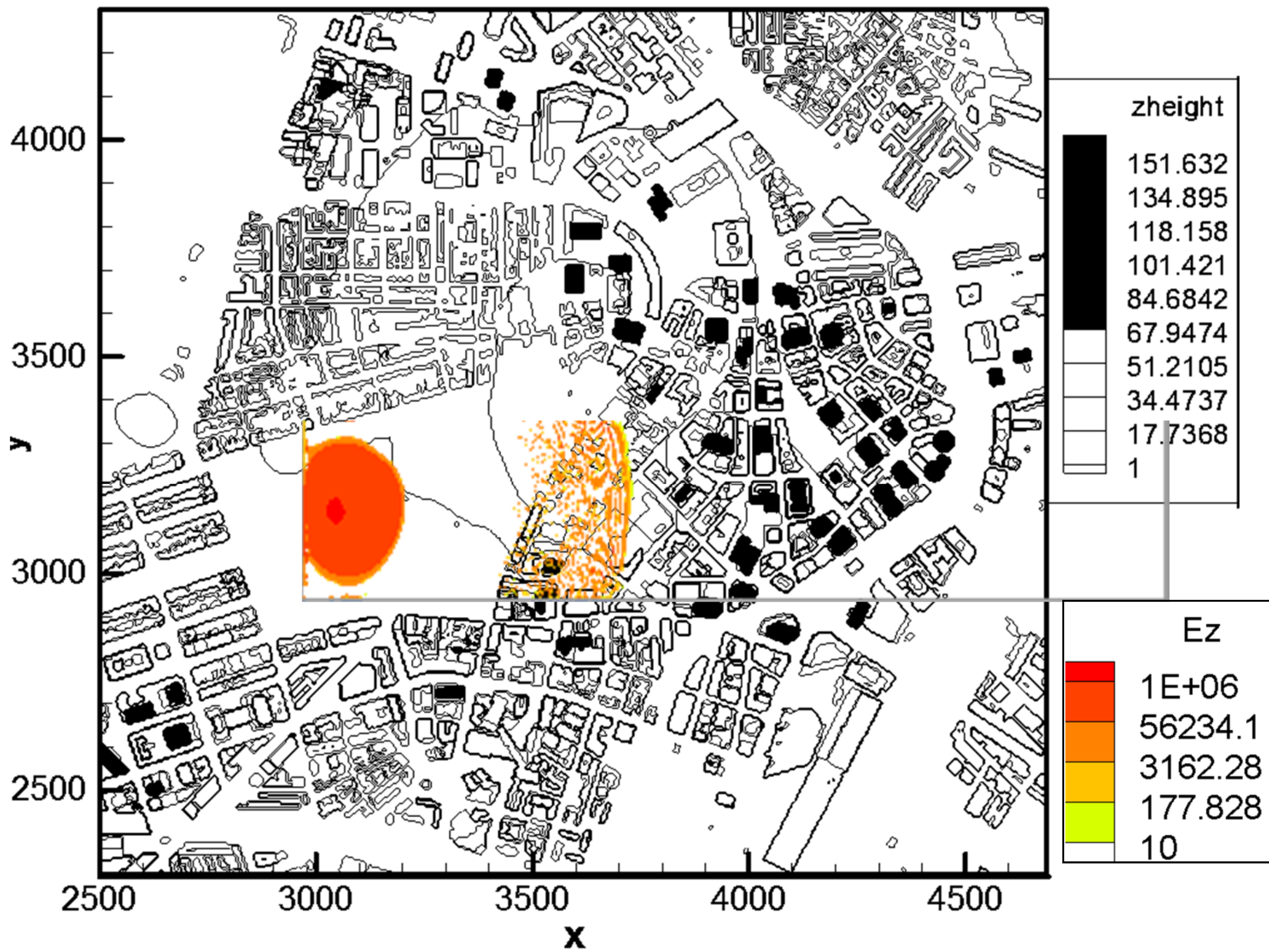
Ez magnitude from NUDET



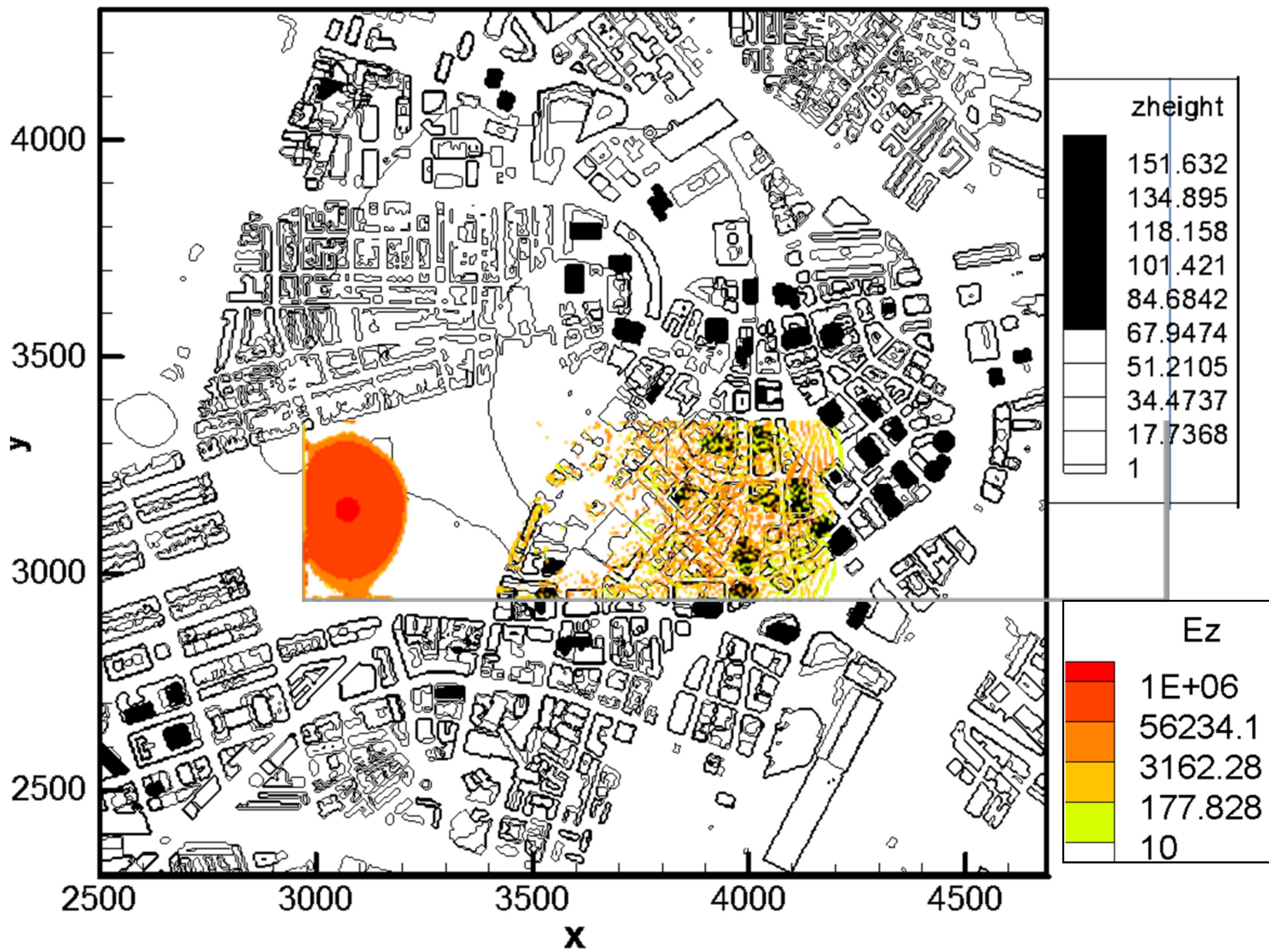
Ez magnitude from NUDET



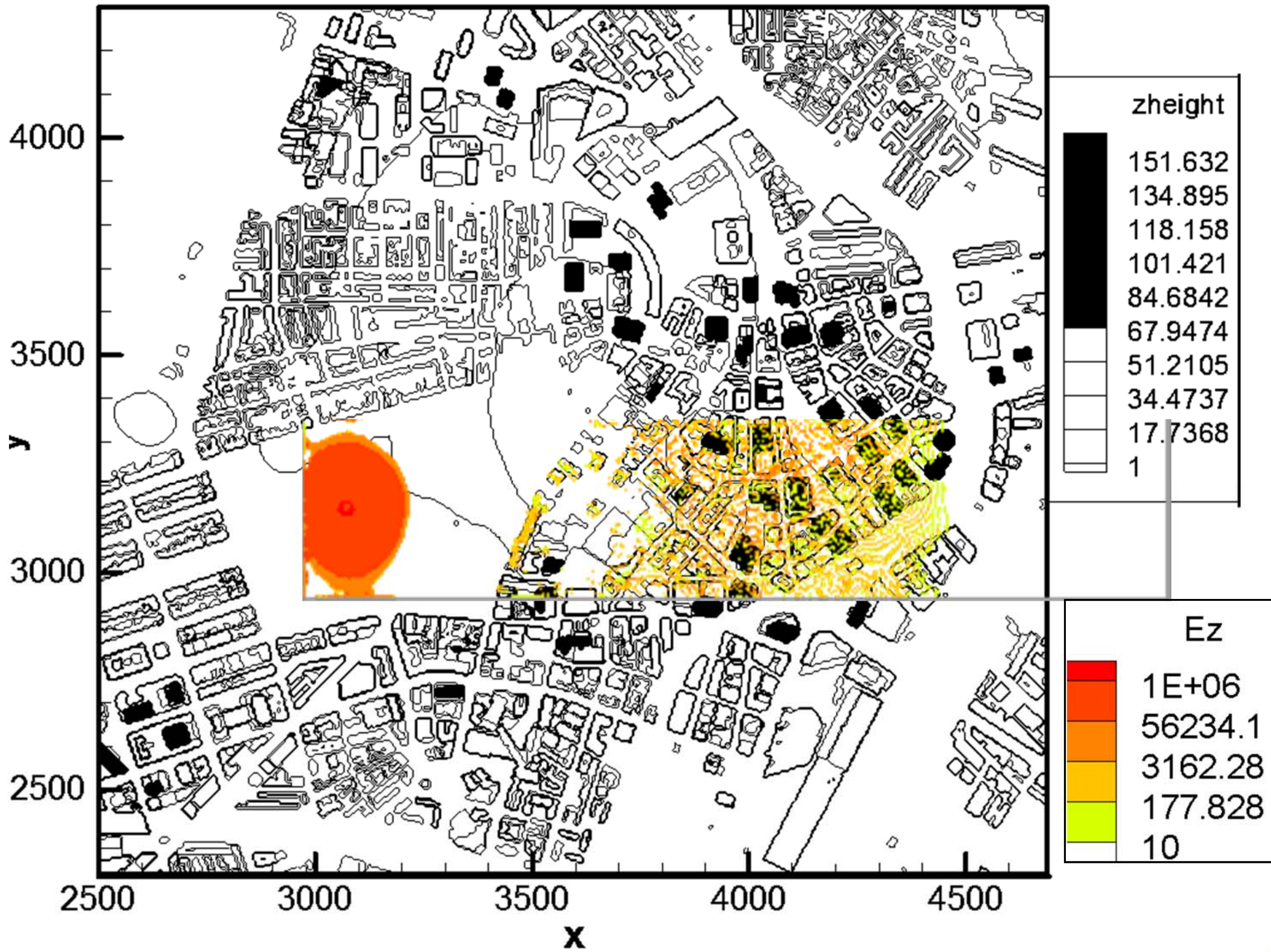
Ez magnitude from NUDET



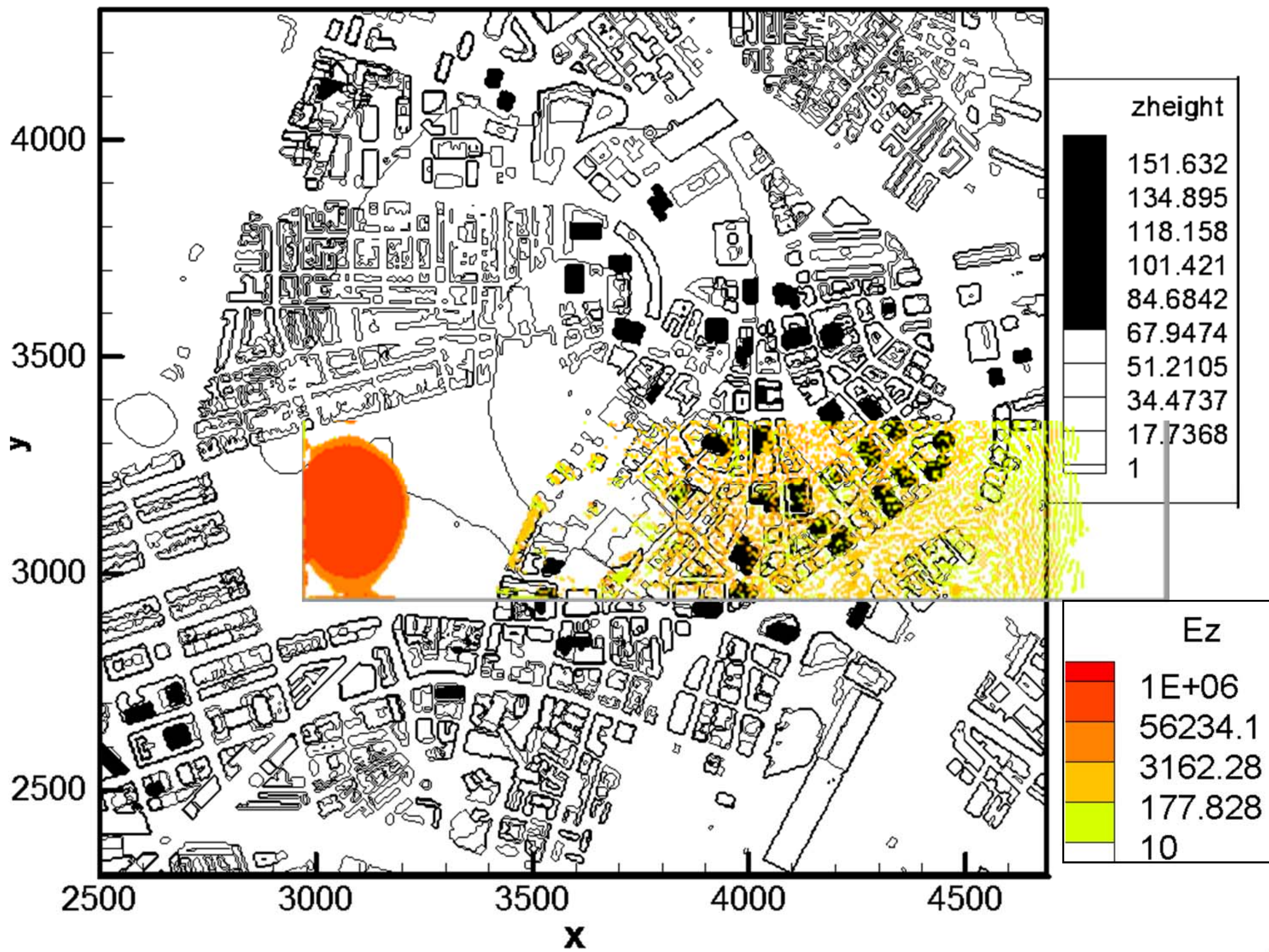
Ez magnitude from NUDET



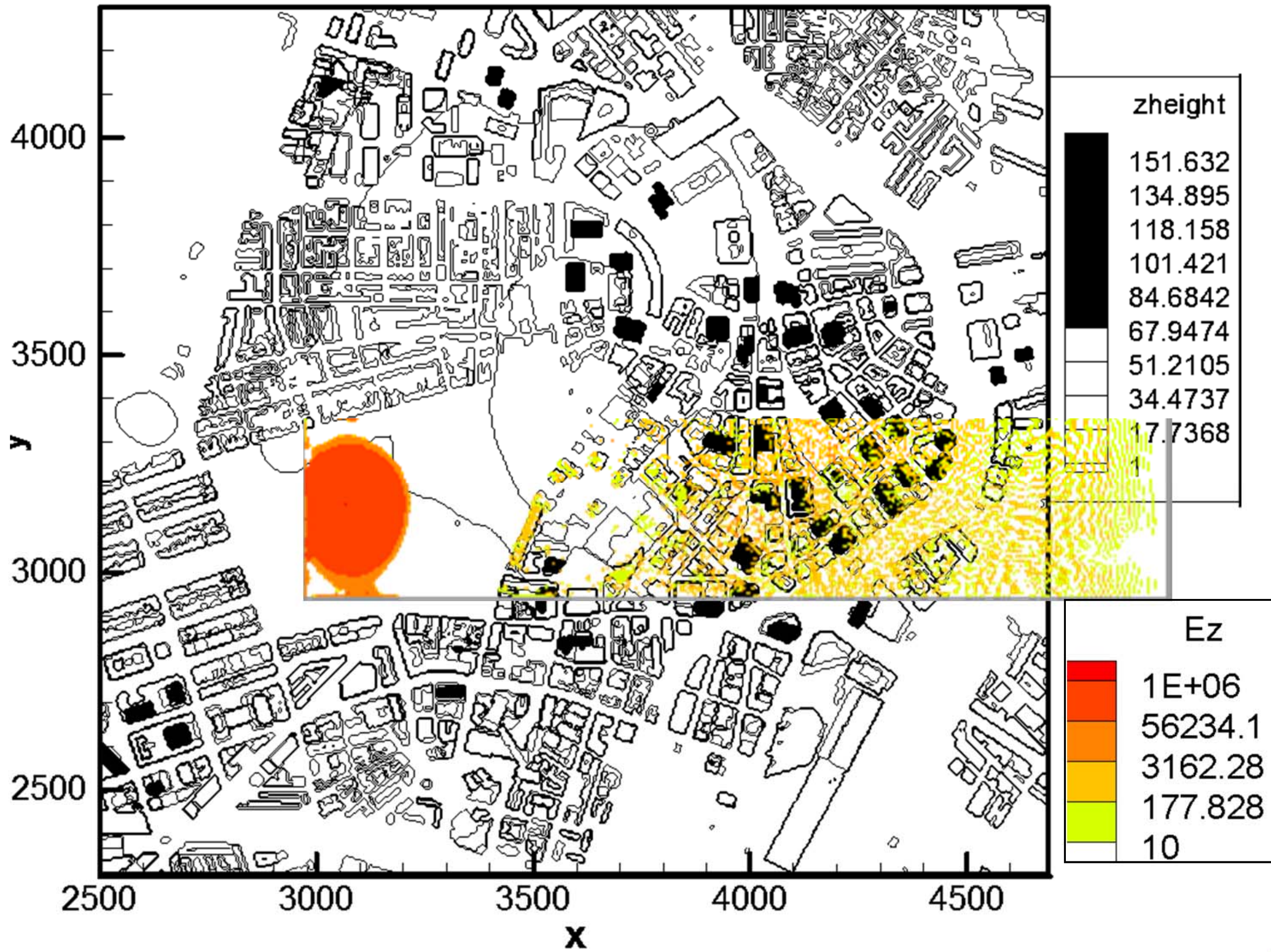
Ez magnitude from NUDET



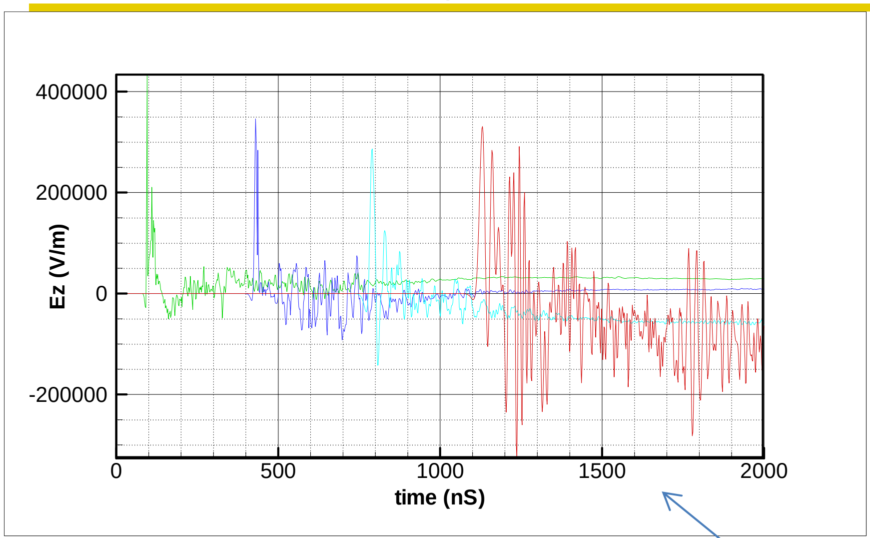
Ez magnitude from NUDET

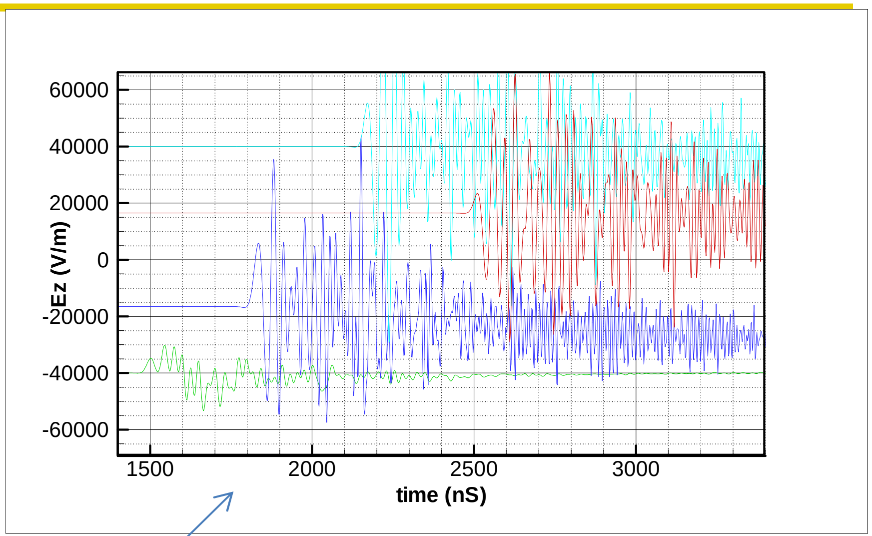


Ez magnitude from NUDET



Ez (x distance) for selected points in Boston area





Houston 3-D model

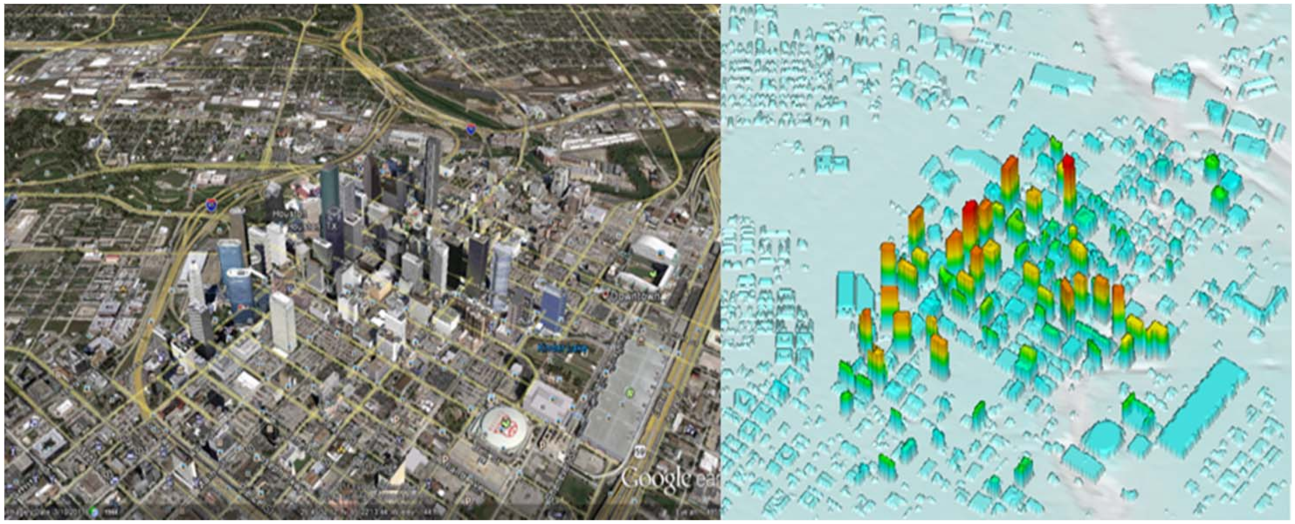
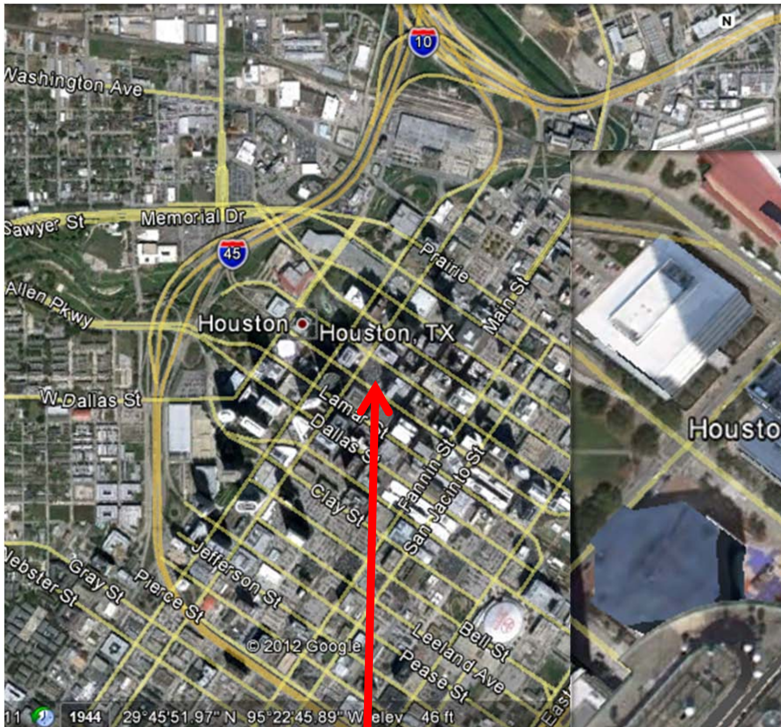
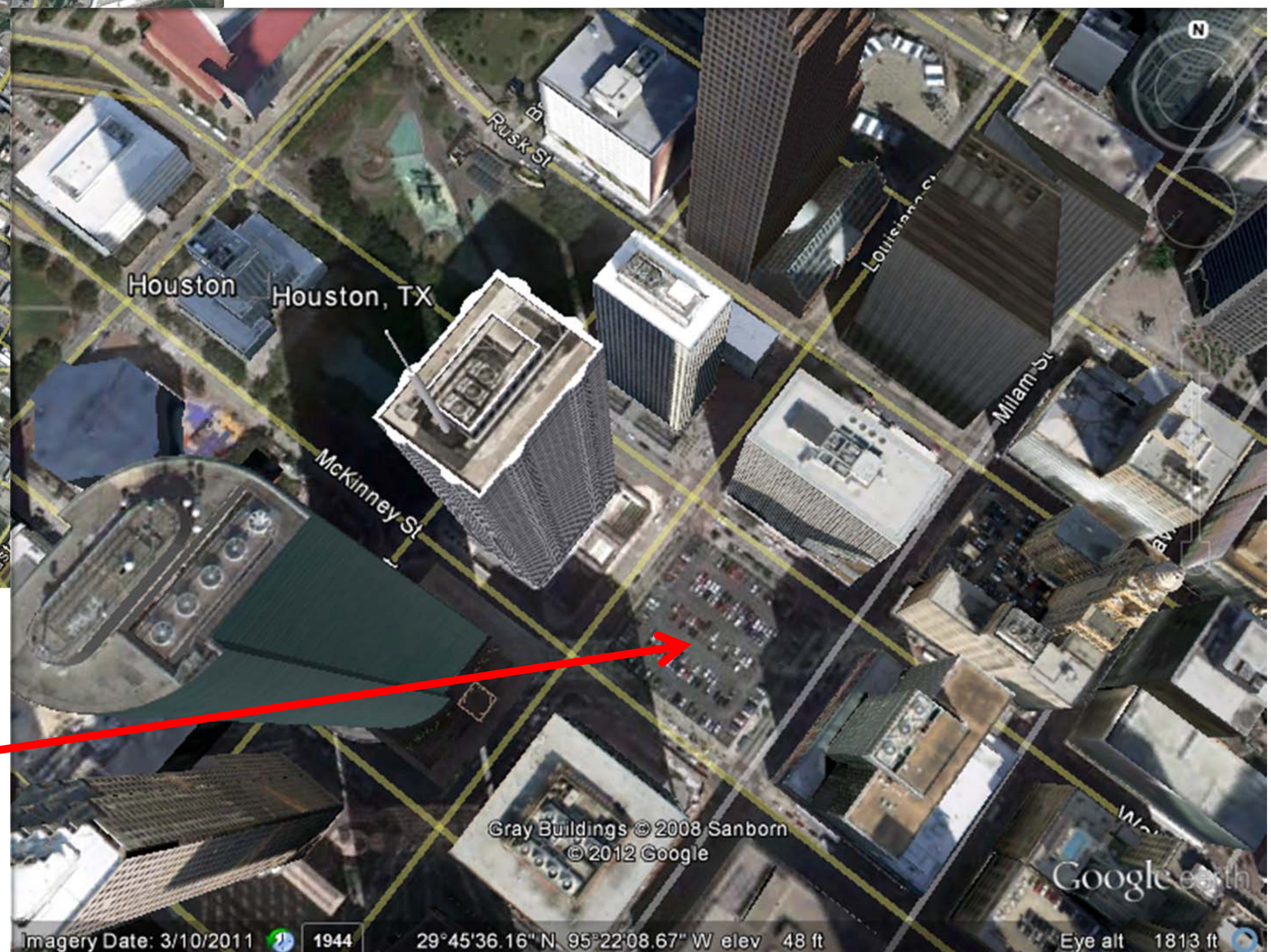


Figure 1. Left: Google image of downtown Houston. Right: Corresponding model grid representation. The modeled Houston area is approximately 2.5km x 2.5km.

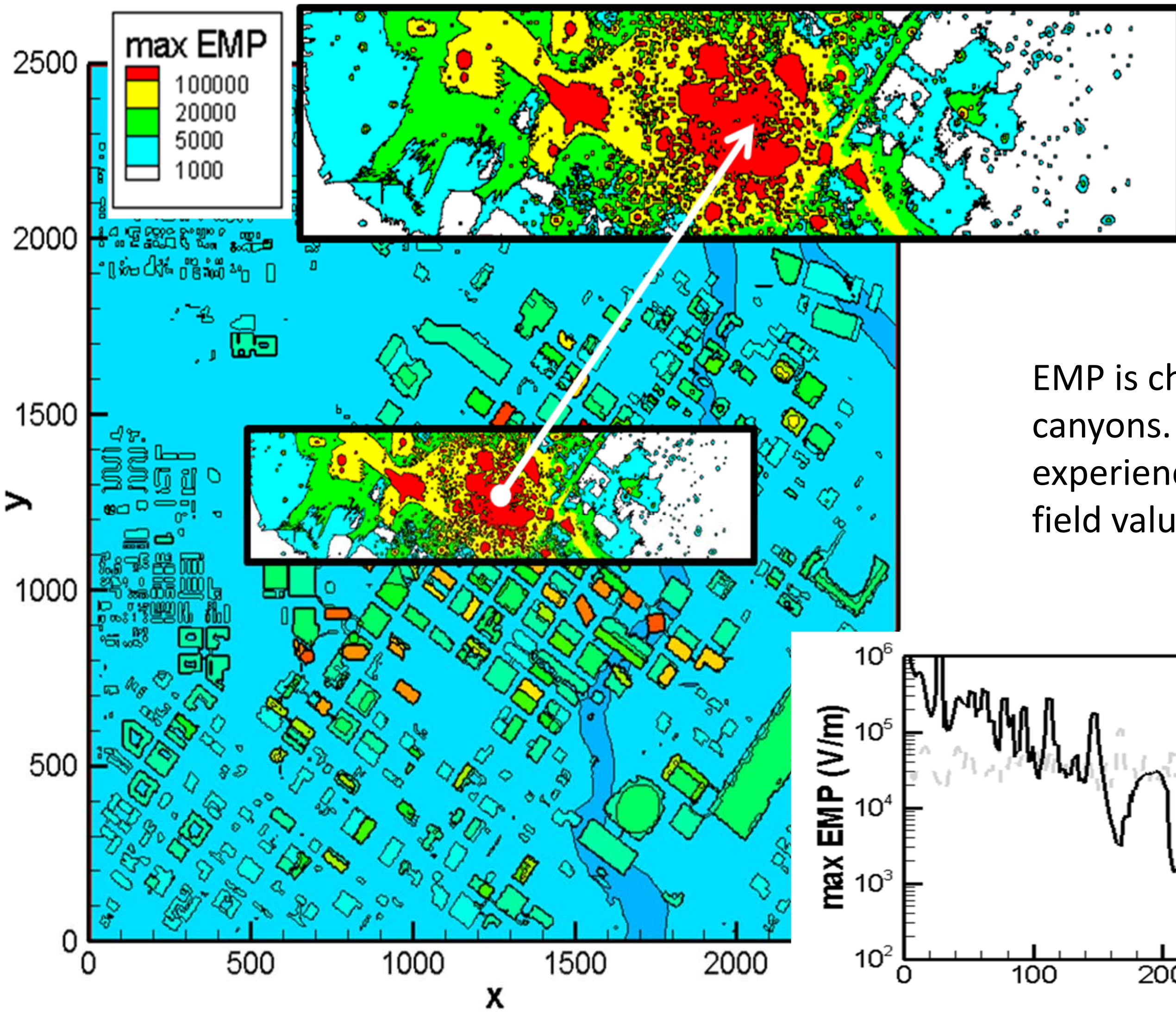
NUDET location and surrounding buildings





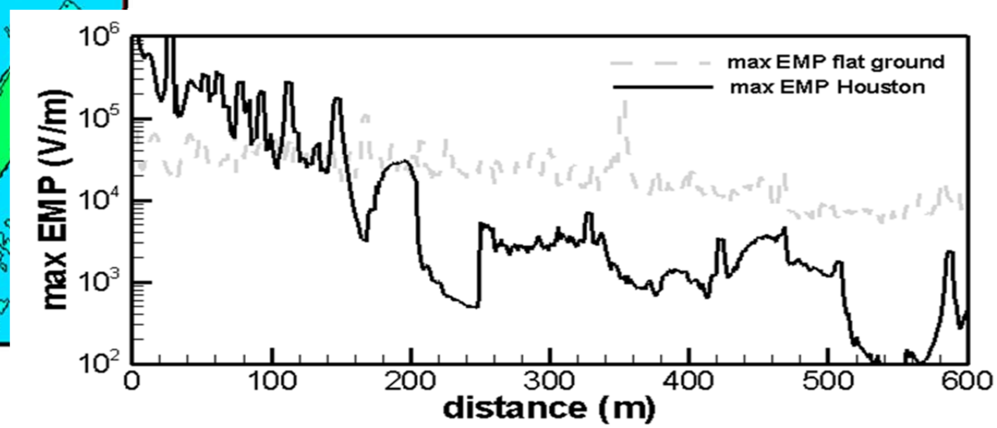
NUDET location

3-D Urban EMP FDTD; downtown Houston, TX



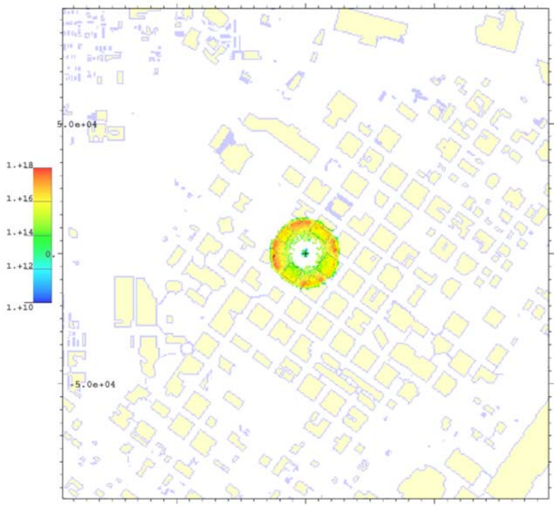
Horizontal cross section of downtown Houston - expanded inset showing the maximum magnitude EMP (V/m).

EMP is channeled outward along street canyons. Yellow and red contoured areas experience maximum electromagnetic field values above 20 kV / m.

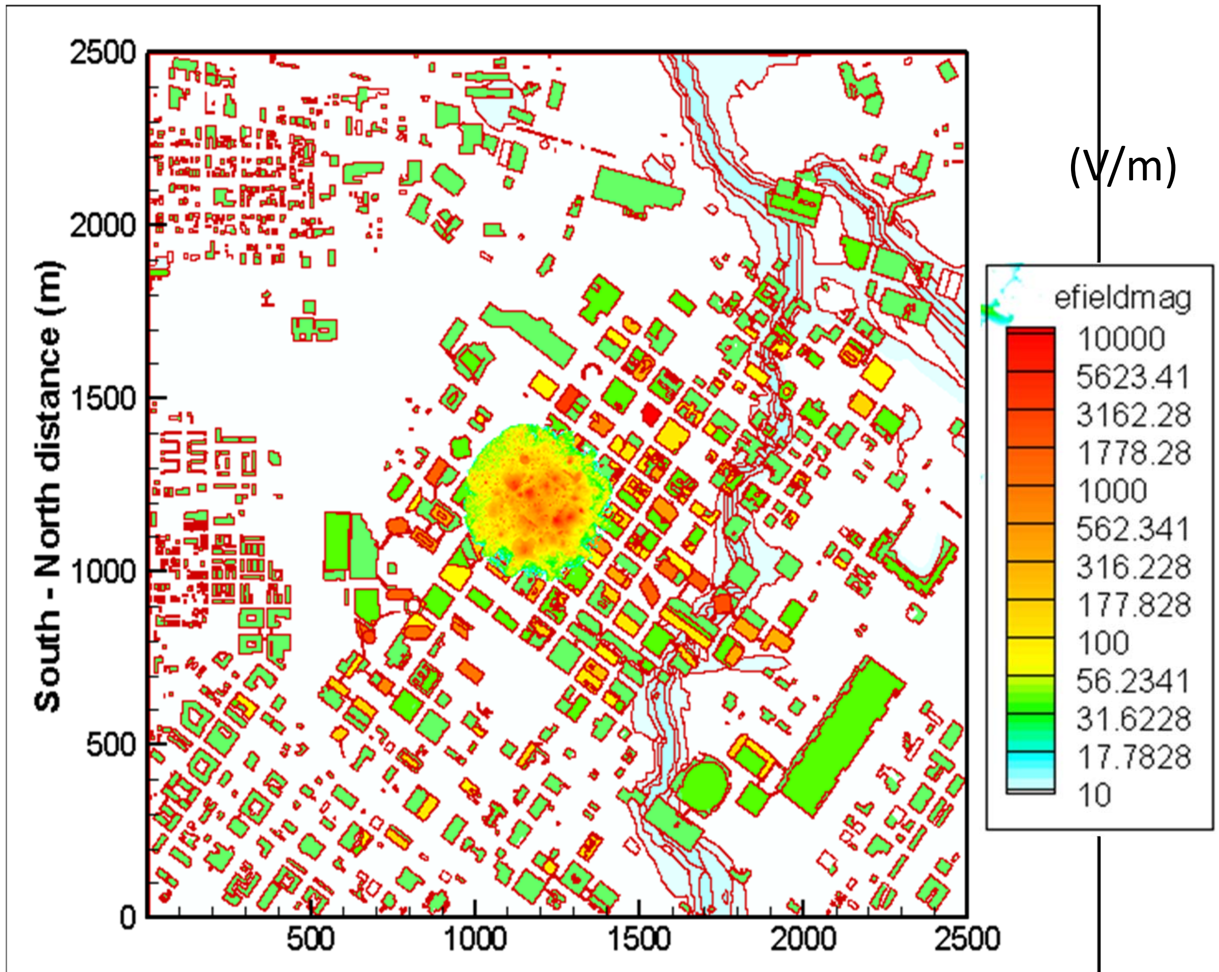


Compton currents and maximum magnitude EMP

downtown Houston, TX



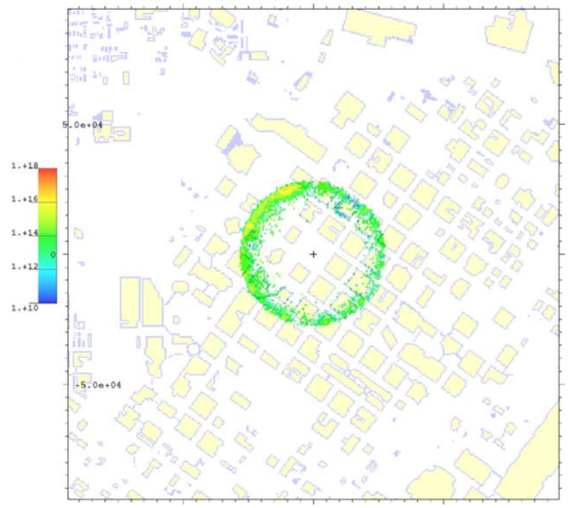
T=60 shakes



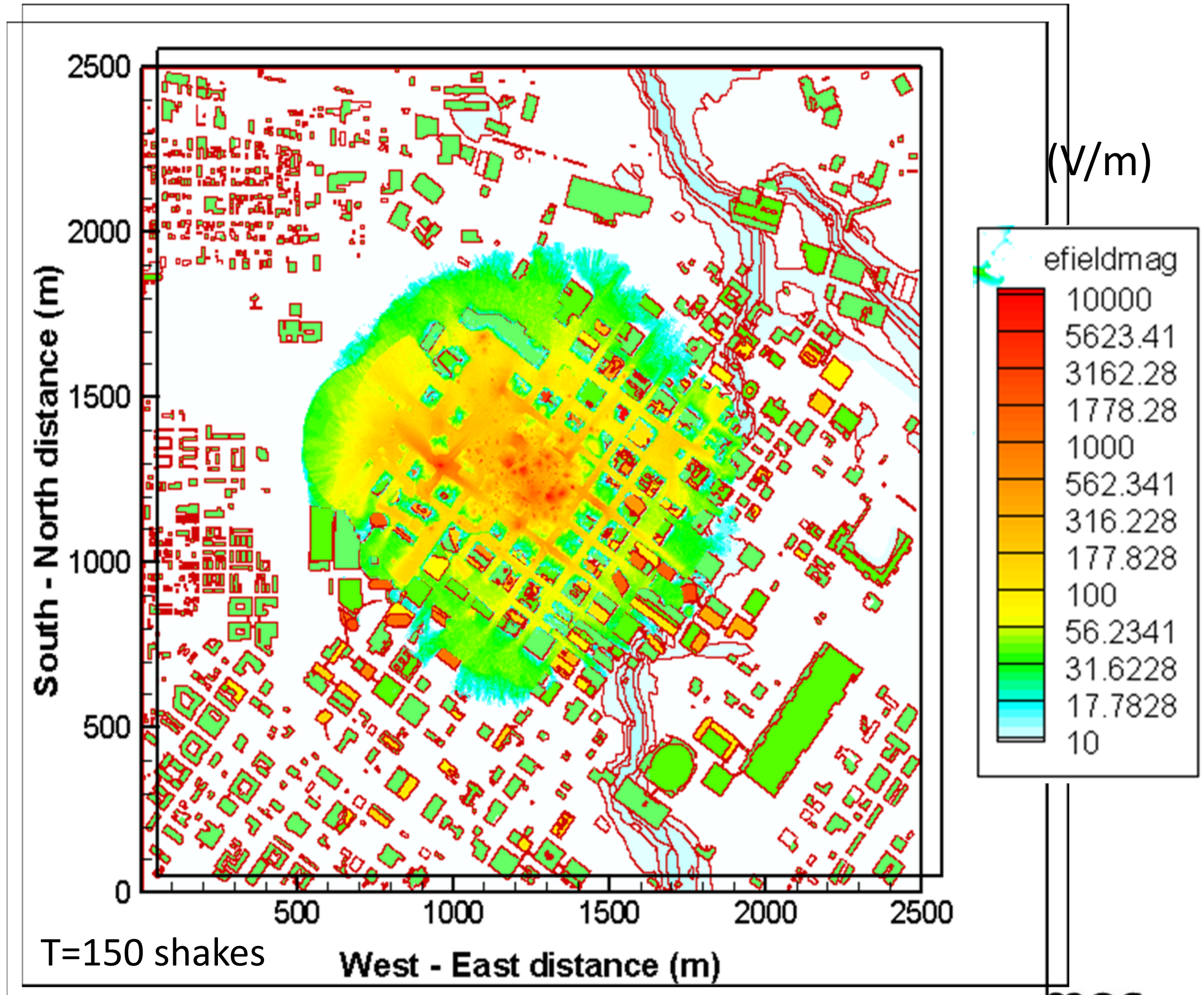
T=50 shakes

Compton currents and maximum magnitude EMP

downtown Houston, TX



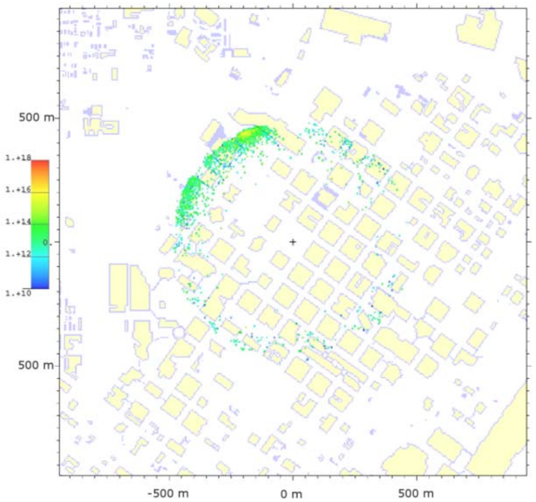
T=110 shakes



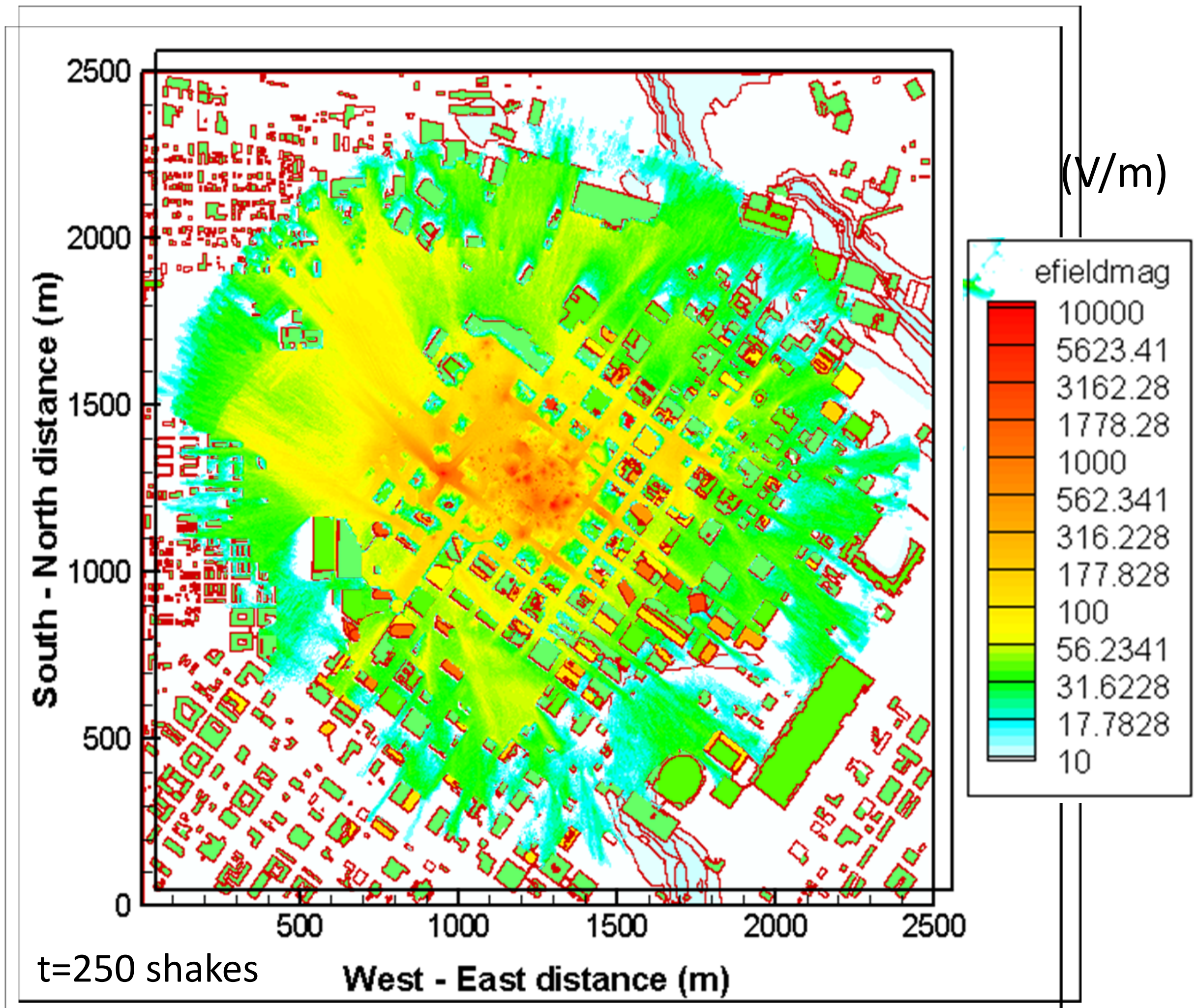
T=150 shakes

Compton currents and maximum magnitude EMP

downtown Houston, TX



t=180 shakes



t=250 shakes

Summary

- Developed two new high-order, isotropic algorithms for electrically large problems.
  - Smith et al., "A hierarchy of explicit low-dispersion FDTD methods for electrically large problems, IEEE trans. Antenna propagat., 2012 (in print)
- Corrected air chemistry package
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