Sensitivity Plots Using COMSOL 5.1 Multiphysics; A Tool for Optimizing Geophysical Field Survey

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What is Sensitivity ?

The sensitivity function of an array basically tells us about the degree to which a small change in the resistivity of a section of the subsurface will influence the potential measured by that array.

The higher the value of the sensitivity function, the greater is the influence of the subsurface region on the measurement.

Mathematically it is given by derivative.

$$F_{3D}(x,y,z) = \frac{1}{4\pi^2} \cdot \frac{x(x-a)+y^2+z^2}{[x^2+y^2+z^2]^{1.5}\,[(x-a)^2+y^2+z^2]^{1.5}}$$

Where z= depth, a= electrode spacing, x,y= co-ordinate

WHY SENSITIVITY ANALYSIS IS REQUIRED??

Because different array gives different type of response over same sub-surface feature. Some array gives better response over vertical changes & some gives better for horizontal.

Different arrays have different **sensitivity**, **depth of investigation** & different **signal strength**.

If we have any idea of geological structure to be delineated it is better to use the best suitable array, So that we get better result.

Use of COMSOL Multiphysics

The electric current interface of AC/DC module of COMSOL Multiphysics 5.1 was used in this work. The AC/DC Module provides a unique environment for simulation of AC/DC electromagnetic in 2D and 3D.

Model Definition in COMSOL Multiphysics:-

- The model illustrates the forward step and the sensitivity calculation for a typical situation of near-surface ERT with point electrodes spaced one meter from each other.

- As a material, a homogeneous half-space of electric conductivity is σ = 0.01 S/m, which corresponds to a resistivity of 100 Ω-m is used.

- The sensitivity of a different electrode configuration according to the equation given below,

S=with(1,ec.Jx)*with(2,ec.Jx)+with(1,ec.Jy)* with(2,ec.Jy)
+with(1,ec.Jz)*with(2,ec.Jz))

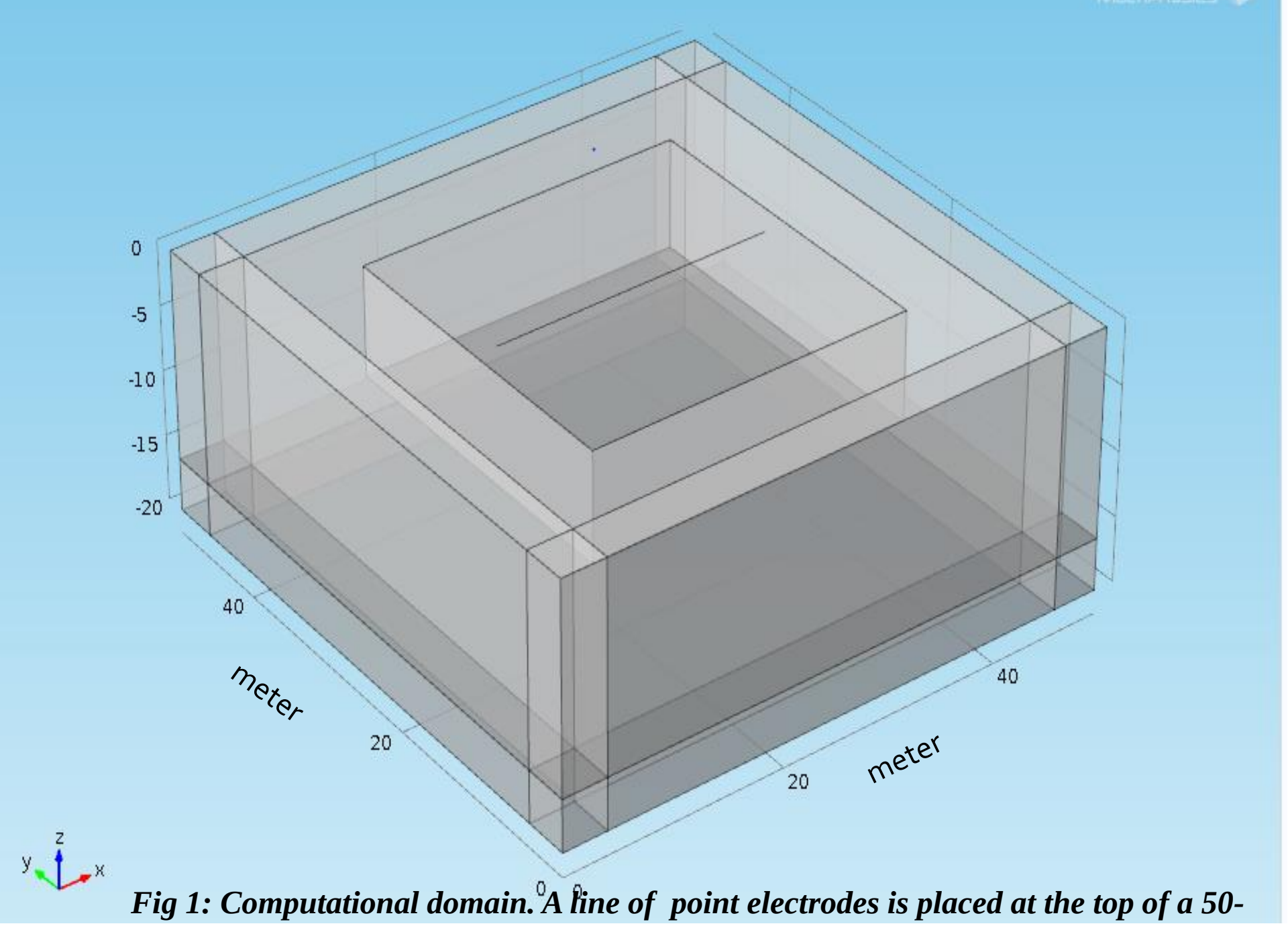
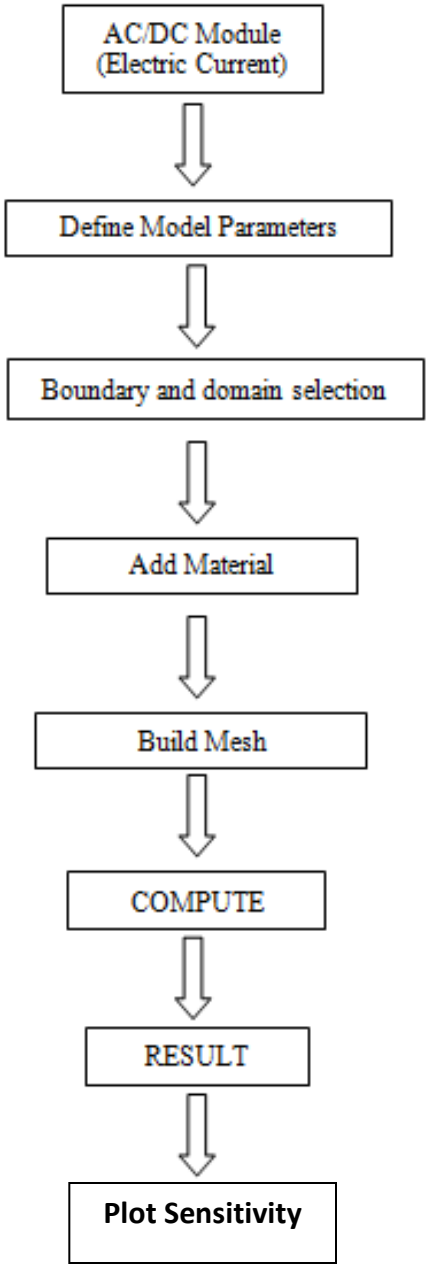


Fig 1: Computational domain. A line of point electrodes is placed at the top of a 50-by-50-by-20 meters box bounded by infinite element regions.

Work flow in COMSOL Multiphysics



Sensitivity is calculated for different resistivity arrays

Surface Arrays

Wenner
Schlumberger
Dipole- dipole
Pole- pole
Pole-dipole
Double wenner
Half schlumberger

Cross Borehole

Pole-bipole
Bipole-bipole

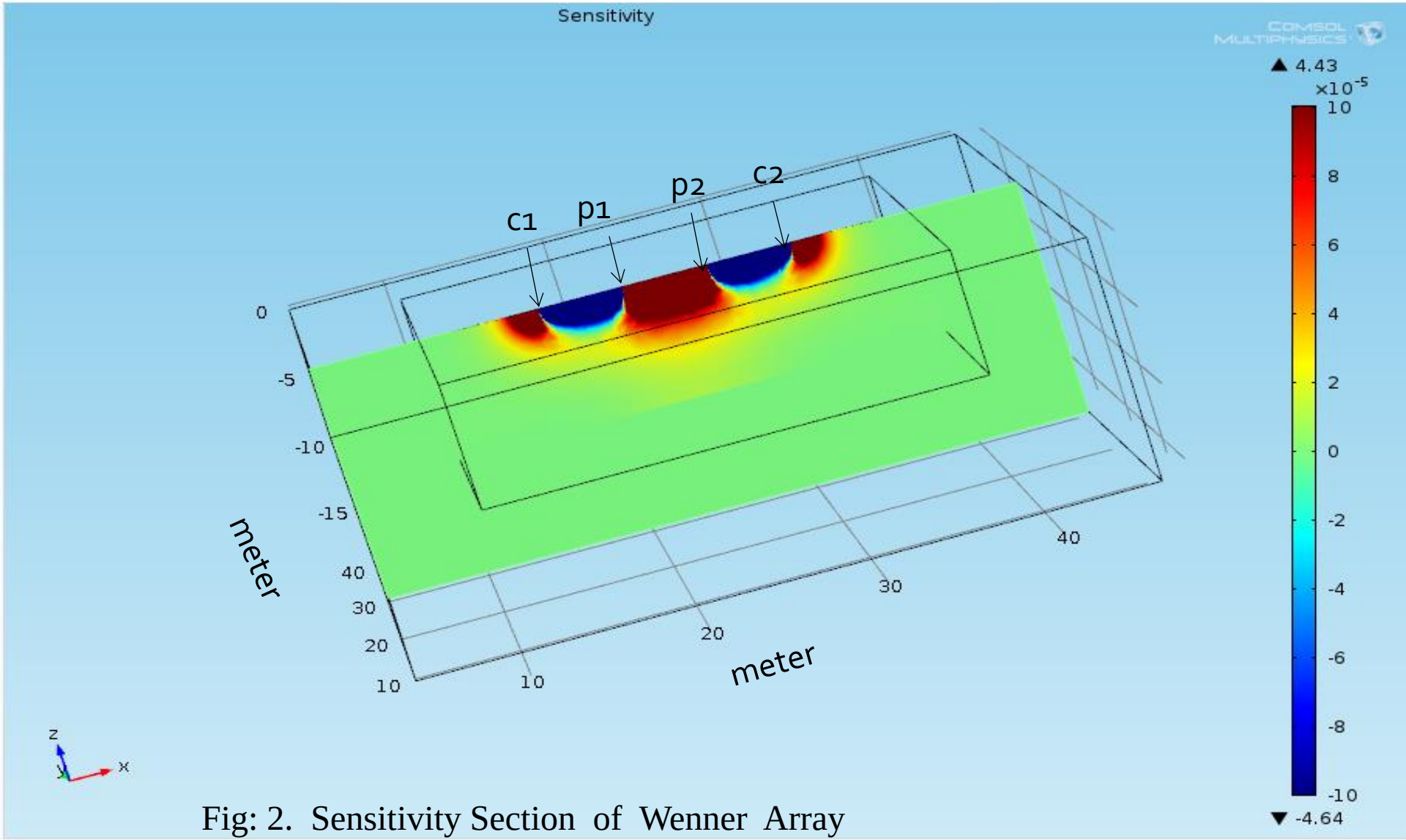
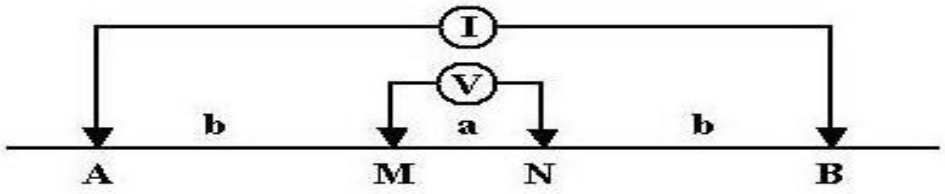


Fig: 2. Sensitivity Section of Wenner Array

$$\rho_A = \frac{V}{I}\pi\frac{b\,(b+a)}{a} \approx \frac{V}{I}\pi\frac{b^2}{a} \quad \text{if } a \ll b$$



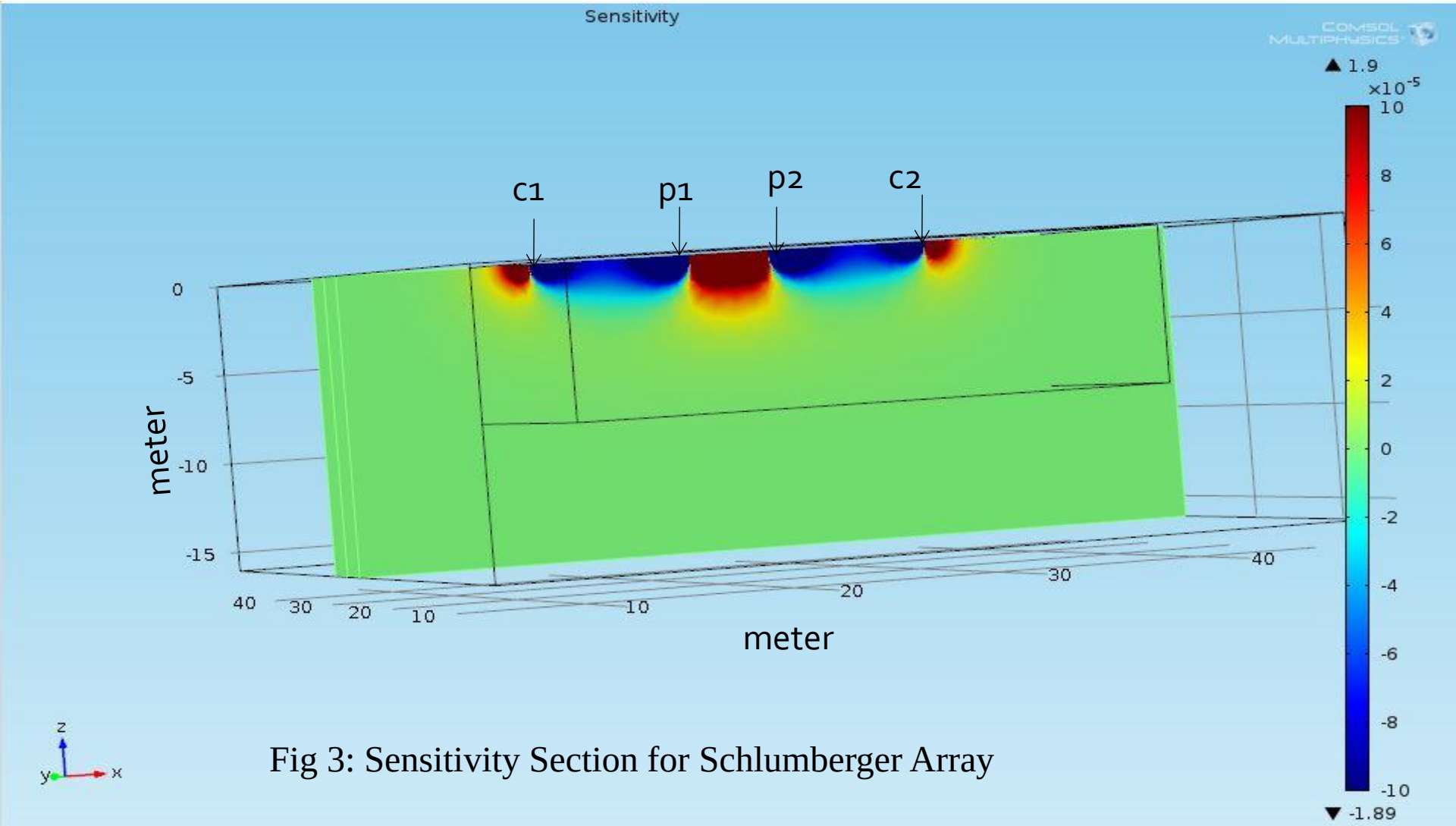


Fig 3: Sensitivity Section for Schlumberger Array

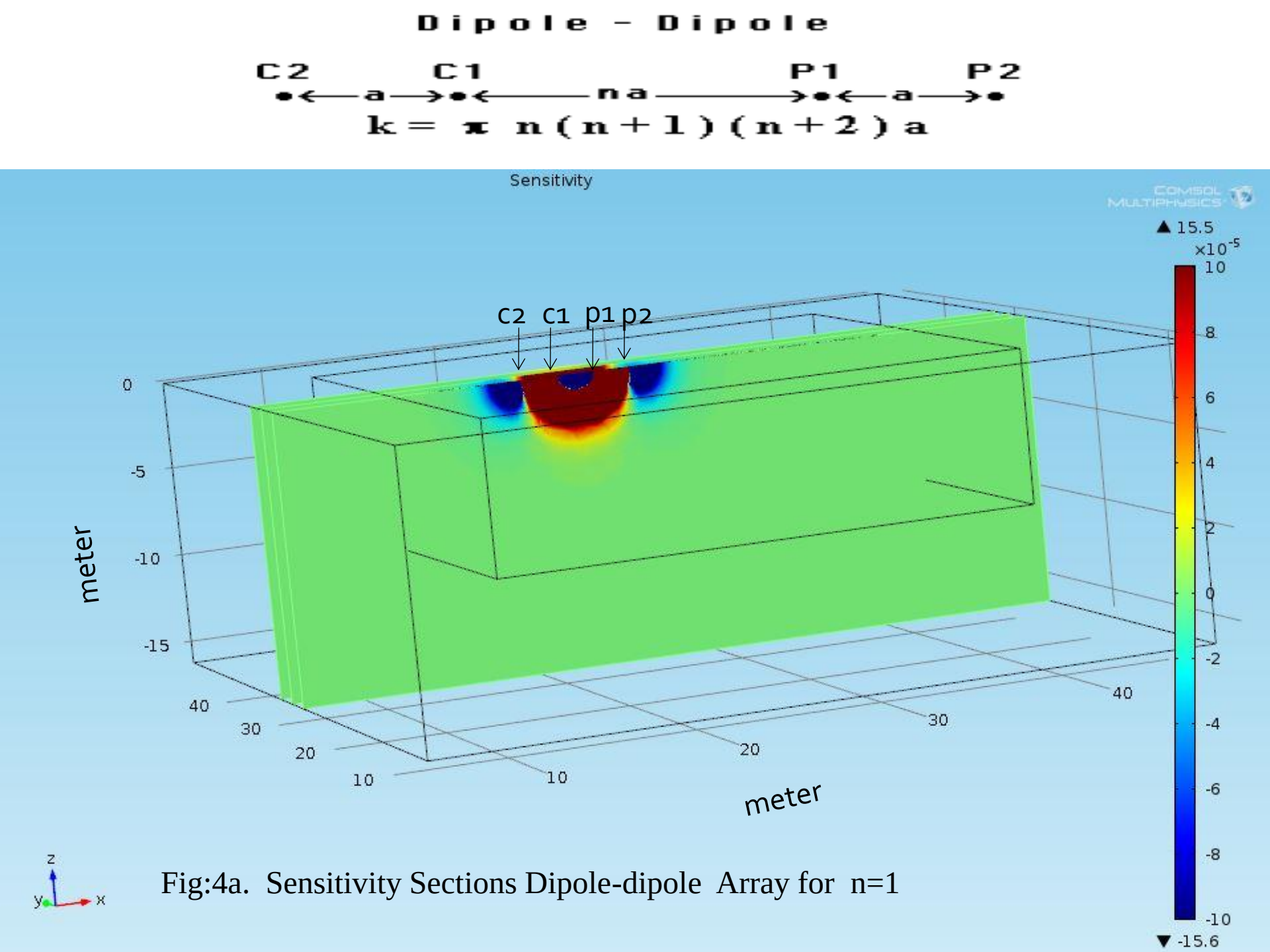


Fig:4a. Sensitivity Sections Dipole-dipole Array for n=1

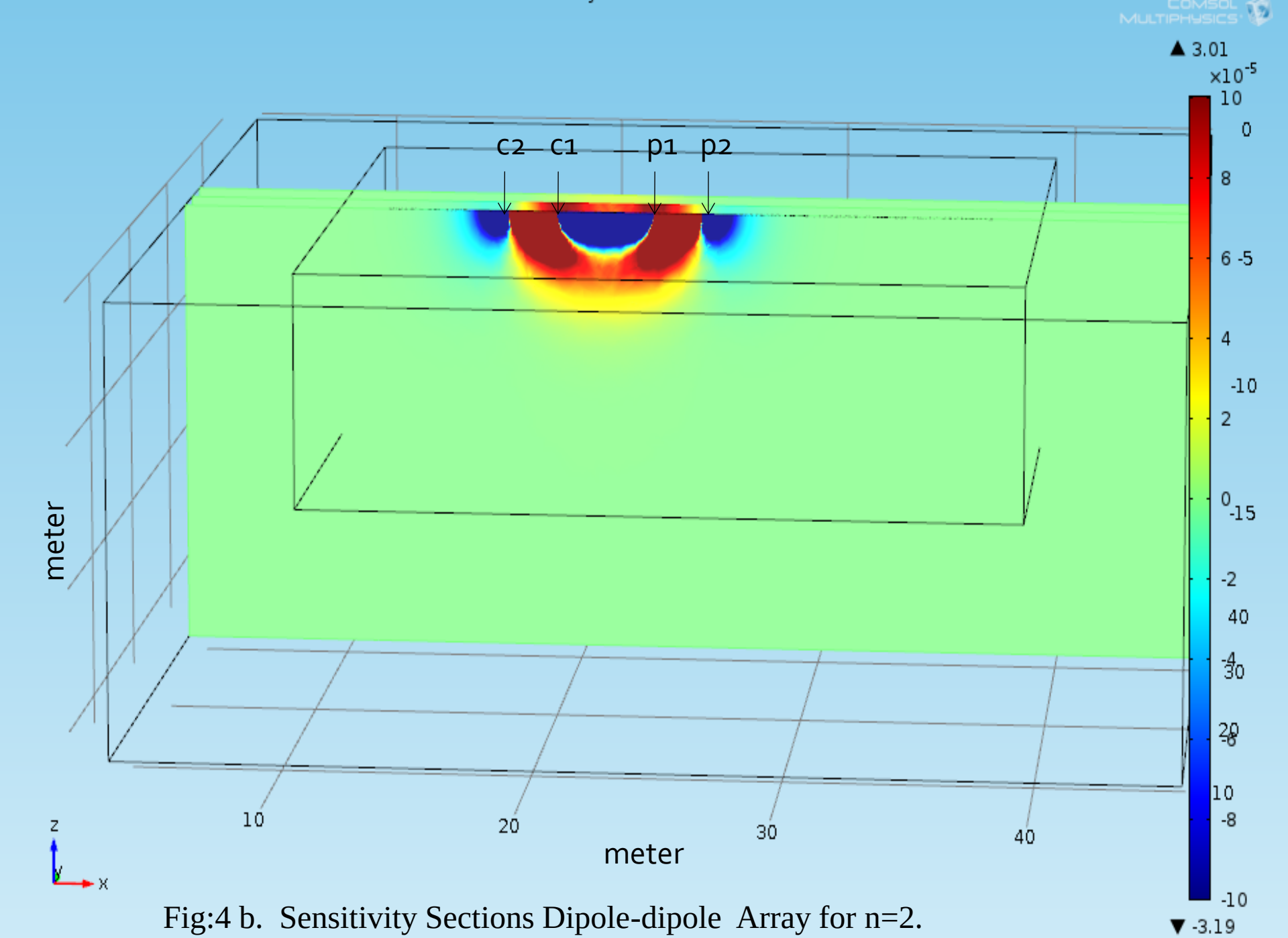


Fig:4 b. Sensitivity Sections Dipole-dipole Array for n=2.

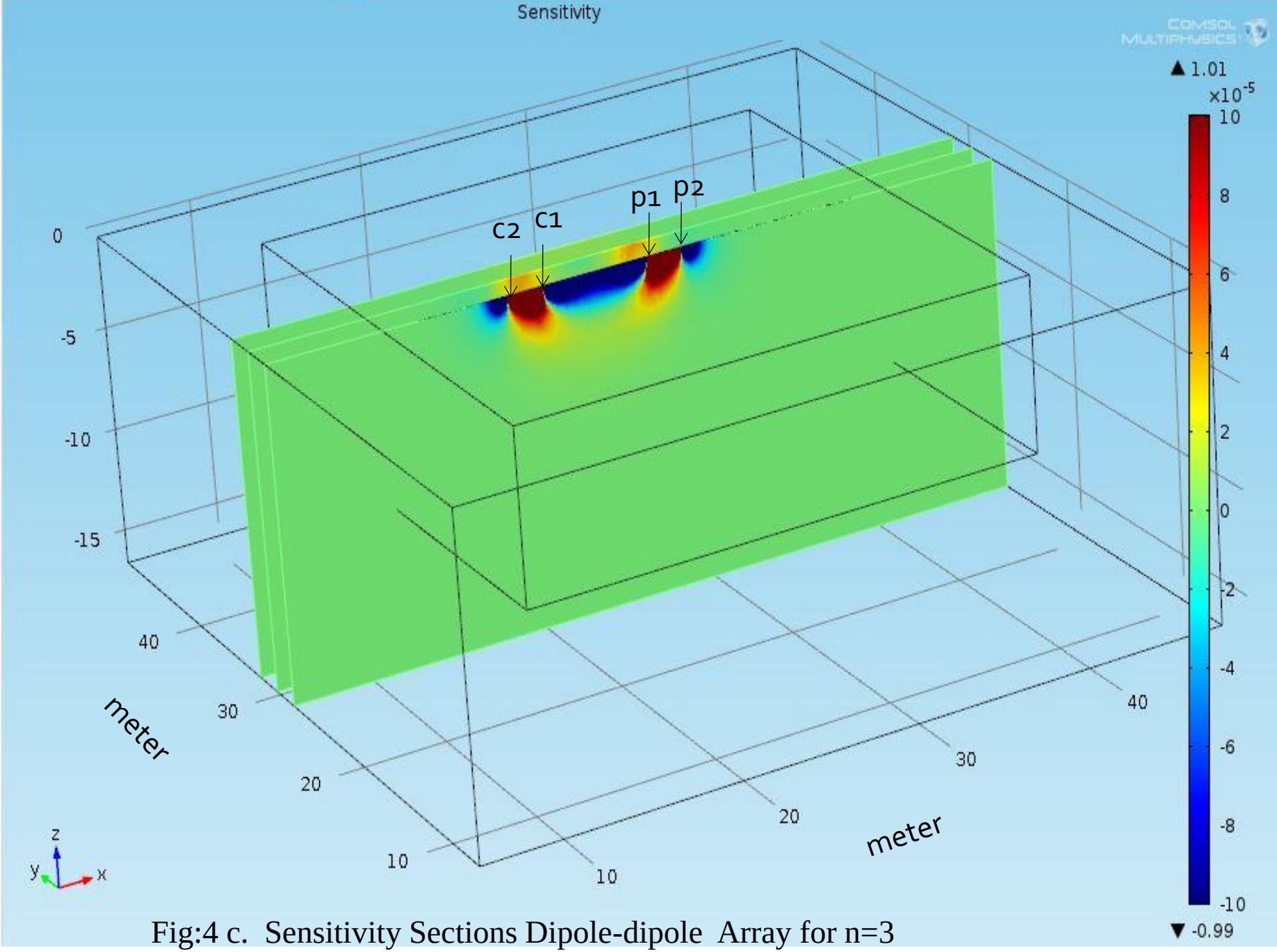


Fig:4 c. Sensitivity Sections Dipole-dipole Array for n=3

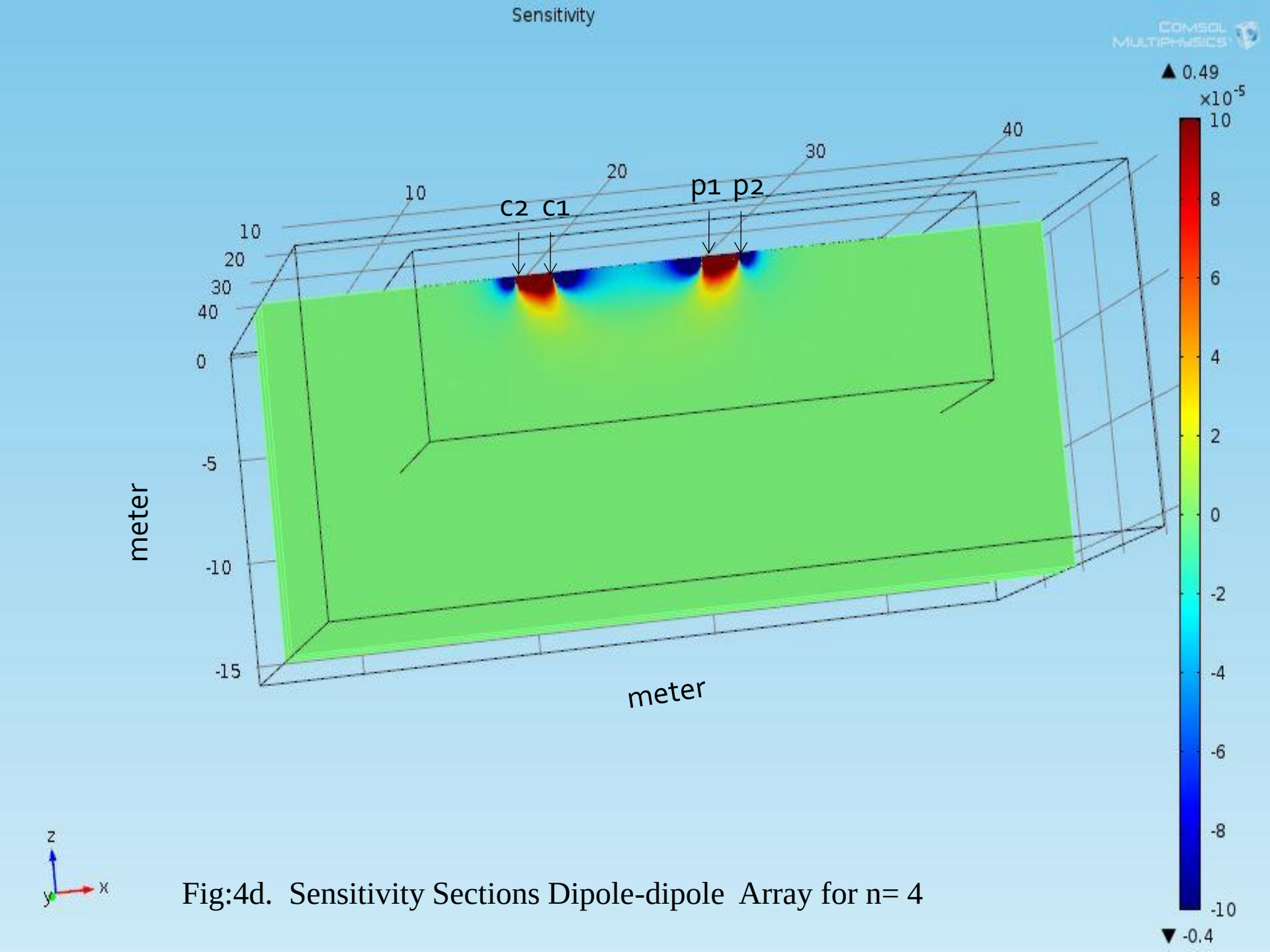


Fig:4d. Sensitivity Sections Dipole-dipole Array for n= 4

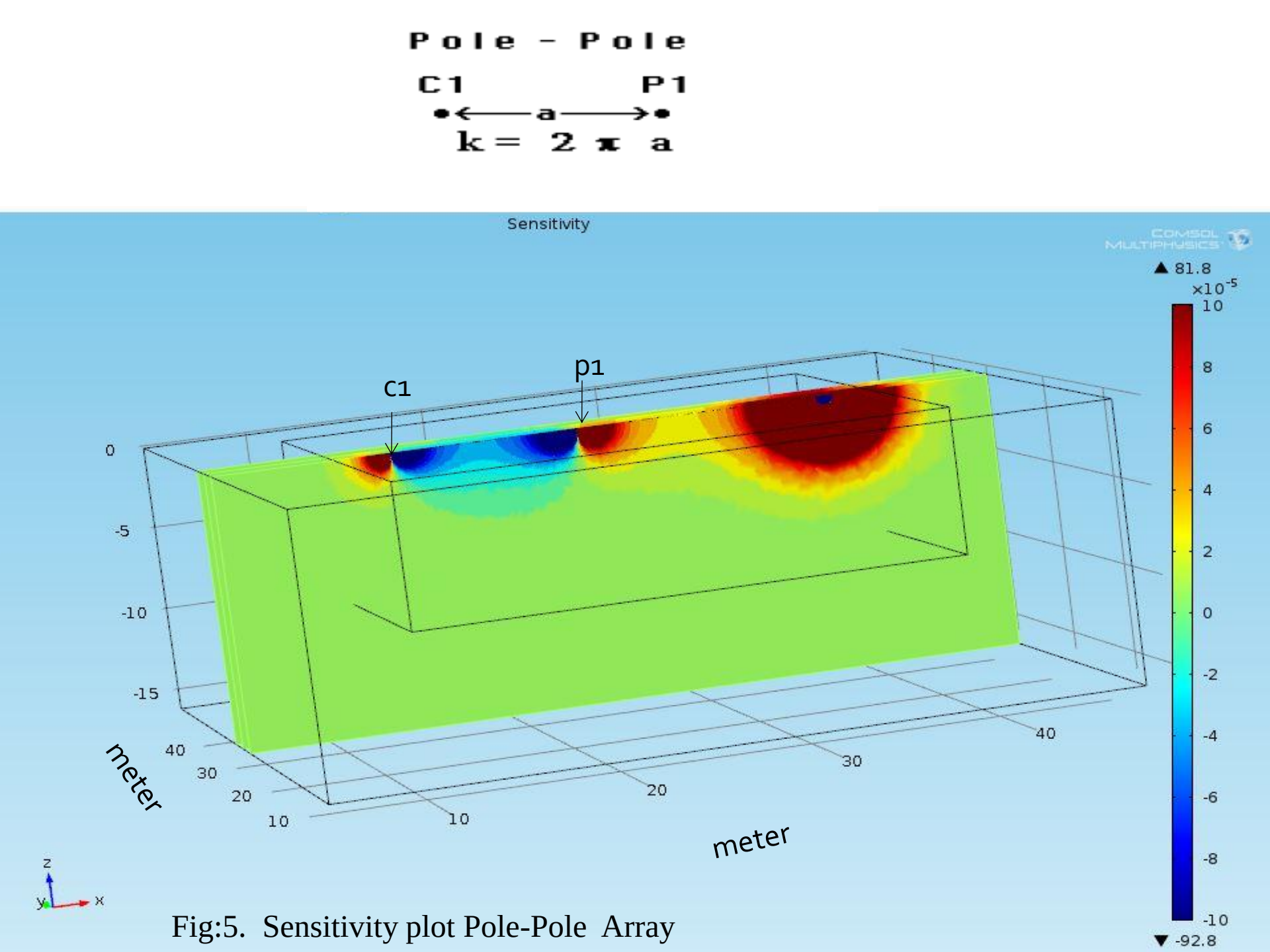


Fig:5. Sensitivity plot Pole-Pole Array

Pole - Dipole

C1 ●←——— na ———→ P1 ●←— a —→● P2

$$k = 2\pi n(n+1)a$$

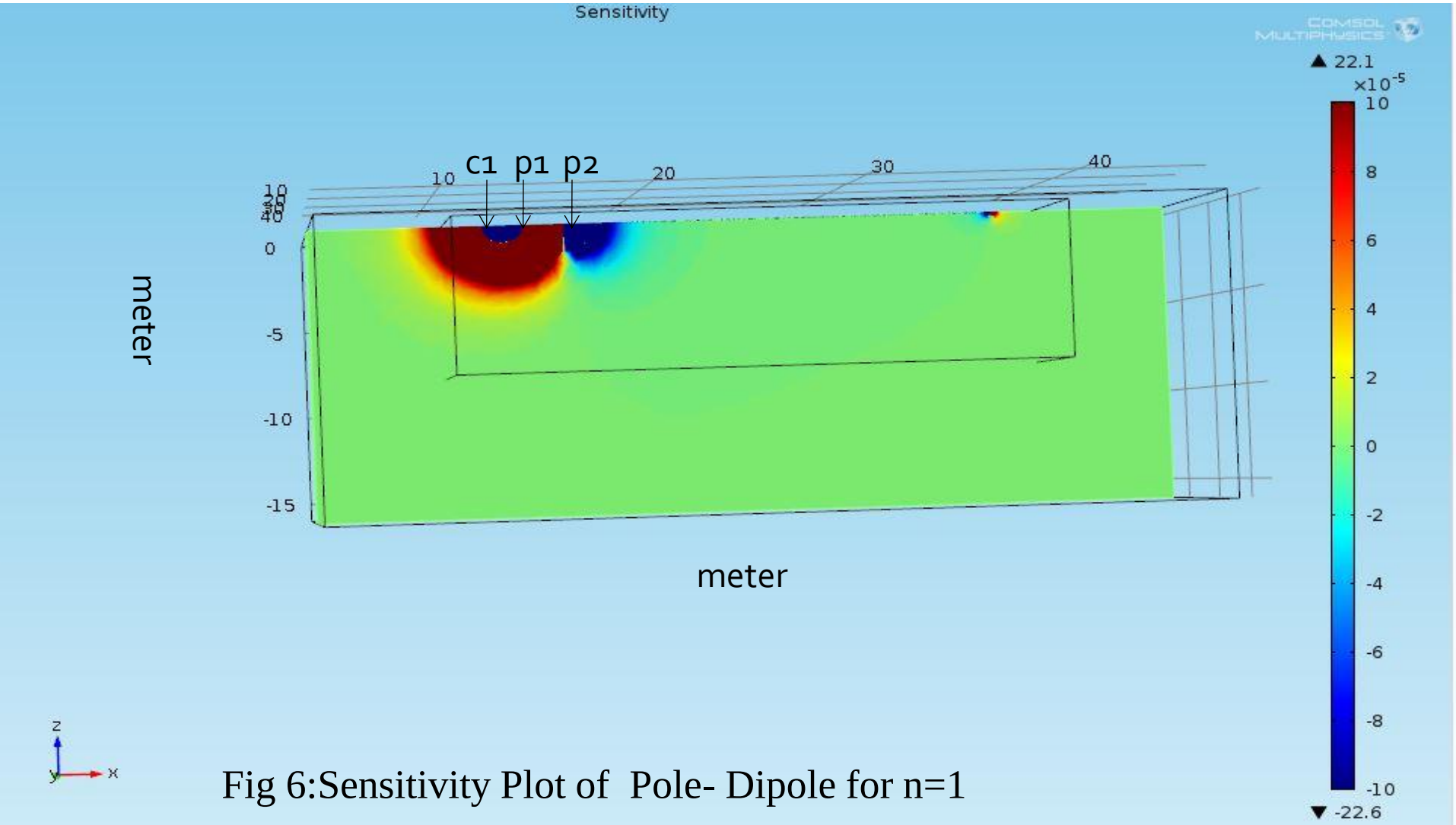


Fig 6:Sensitivity Plot of Pole- Dipole for n=1

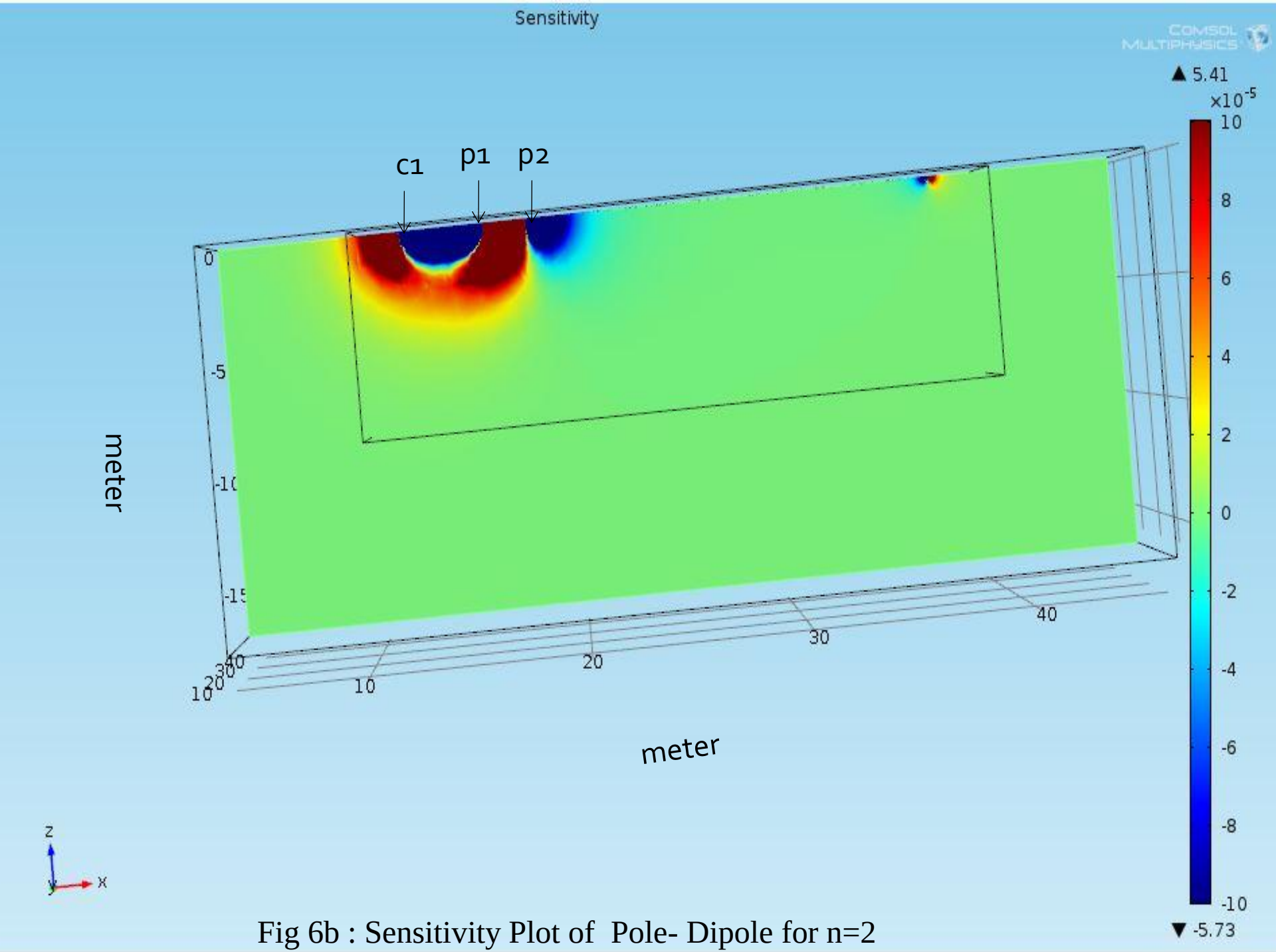


Fig 6b : Sensitivity Plot of Pole- Dipole for n=2

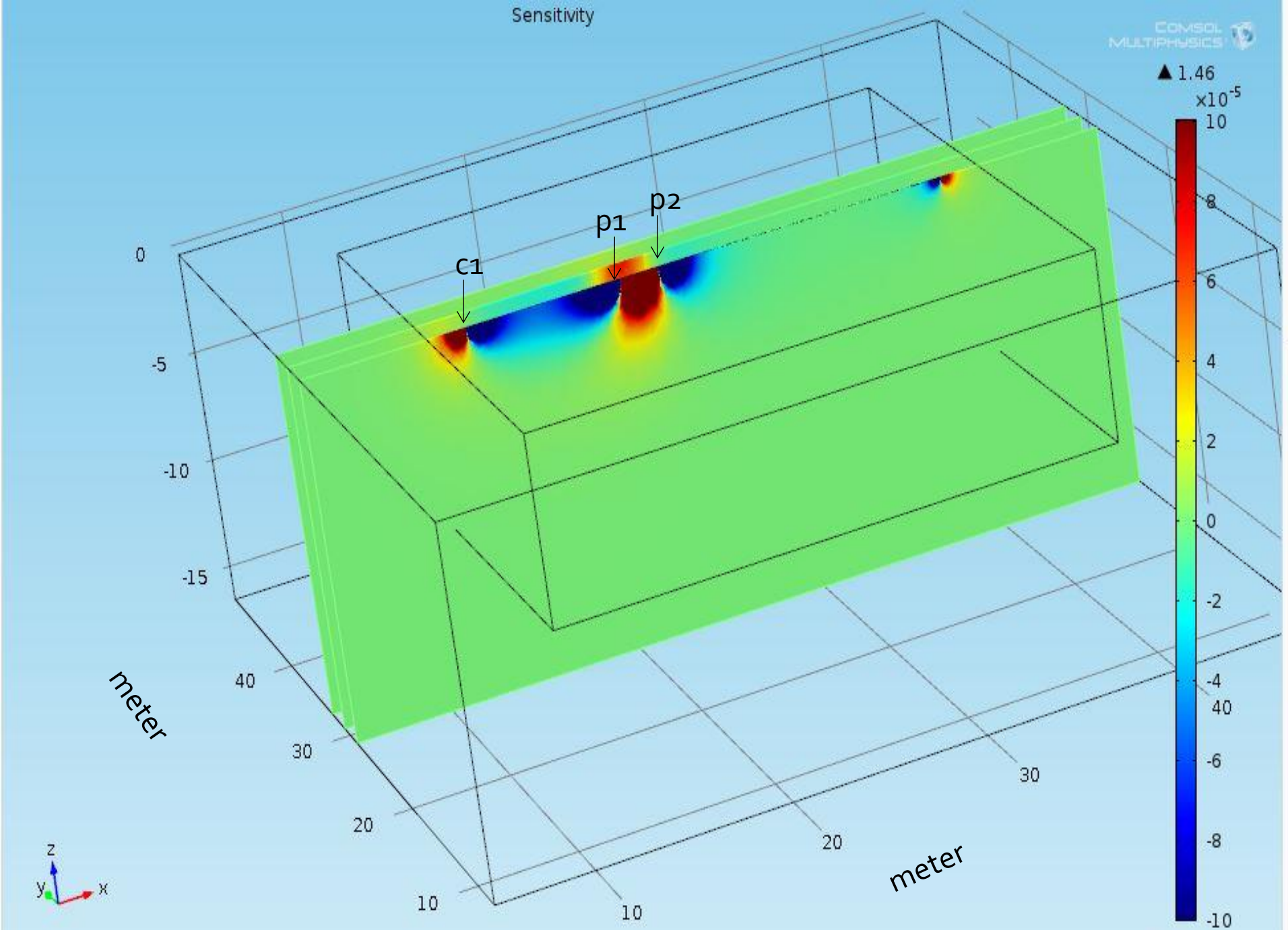


Fig 6c: Sensitivity Plot of Pole- Dipole for n=4

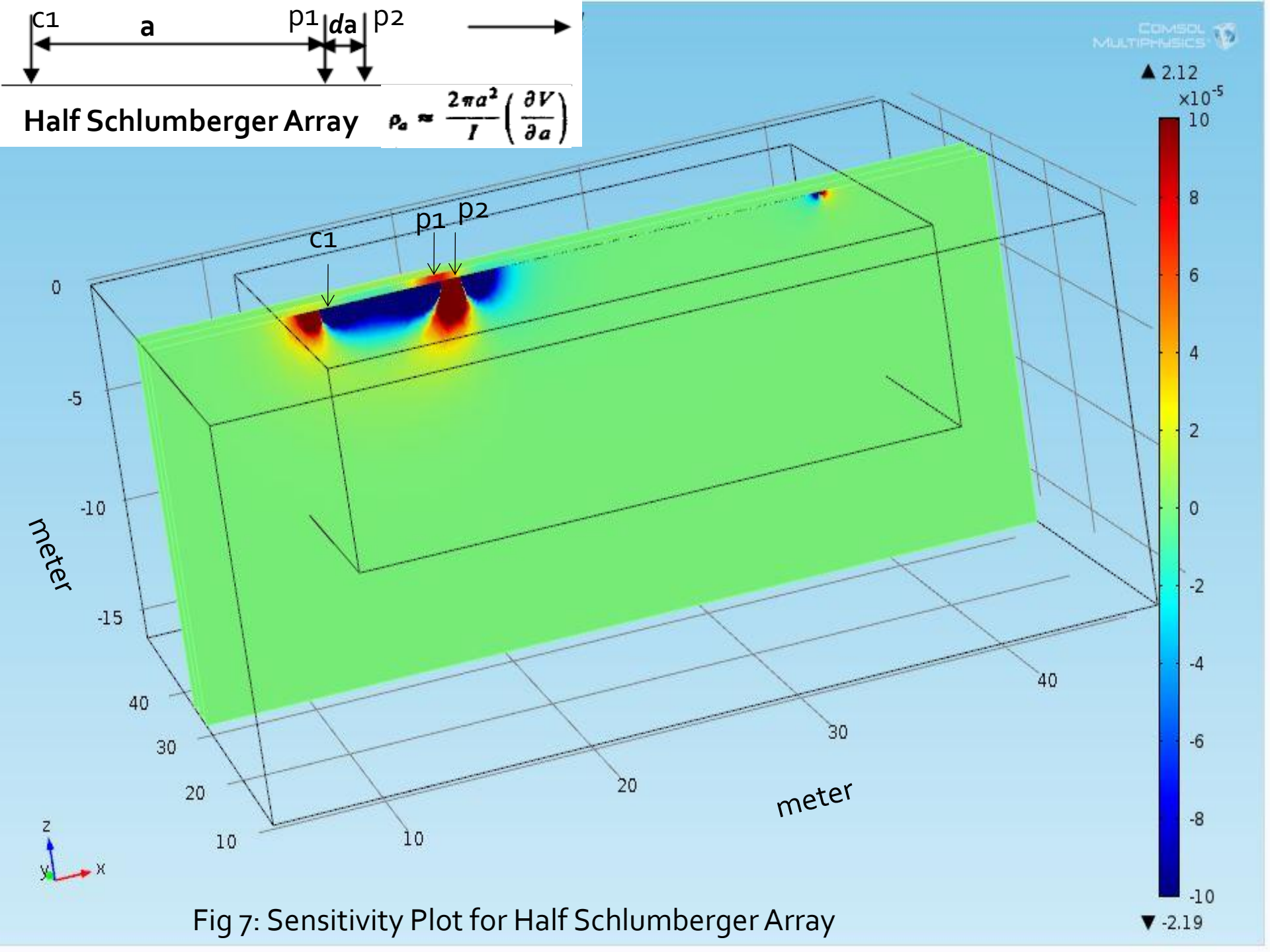


Fig 7: Sensitivity Plot for Half Schlumberger Array

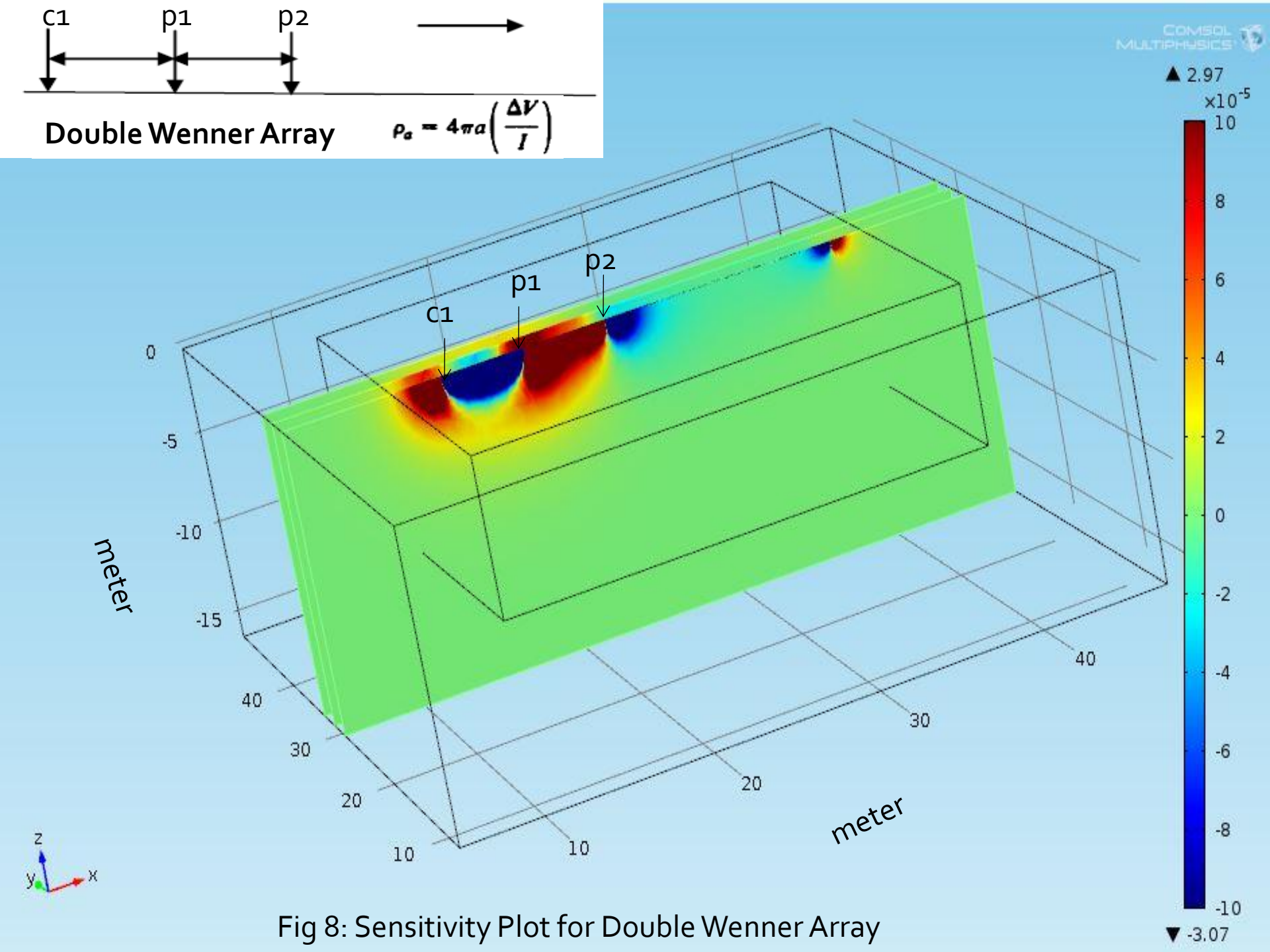
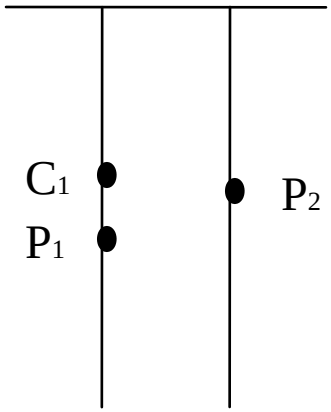
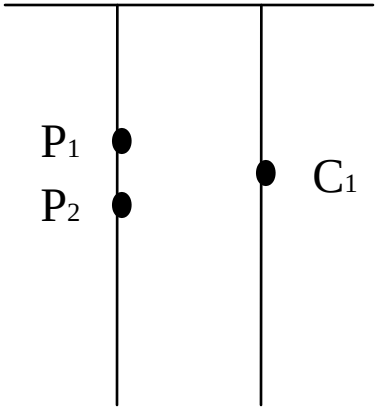


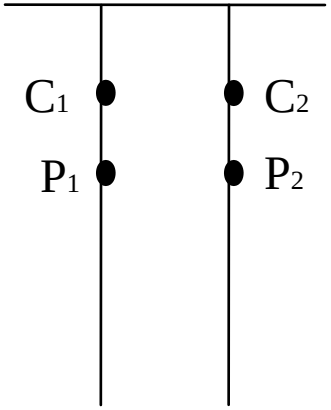
Fig 8: Sensitivity Plot for Double Wenner Array

Crosshole survey design

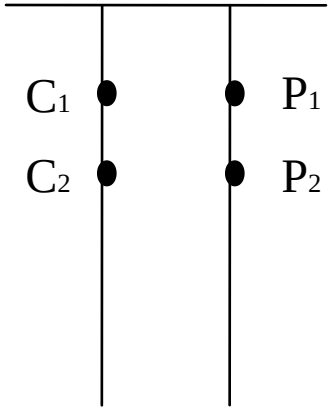


3 electrode arrangement





4 electrode arrangement



C_1 , C_2 current electrode P_1 , P_2 potential electrode

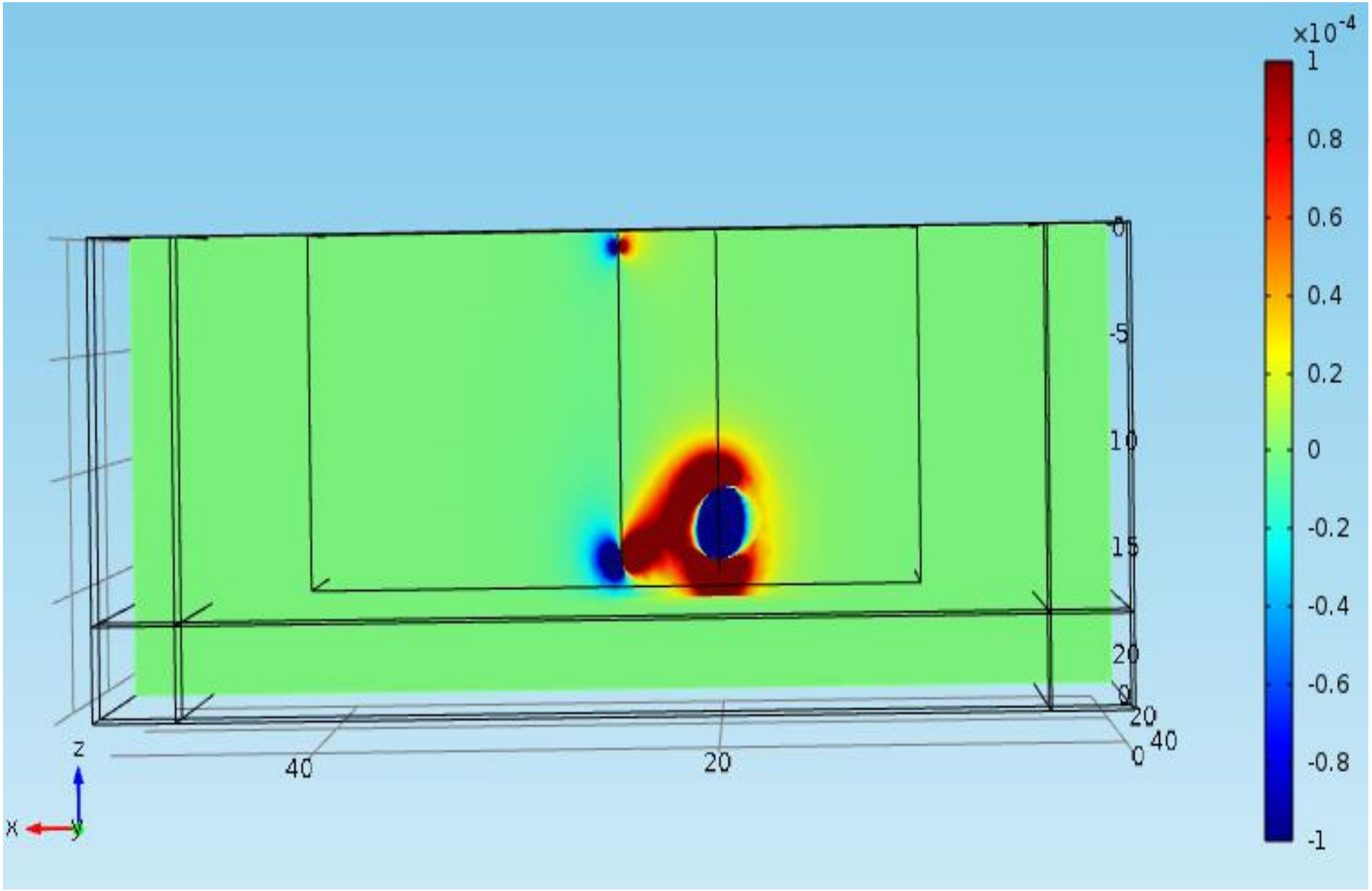


Fig: 9 Sensitivity plot for Pole-bipole for C1P1 in one borehole and P2 in another borehole

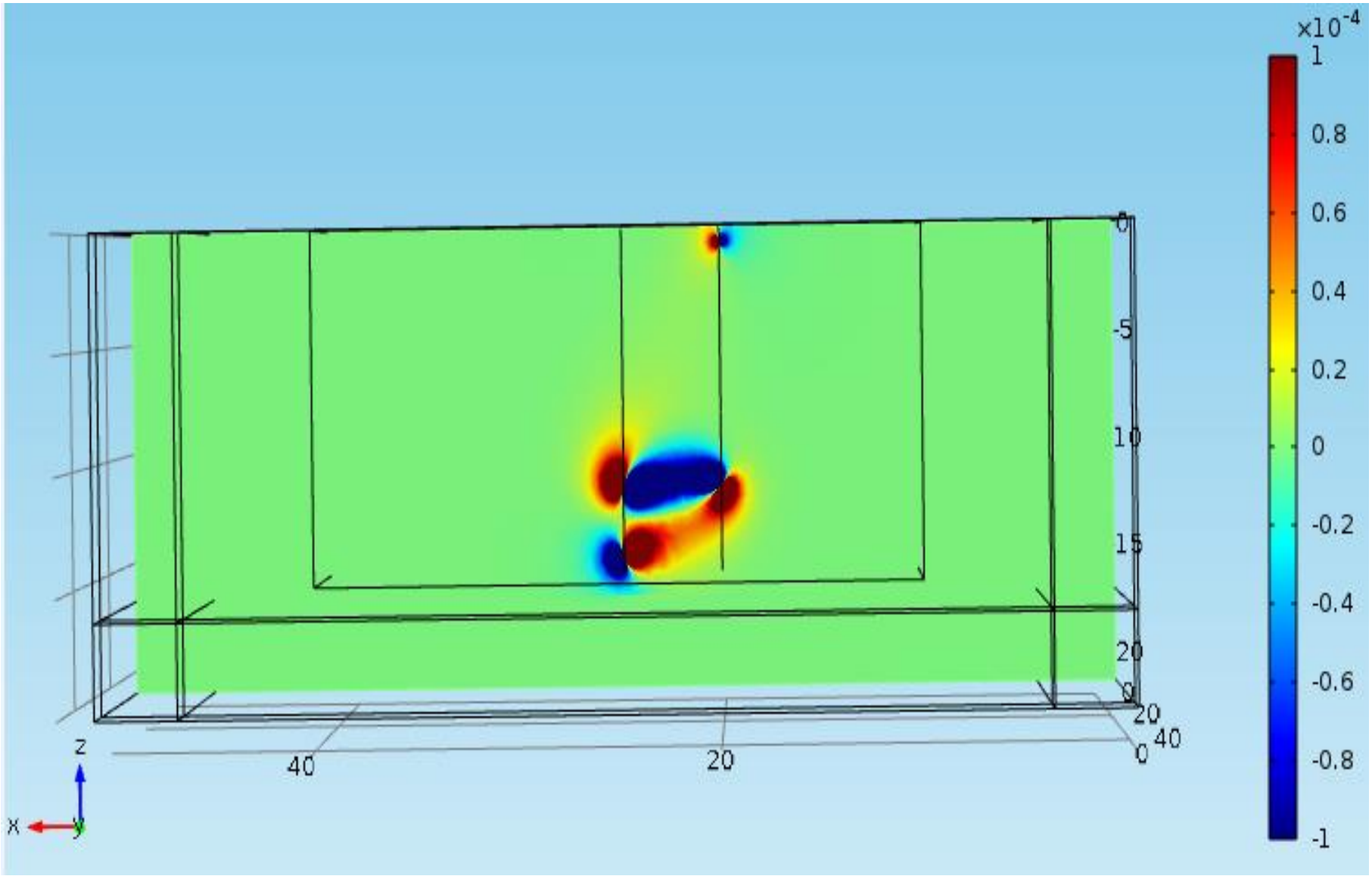


Fig: 10 Sensitivity plot for Pole- bipole array for C1 in one borehole and P1P2 in another

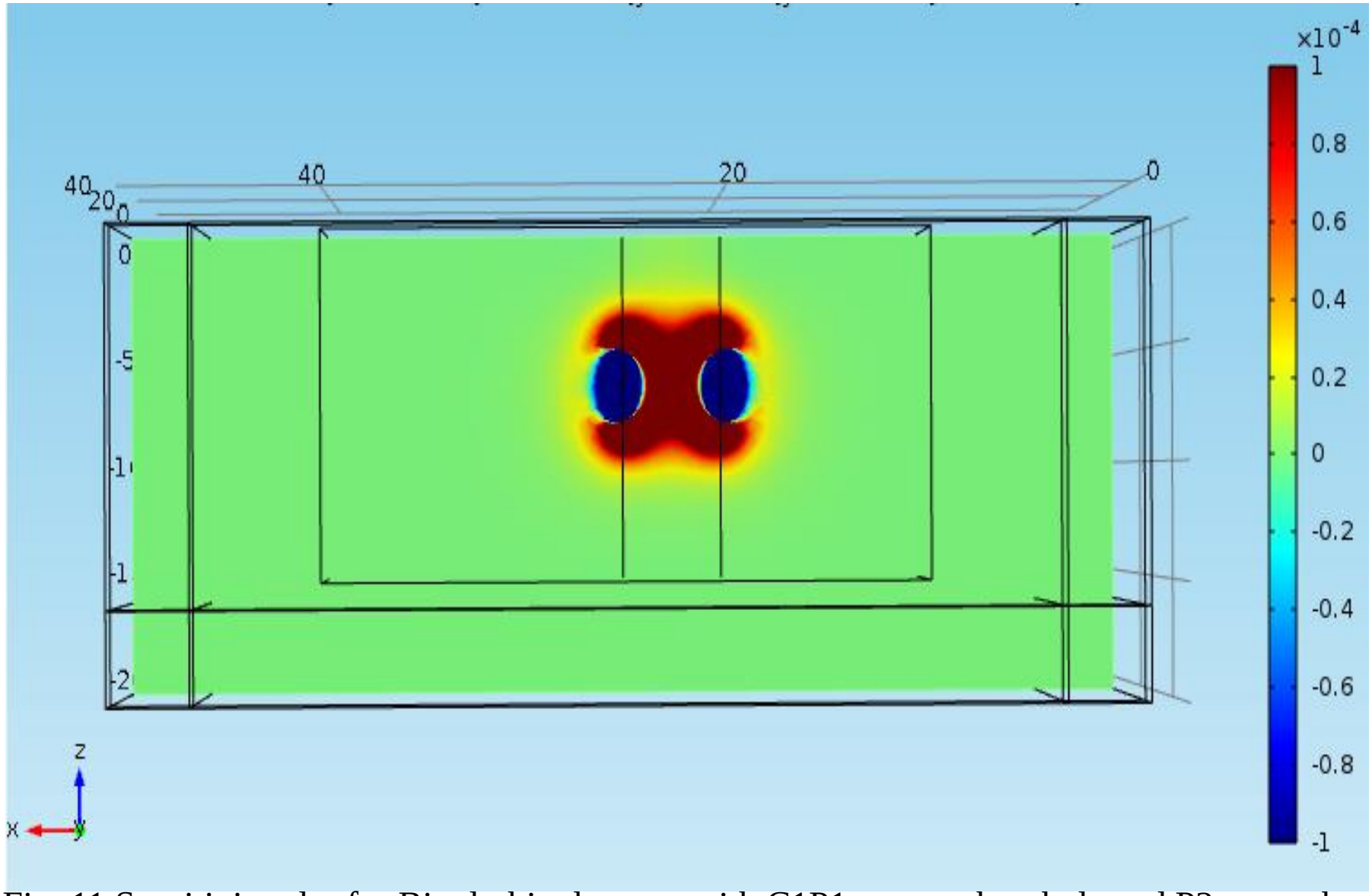


Fig: 11 Sensitivity plot for Bipole-bipole array with C1P1 at same borehole and P2 at another borehole

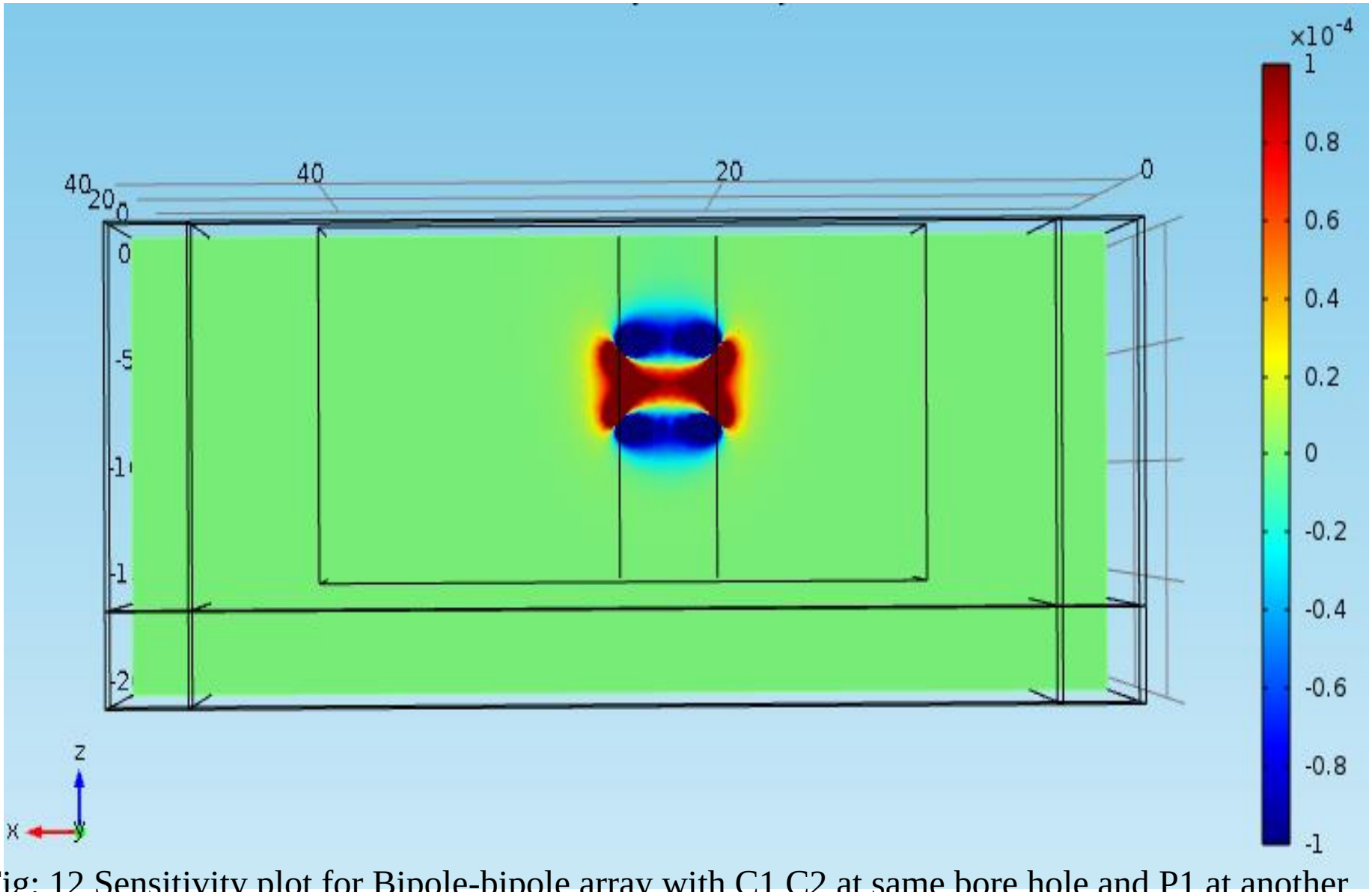


Fig: 12 Sensitivity plot for Bipole-bipole array with C1 C2 at same bore hole and P1 at another borehole

CONCLUSION:-

❖The highest sensitivity values are found near the electrodes for all the arrays. At larger distances from the electrodes, the contour patterns are different for the different arrays. The difference in the contour pattern of the sensitivity function plot helps to explain the response of the different arrays to different types of structures.

❖Pole-pole array gives the widest horizontal coverage, while the coverage obtained by the Wenner array decreases much more rapidly with increasing electrode spacing.

❖Wenner and Schlumberger array both resolves the vertical resistivity changes, but out of these two Wenner is more effective for resolving horizontal structures.

❖The Dipole-Dipole array is very sensitive to horizontal changes in resistivity, but relatively insensitive to vertical changes in the resistivity.

❖Similar to the dipole-dipole array, Pole Dipole array is probably more sensitive to vertical structures.

❖The Wenner array is an attractive choice for a survey carried out in a noisy area (due to its high signal strength) and also if good vertical resolution is required. The dipole-dipole array might be a more suitable choice if good horizontal resolution and data coverage is important (assuming your resistivity meter is sufficiently sensitive and there is good ground contact).

❖The Schlumberger array (with overlapping data levels) is an acceptable if both good and vertical resolutions are needed, particularly if good signal strength is also required. If there were a limited number of electrodes, the pole-dipole array with measurements in both the forward and reverse directions might be a viable choice.

❖For surveys with small electrode spacing and require a good horizontal coverage, the pole-pole array might be a suitable choice.

❖In case of crosshole survey the bipole-bipole array can give high resolution image in the vicinity of the two boreholes than pole-bipole. So, bipole-bipole configuration is more desirable for mapping region between two boreholes.

❖ Thus, the sensitivity plots are very useful in planning in field survey.

References

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