

# **Modelagem gravimétrica em coordenadas esféricas**

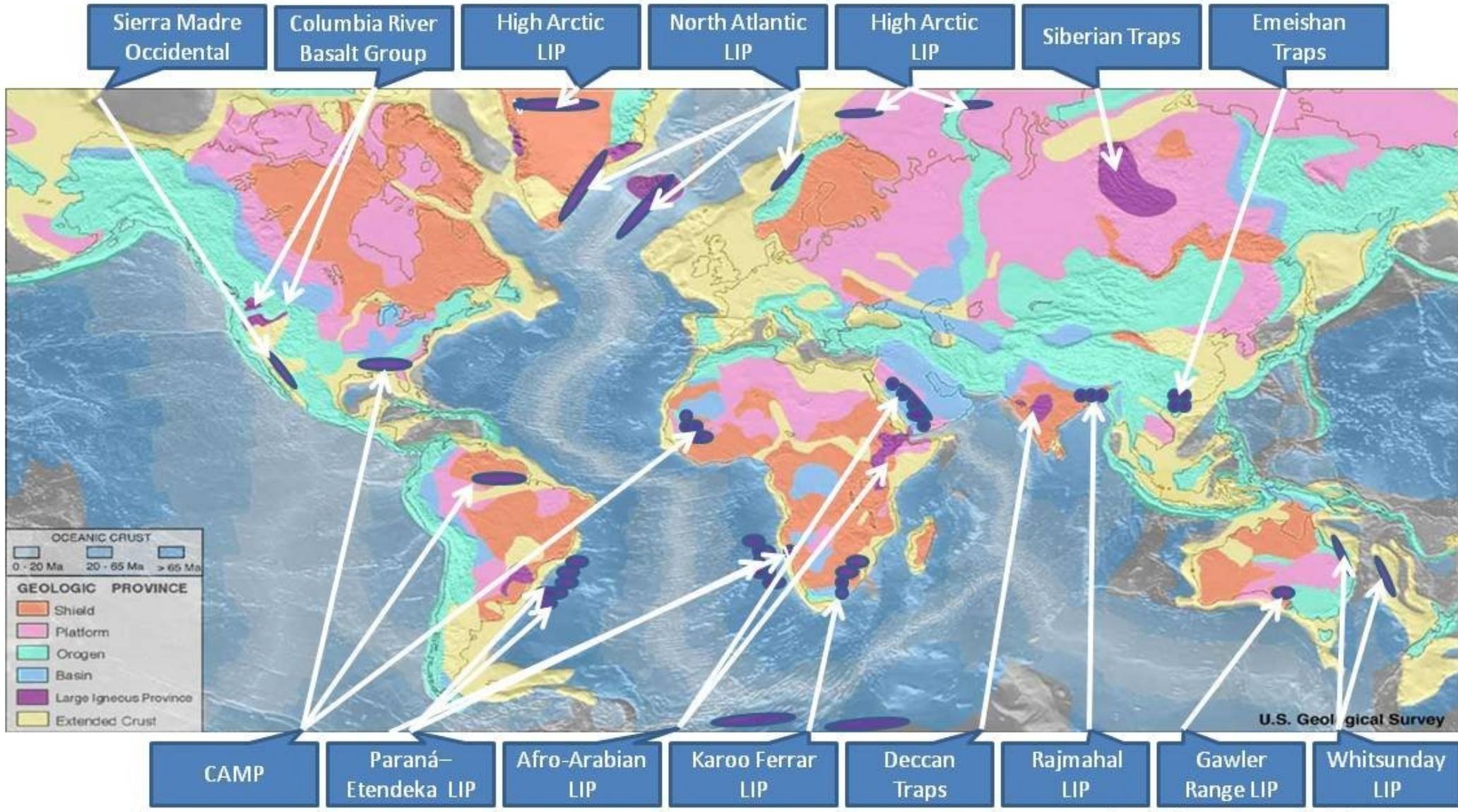
Leonardo Uieda

Valéria C. F. Barbosa  
(orientadora)

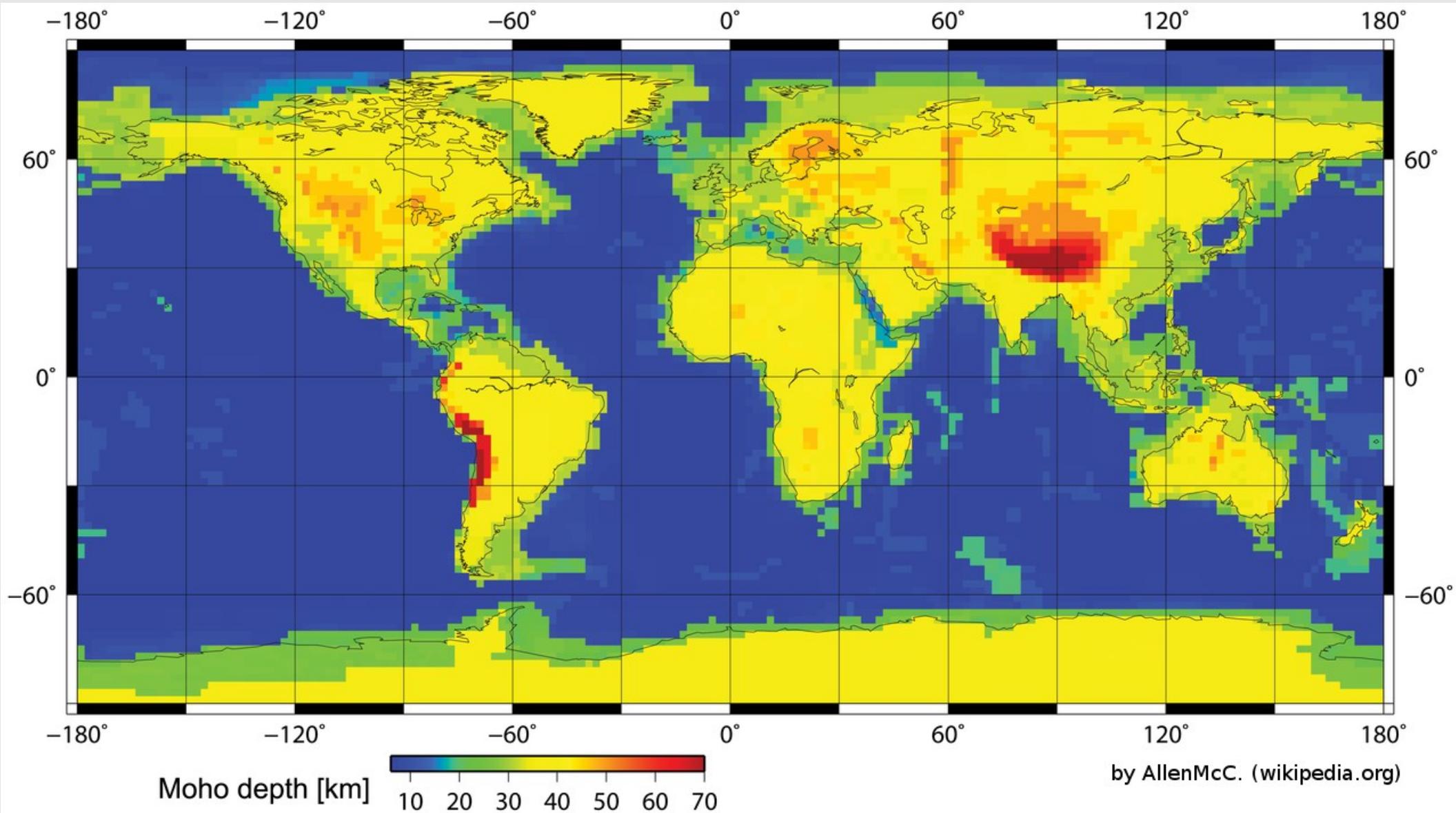
*Exame de qualificação*

# Motivação

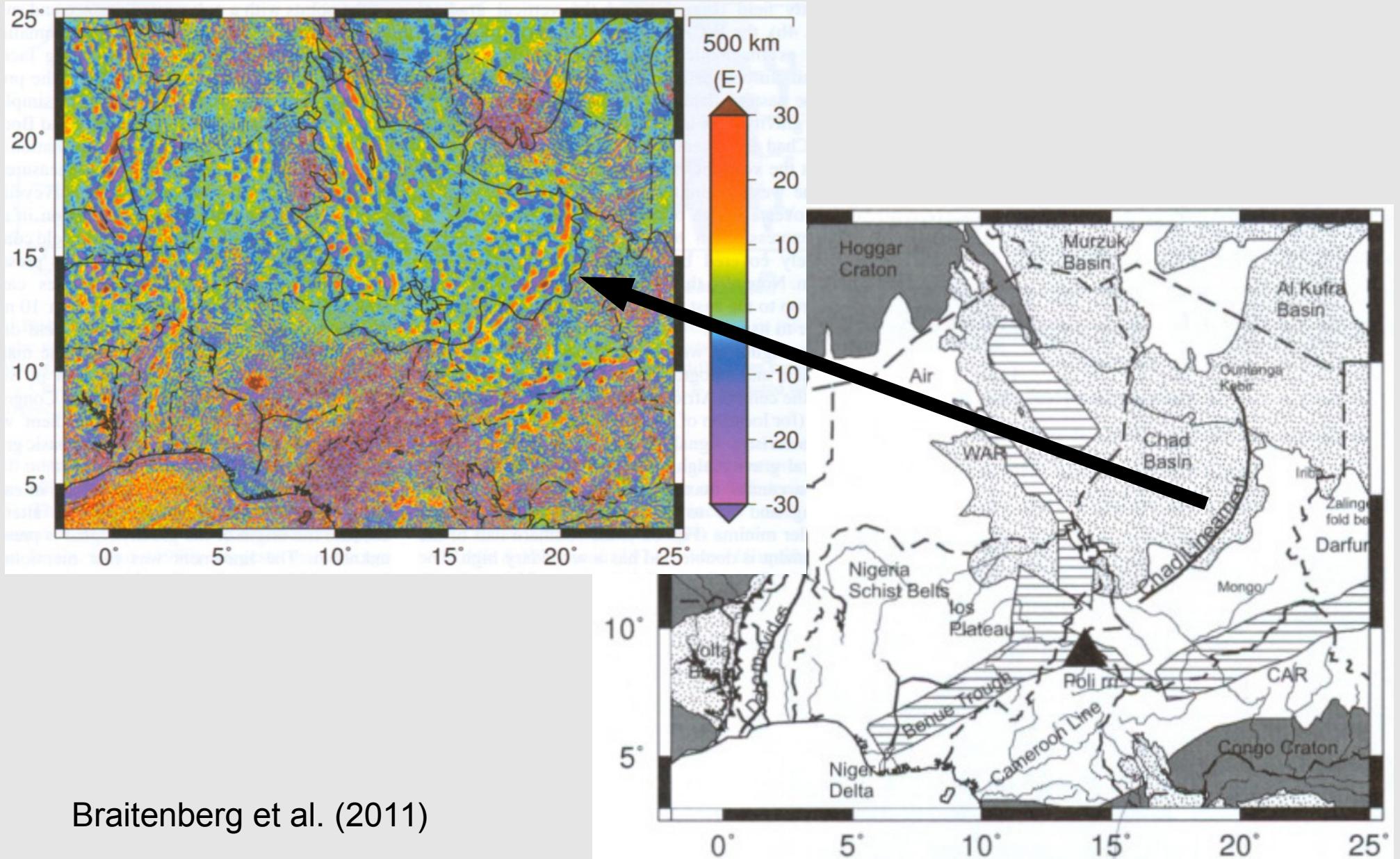
# Grandes estruturas ( $10^3$ km)



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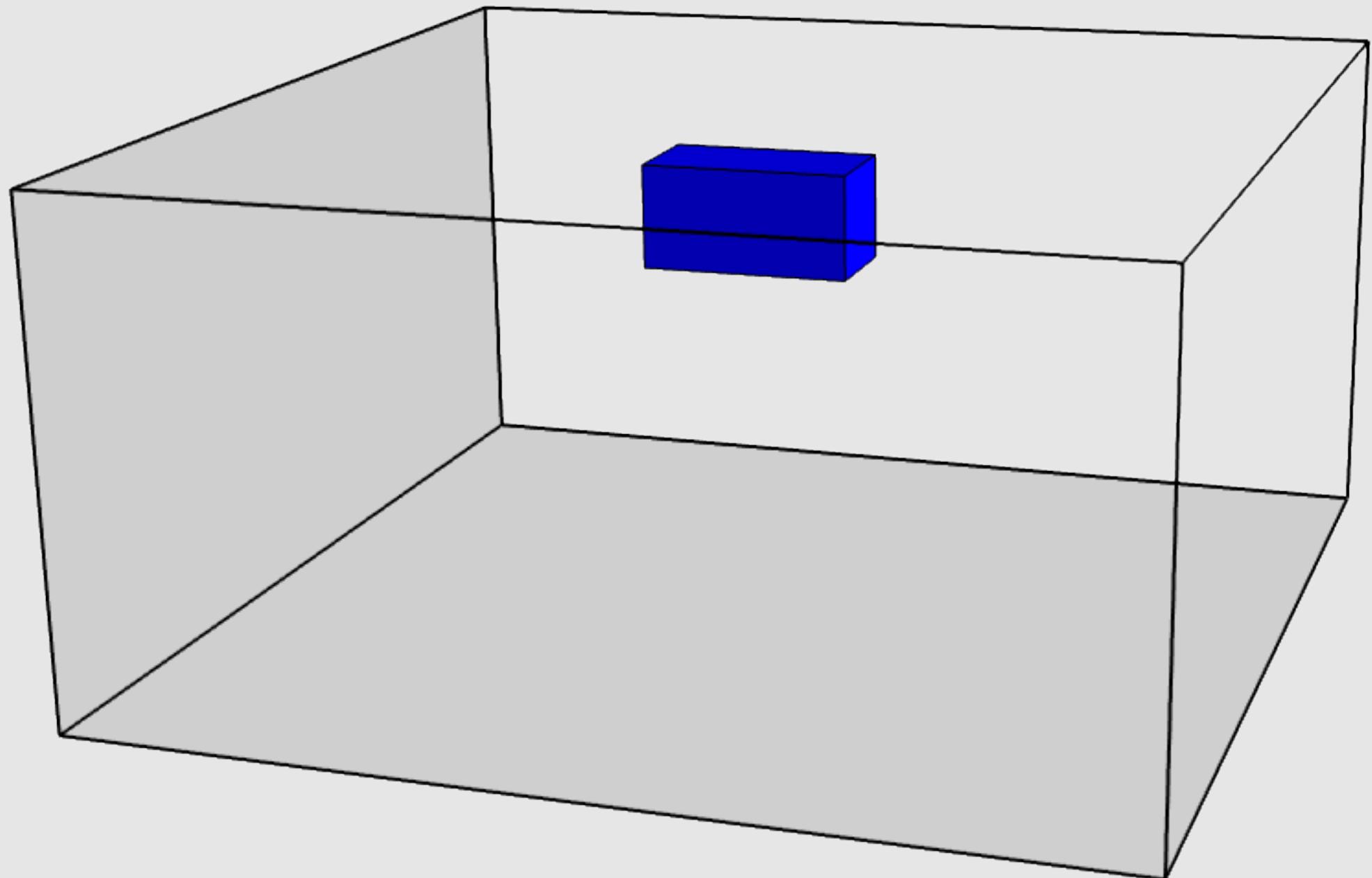


# Grandes estruturas ( $10^3$ km)

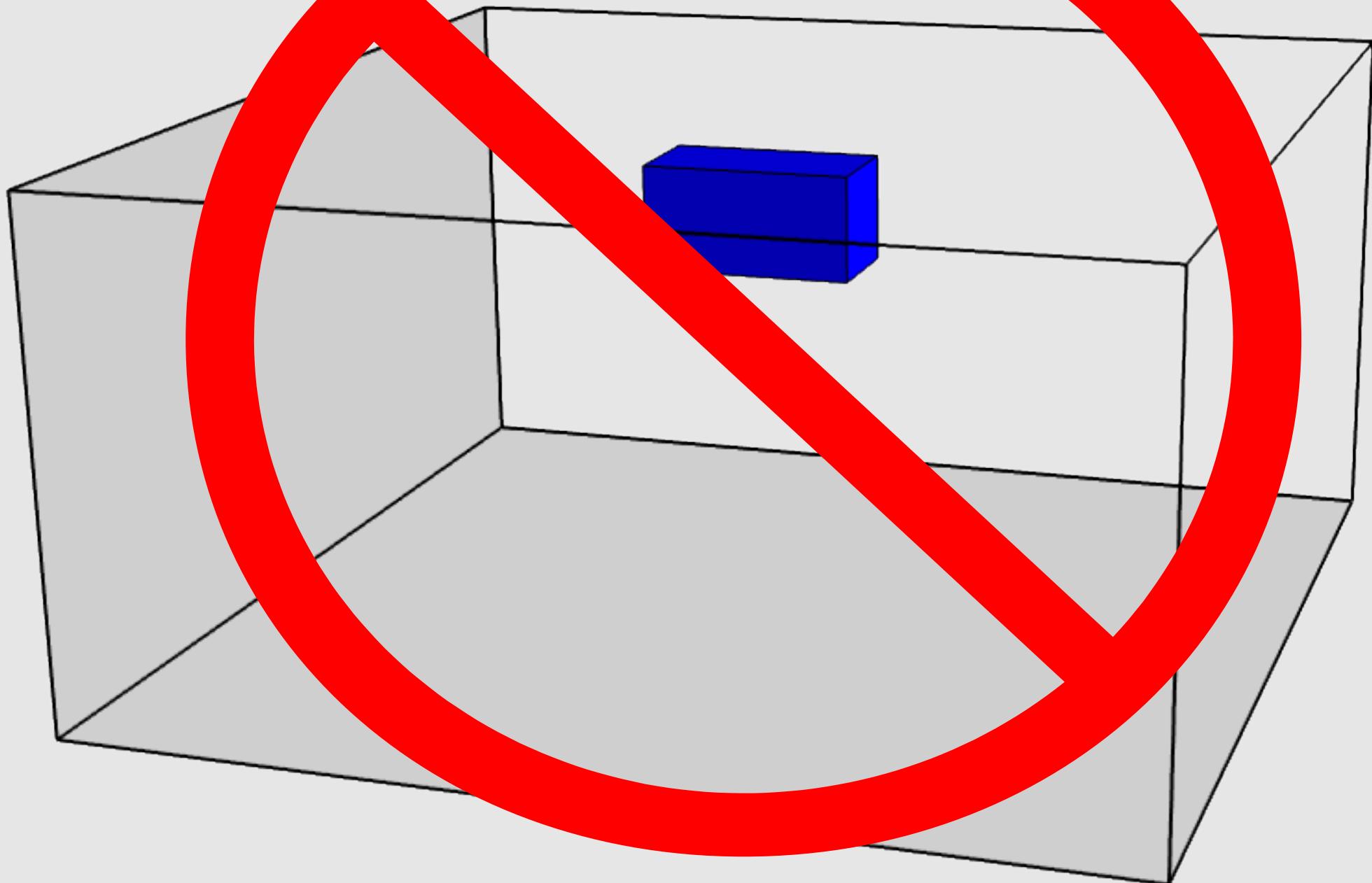


Braitenberg et al. (2011)

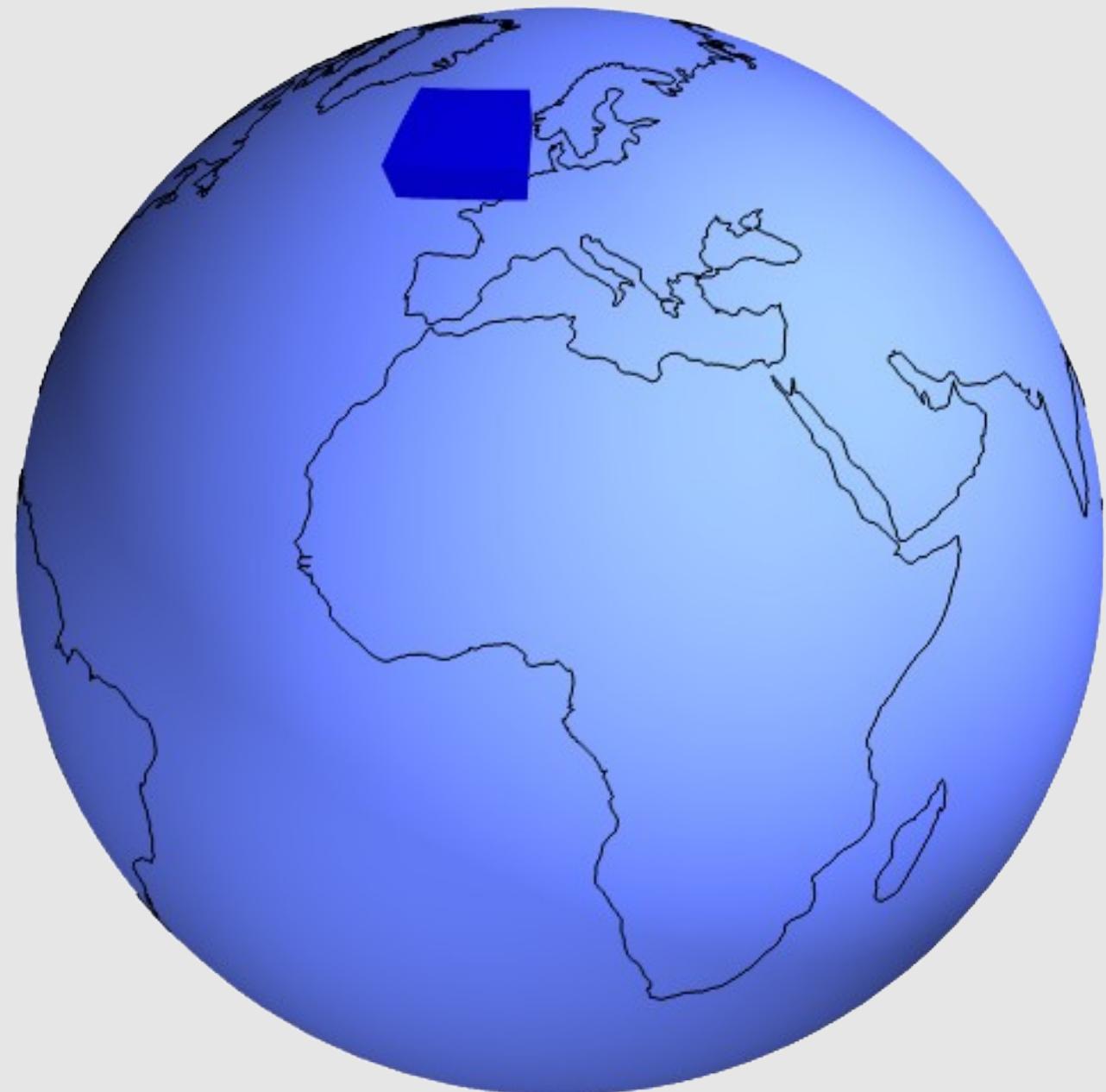
# Terra plana + prismas



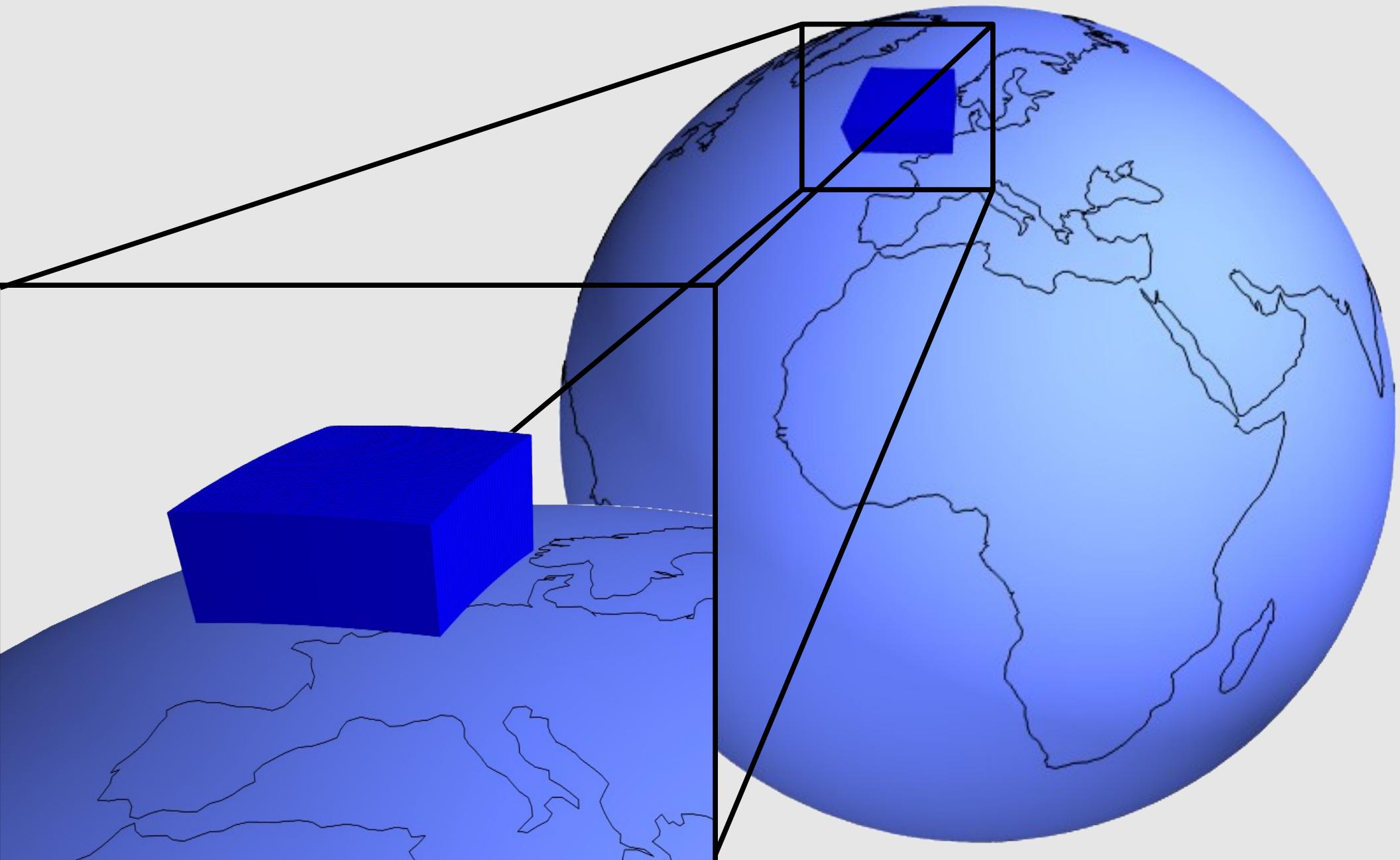
Terra + Diversas



# Terra esférica + tesseroides



# Terra esférica + tesseroides



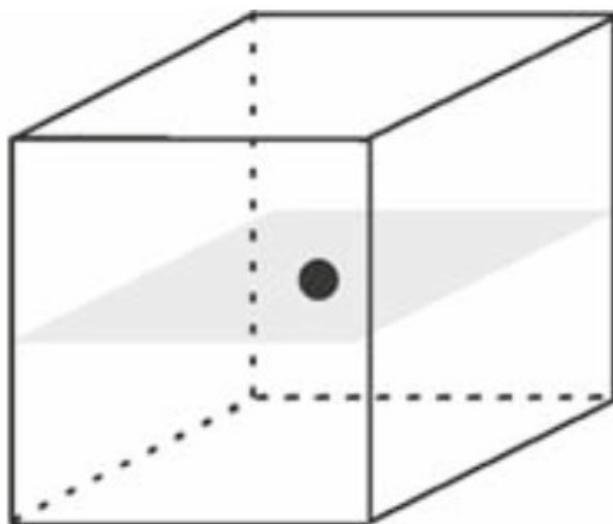
# Projeto

- Métodos de inversão 3D
- Escala regional/global
  - Coordenadas esféricas
- 2 componentes
  - Modelagem direta (tesseroides)
  - Inversão (plantação/sementes)

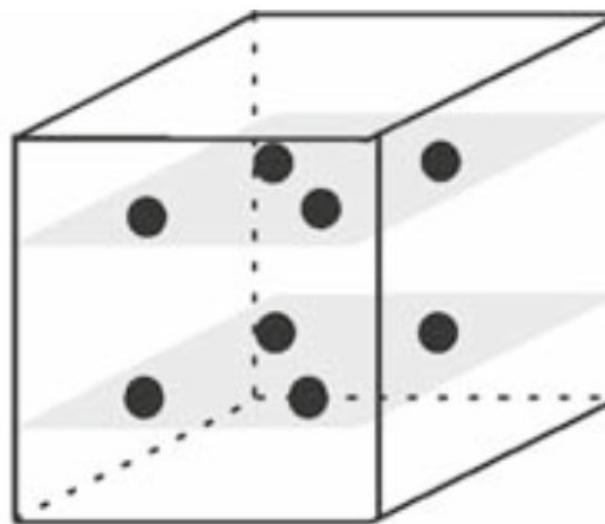
# **Modelagem direta**

# Integração numérica

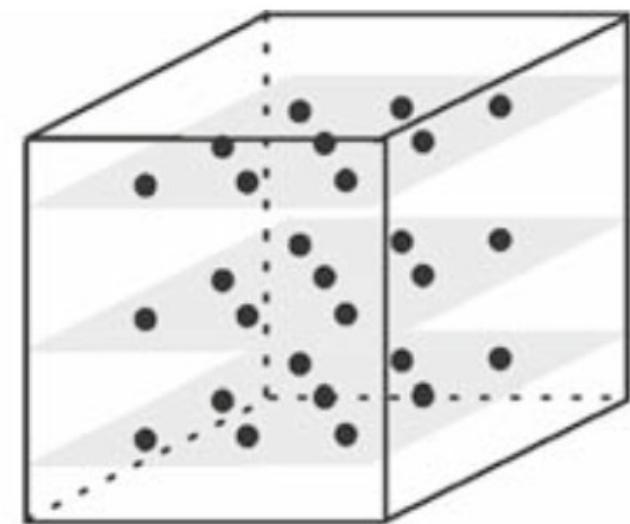
- Quadratura Gauss-Legendre (QGL)



$$n = m = p = 0$$



$$n = m = p = 1$$



$$n = m = p = 2$$

Wild-Pfeiffer (2008)

# Integração numérica

- Acurácia: Ku (1977)

Like other numerical methods, in our method there is always a trade-off between the accuracy and the speed of computing. In using the equivalent-point method, one can use a minimum number of point sources by keeping the spacing between the points less than their distances to the point of observation. In applying the cubic spline in interpolation, the scheme for dividing a body given in this paper is for illustration purposes

# Integração numérica

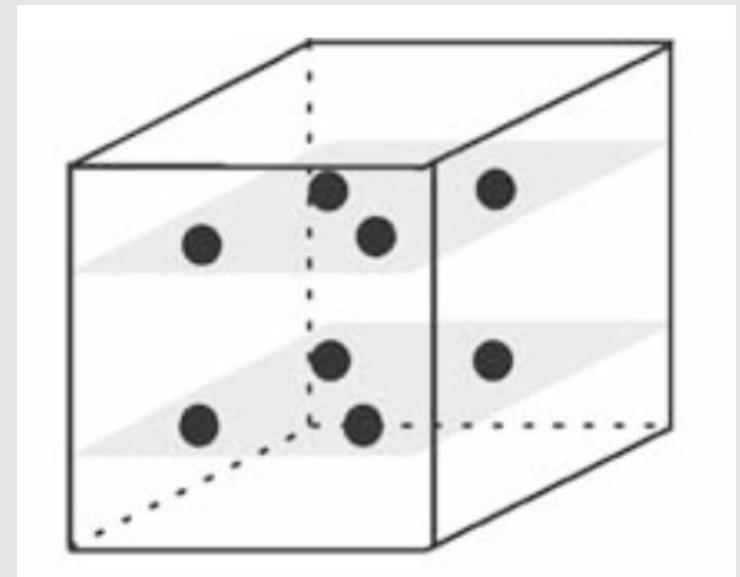
- Acurácia: Ku (1977)

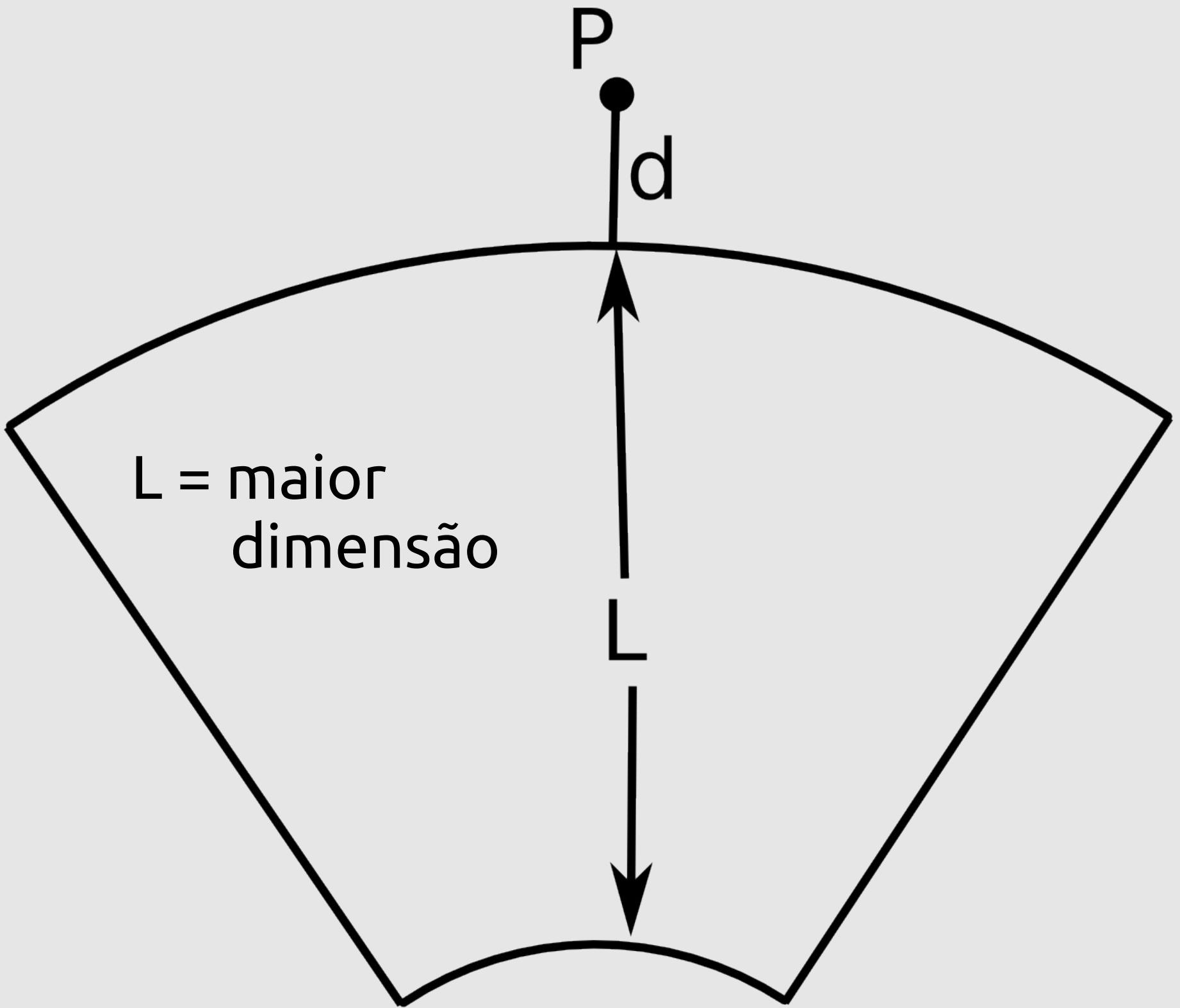
Like other numerical methods, in our method there is always a trade off between the accuracy and the speed of computing. In using the equivalent-point method, one can use a minimum number of point sources by keeping the spacing between the points less than their distances to the point. Applying the cubic spline in interpolation, the scheme for dividing a body given in this paper is for illustration purposes

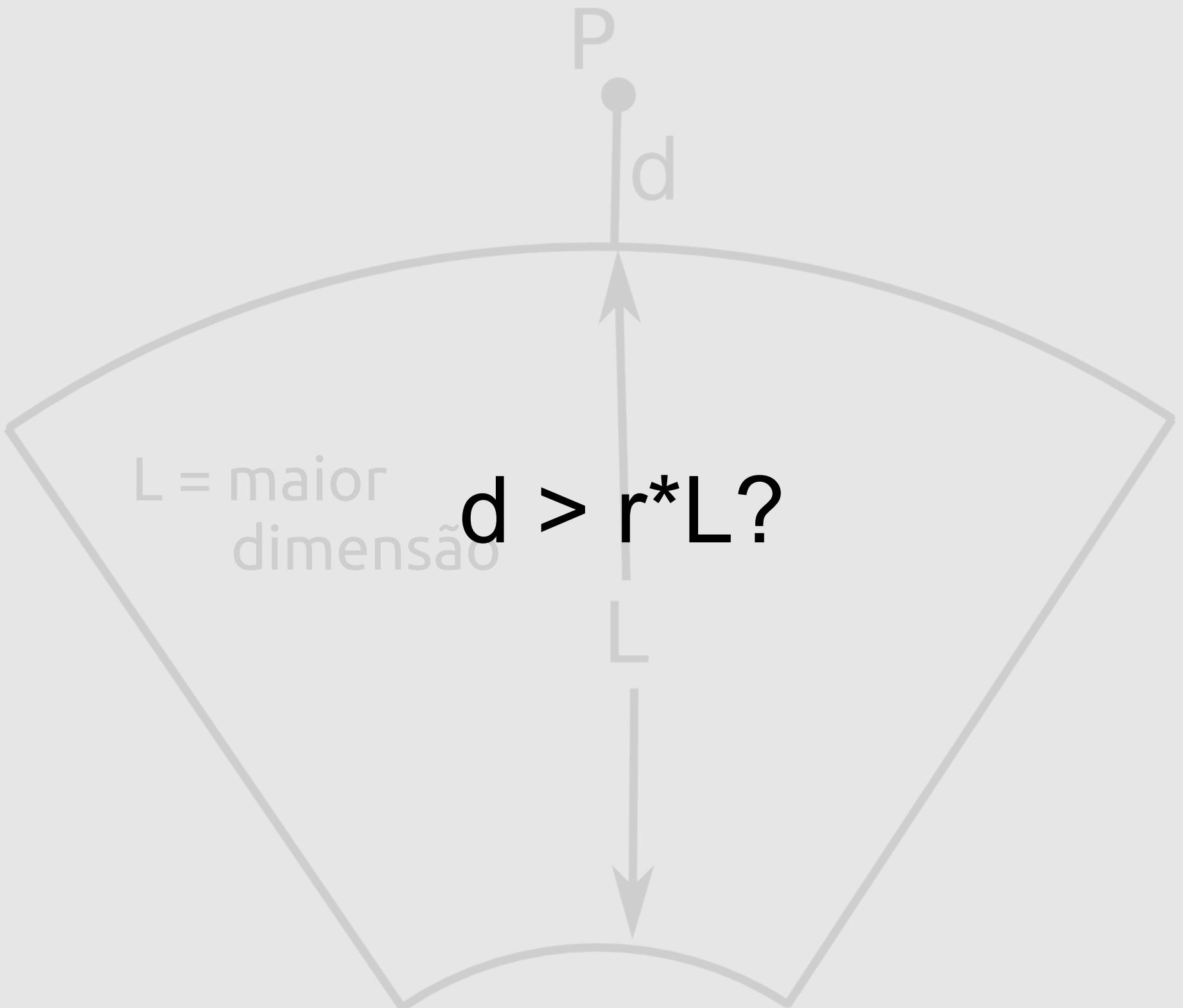
- Resultados para:
  - Prismas
  - $g_z$
- Erro cometido?
- Válido para gradientes?

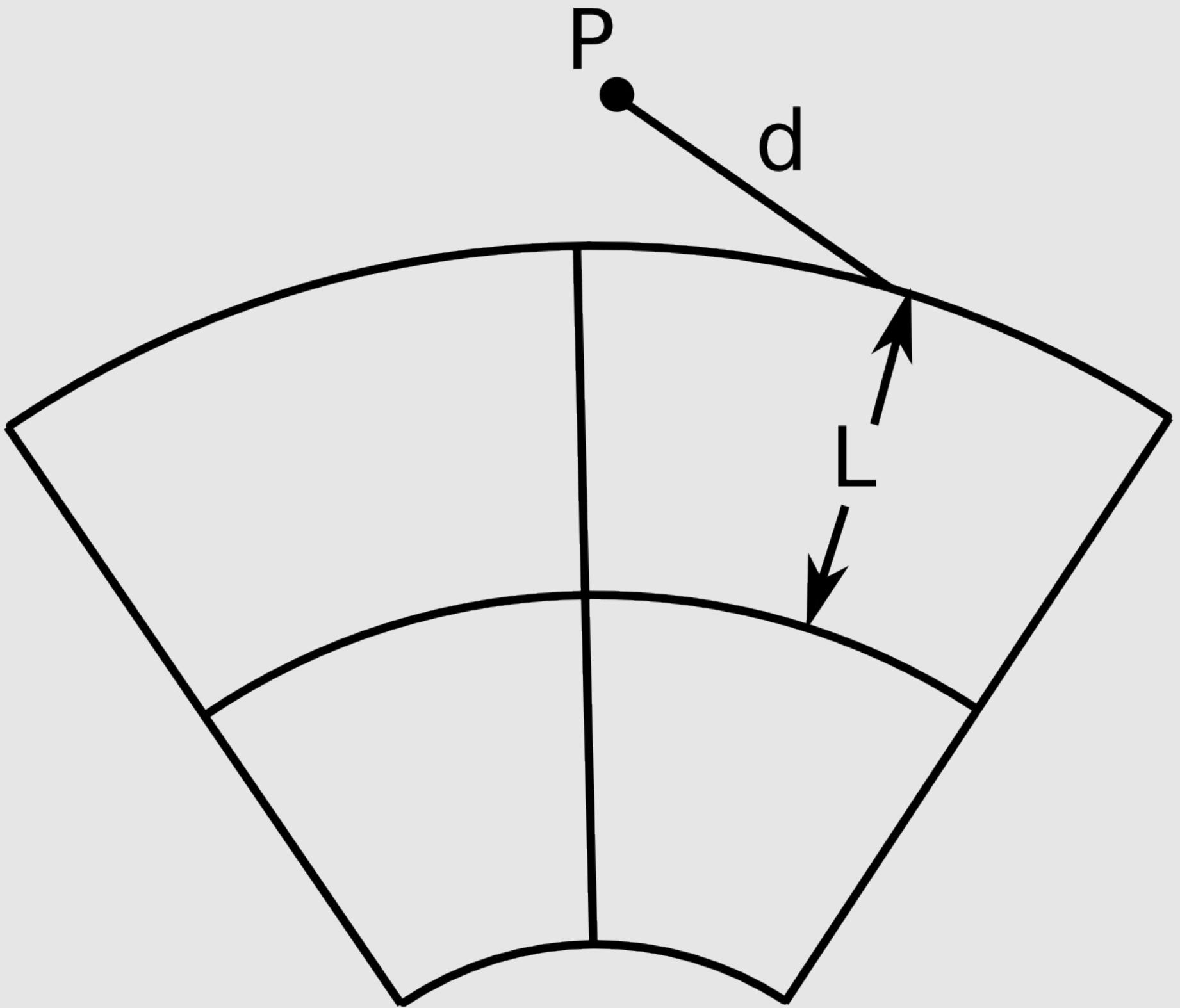
# Automatizar

- Baseado em Li et al. (2011)
- Fixar pontos da quadradatura = 2
- Distância entre pontos ~ maior dimensão
- Regra de Ku (1977)  
 $d > L$







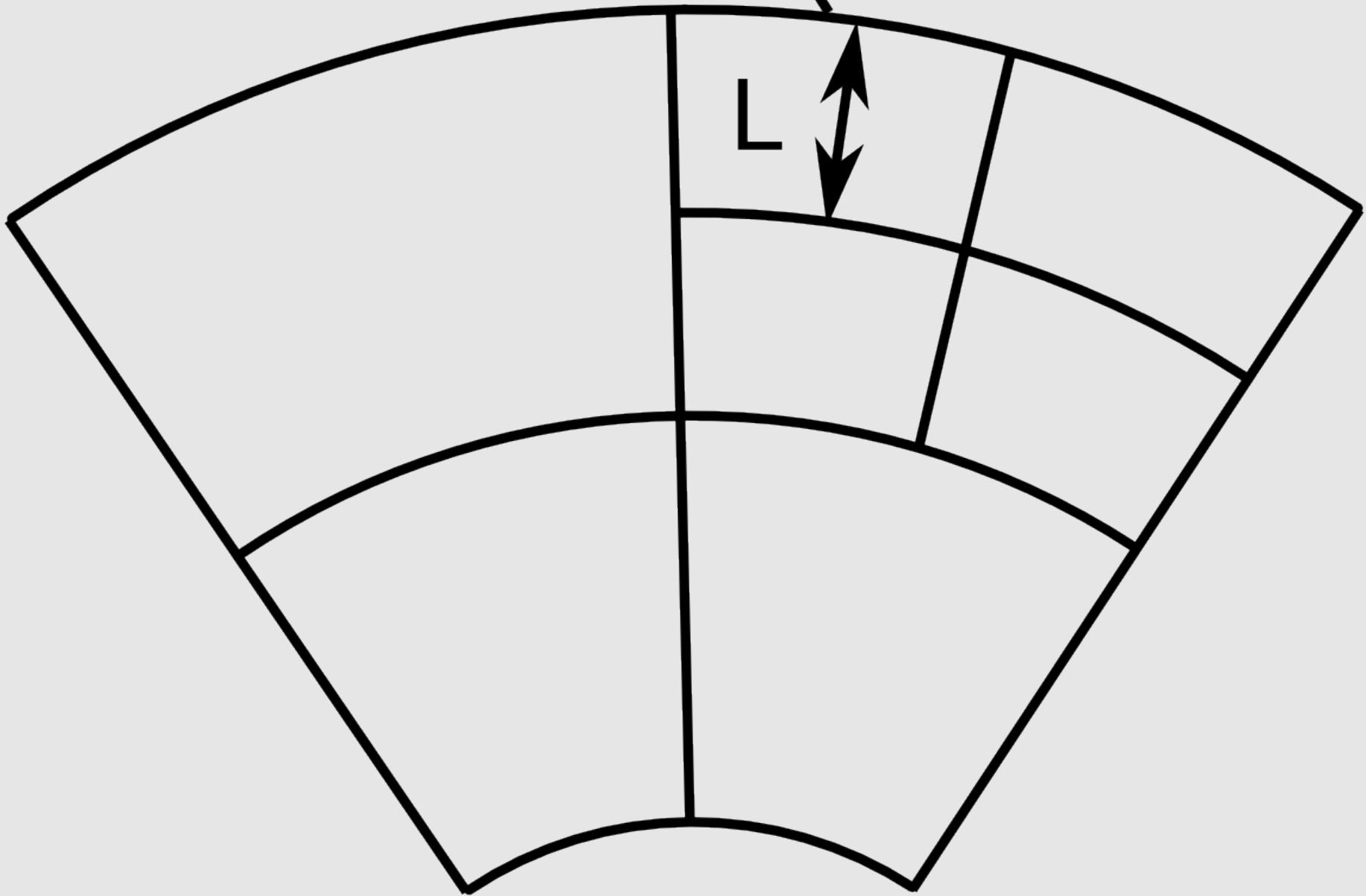




P



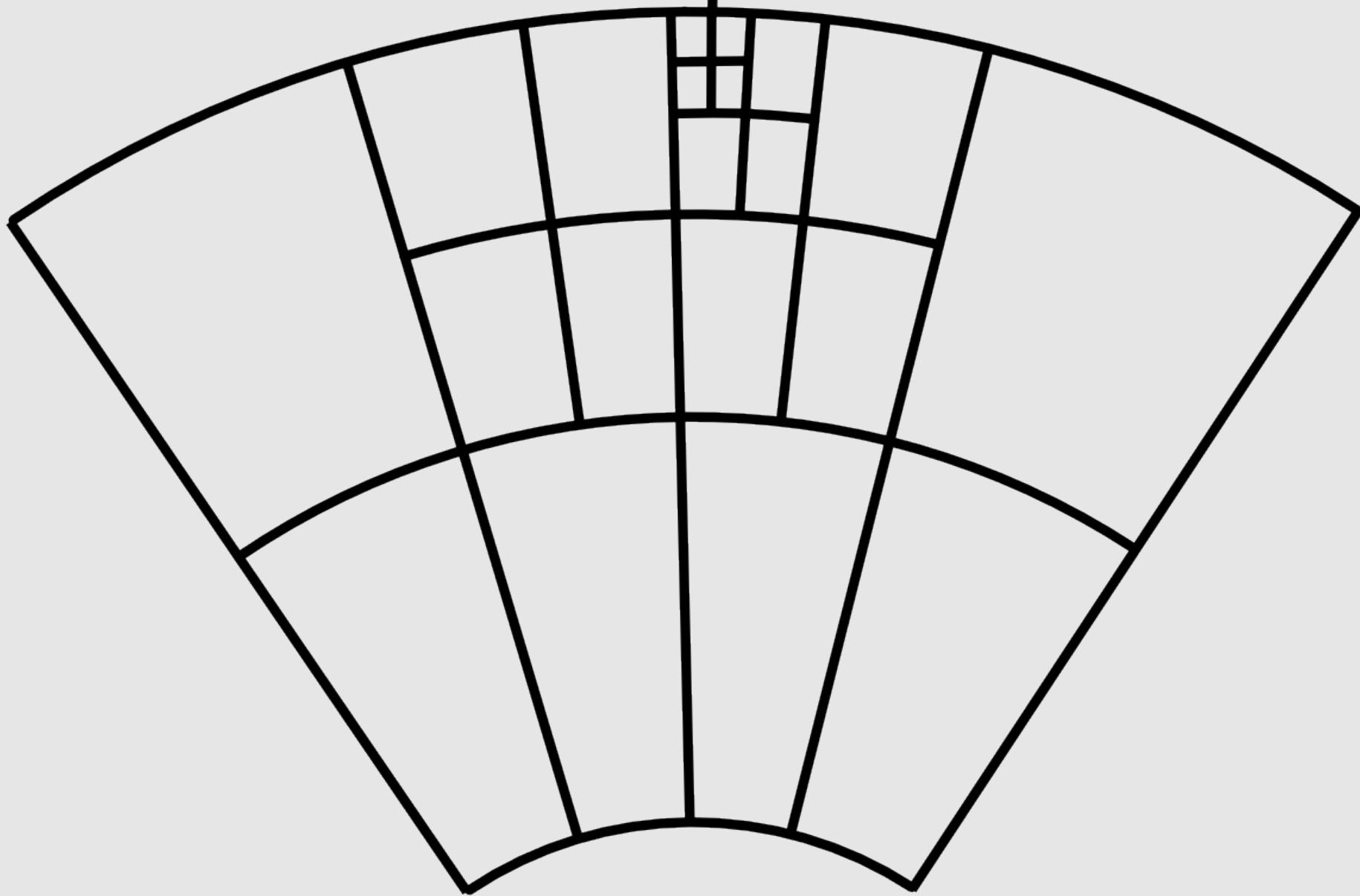
d

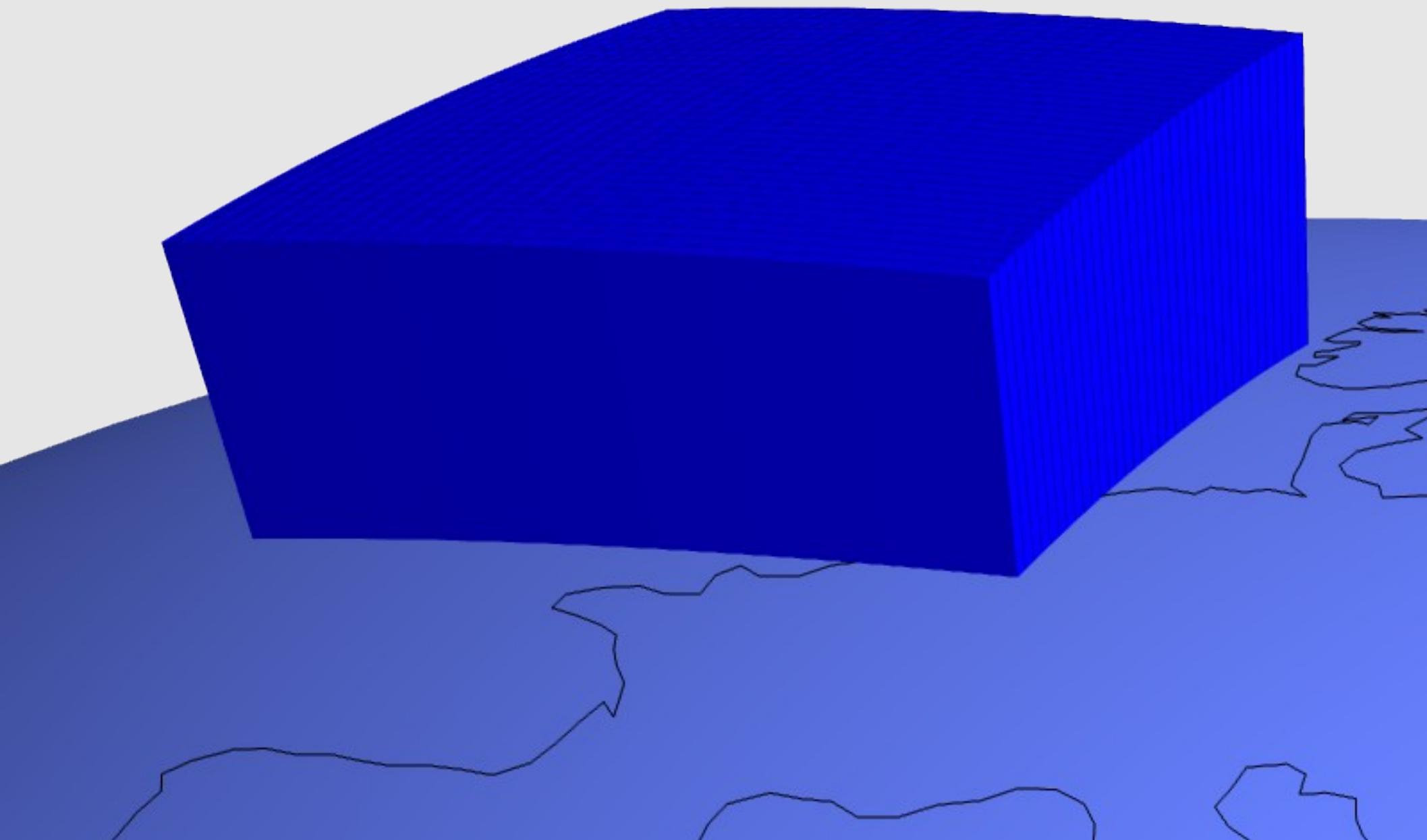


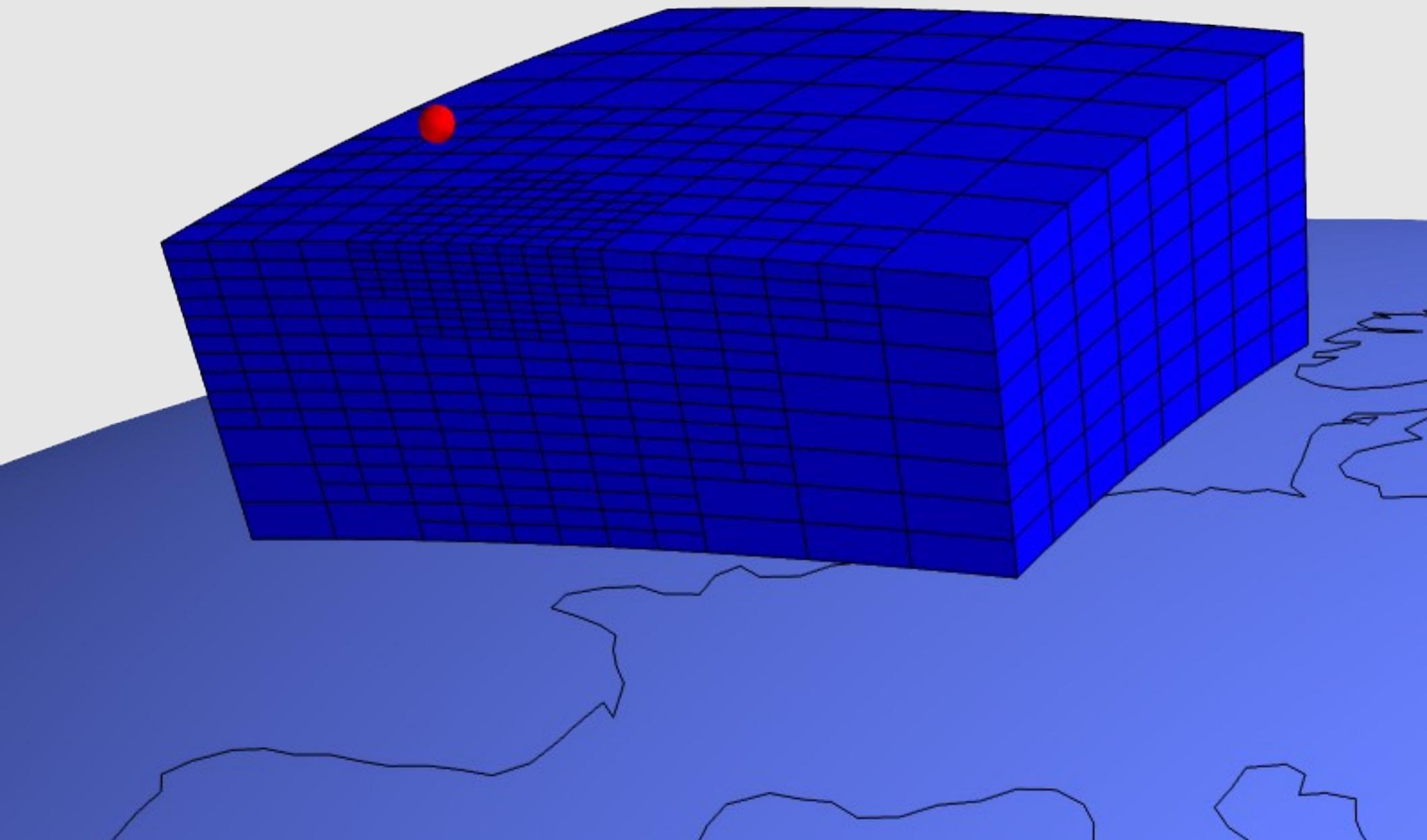
P



d





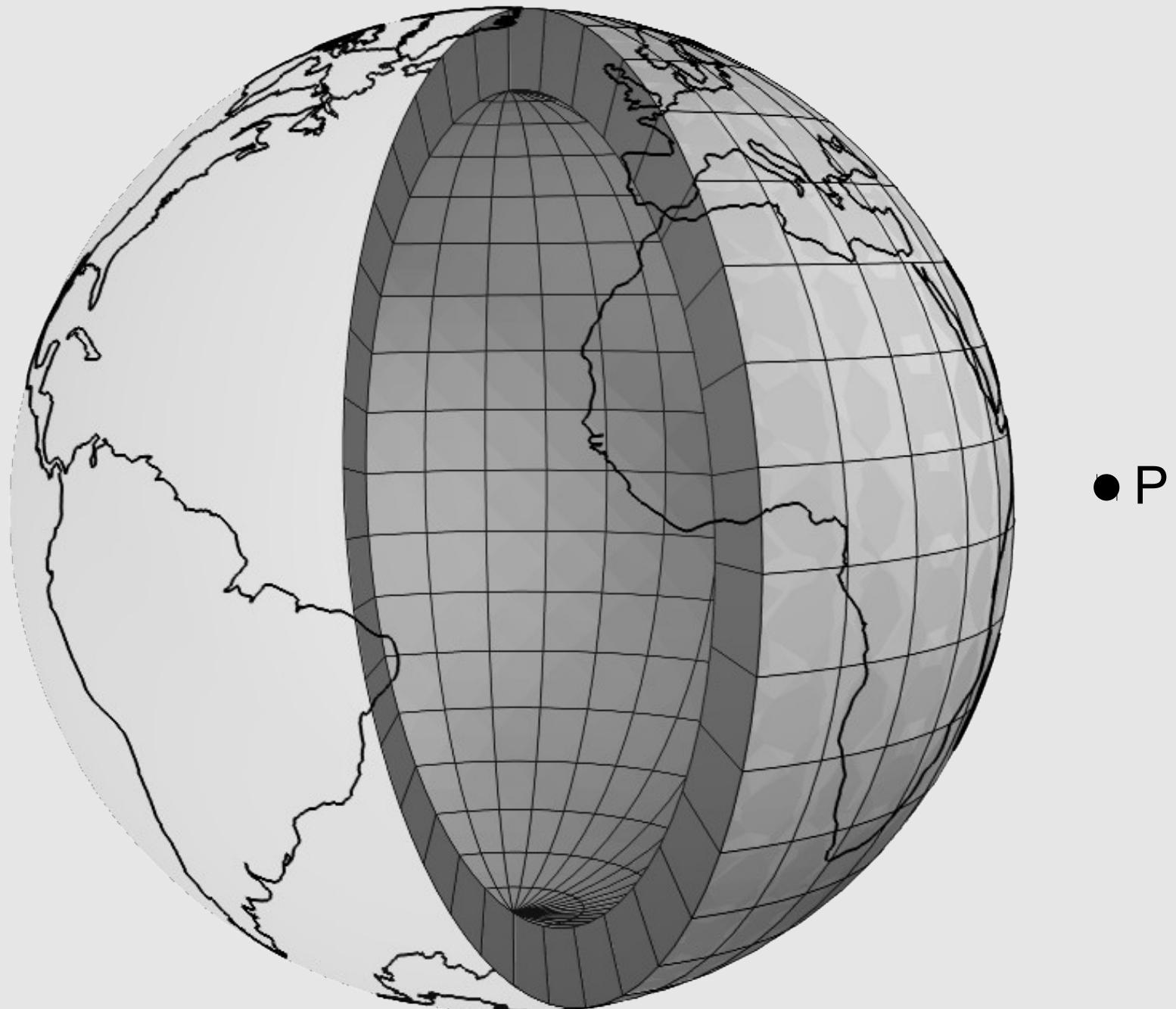


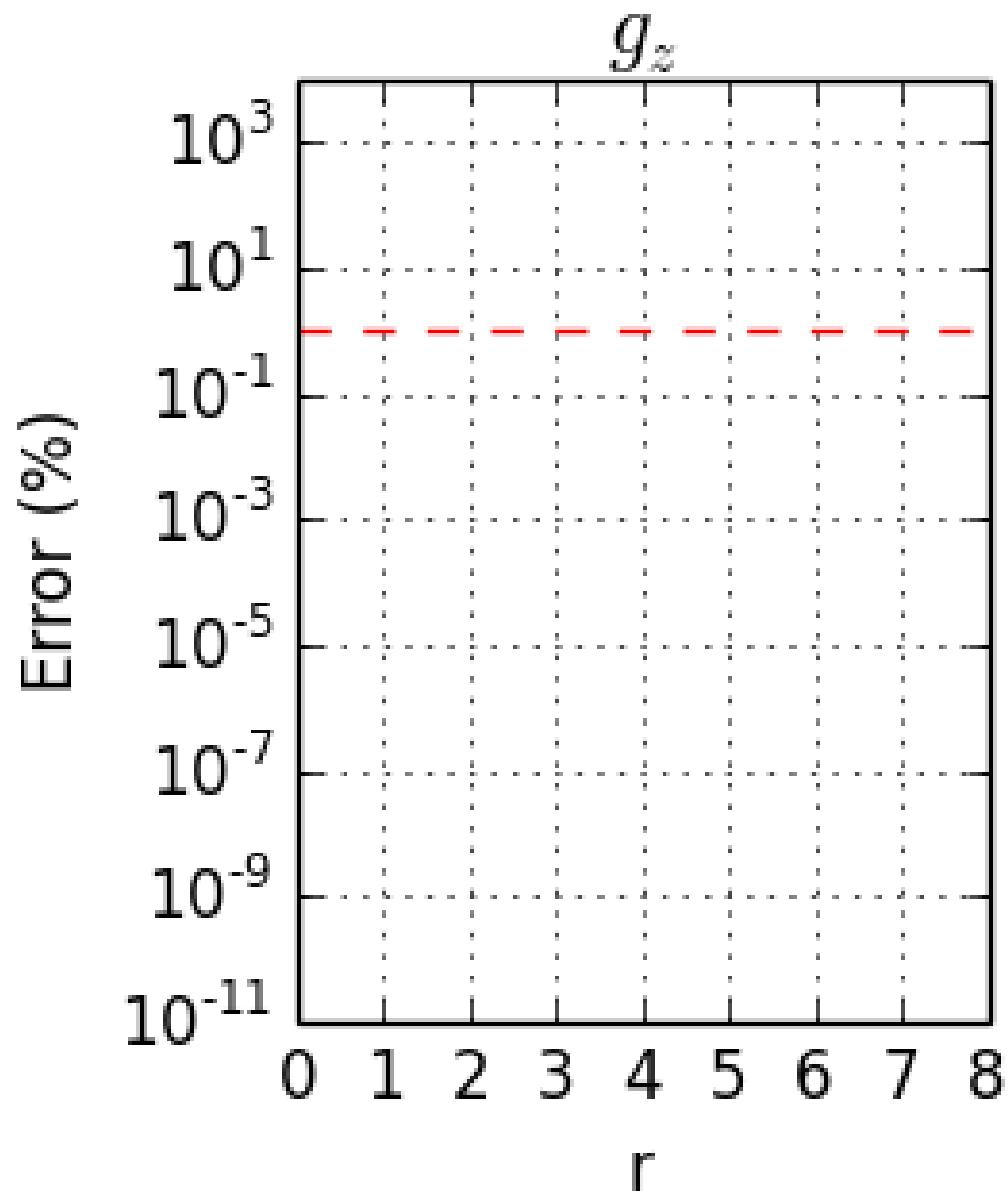
Qual o valor de  $r$ ?

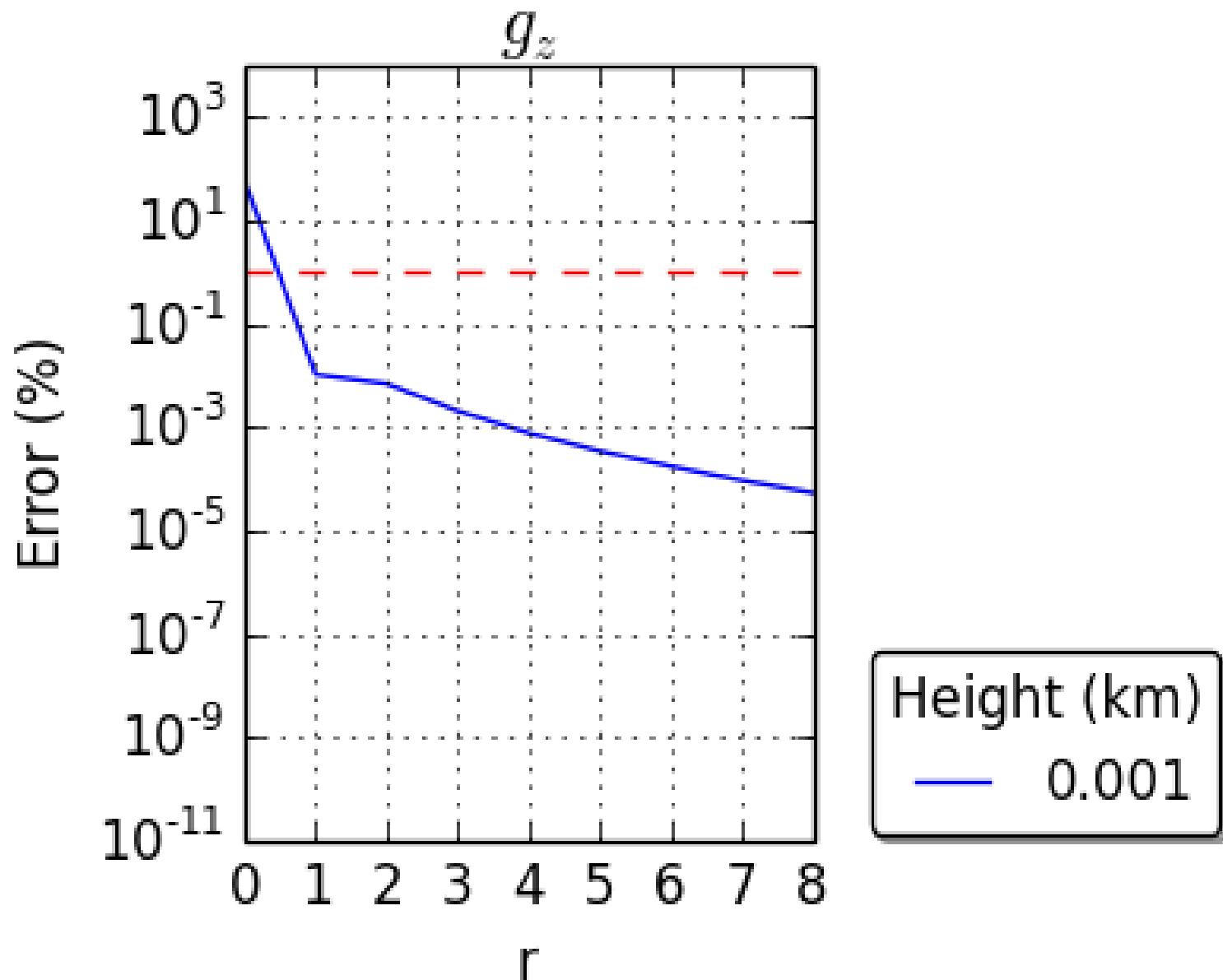
# Meia casca esférica

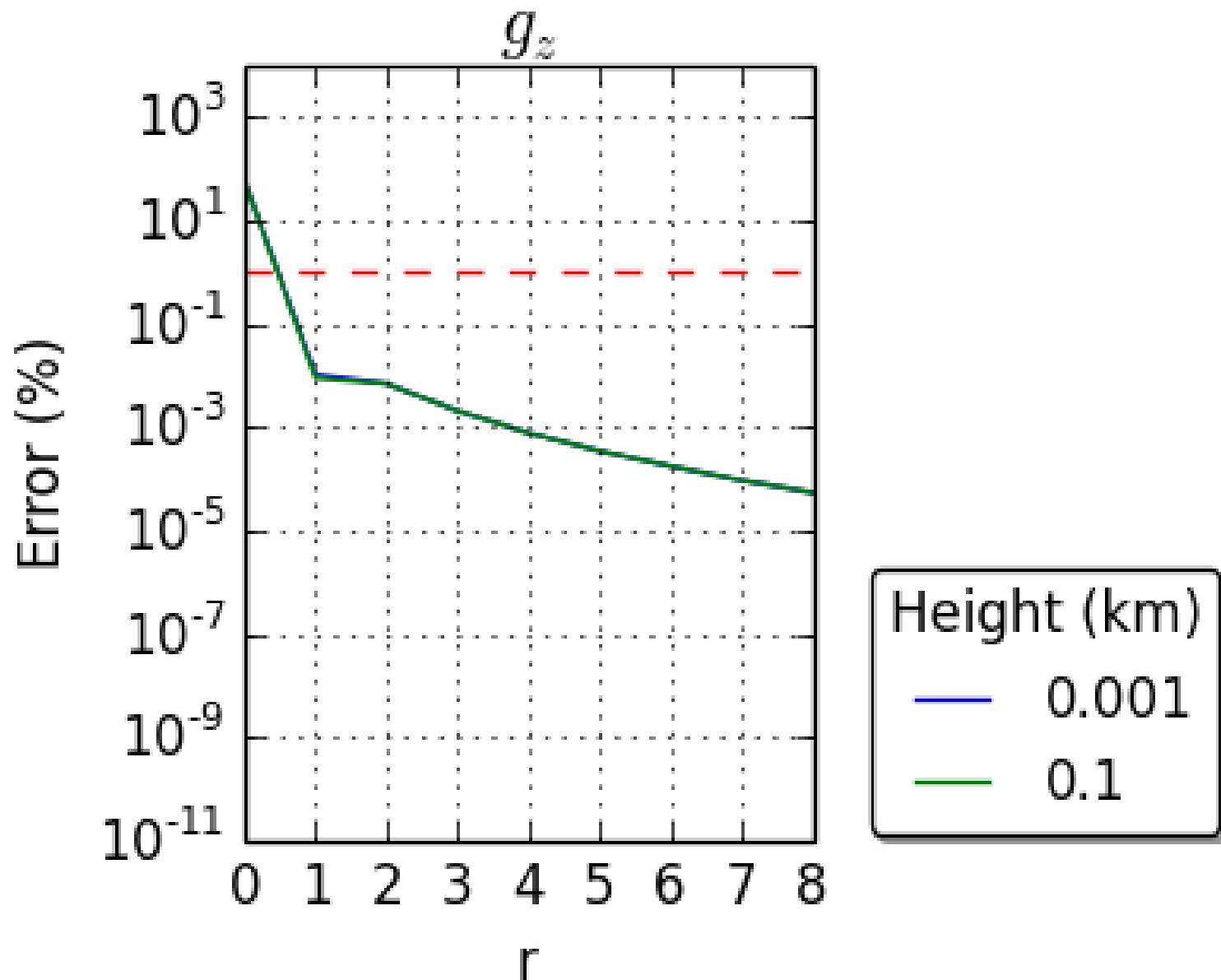


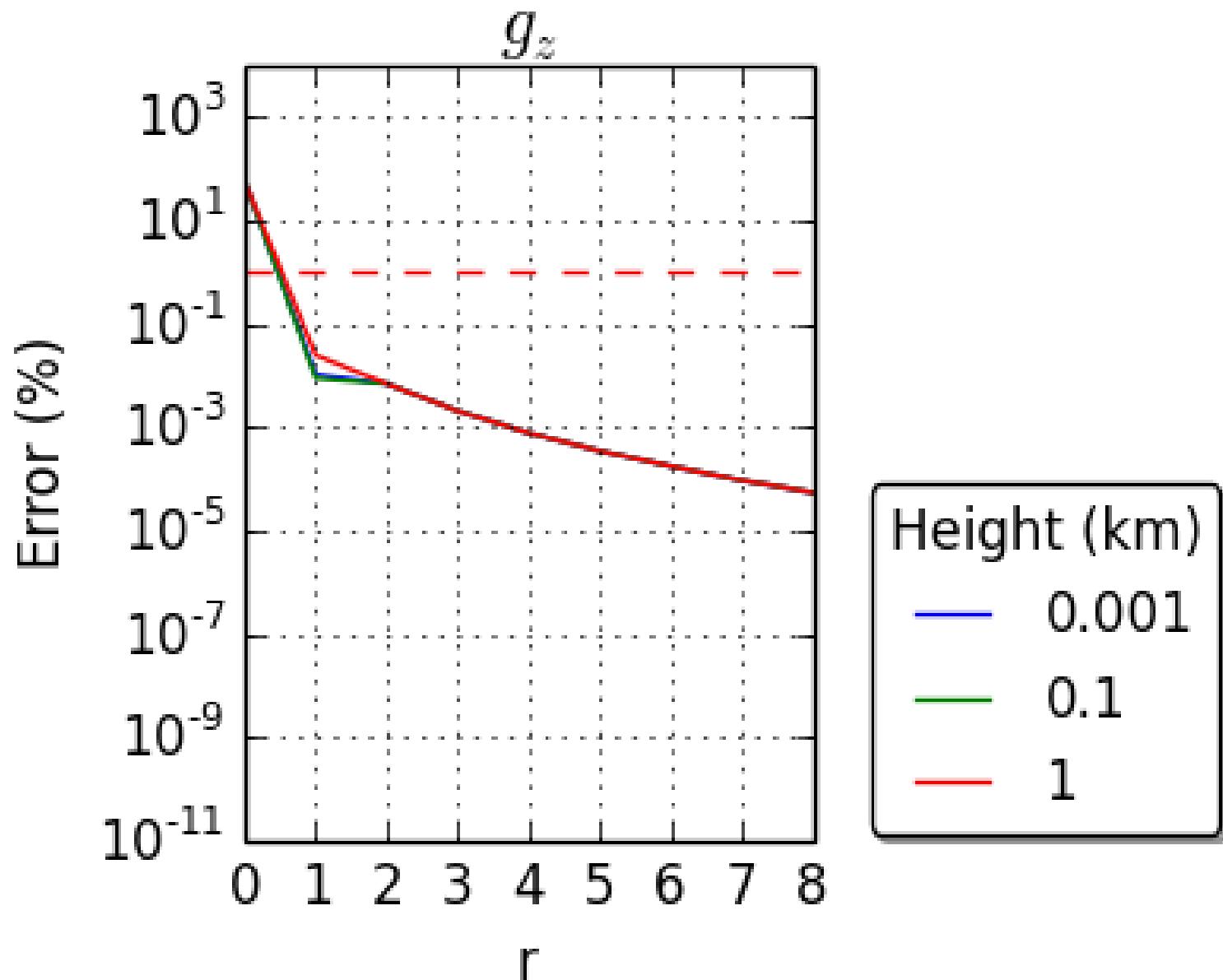
# Discretizar em tesseroides

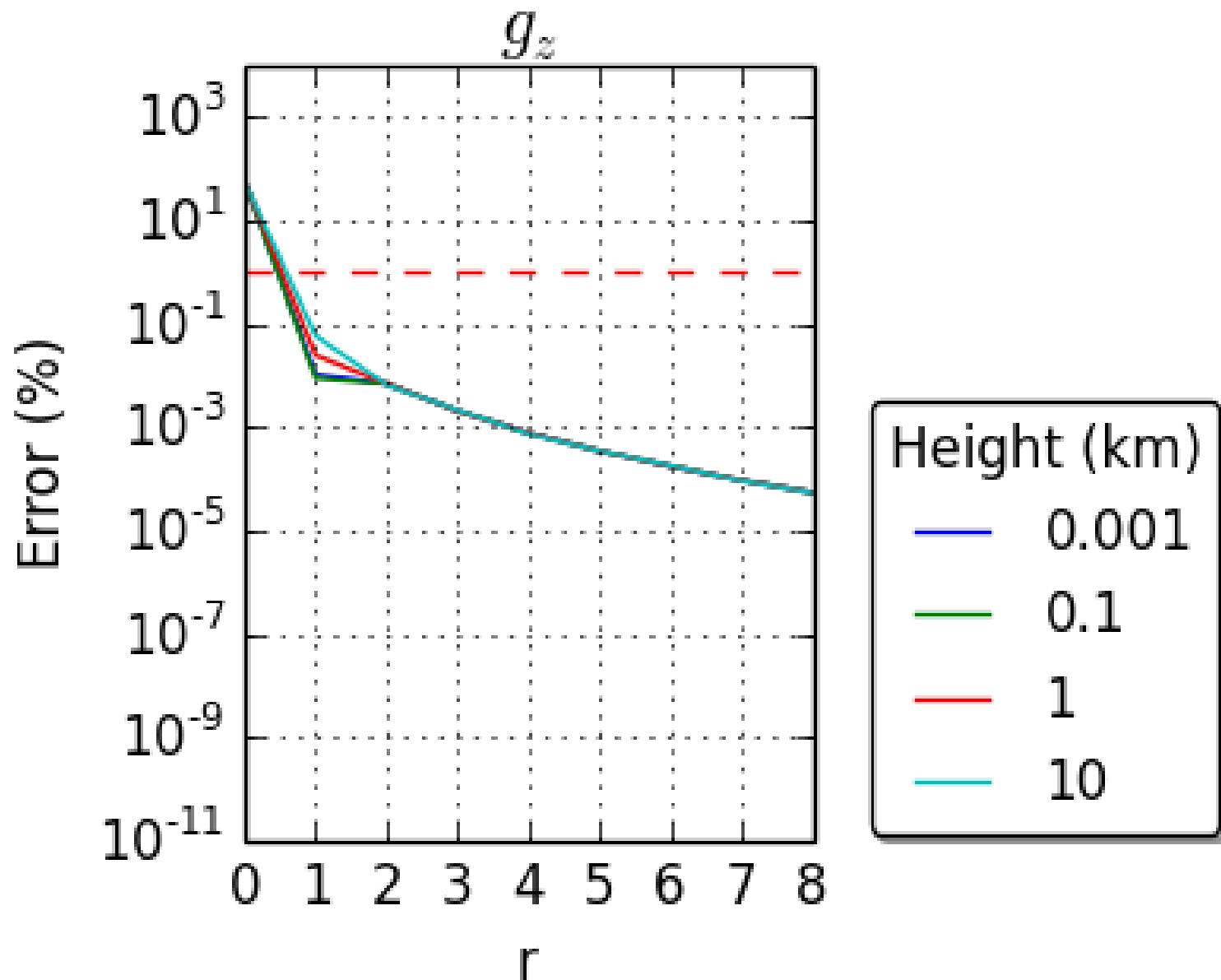


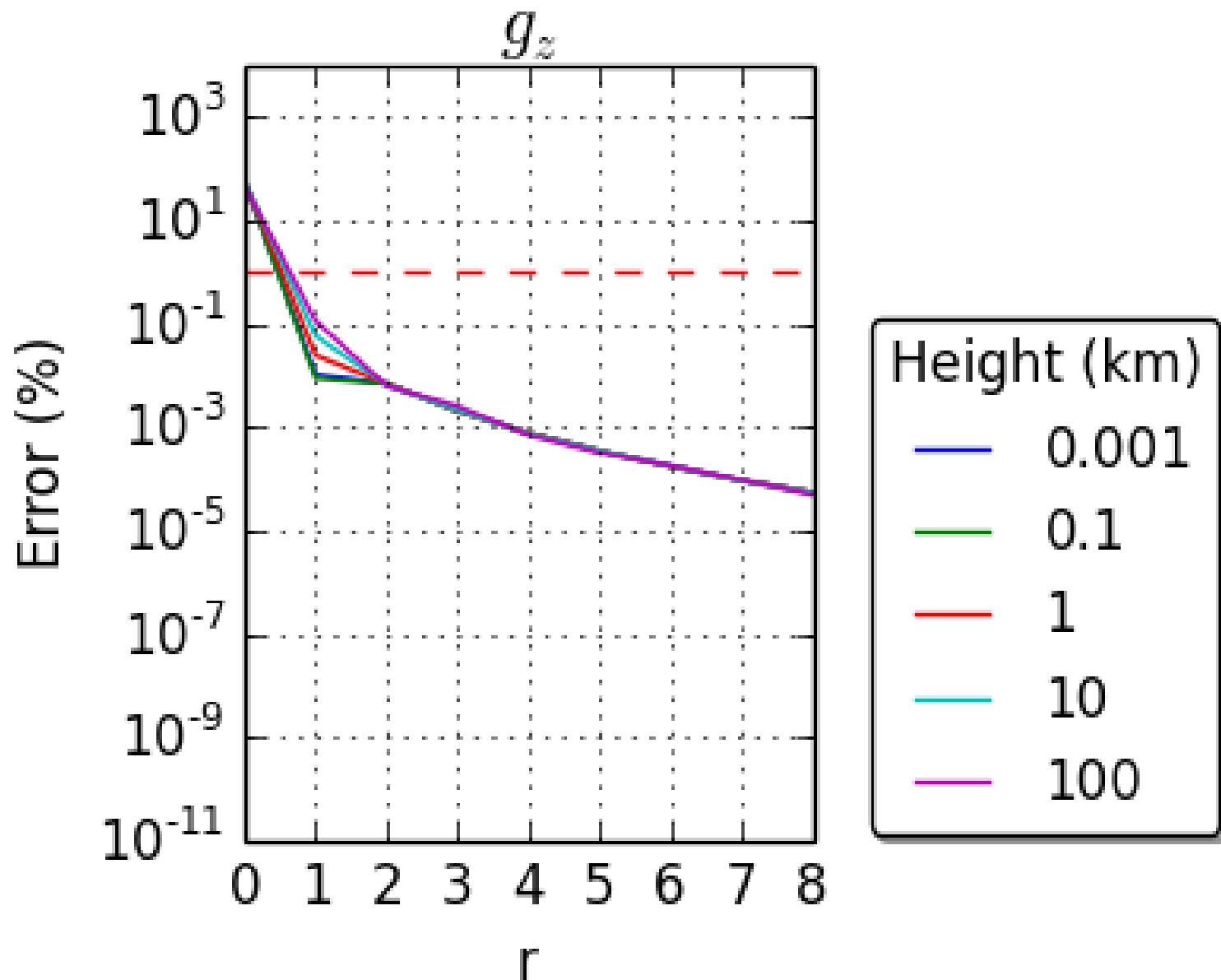


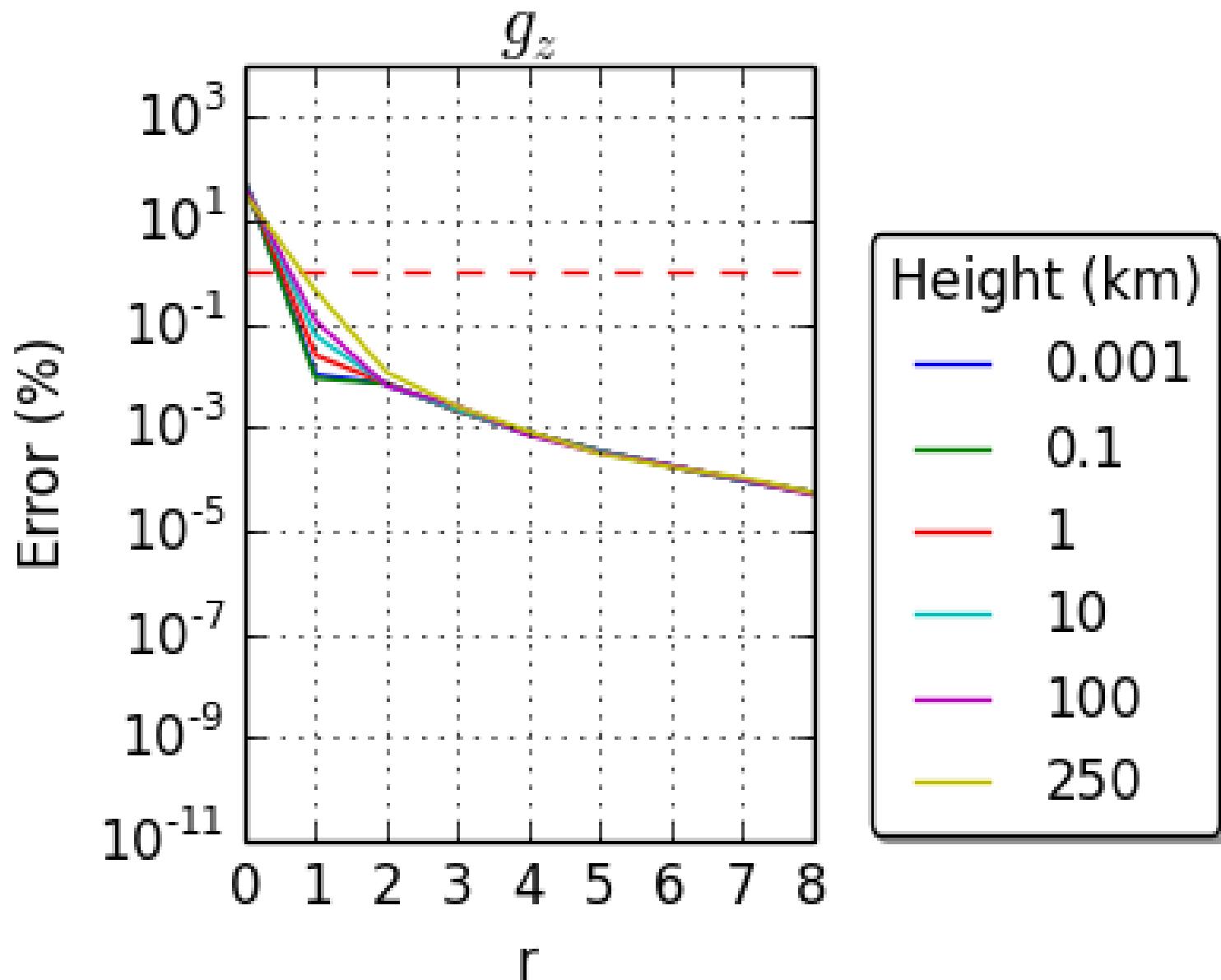


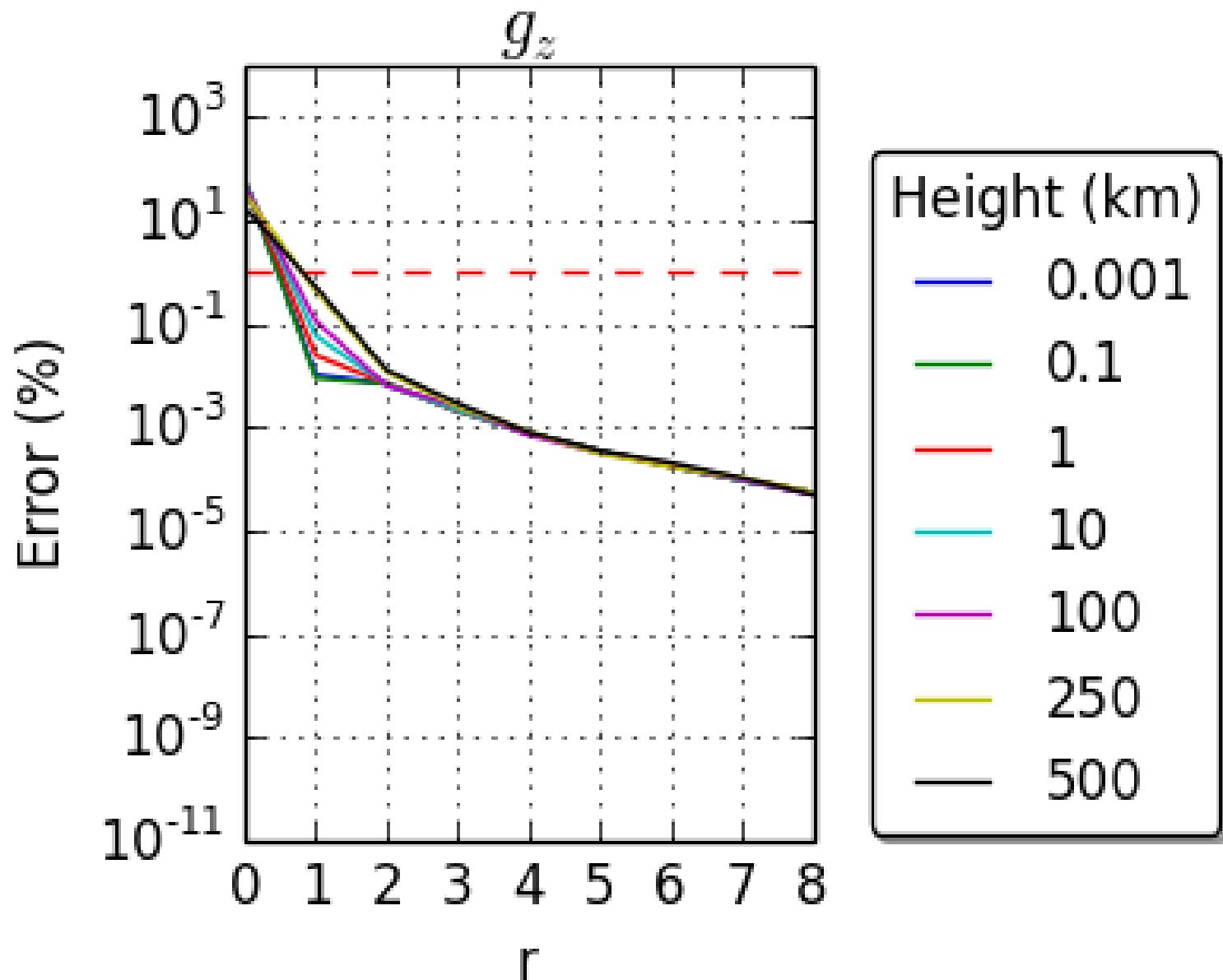


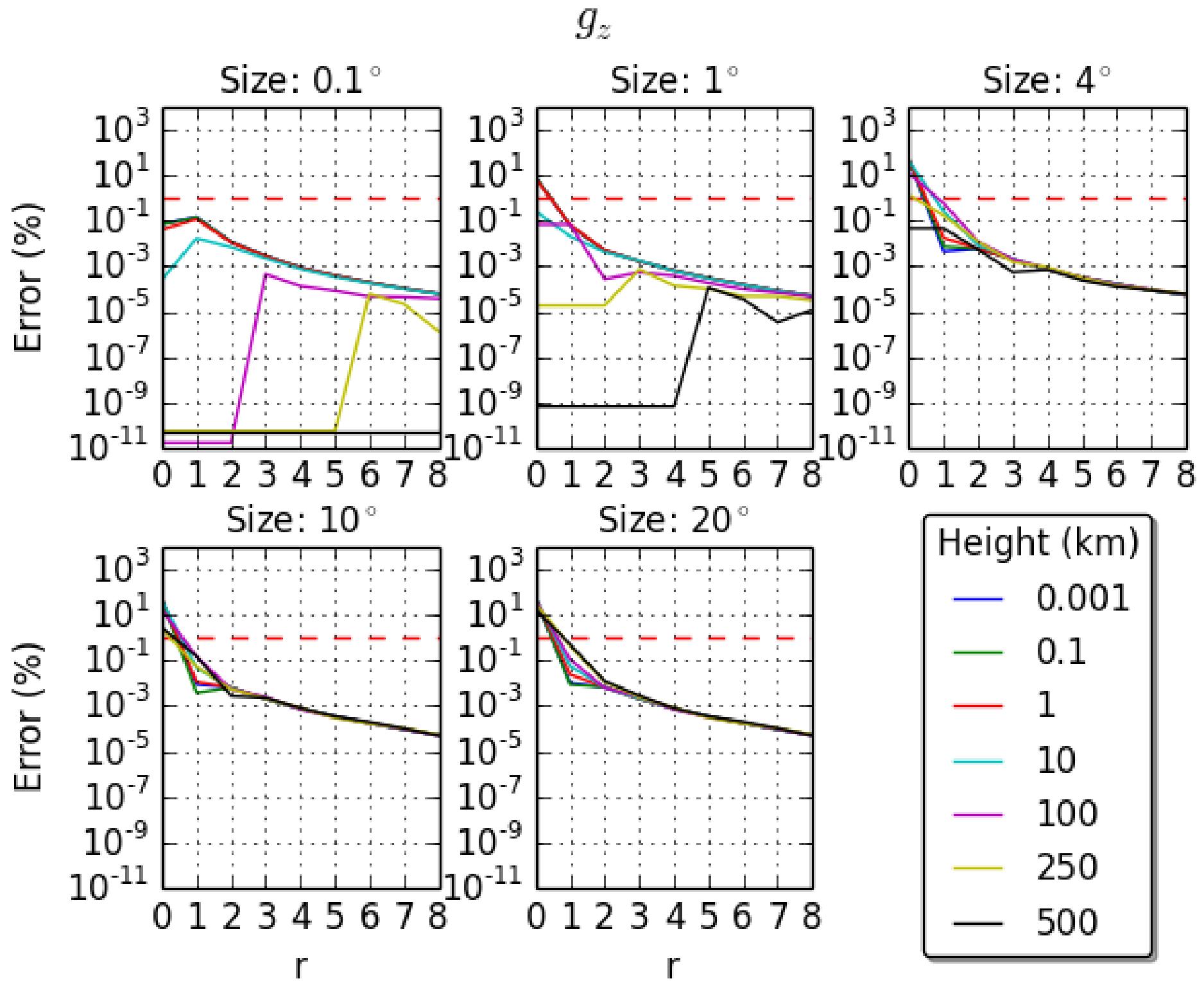


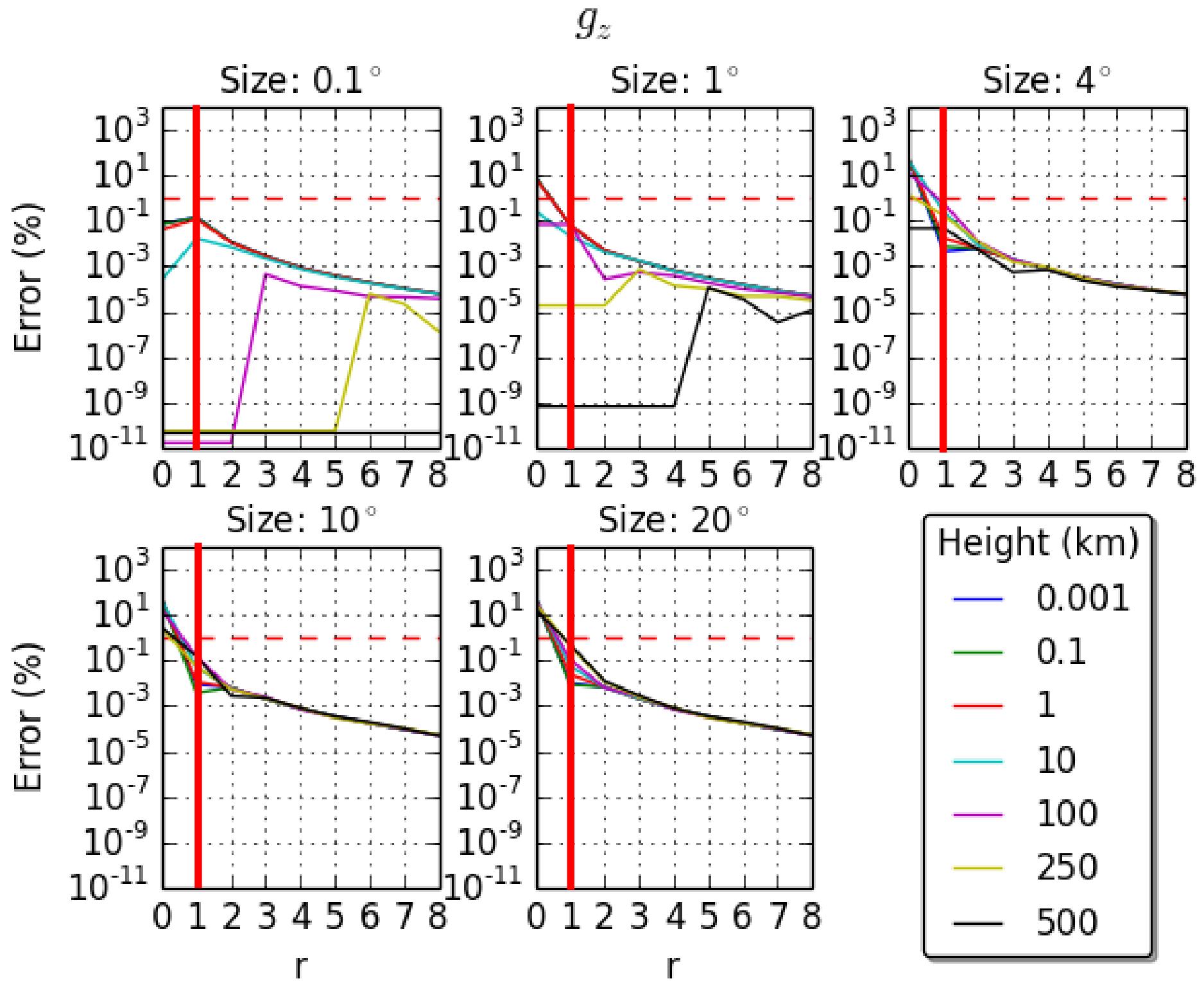




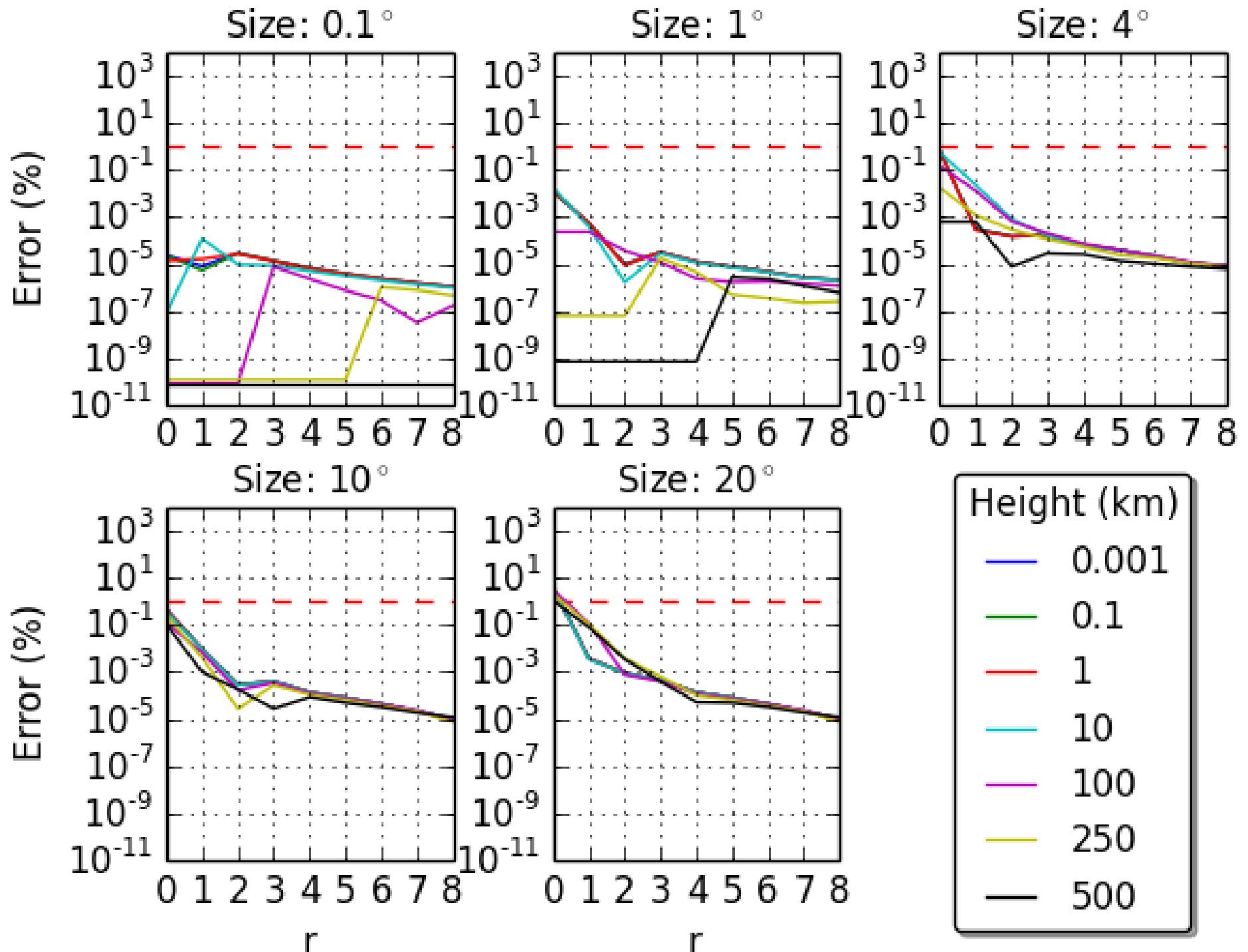




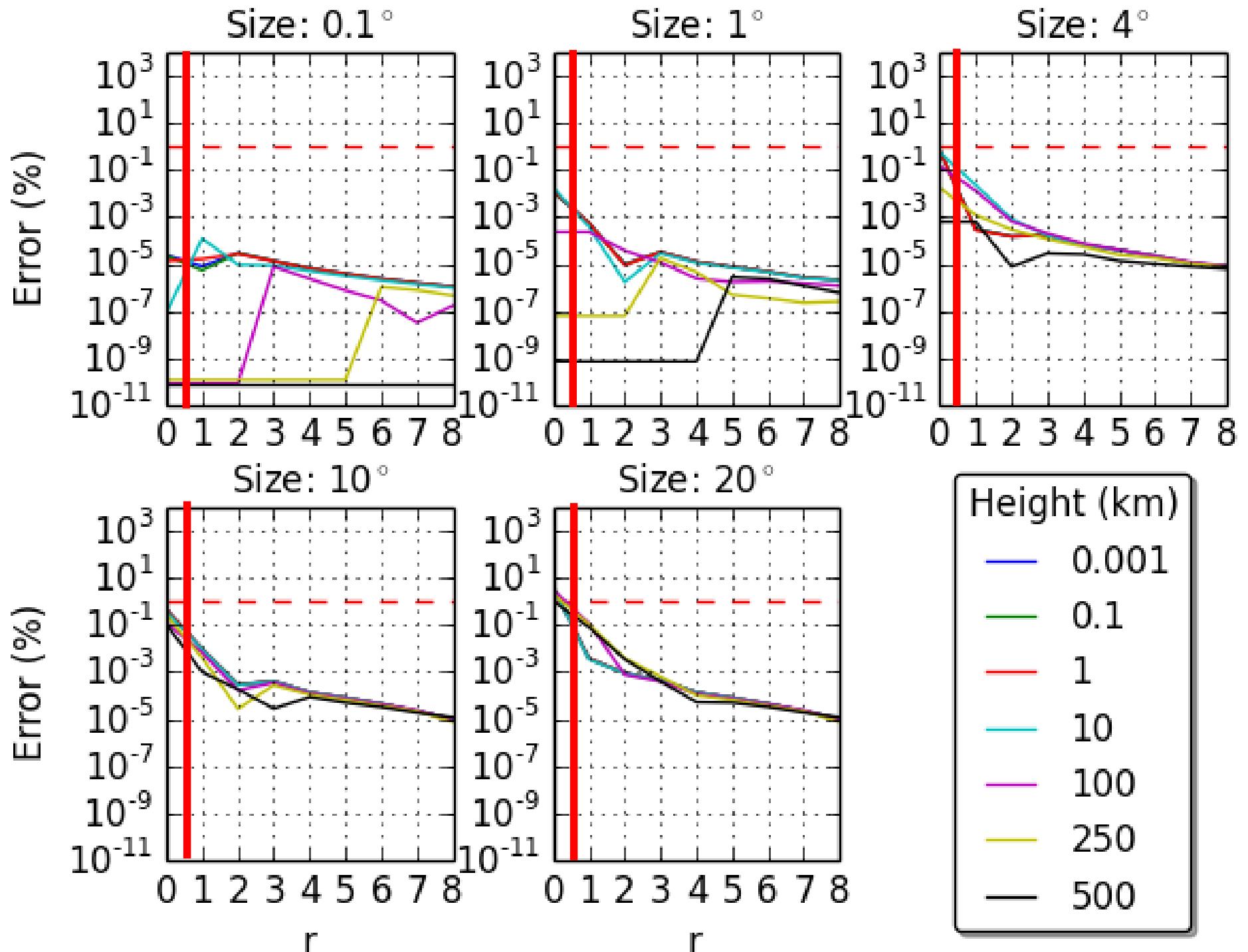


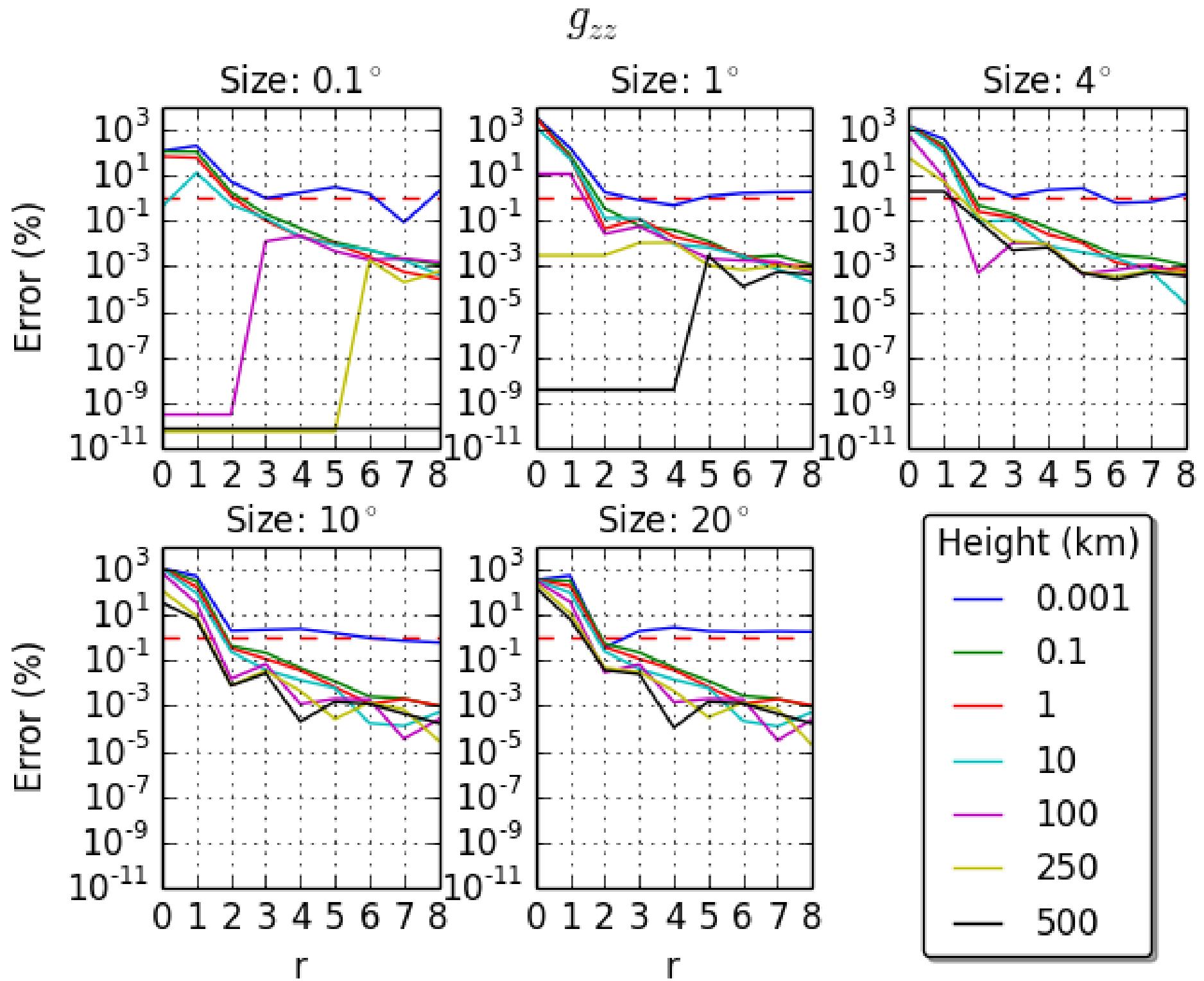


# Potential

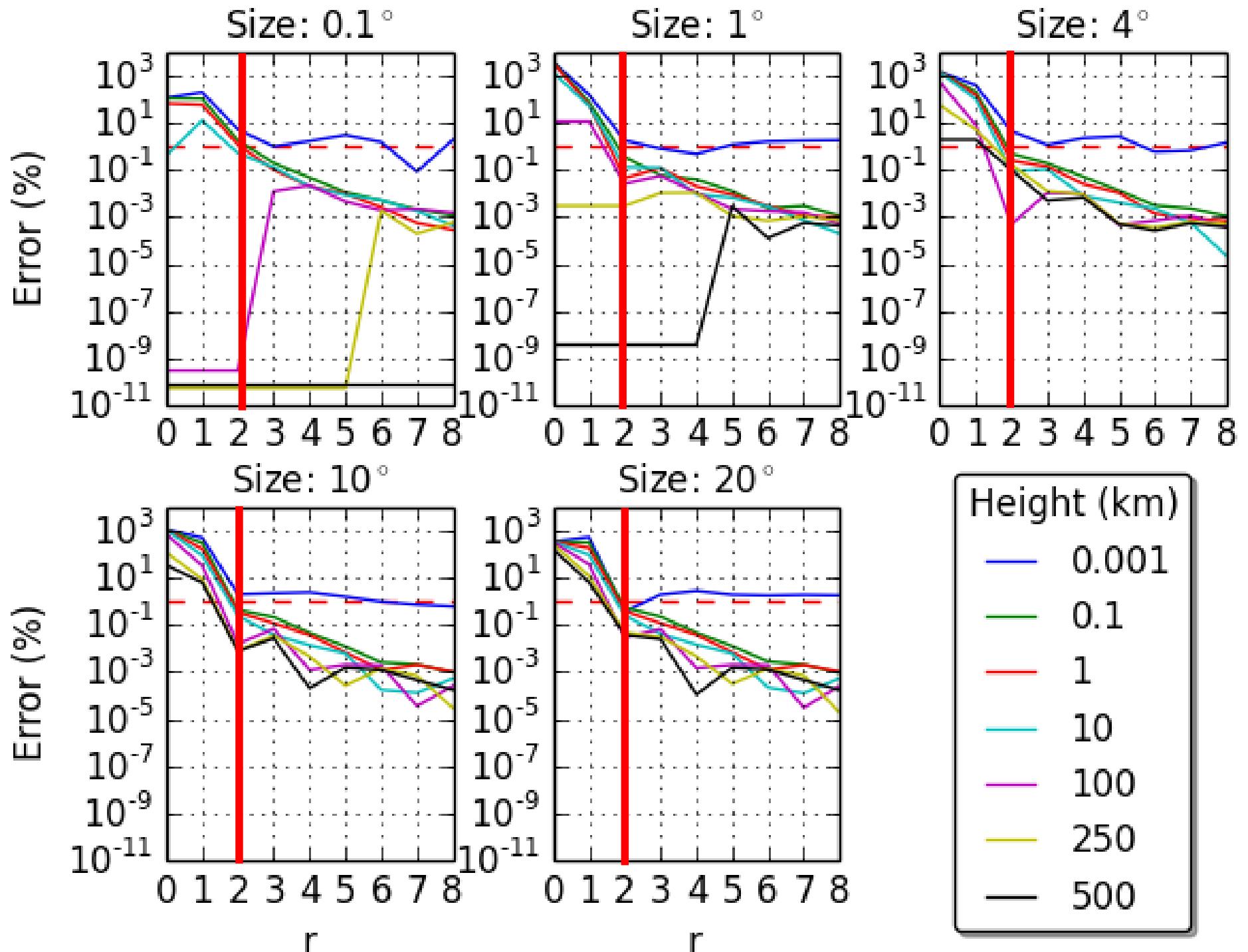


# *Potential*

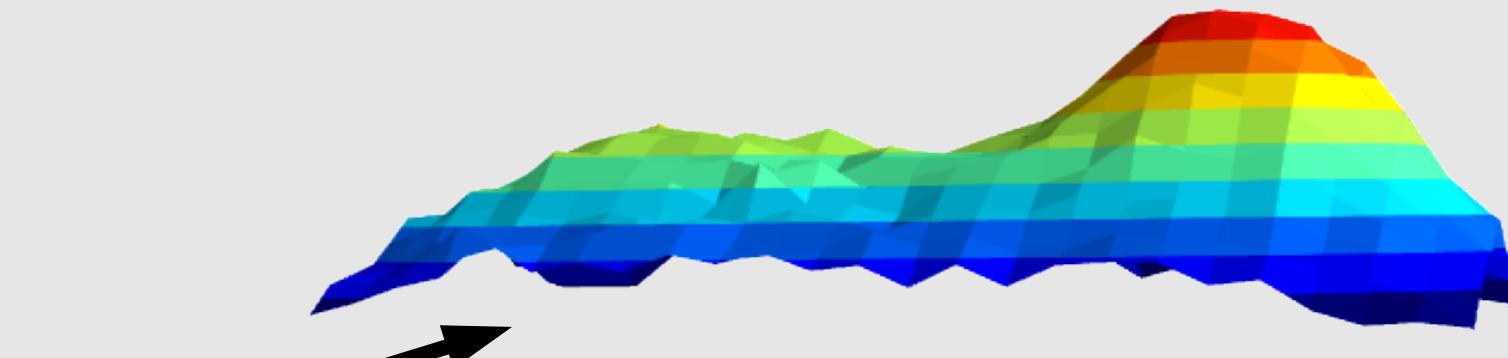




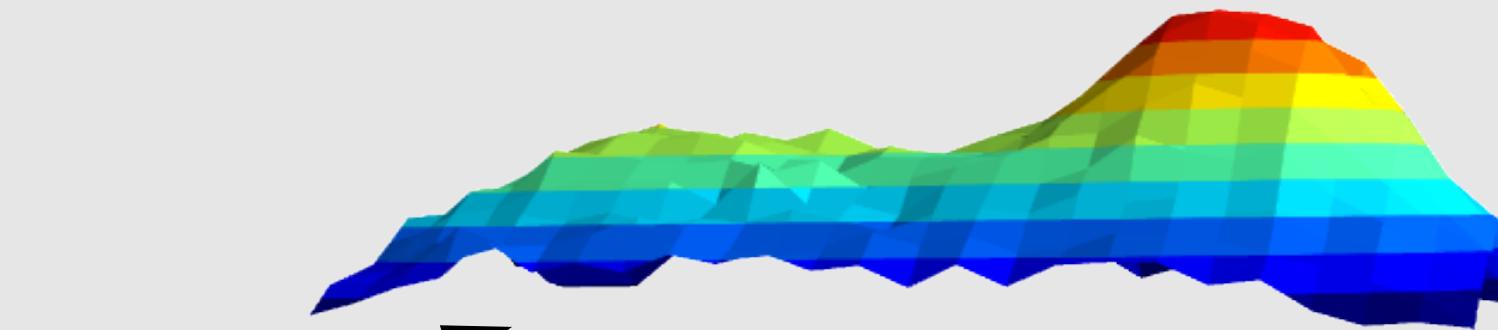
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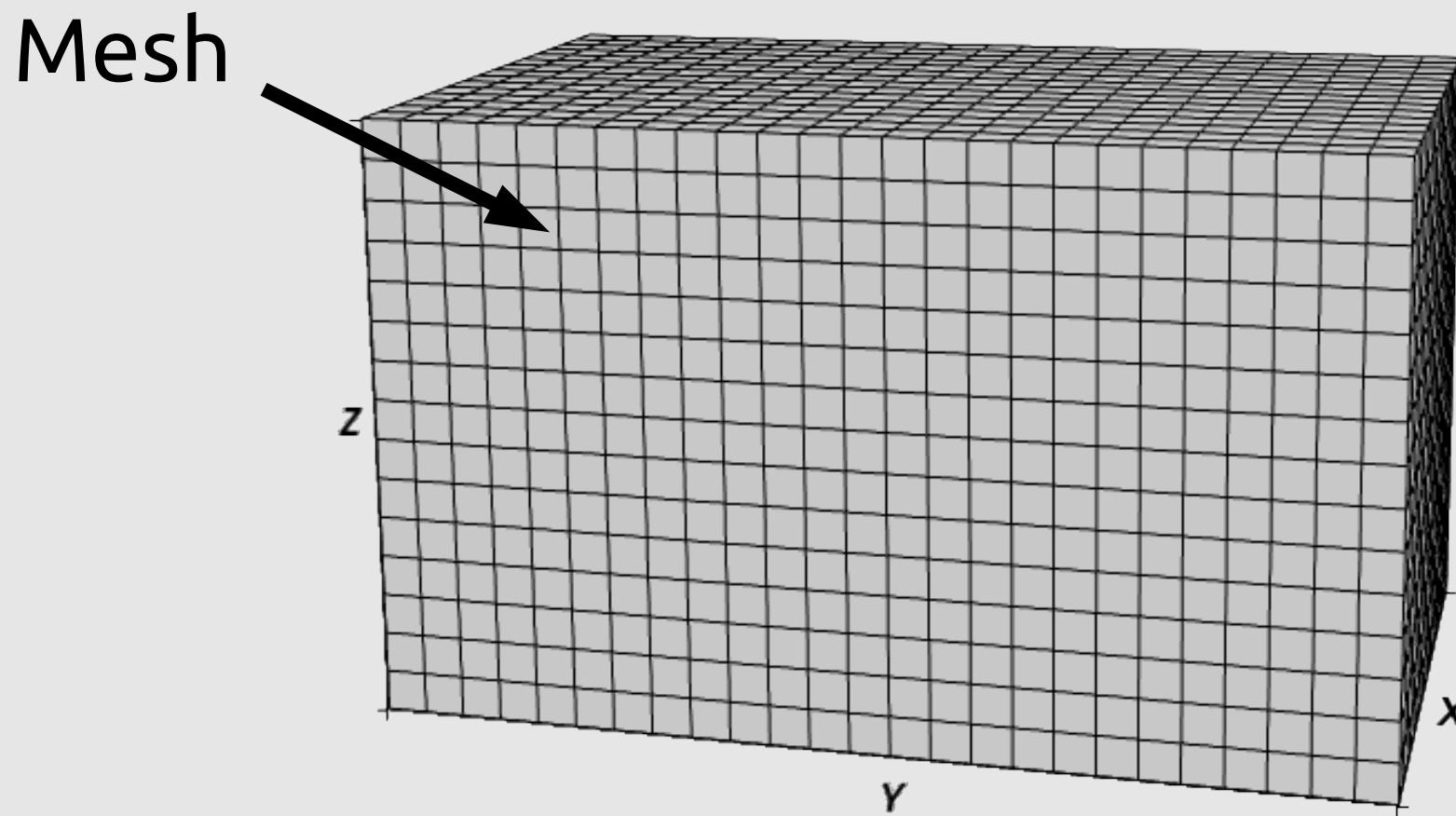
# **Inversão com algoritmo de plantação (sementes)**



Dado

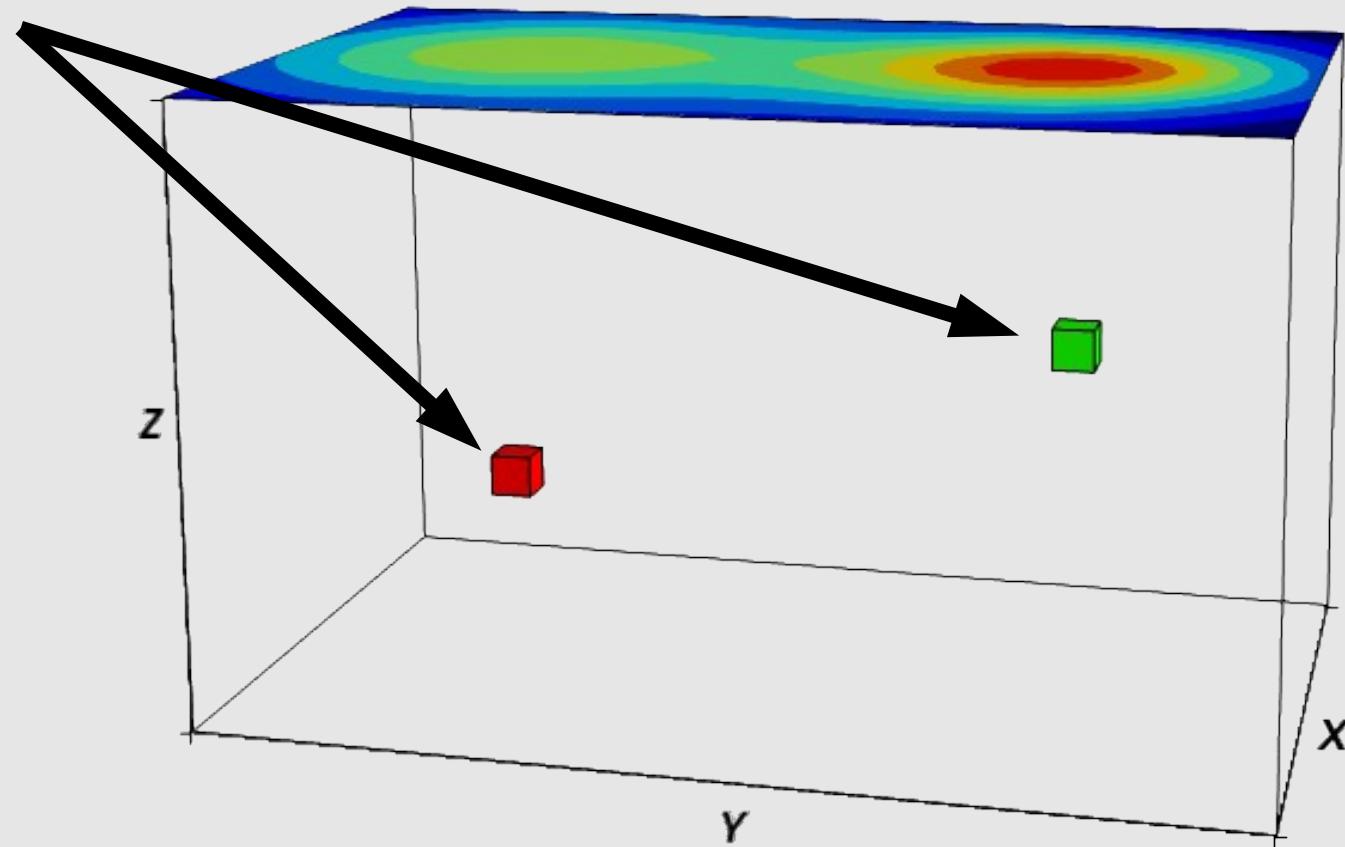


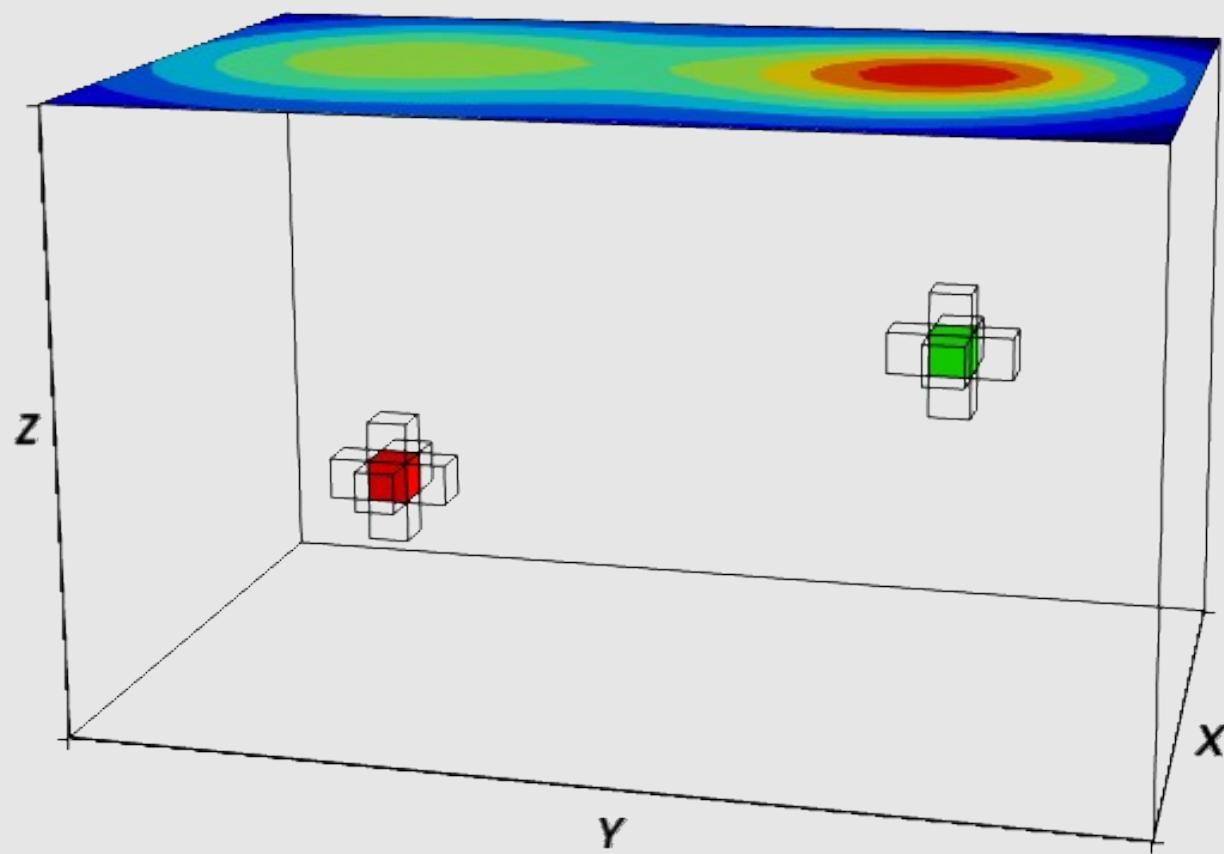
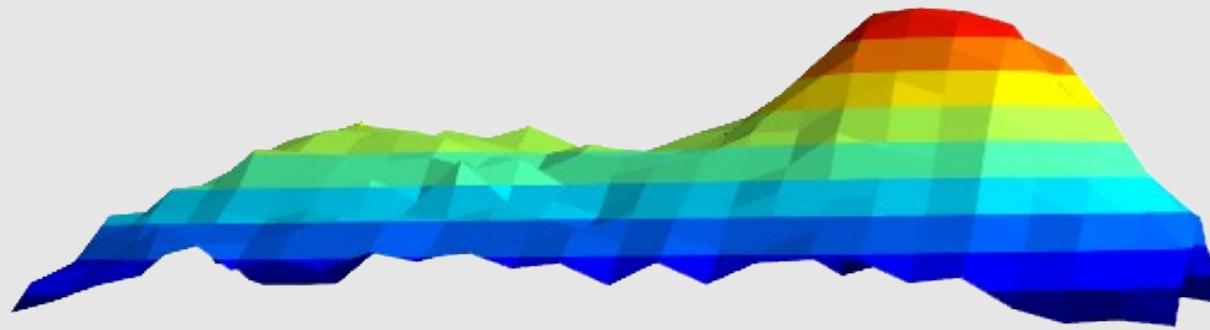
Dado

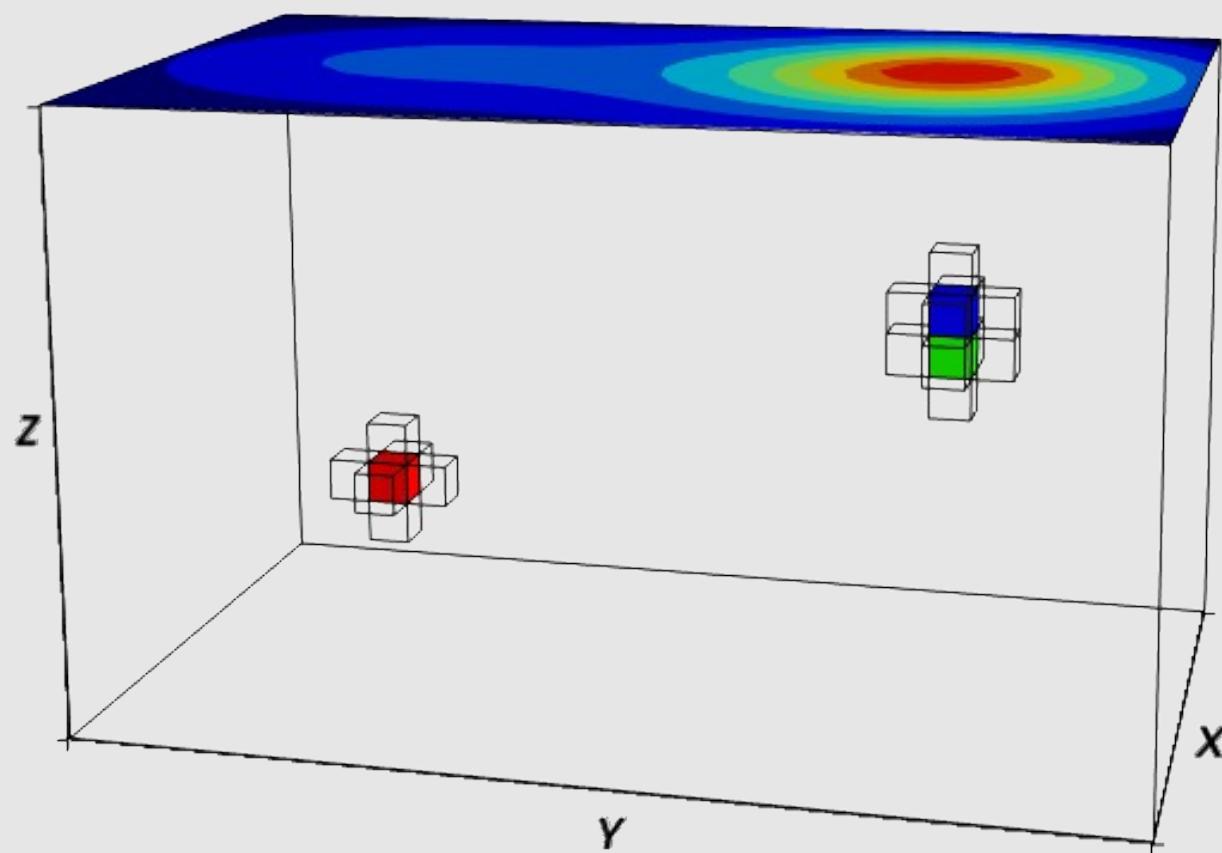
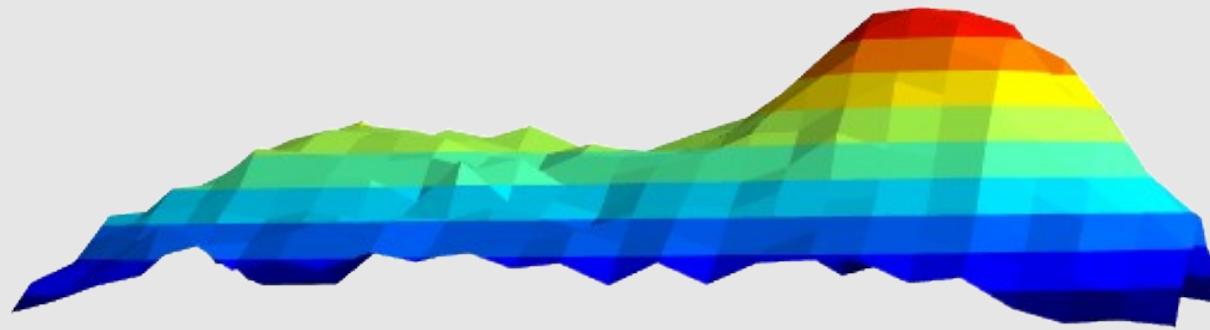


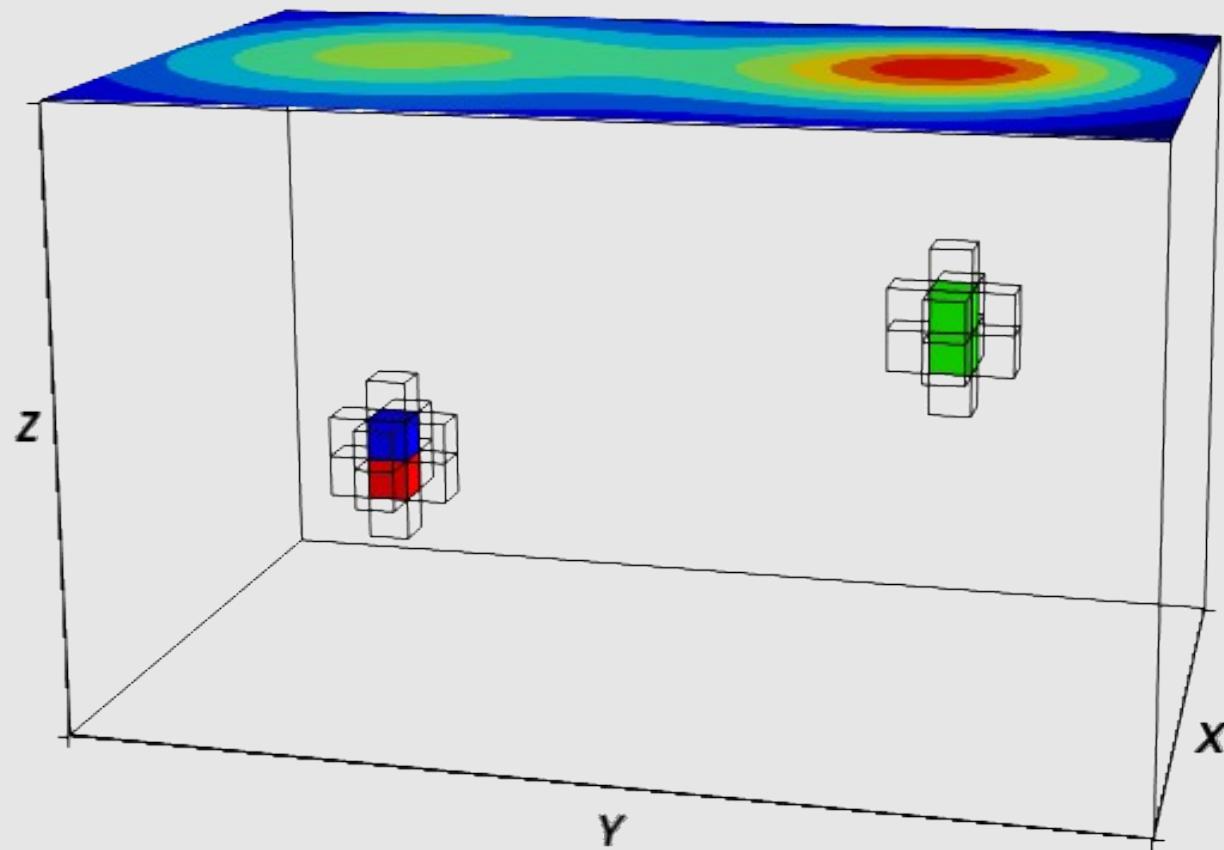
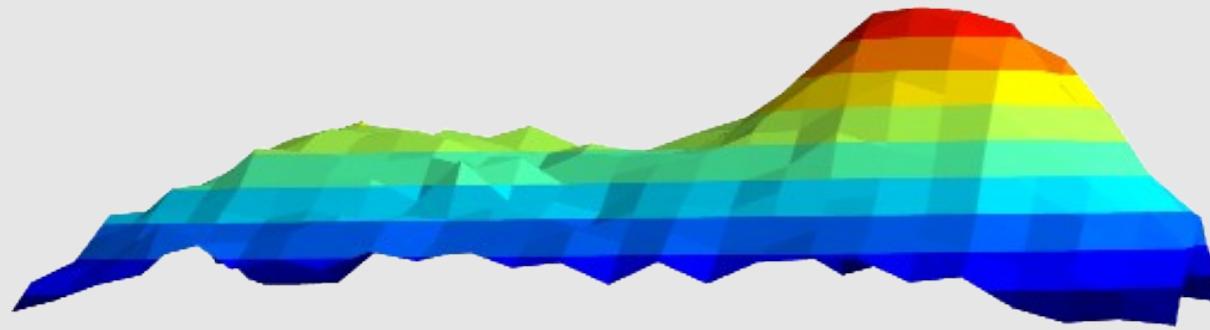
Mesh

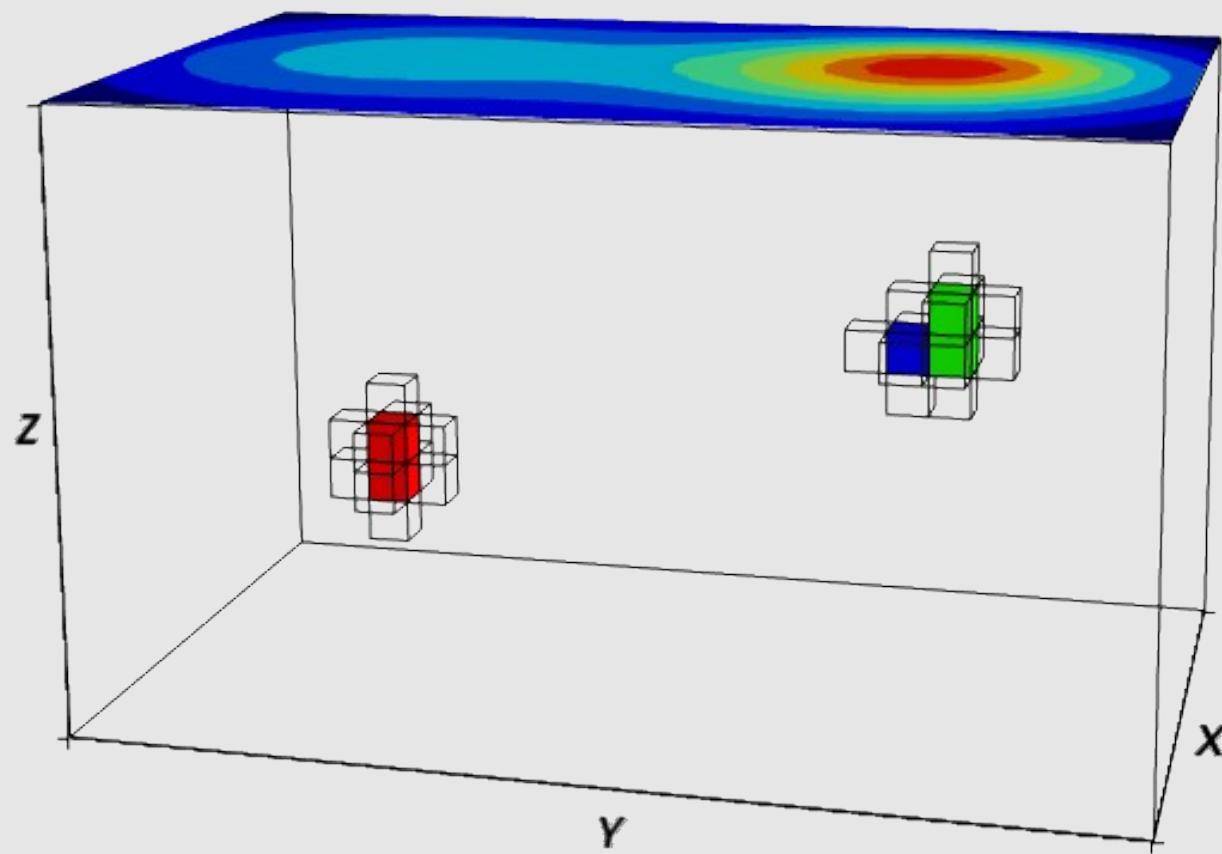
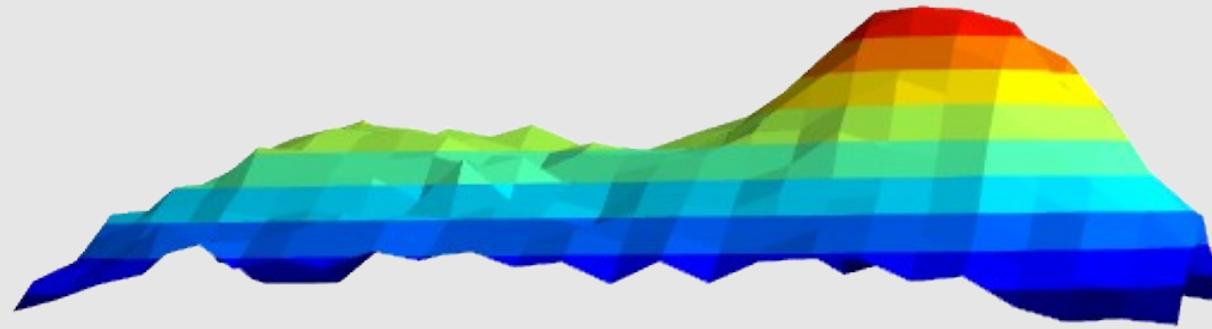
# Sementes

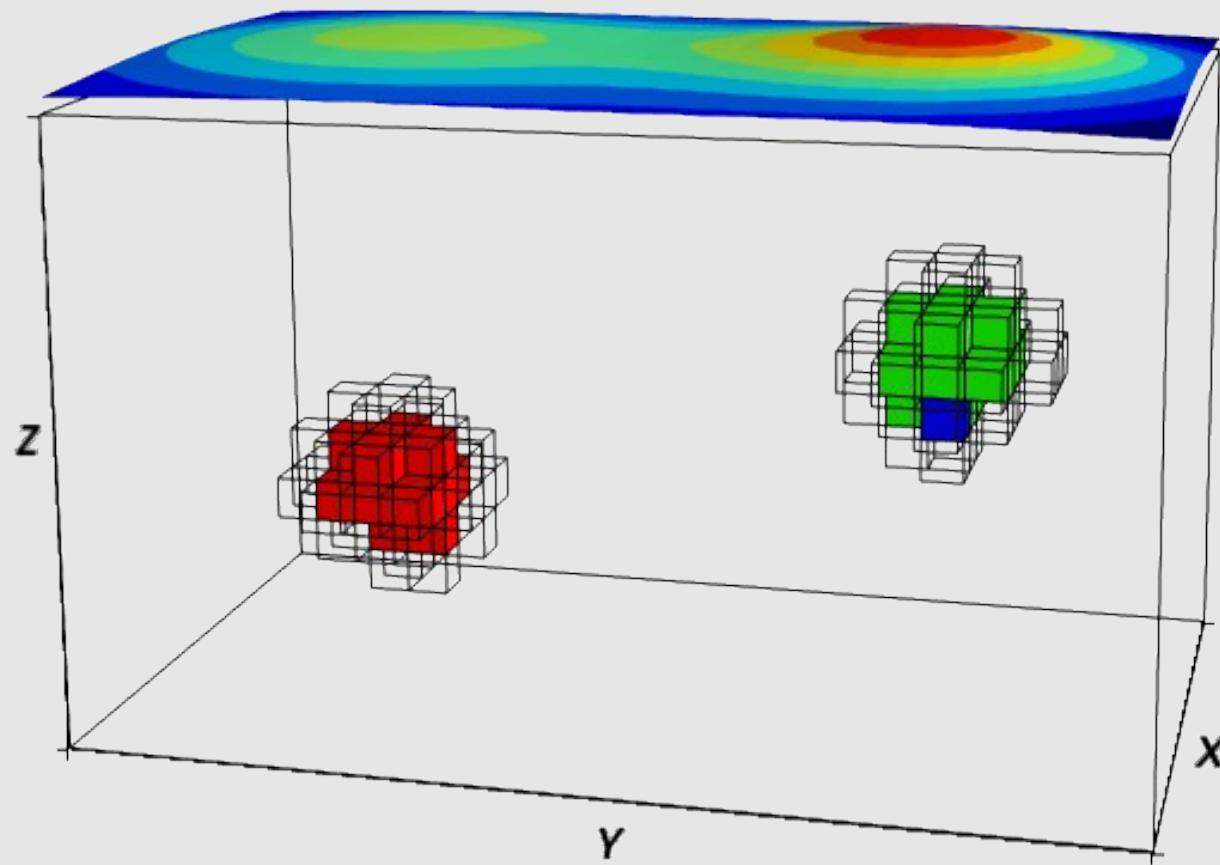
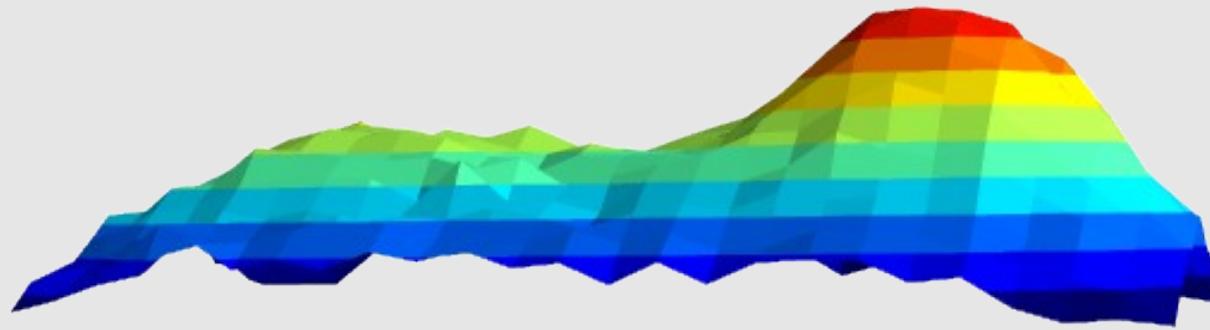


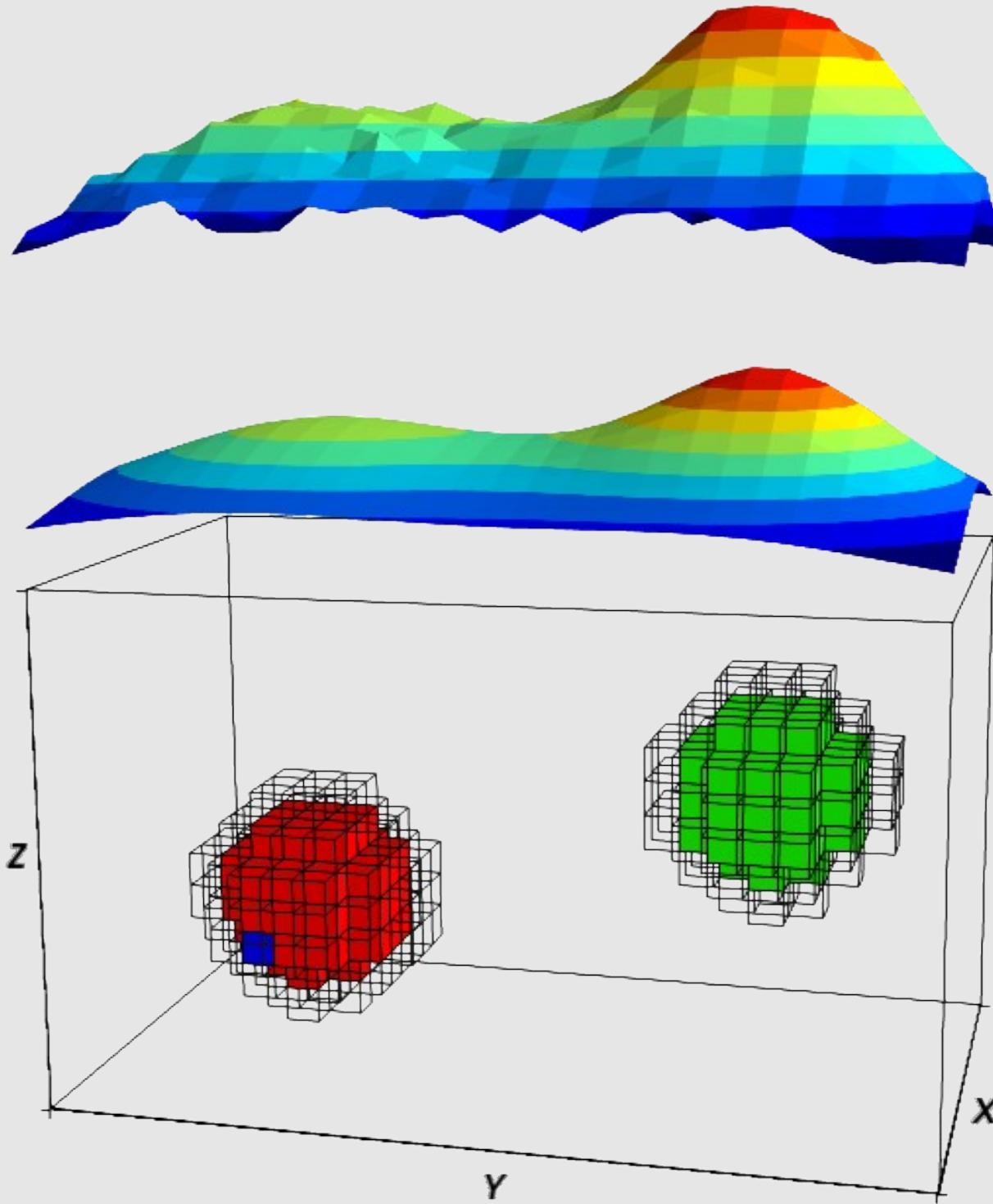


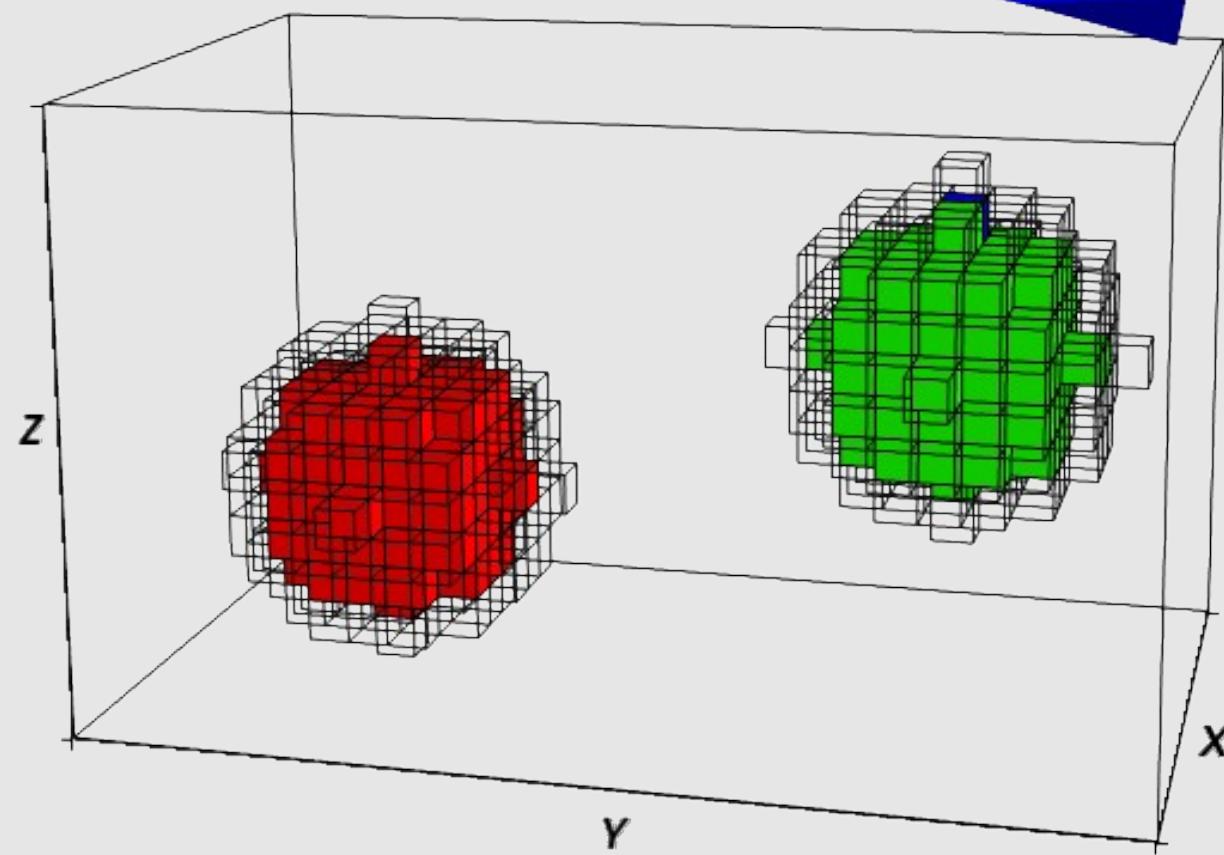
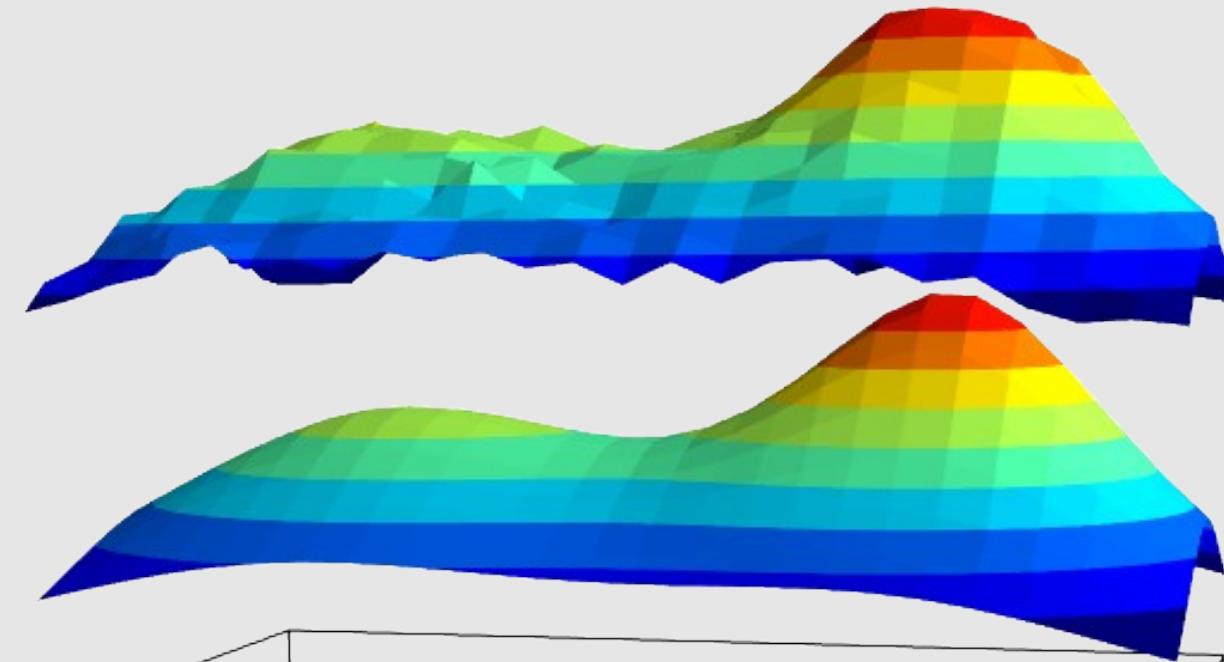


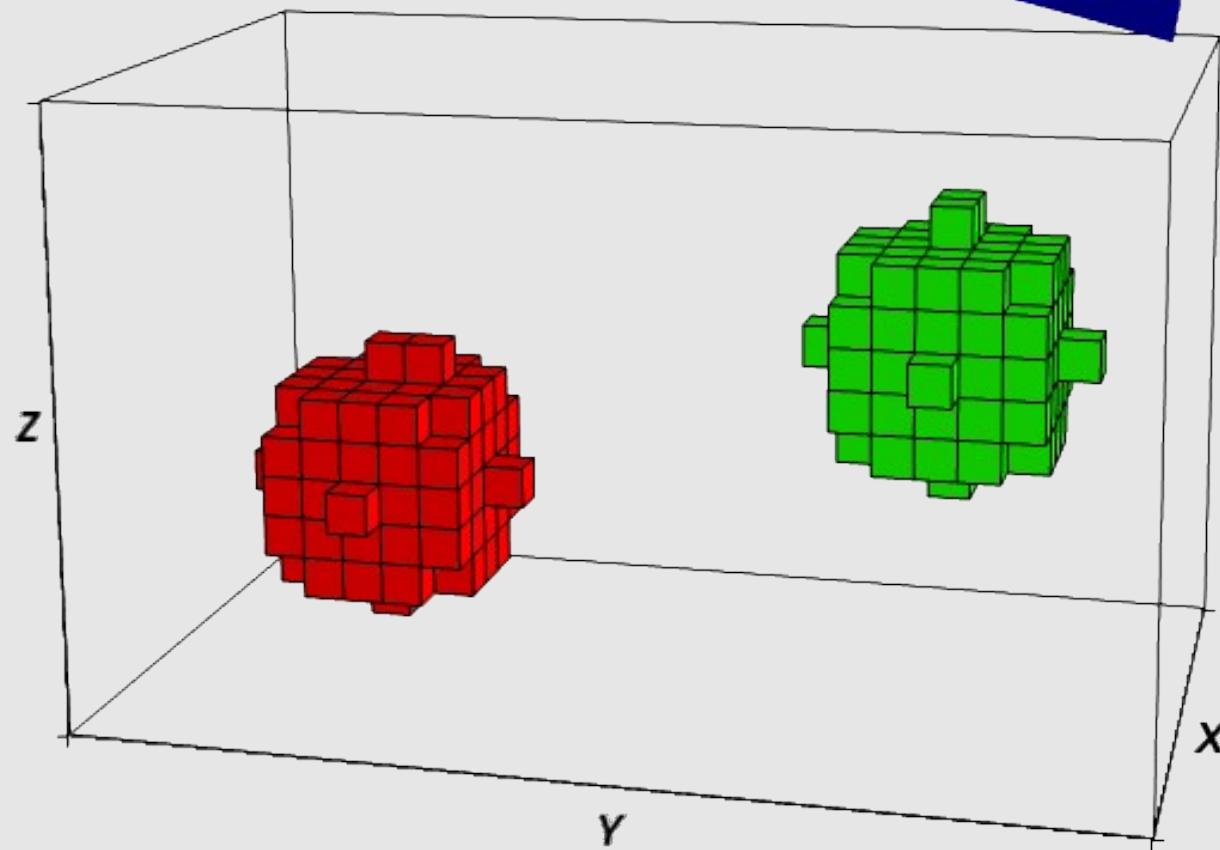
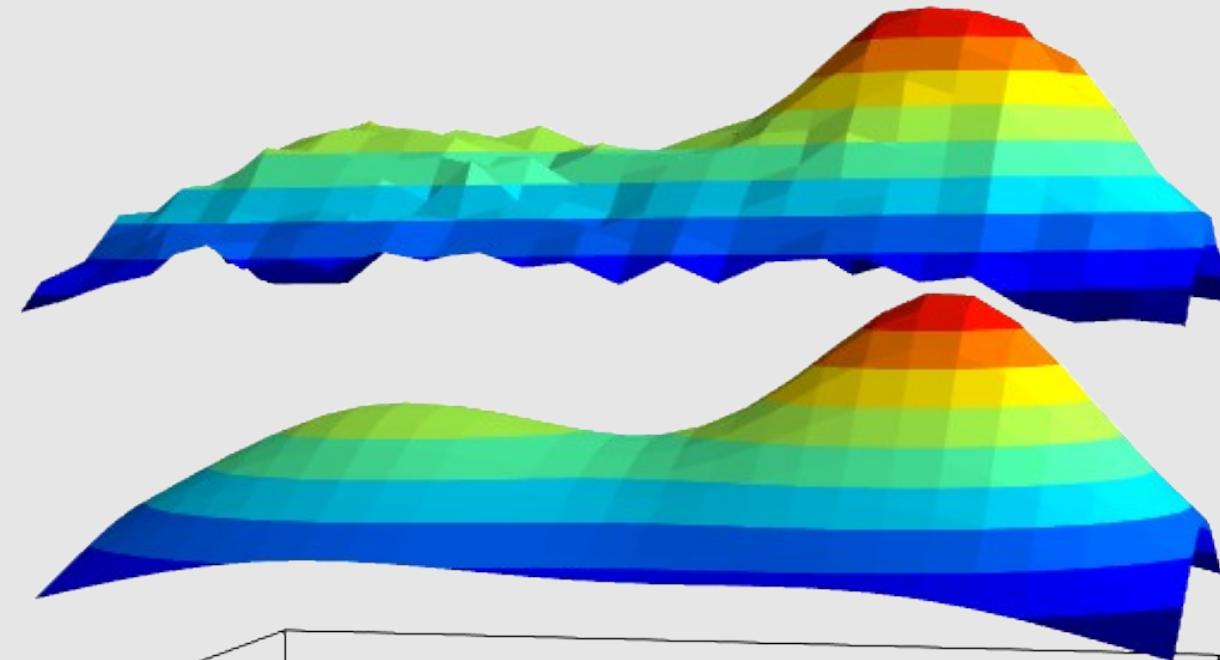










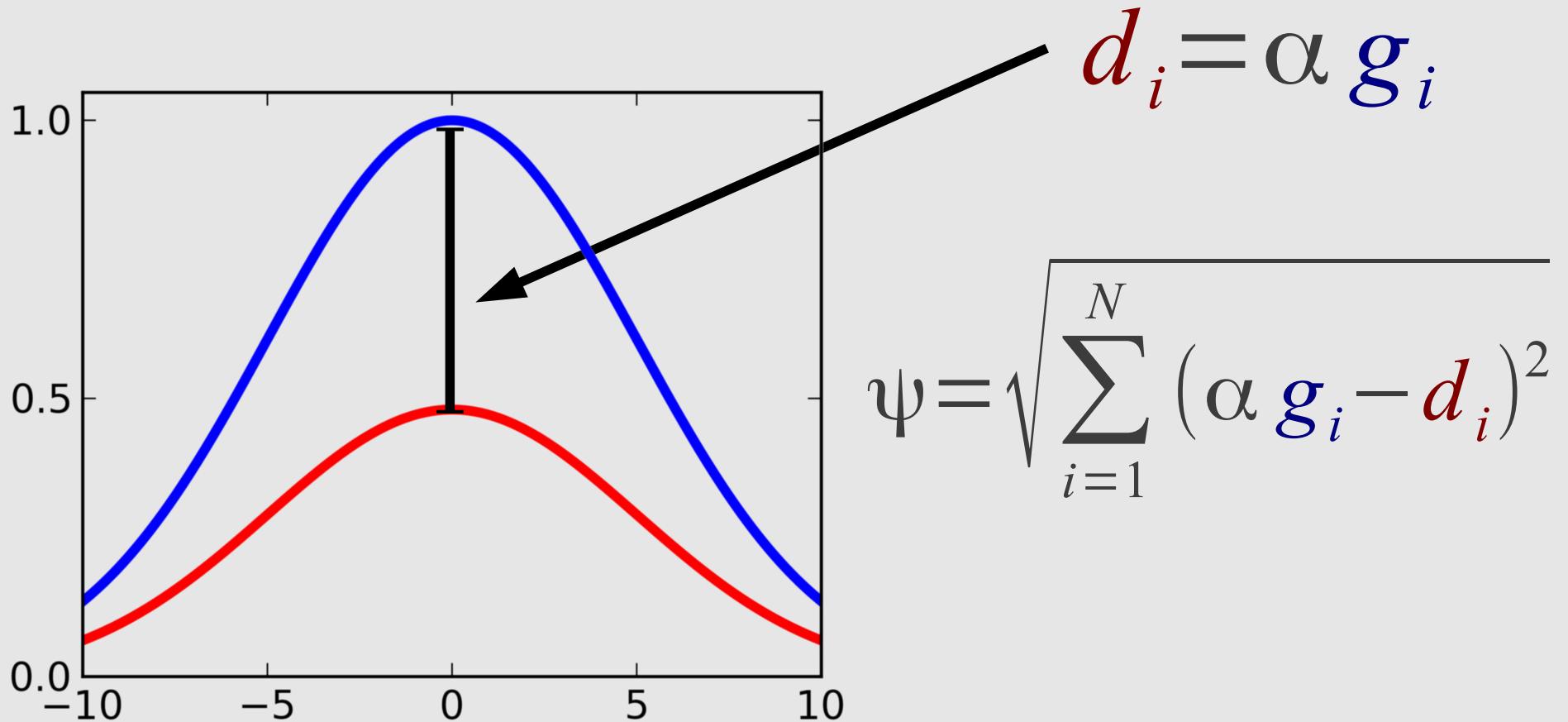


# Vantagens x desvantagens

- ✓ Rápido
- ✓ Pouca memória RAM
- ✓ Incorporar informação geológica
- ✗ Muita informação a priori
- ✗ Sensível a posição das sementes

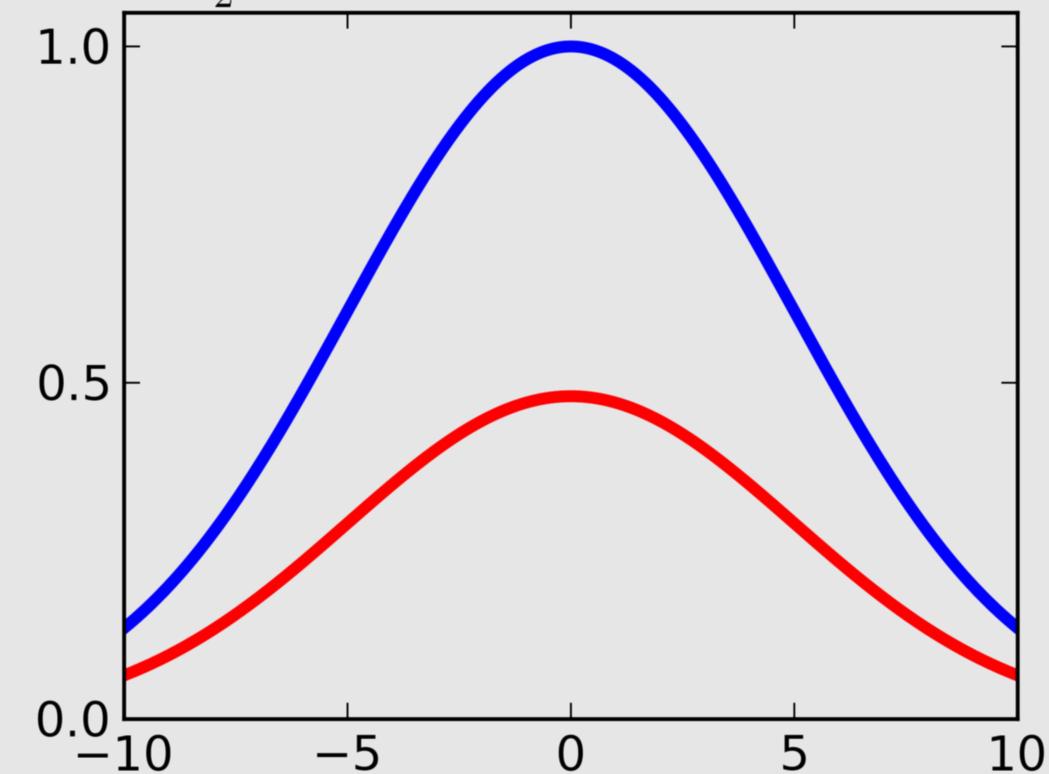
# Aprimoramentos

- Função “shape-of-anomaly”



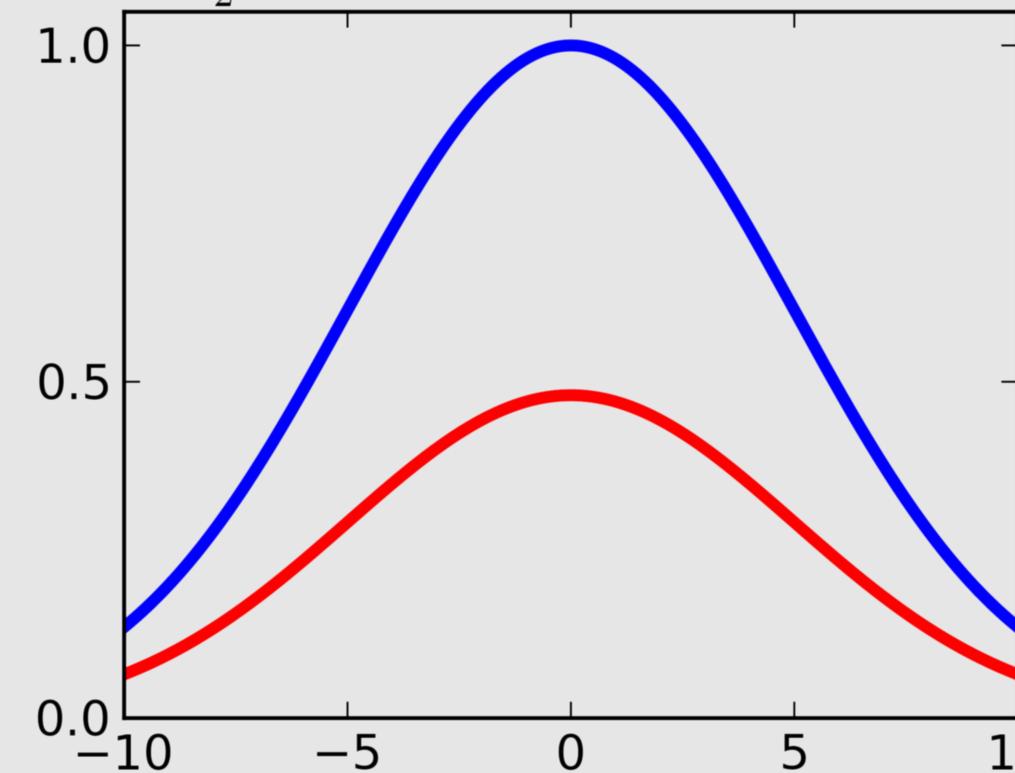
# Diferença de forma

shape-of-anomaly = 0.00  
 $\ell_2$ -norm data-misfit = 0.52

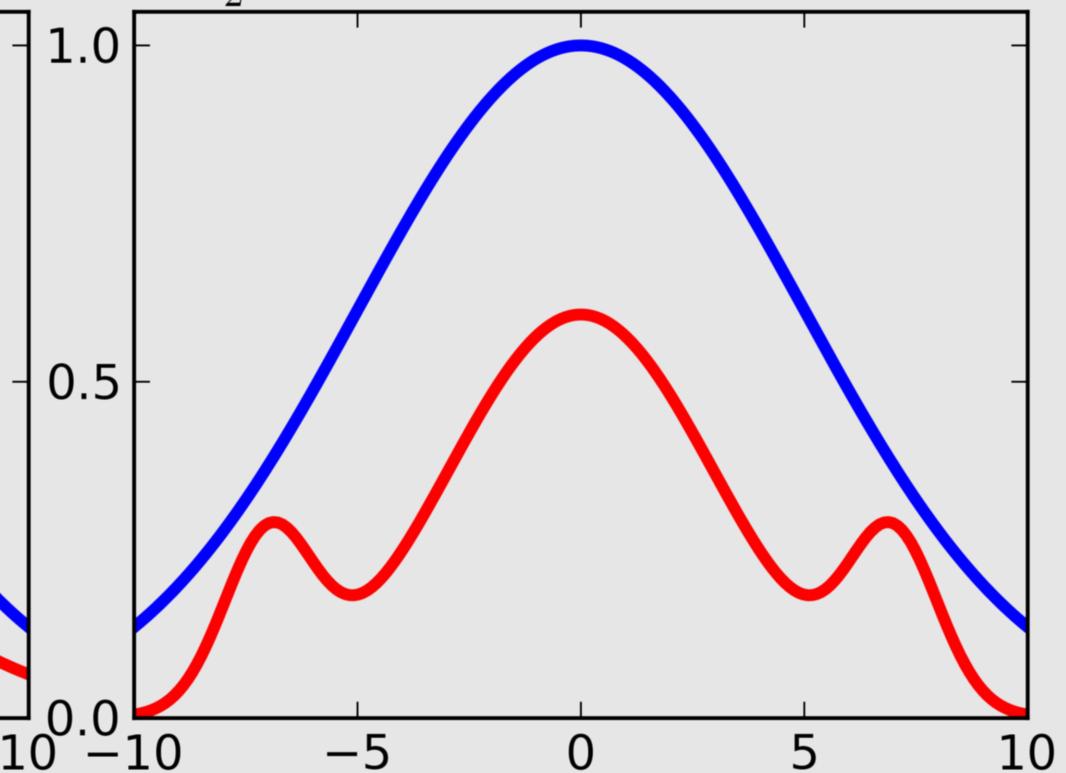


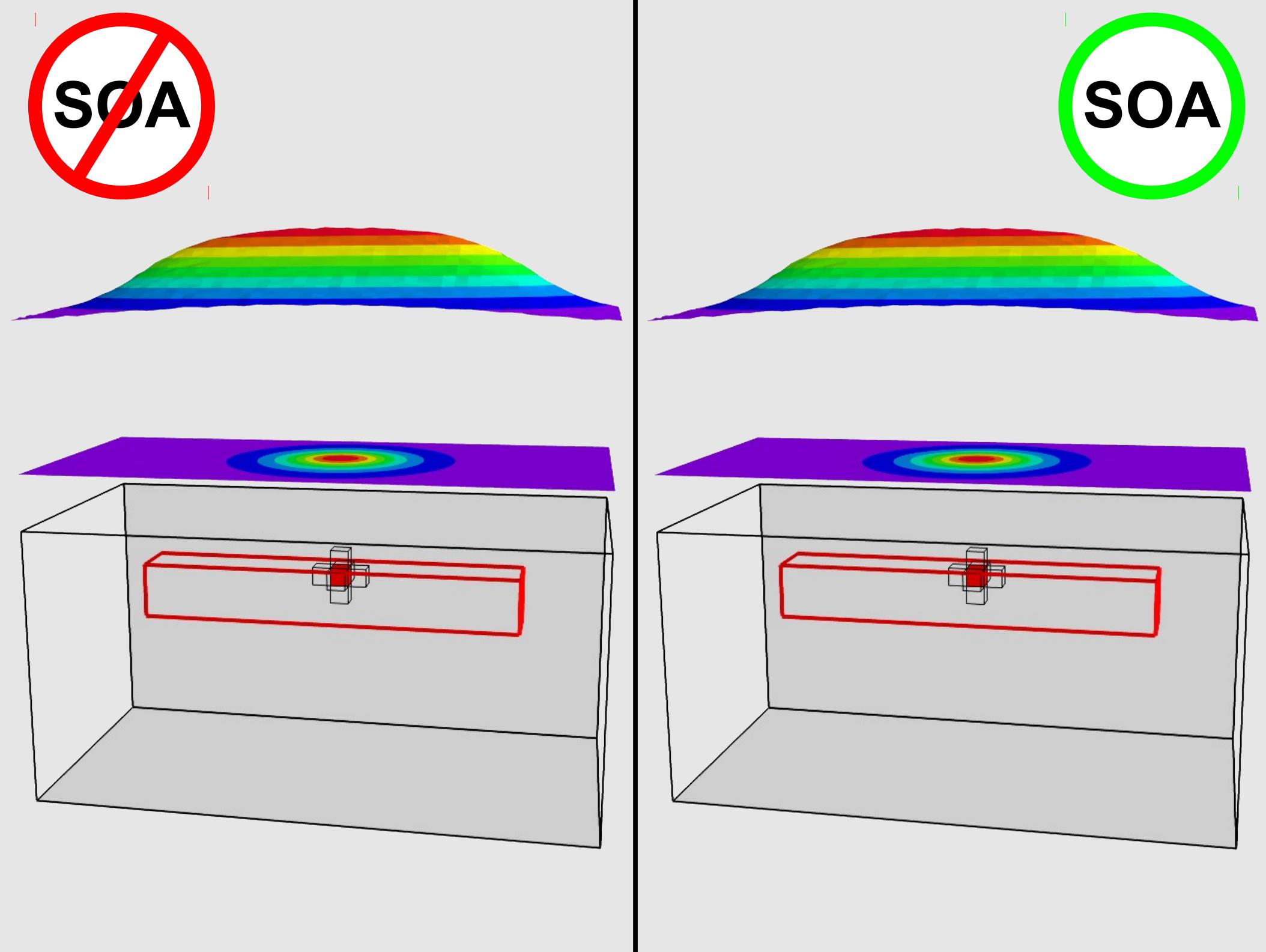
# Diferença de forma

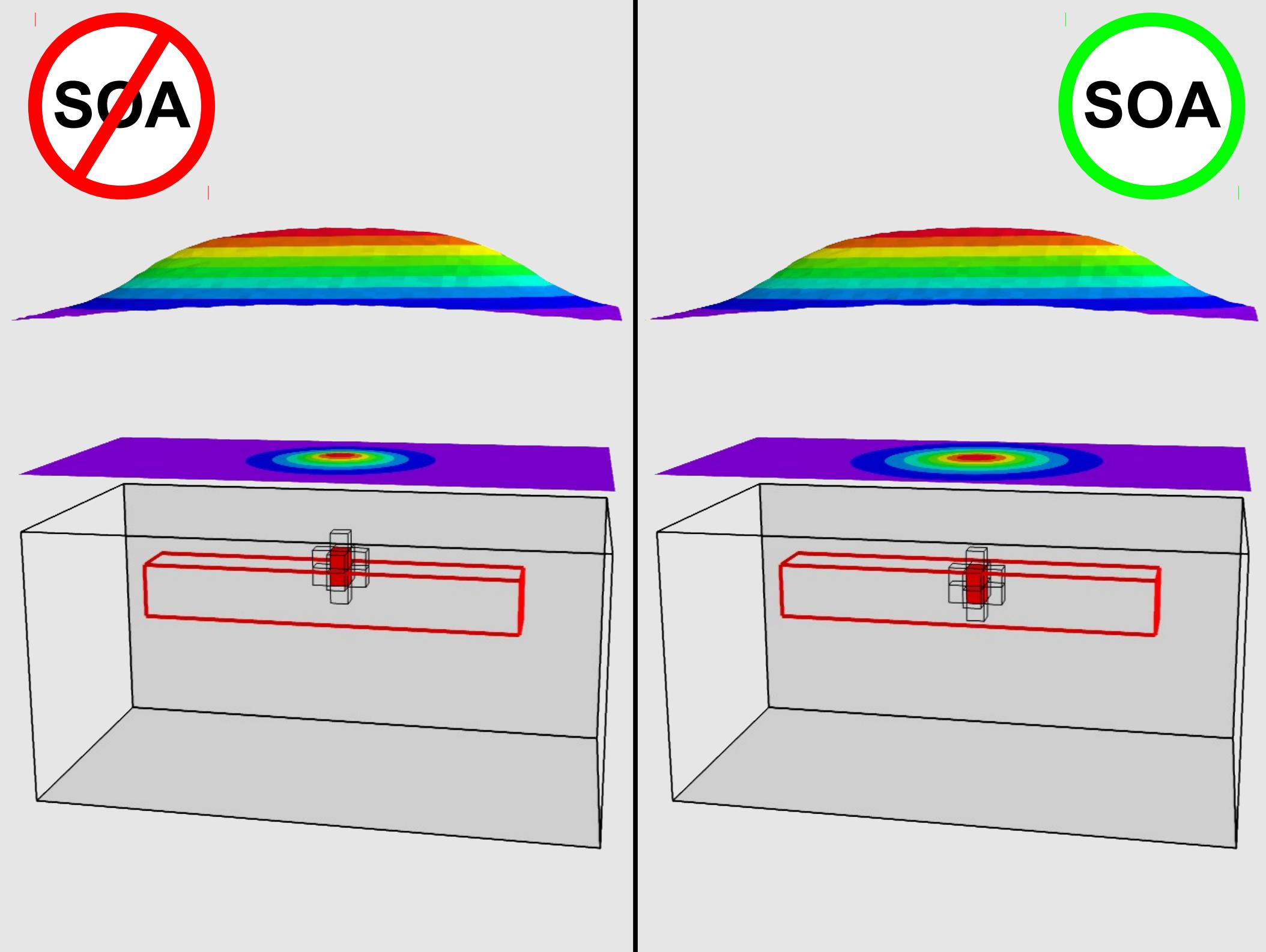
shape-of-anomaly = 0.00  
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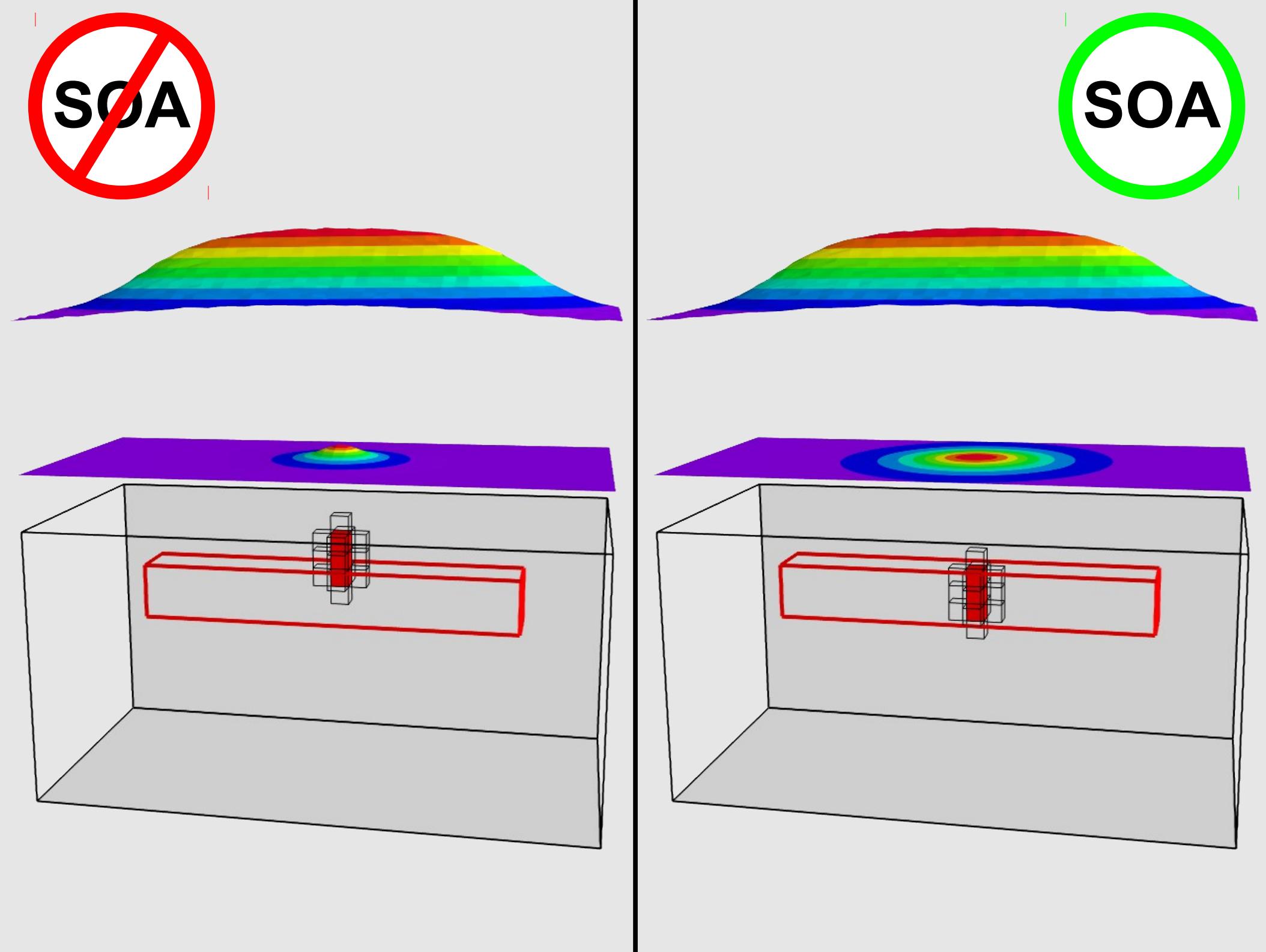


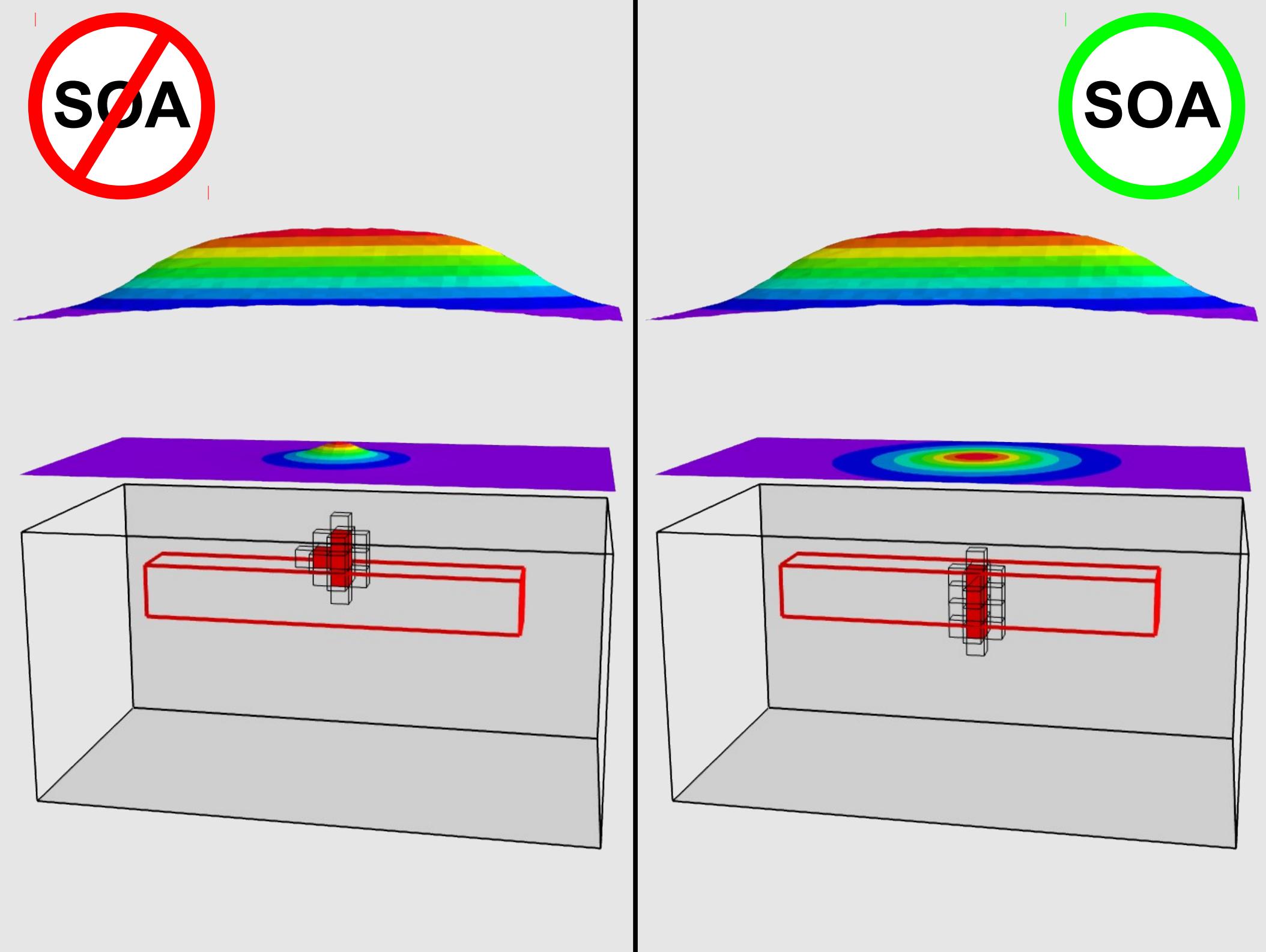
shape-of-anomaly = 1.08  
 $\ell_2$ -norm data-misfit = 0.52









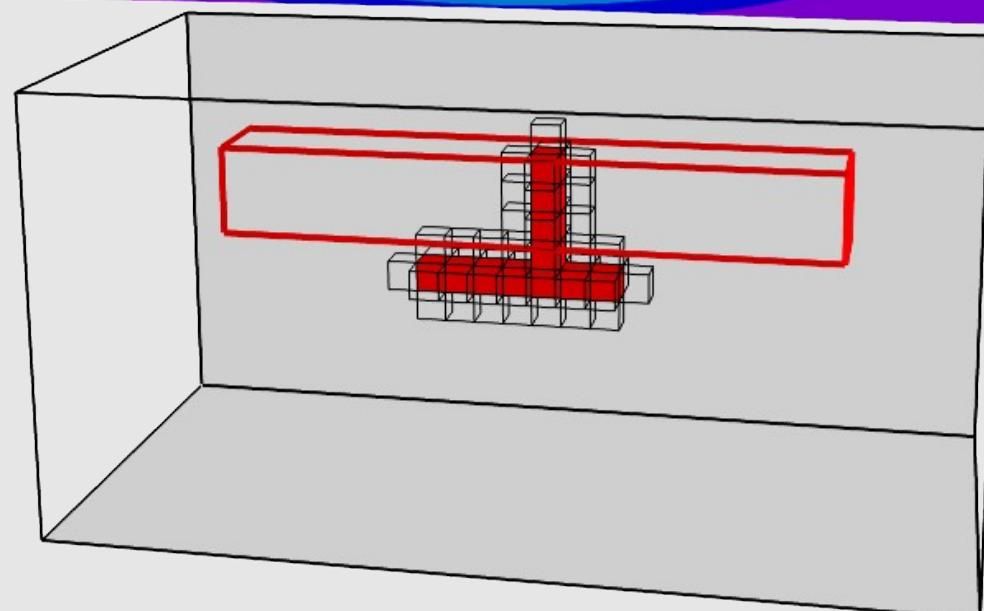
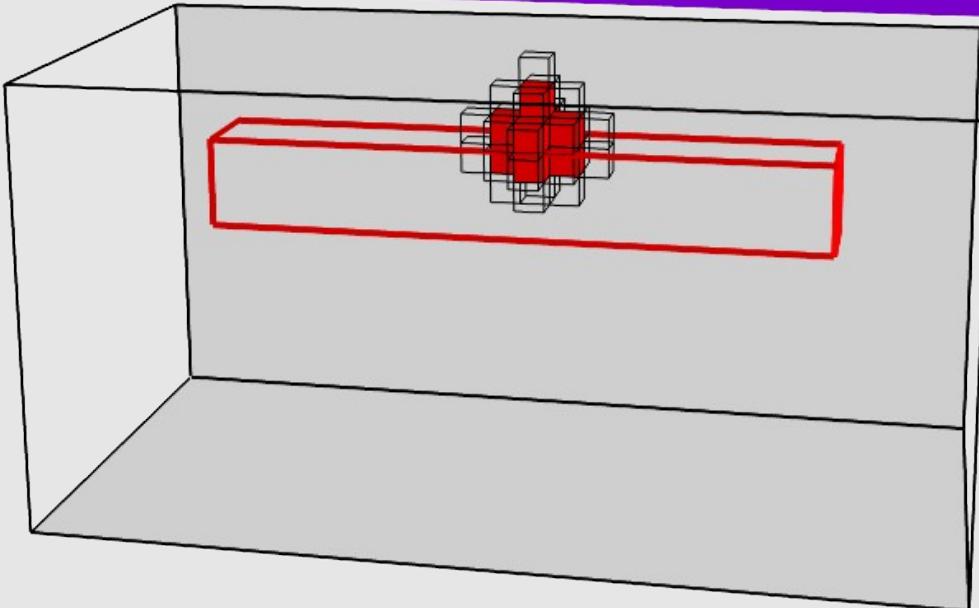
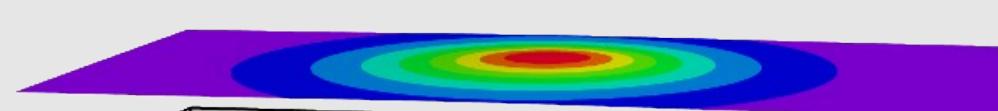
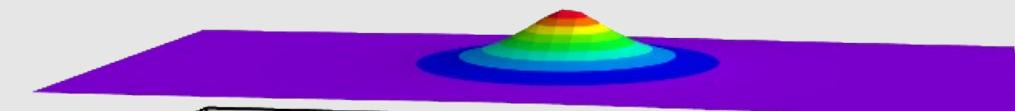
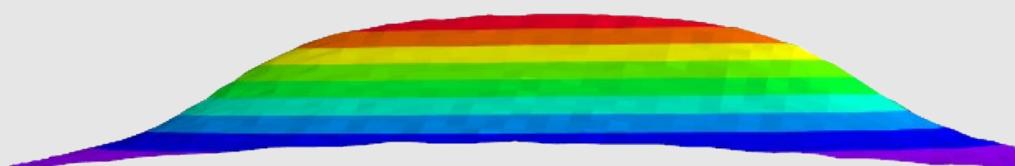
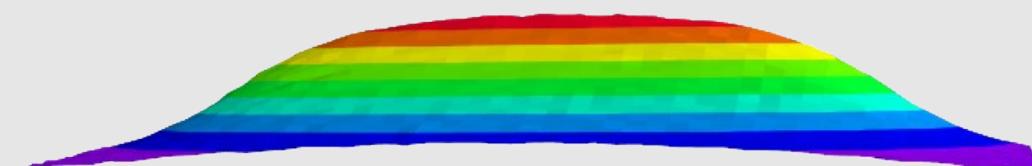


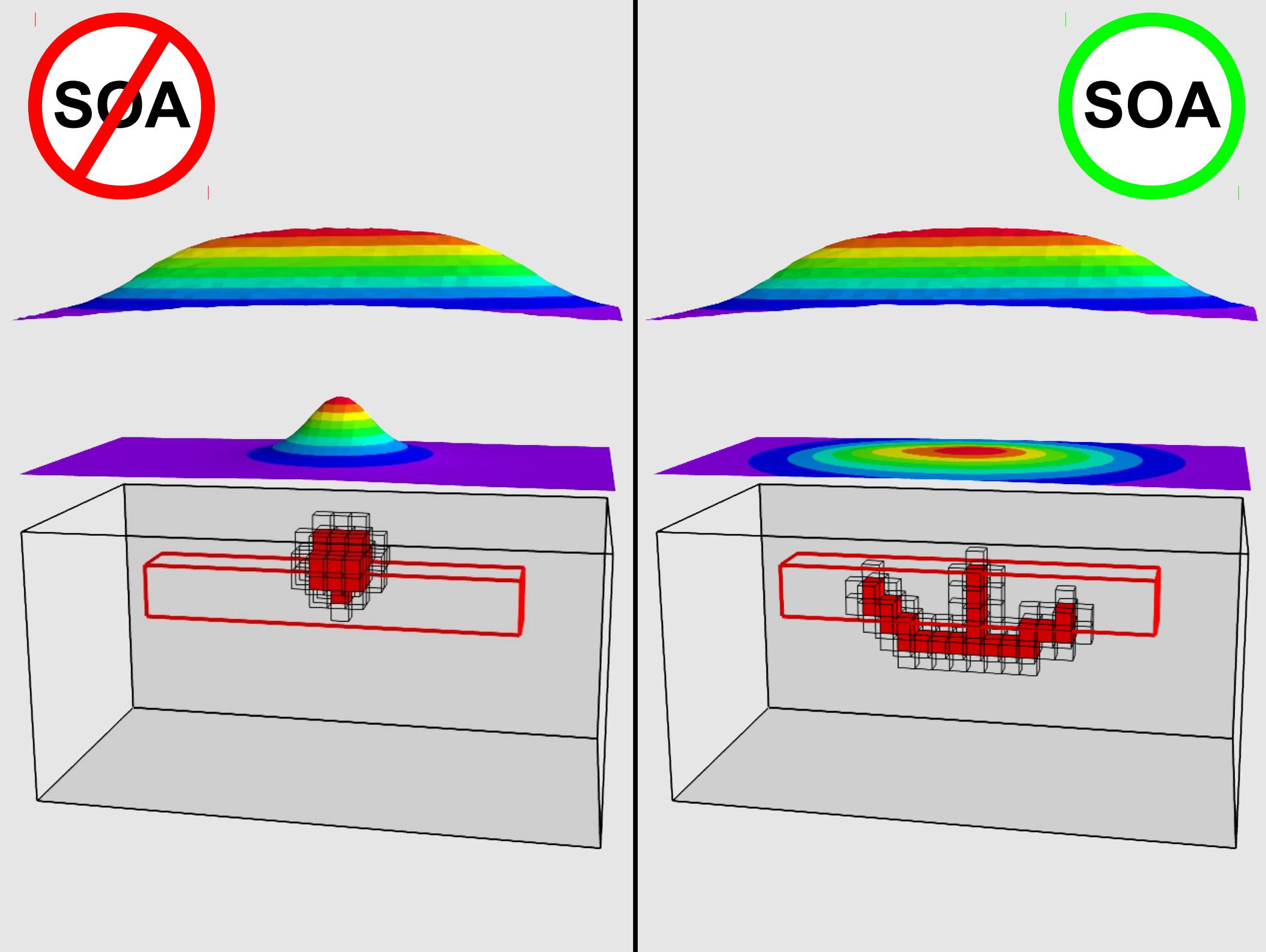


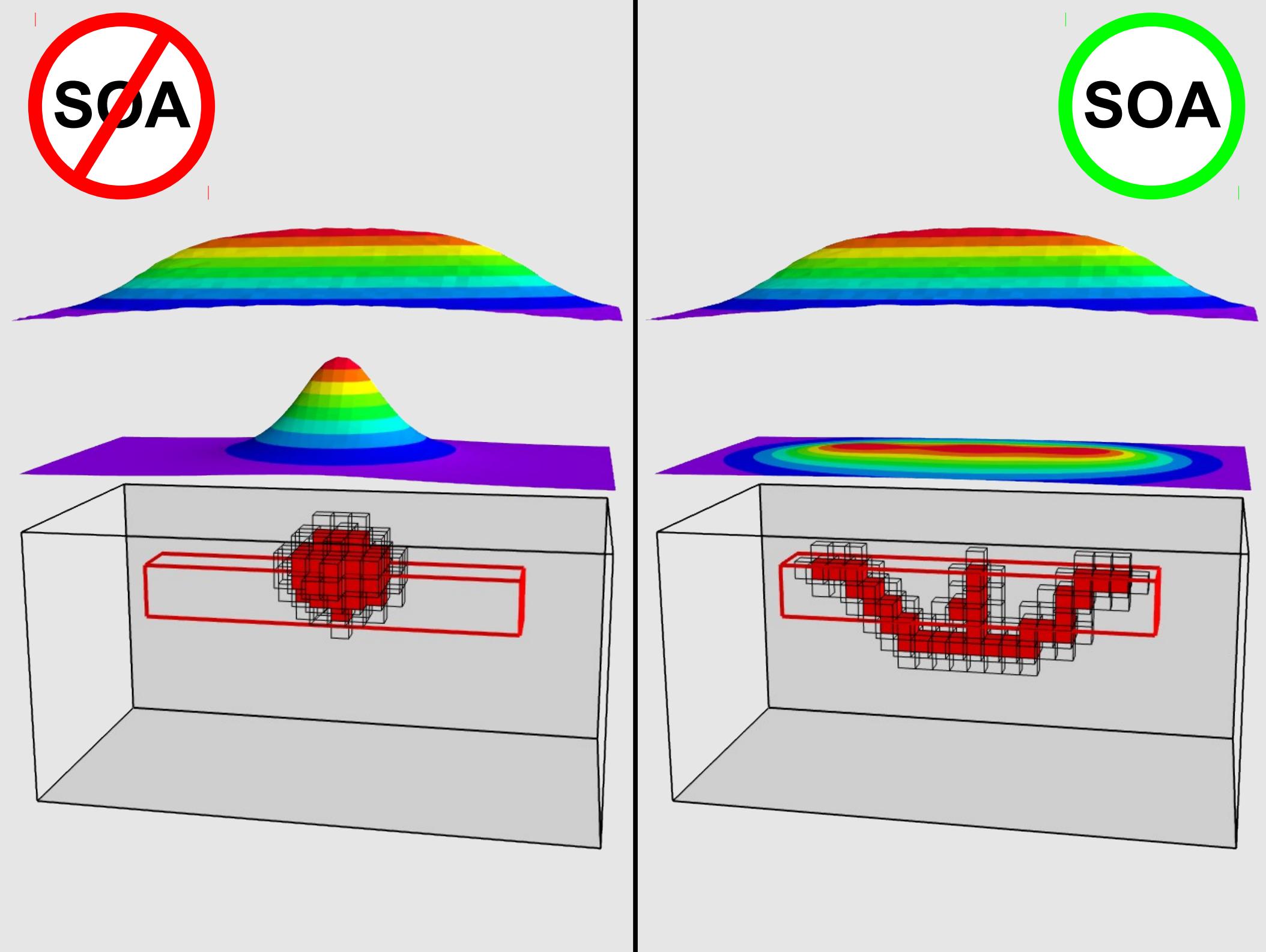
**SOA**

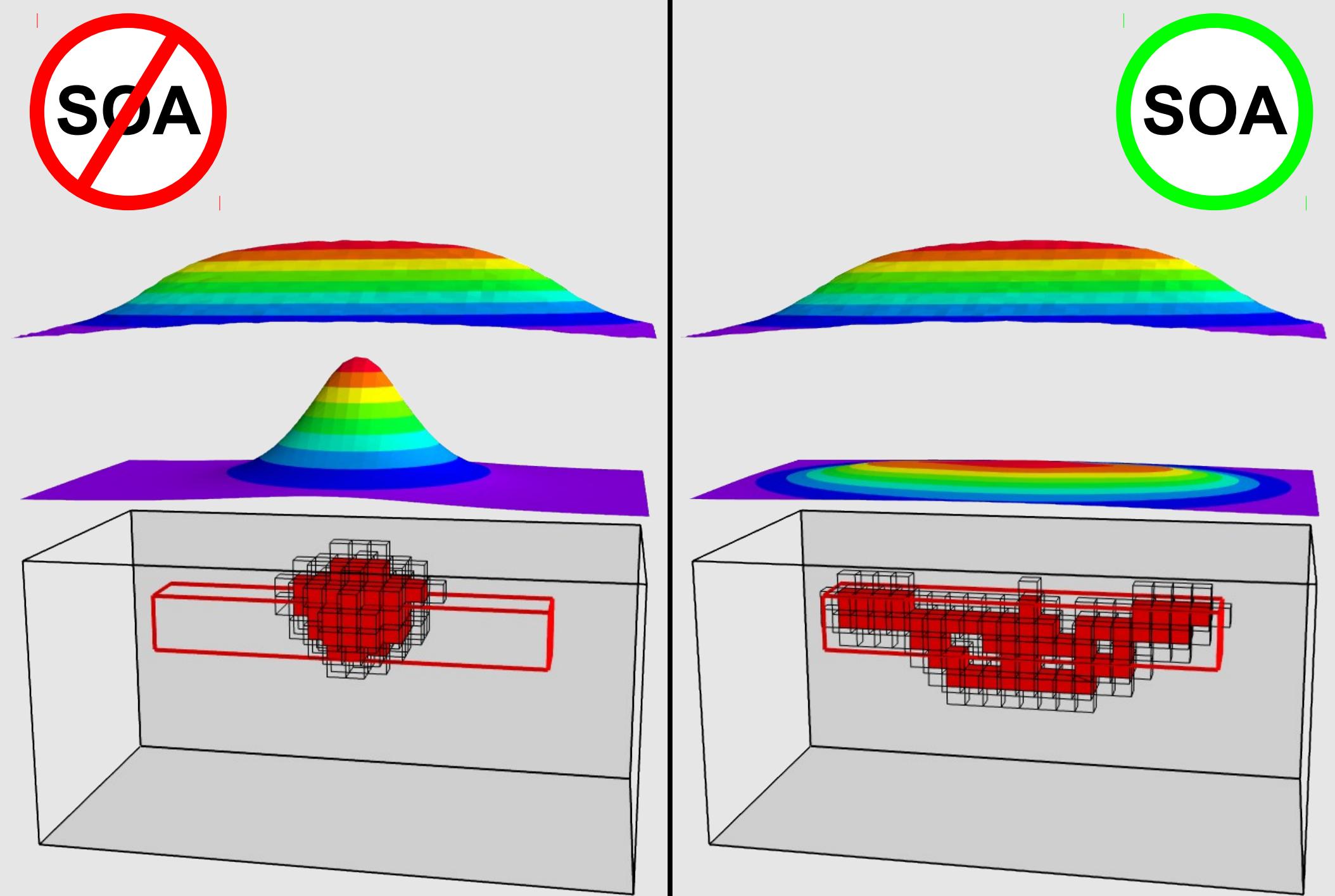


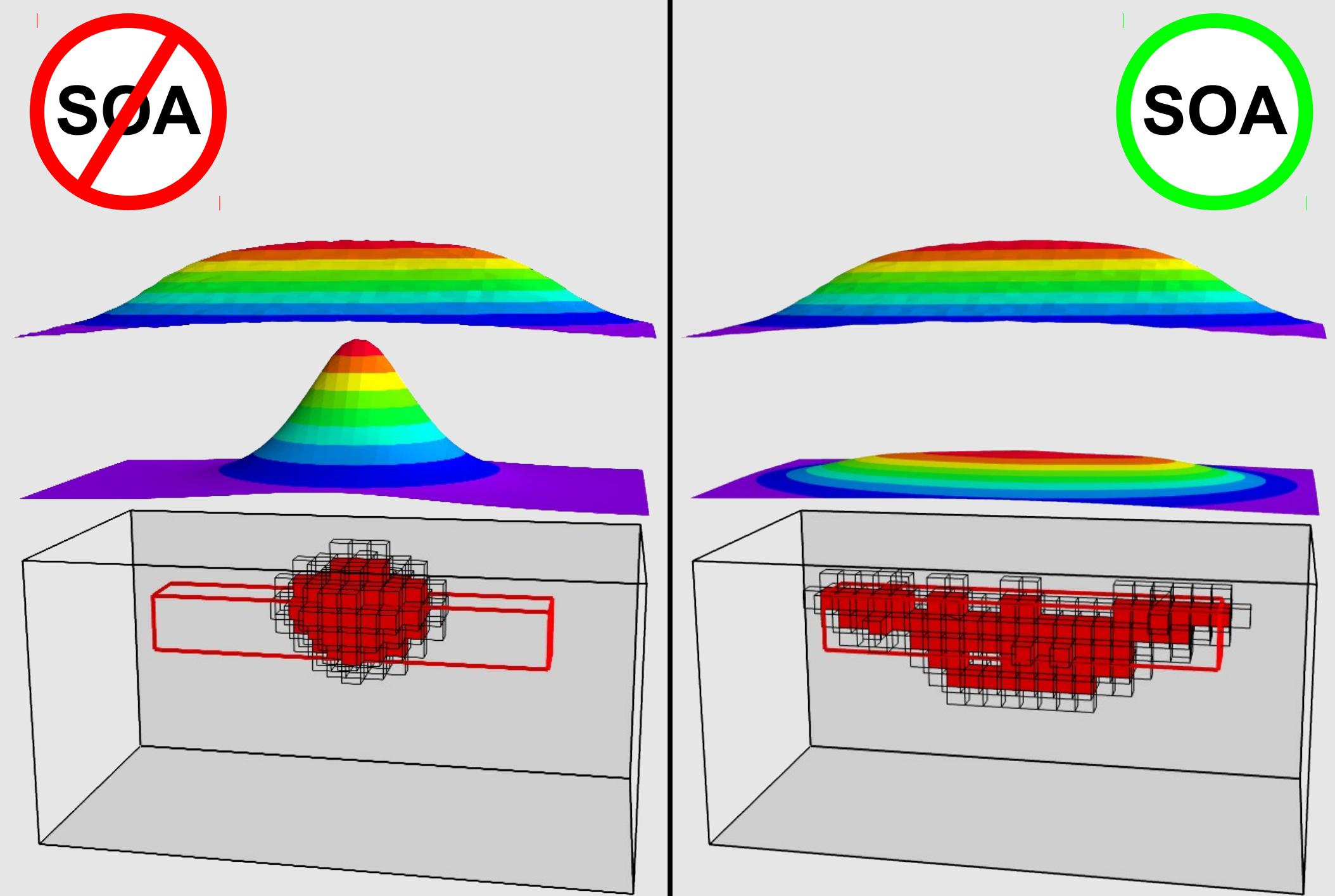
**SOA**

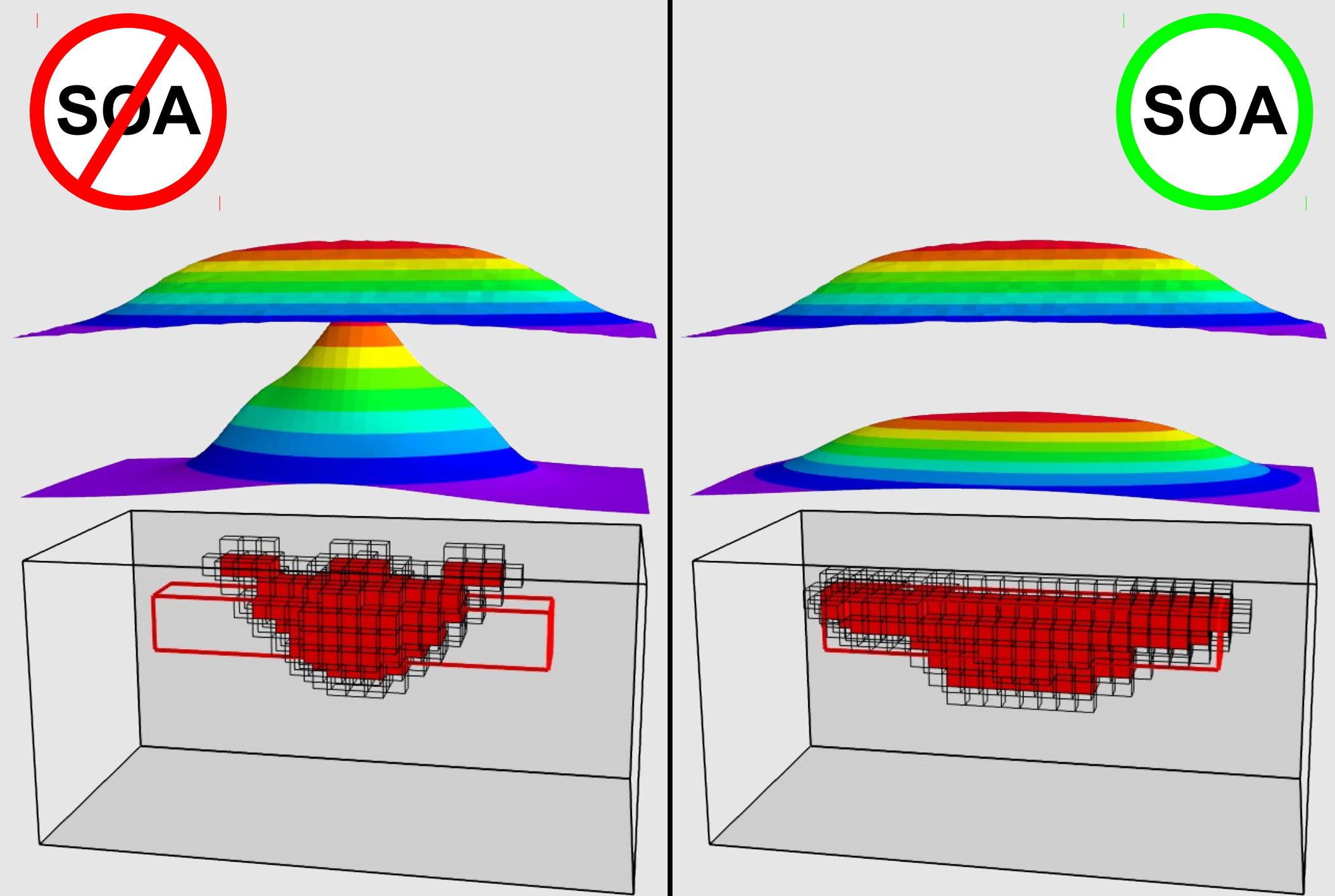










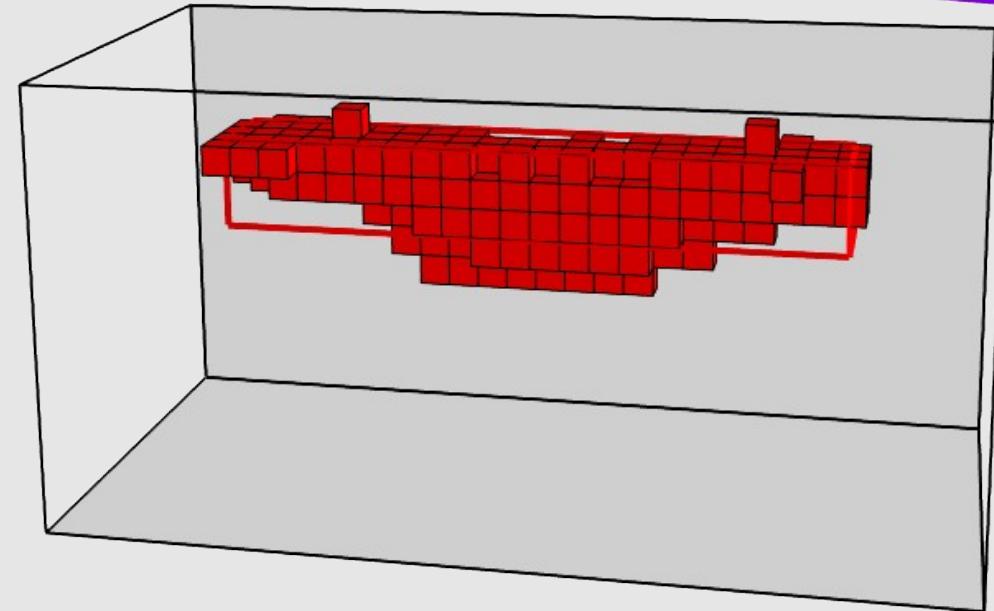
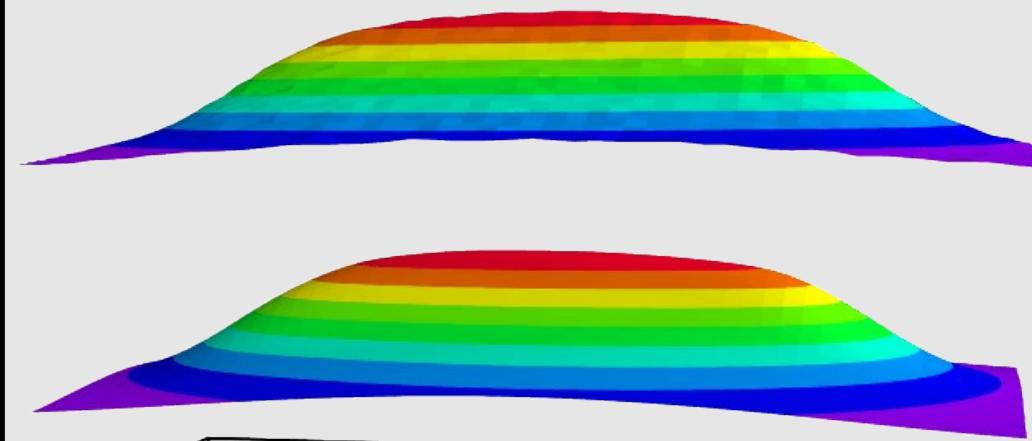
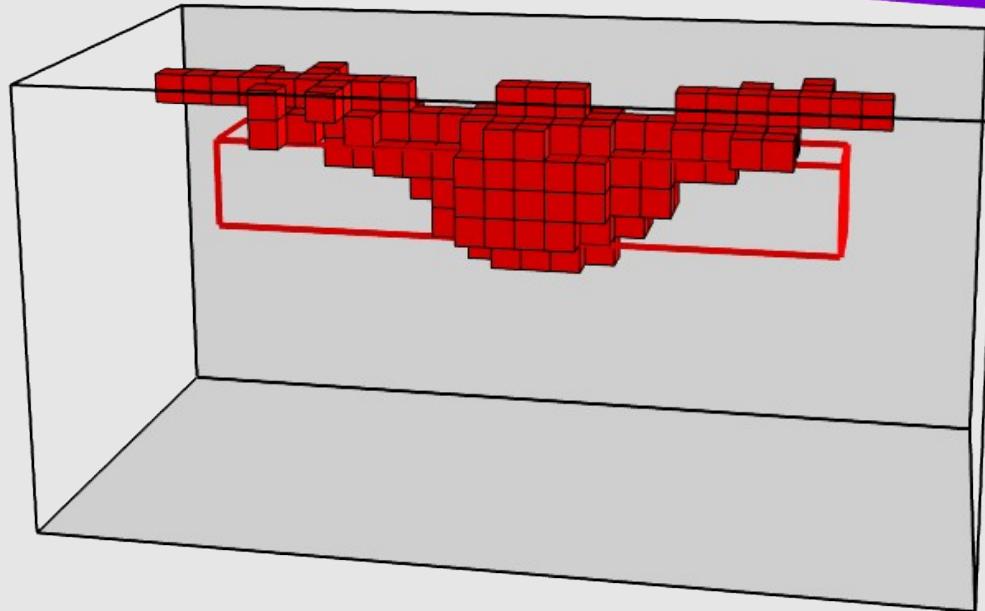
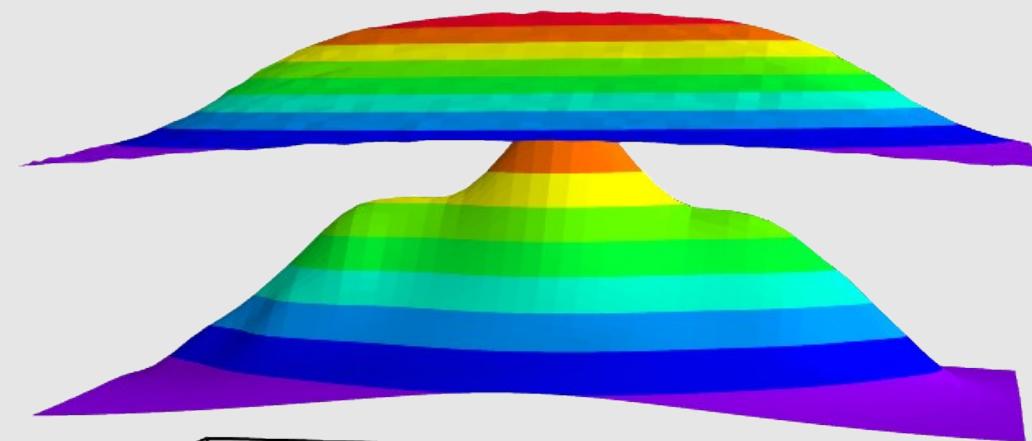




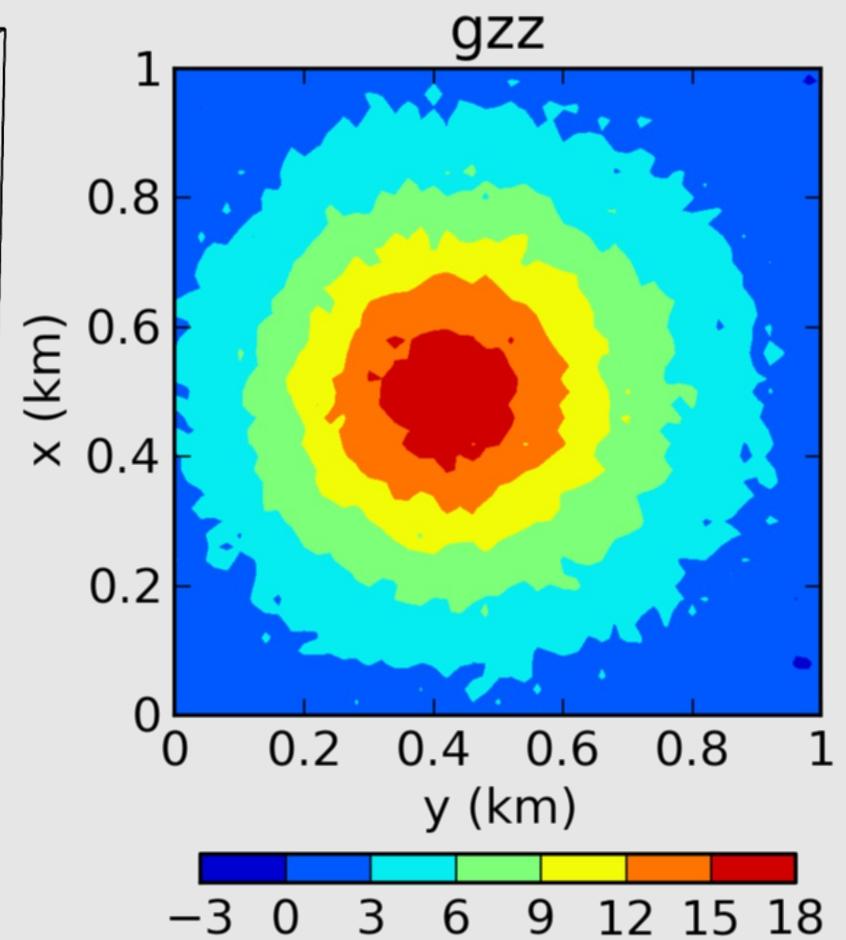
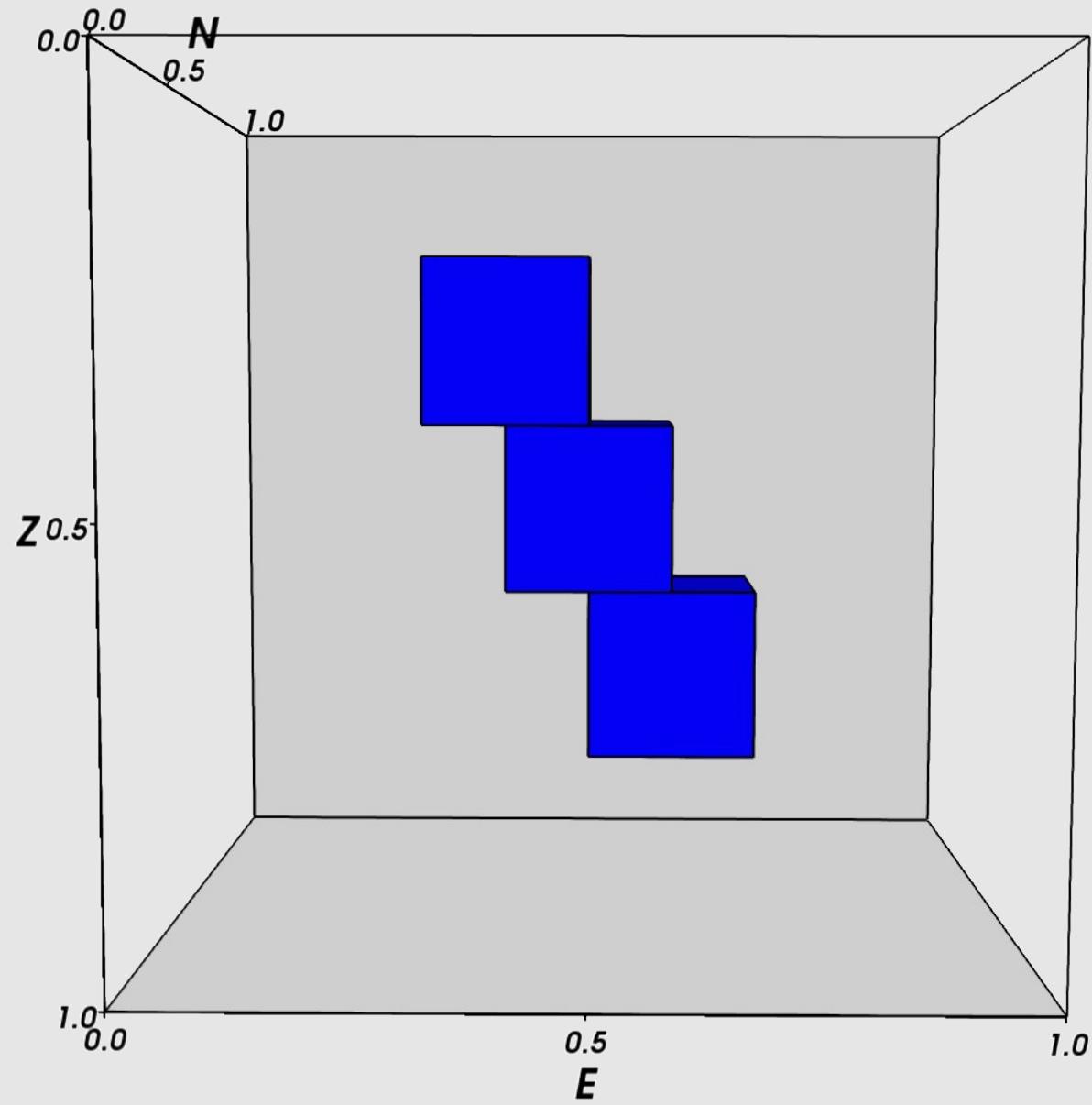
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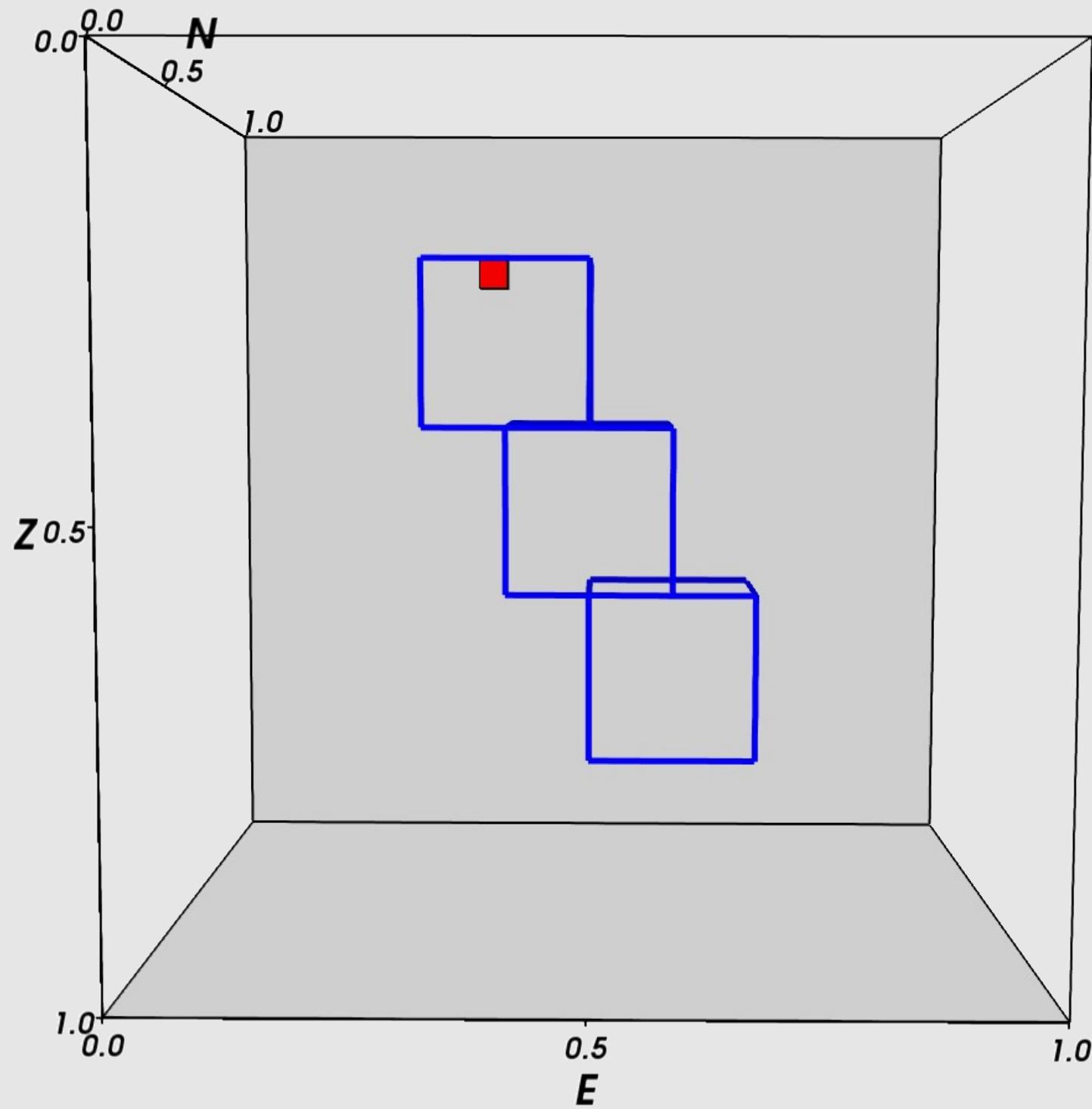


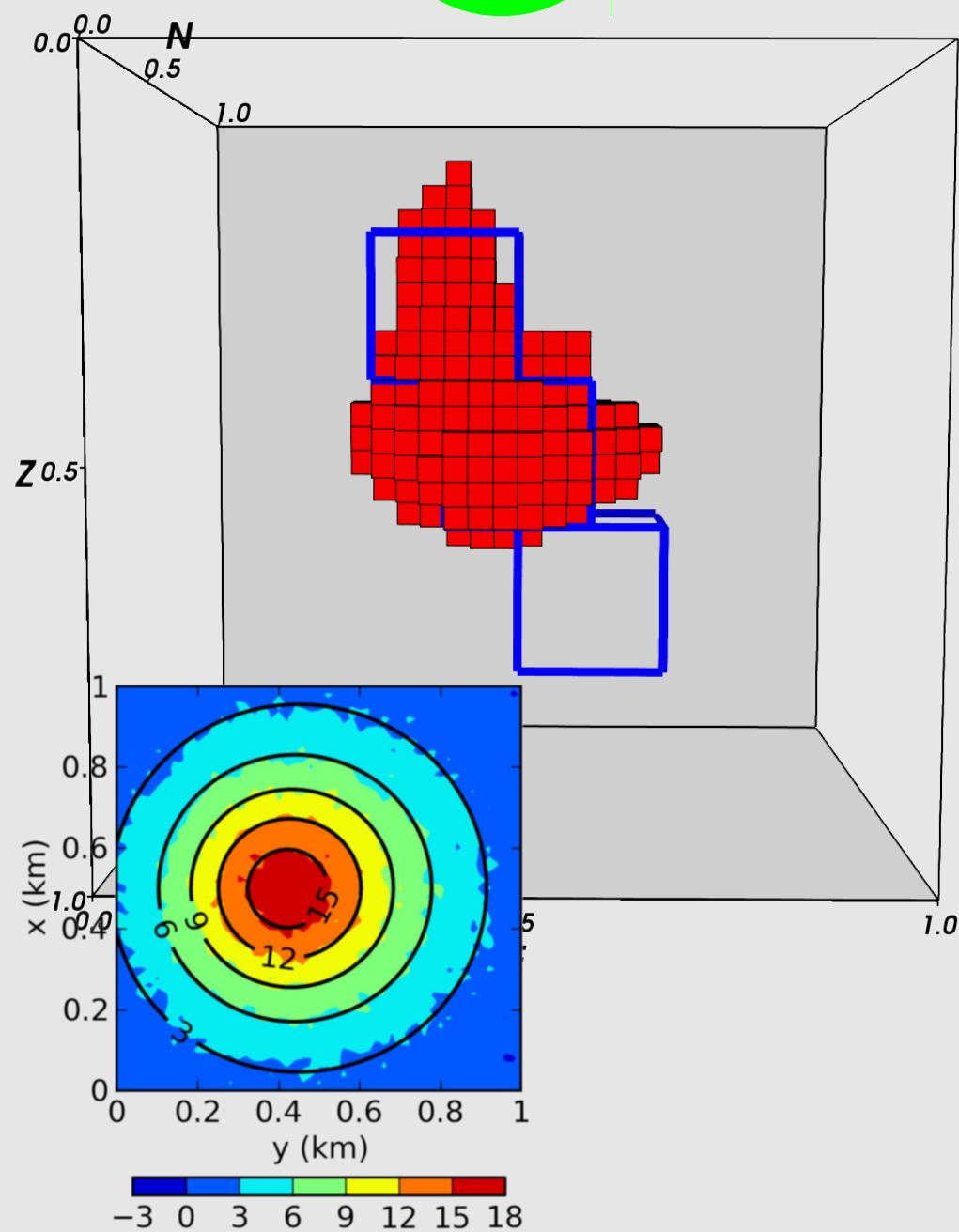
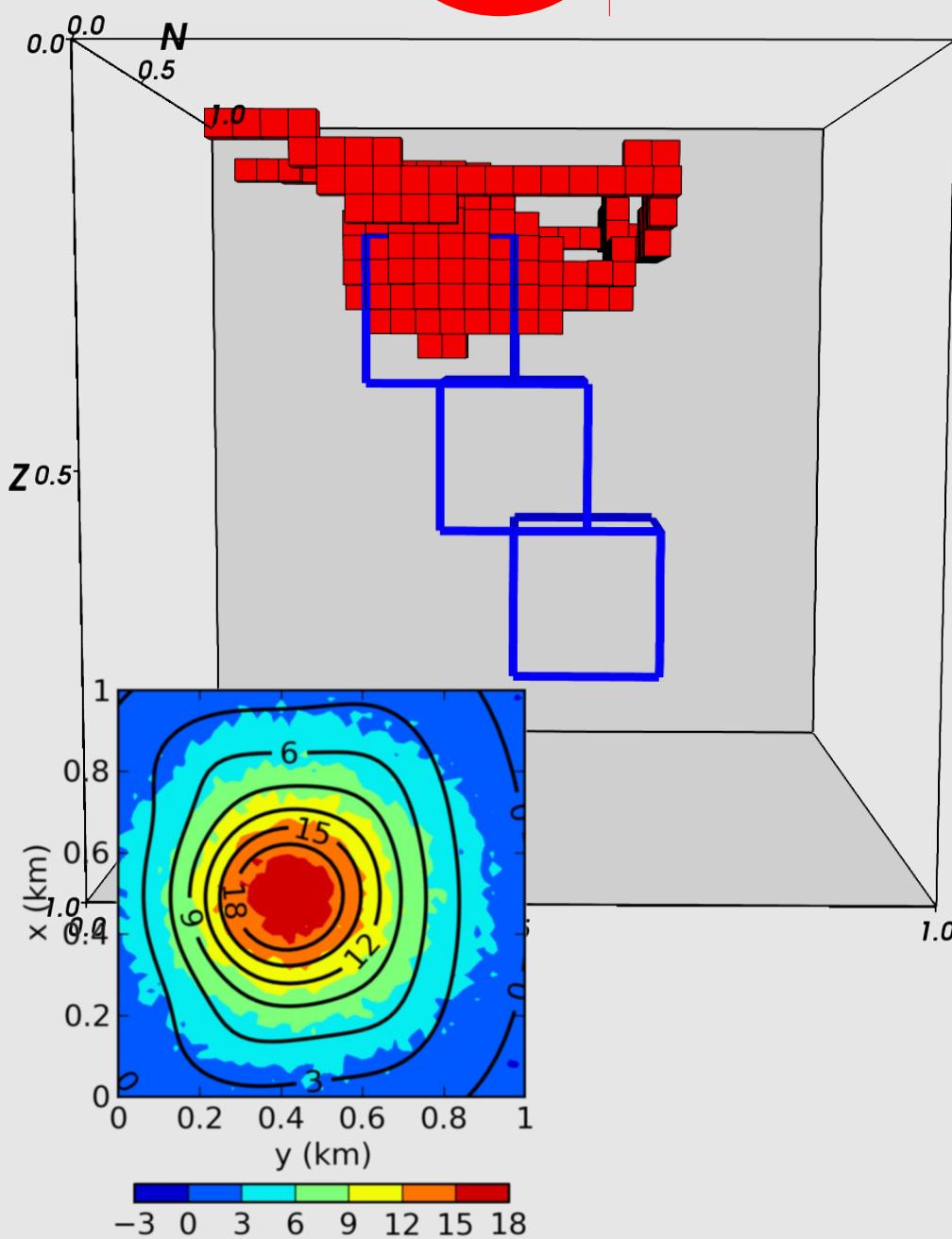
**SOA**

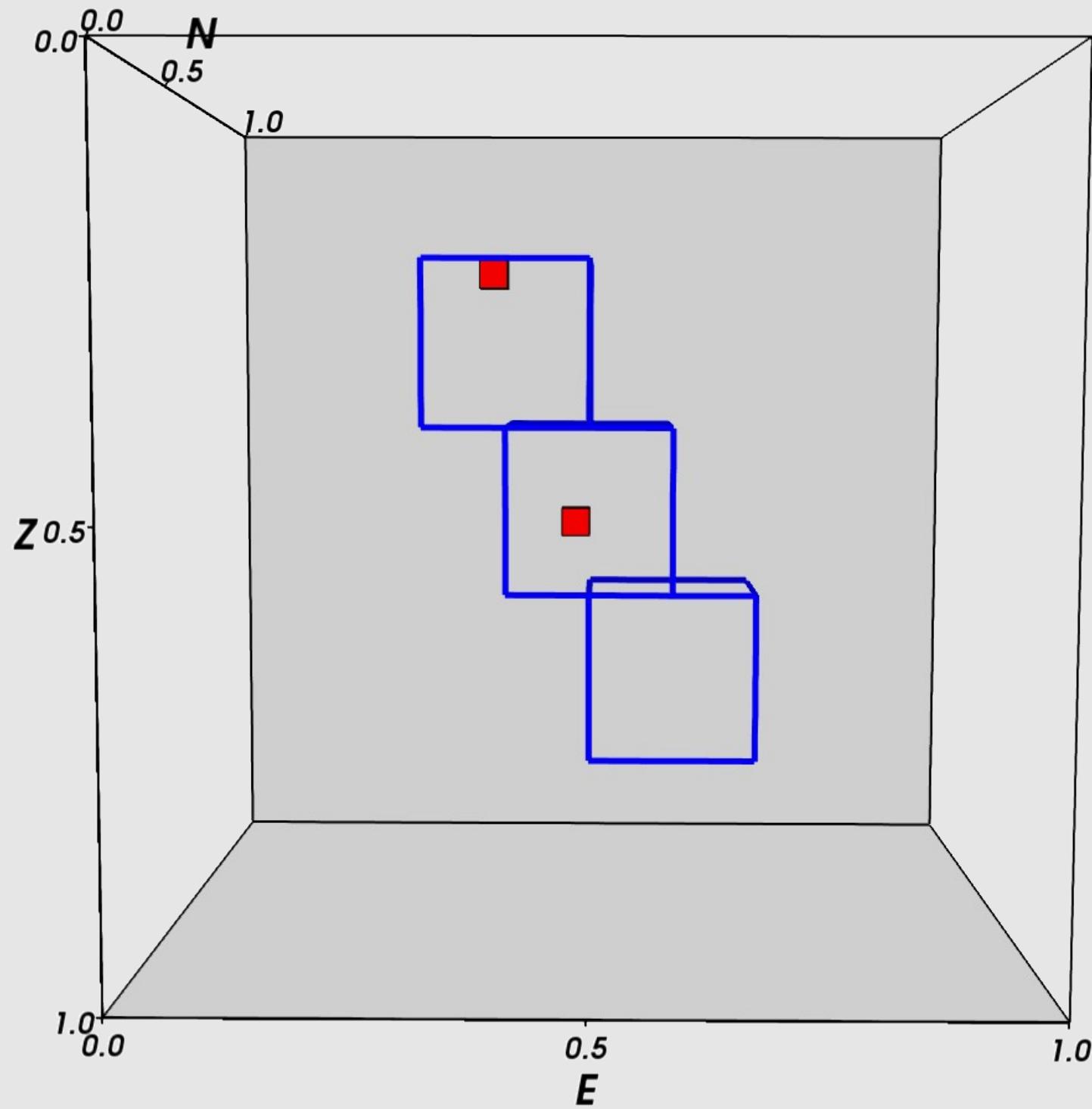


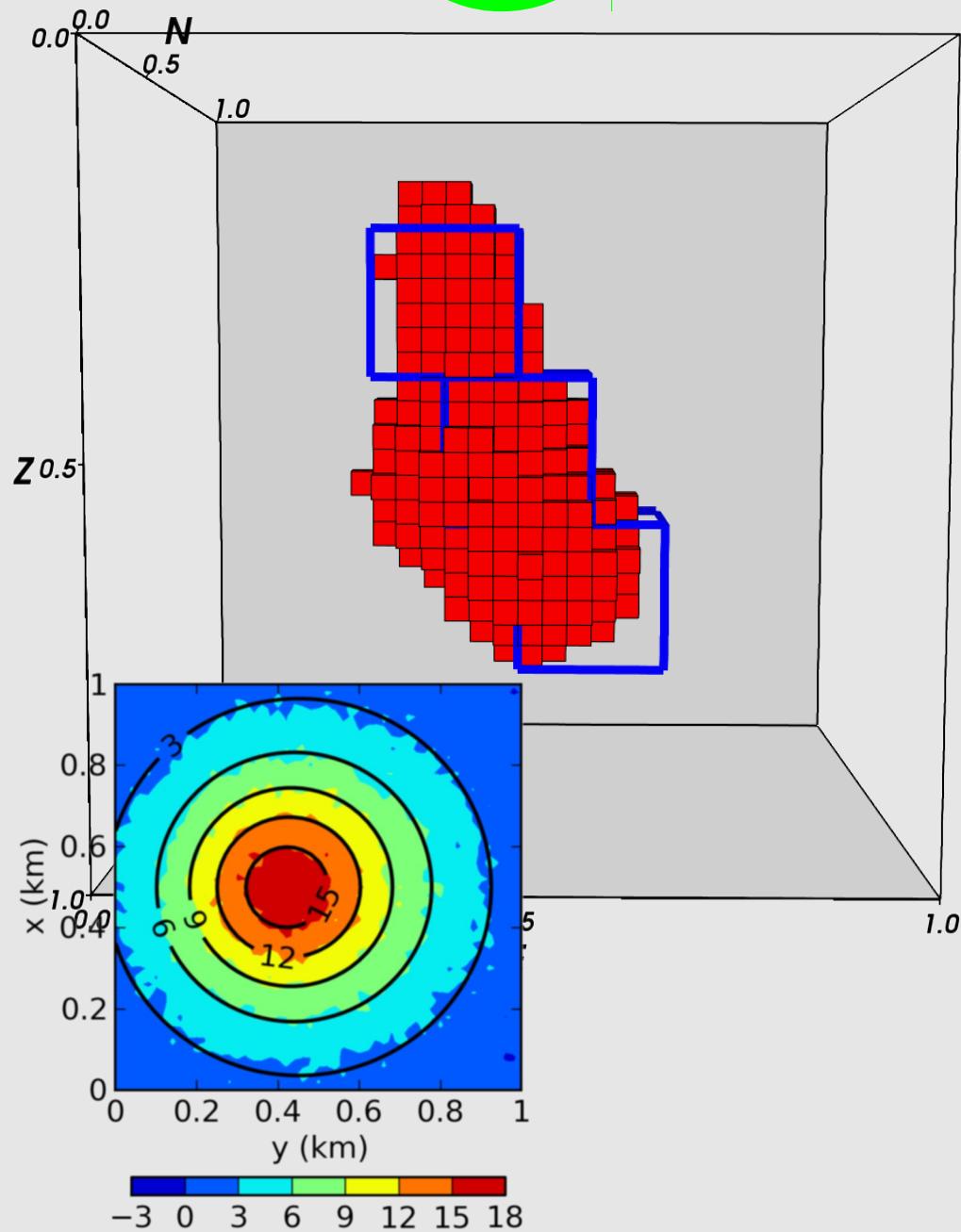
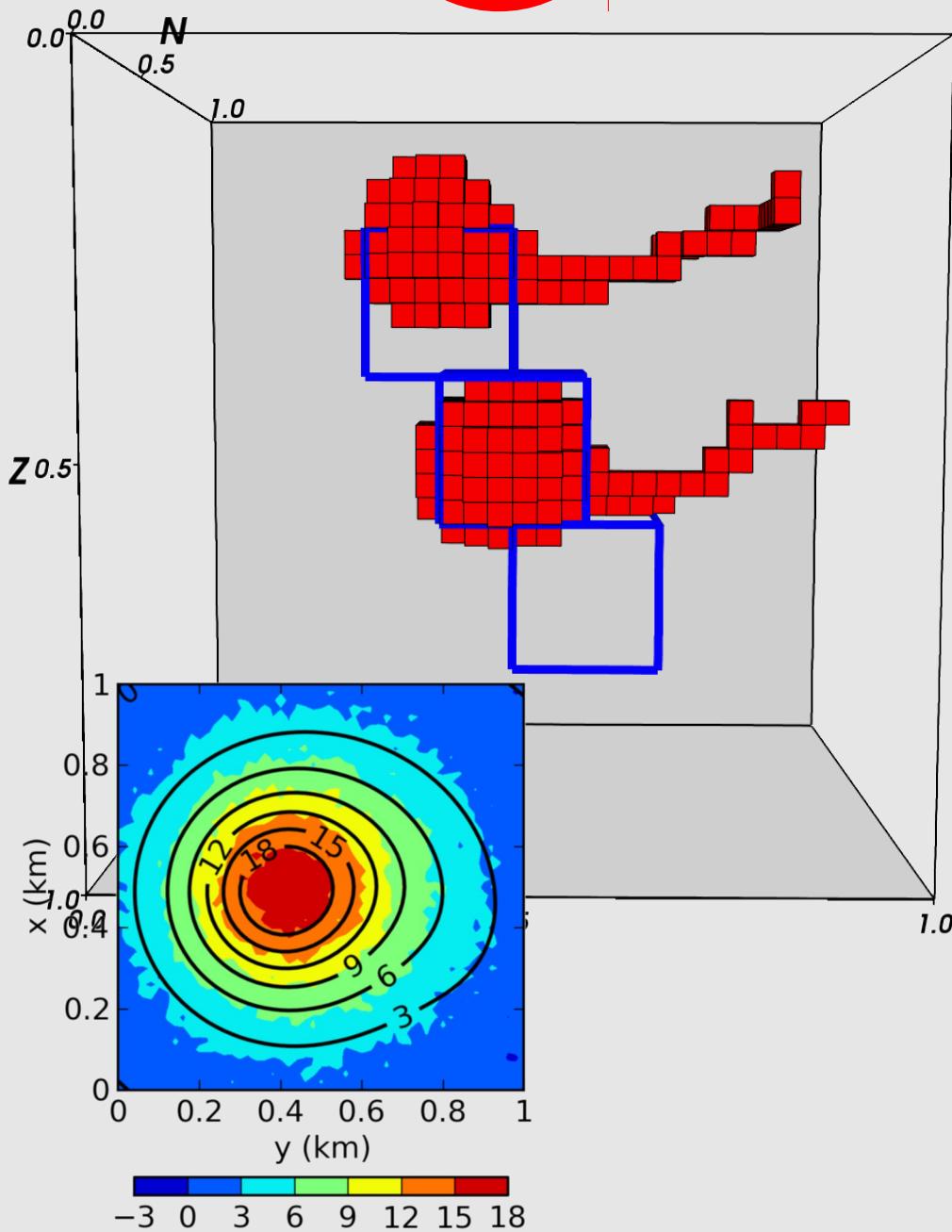
# Sensibilidade

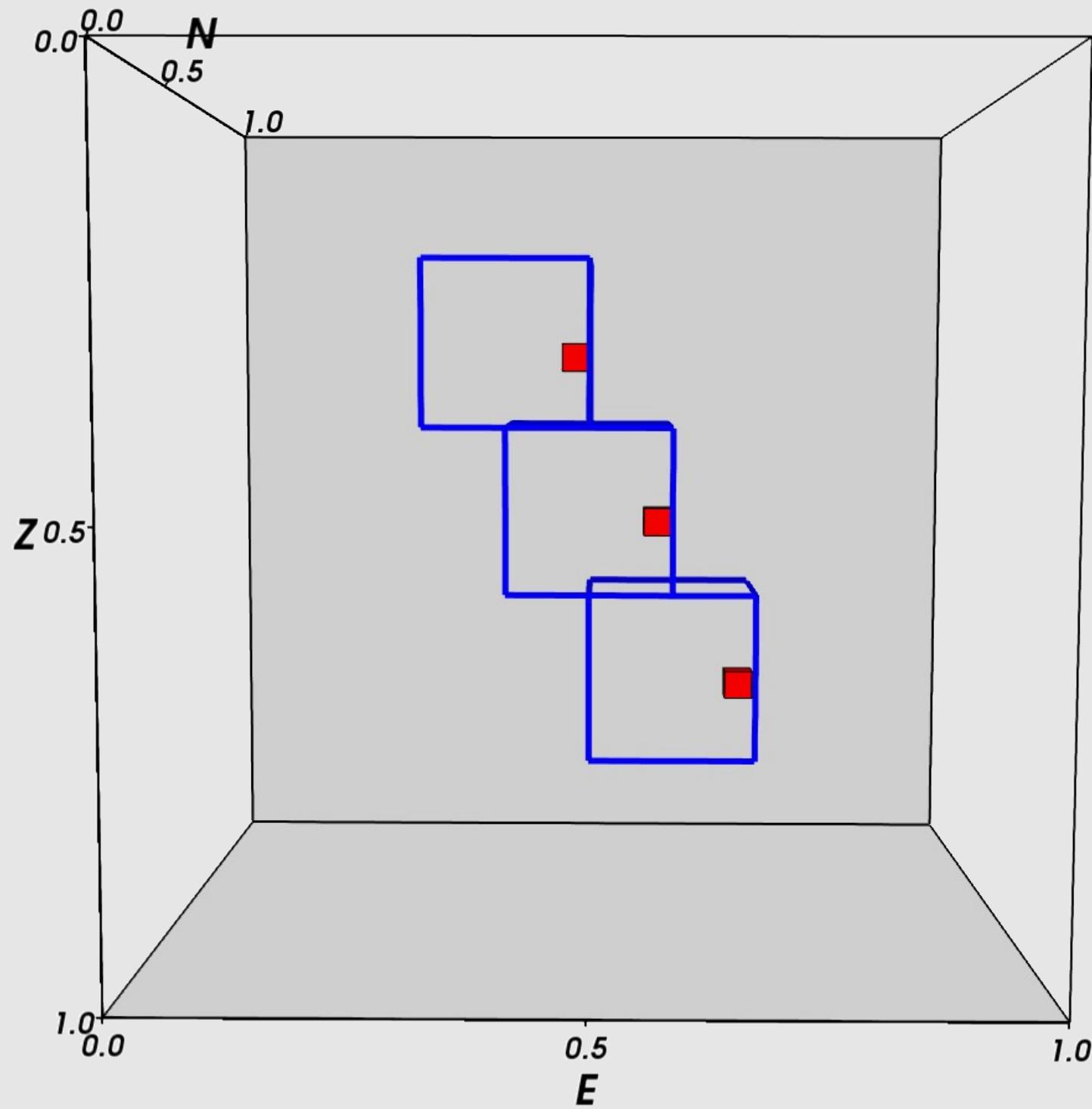


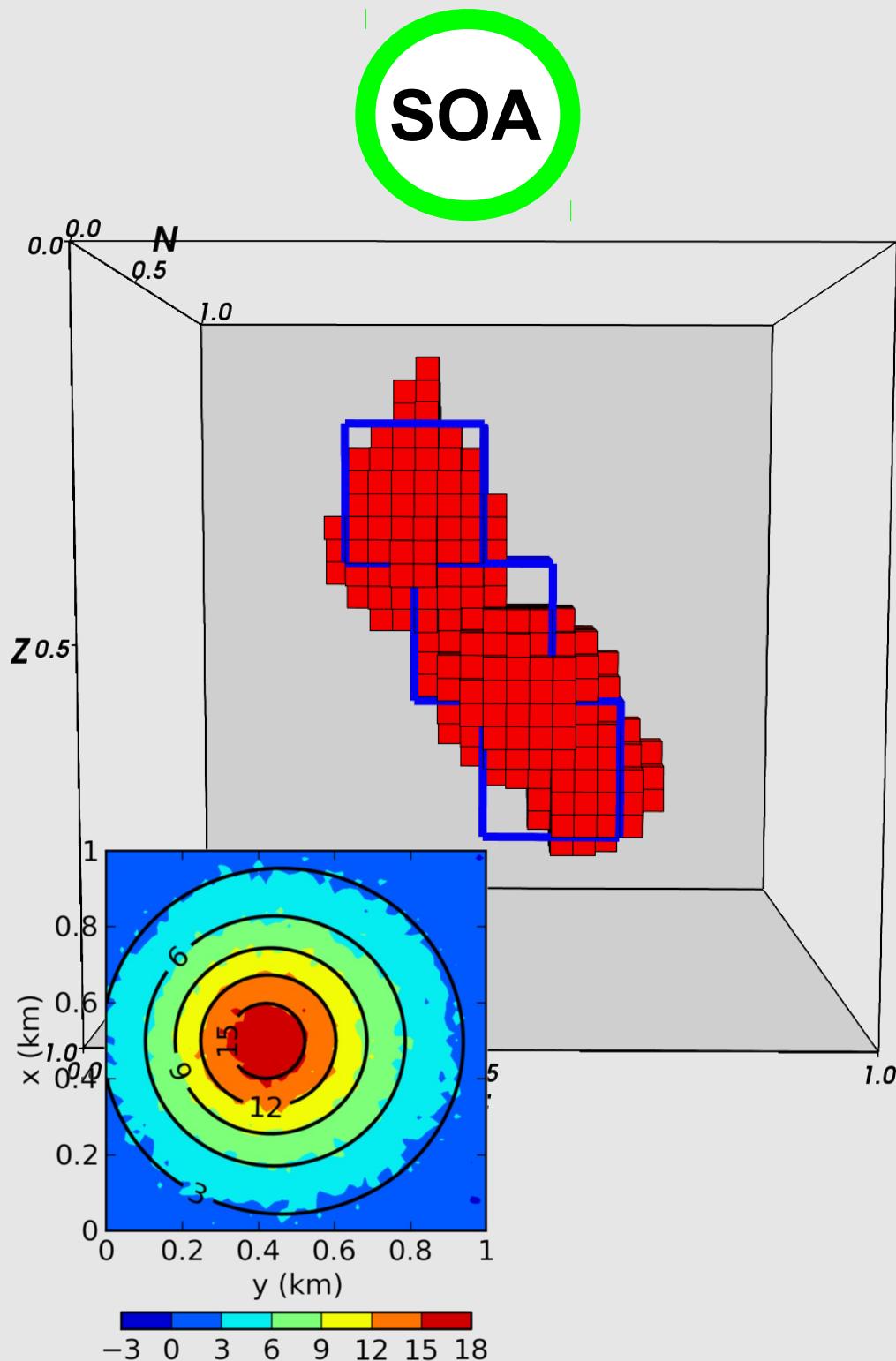
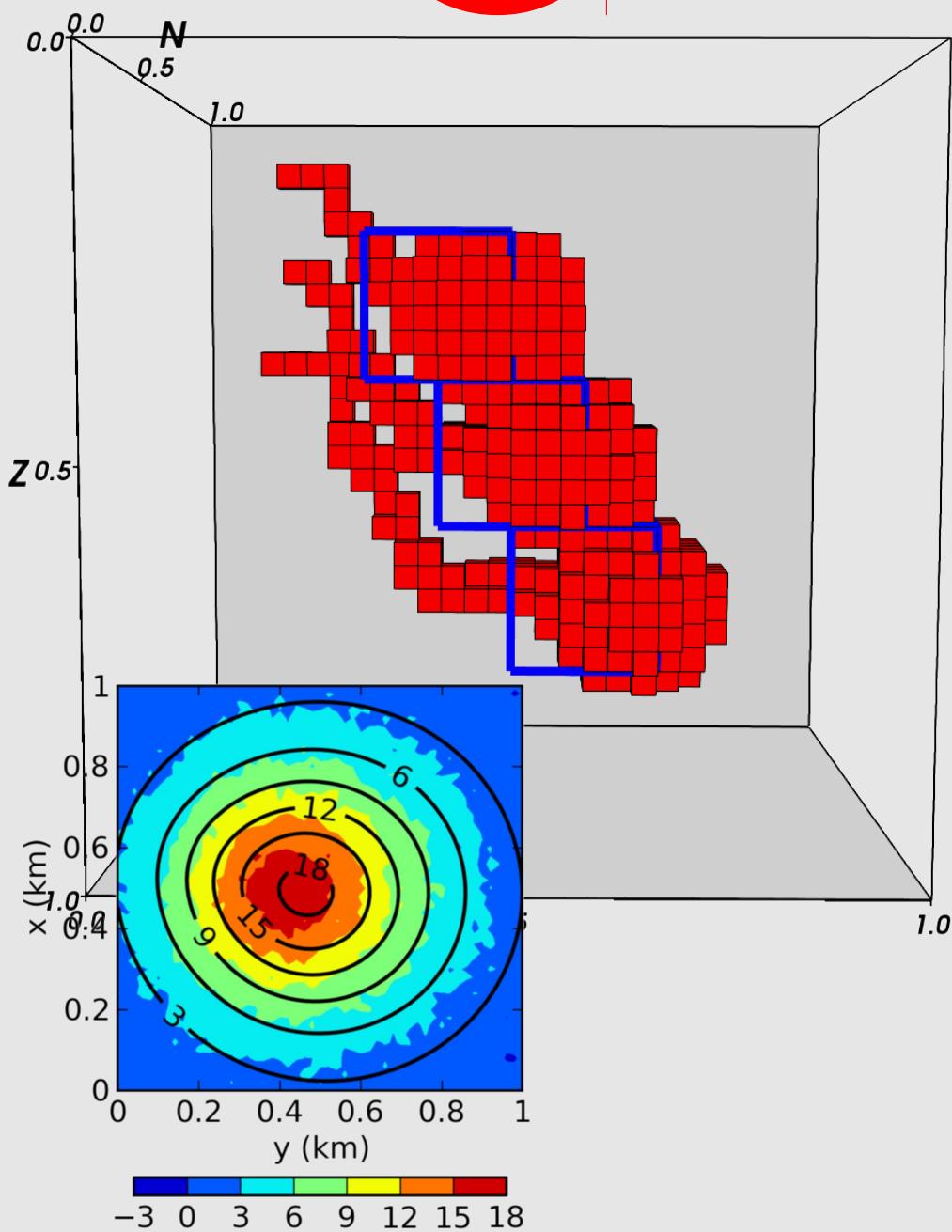








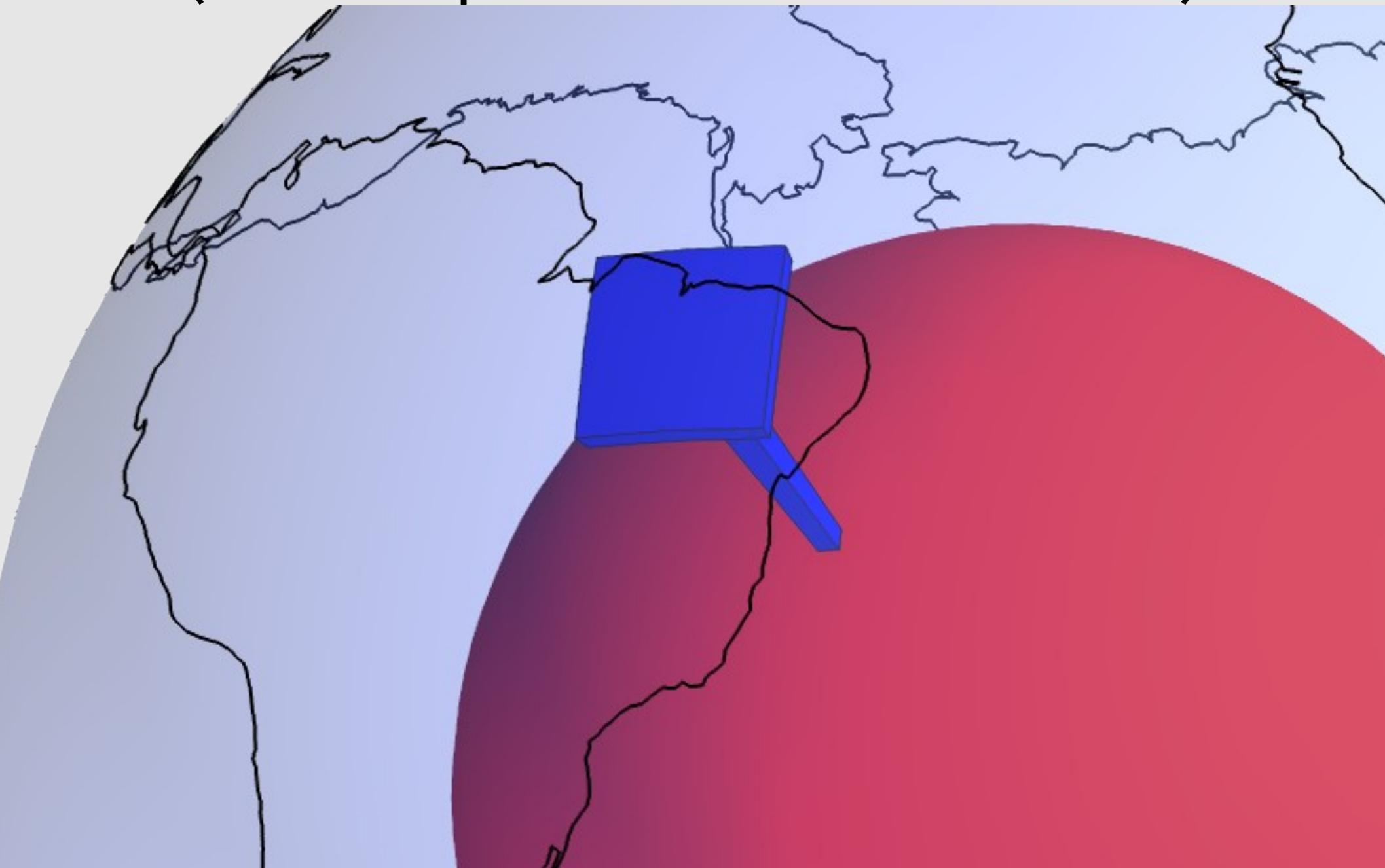




**Juntando as peças**

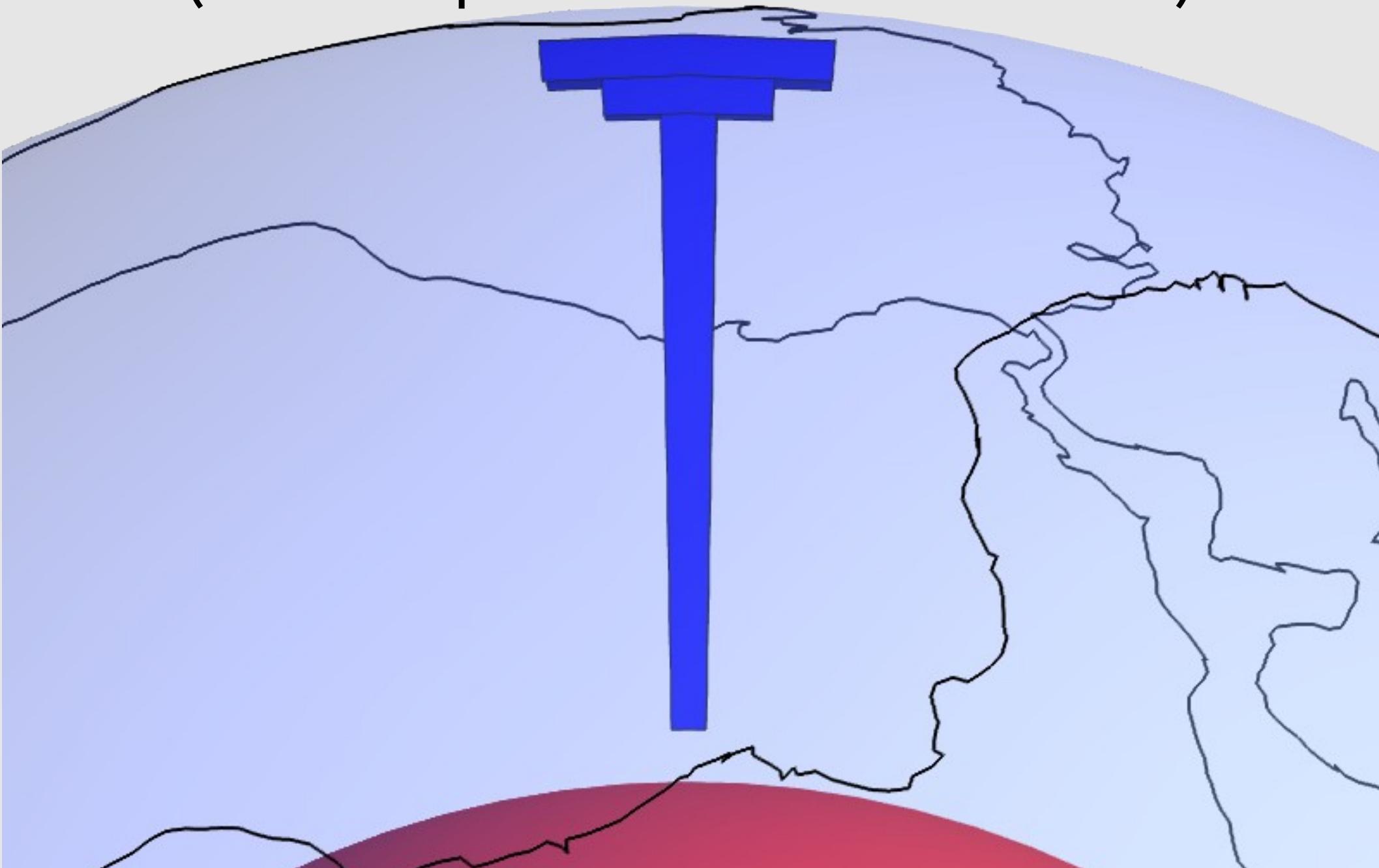
# Modelo 1: pluma

(sem compromisso com a realidade)

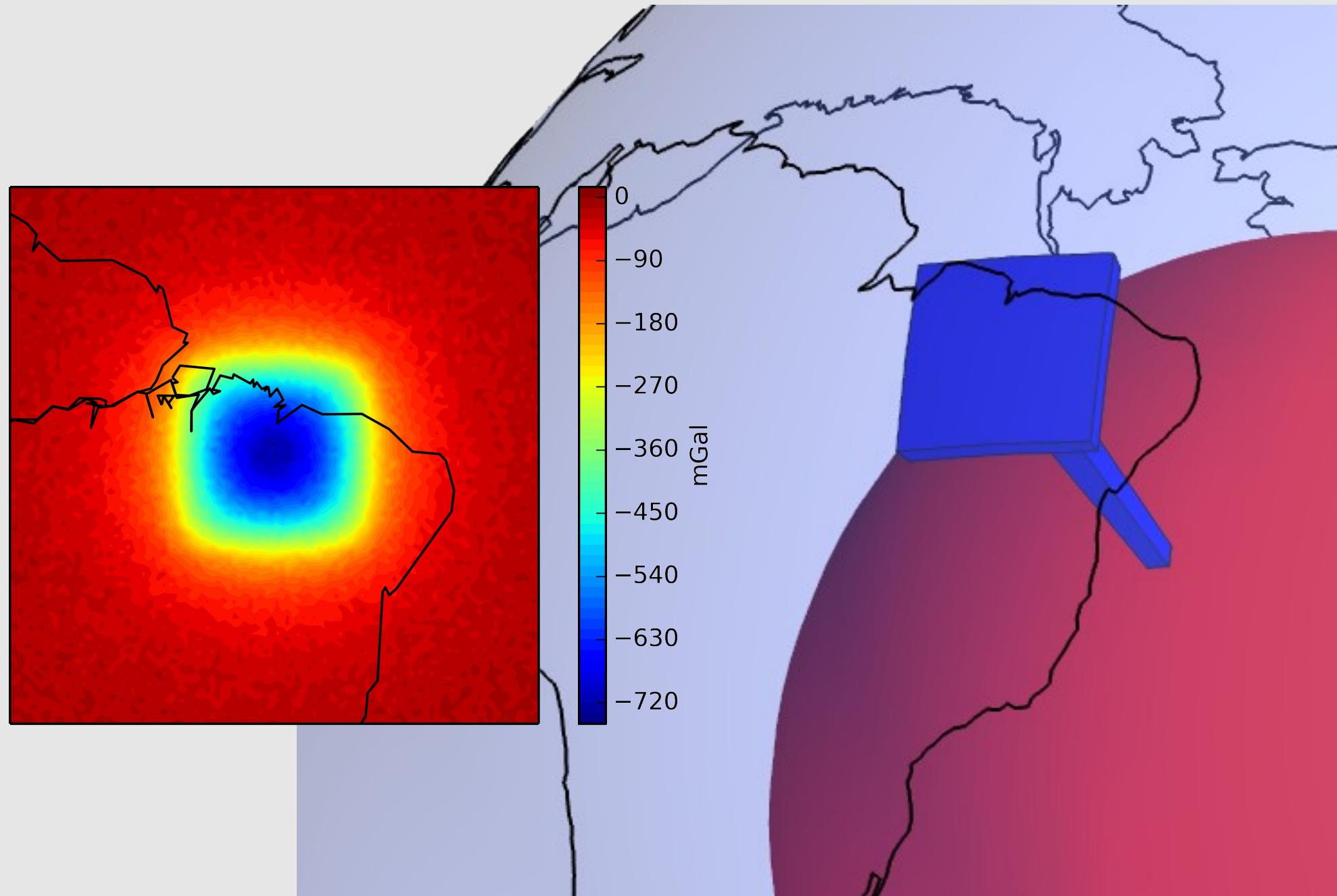


# Modelo 1: pluma

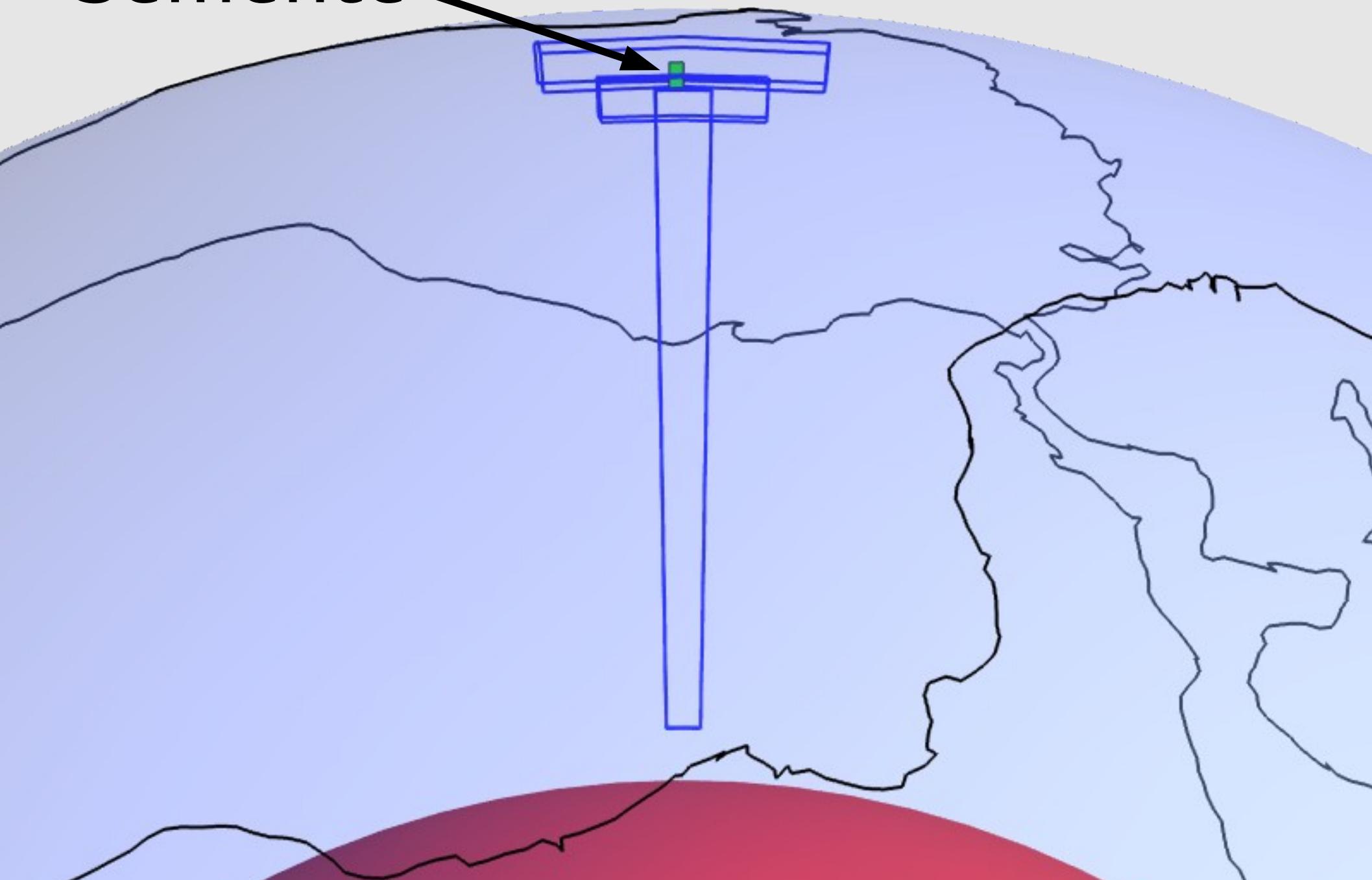
(sem compromisso com a realidade)

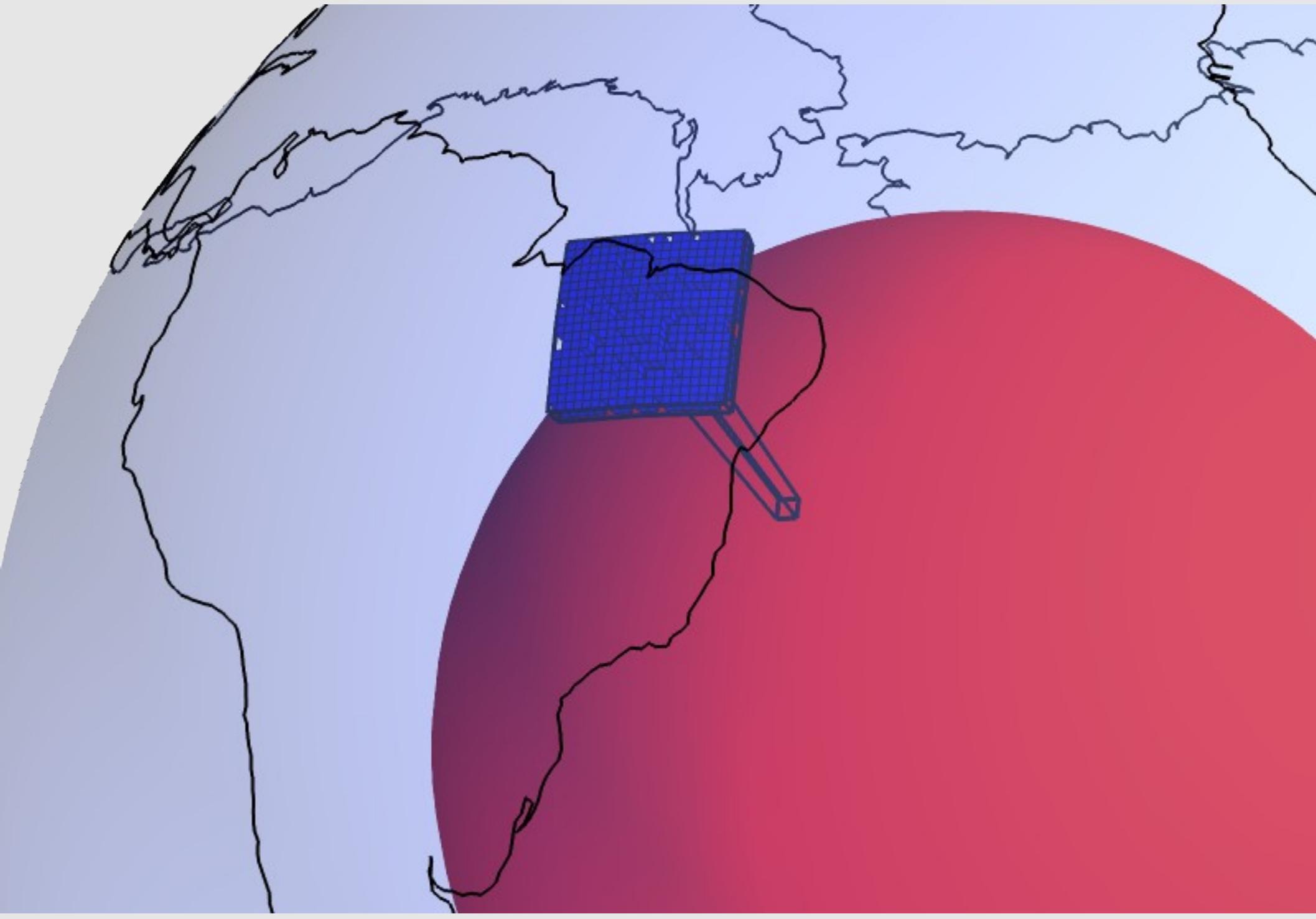


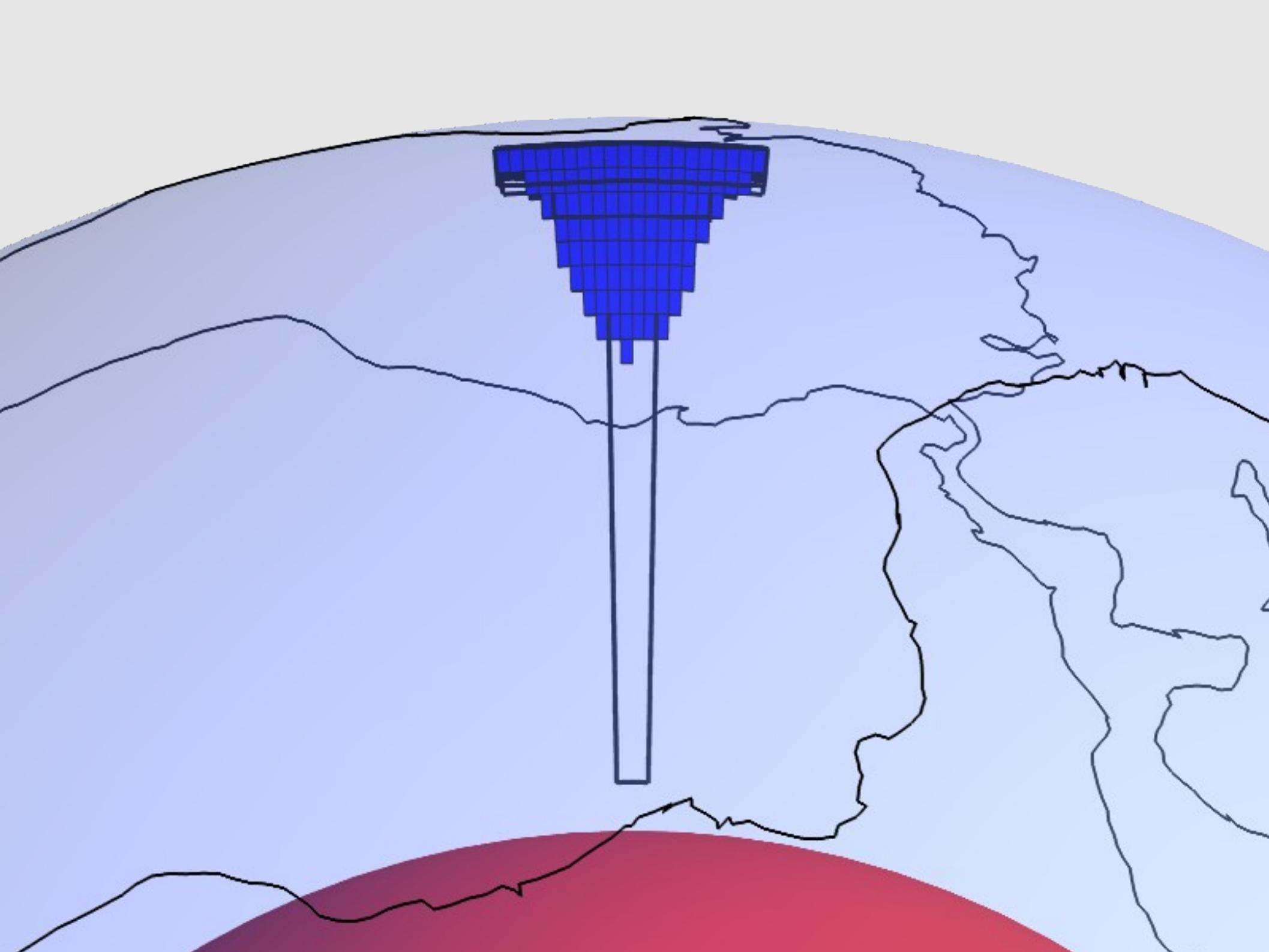
# Dado sintético

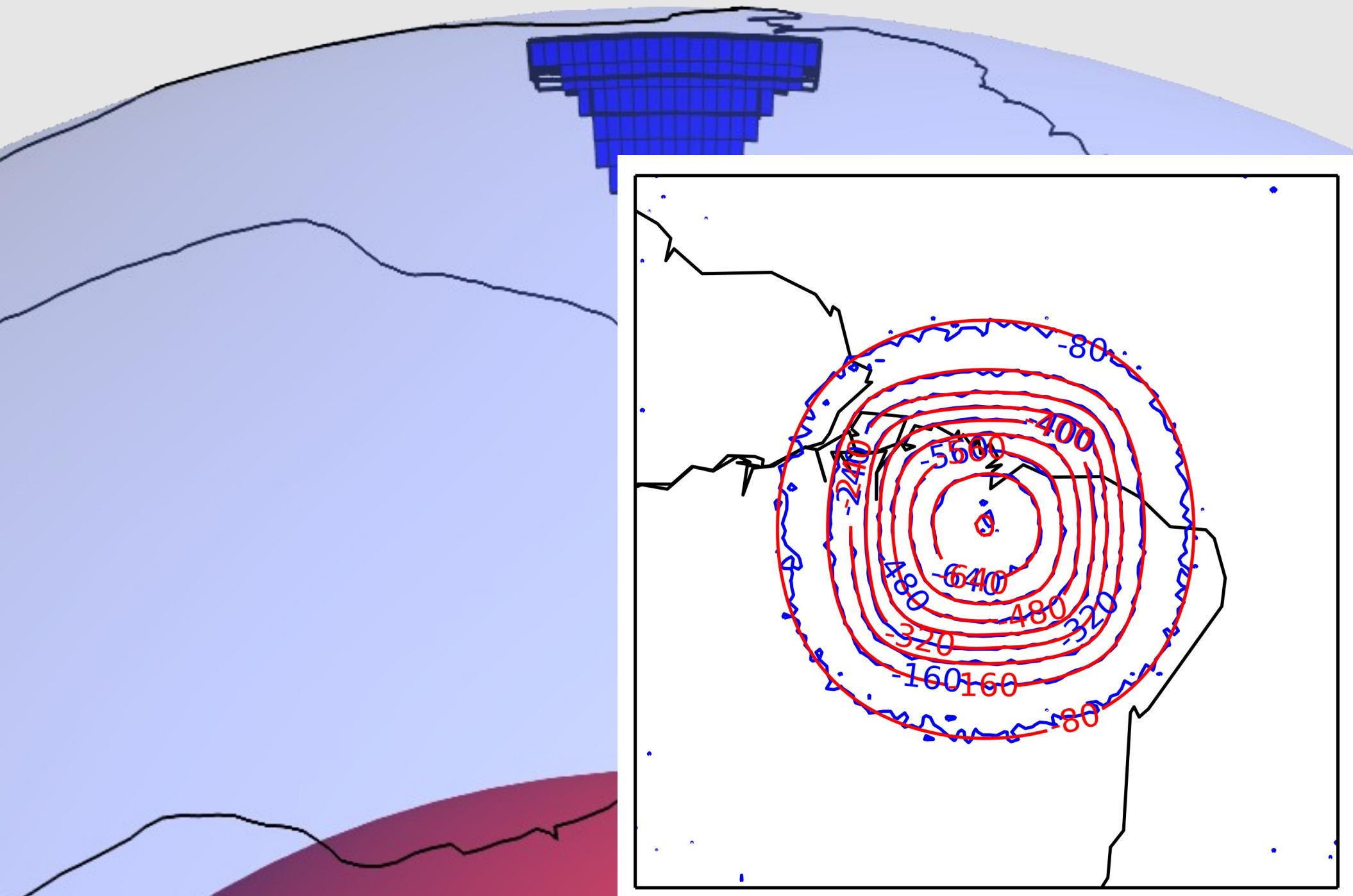


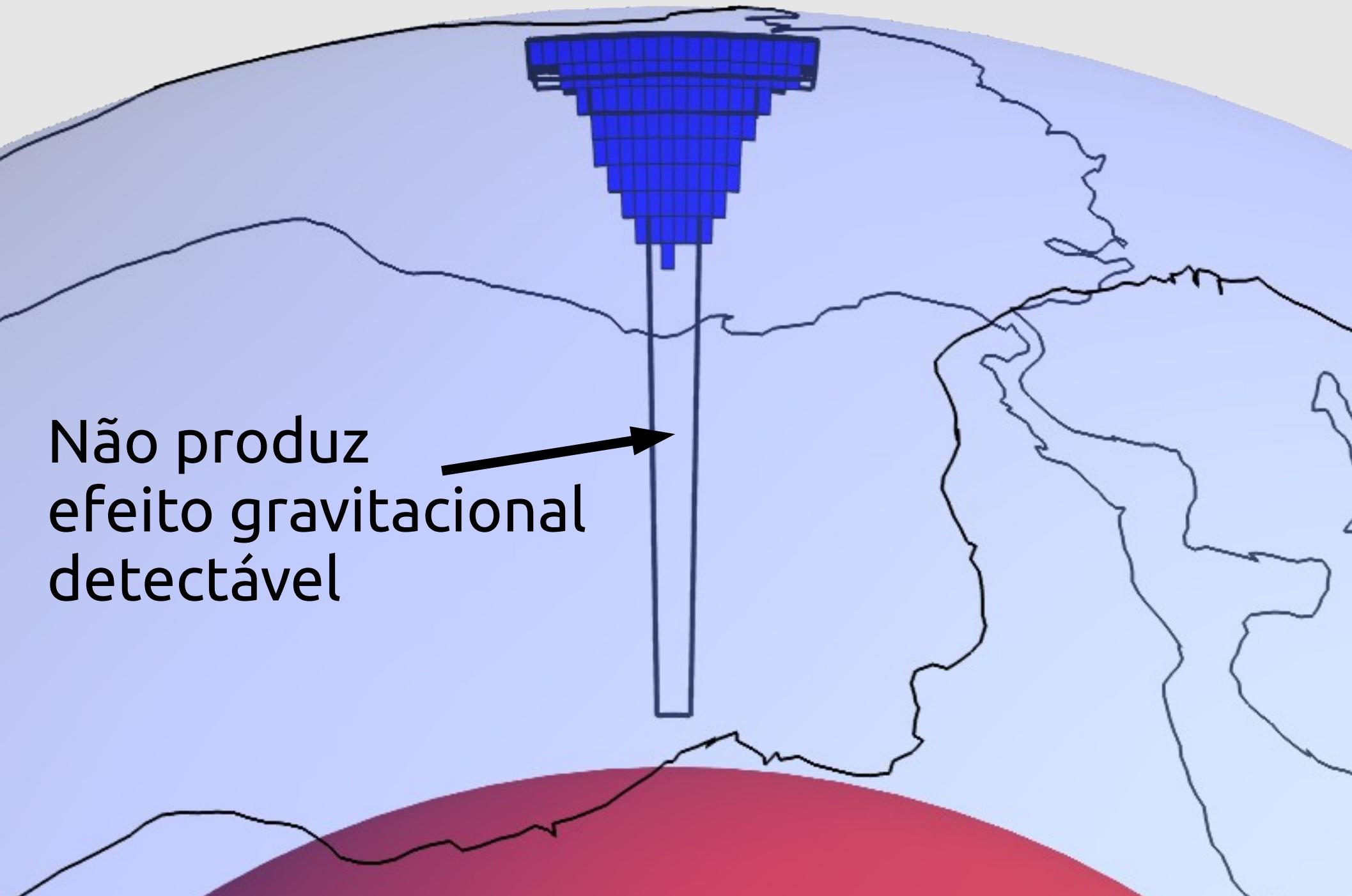
Semente





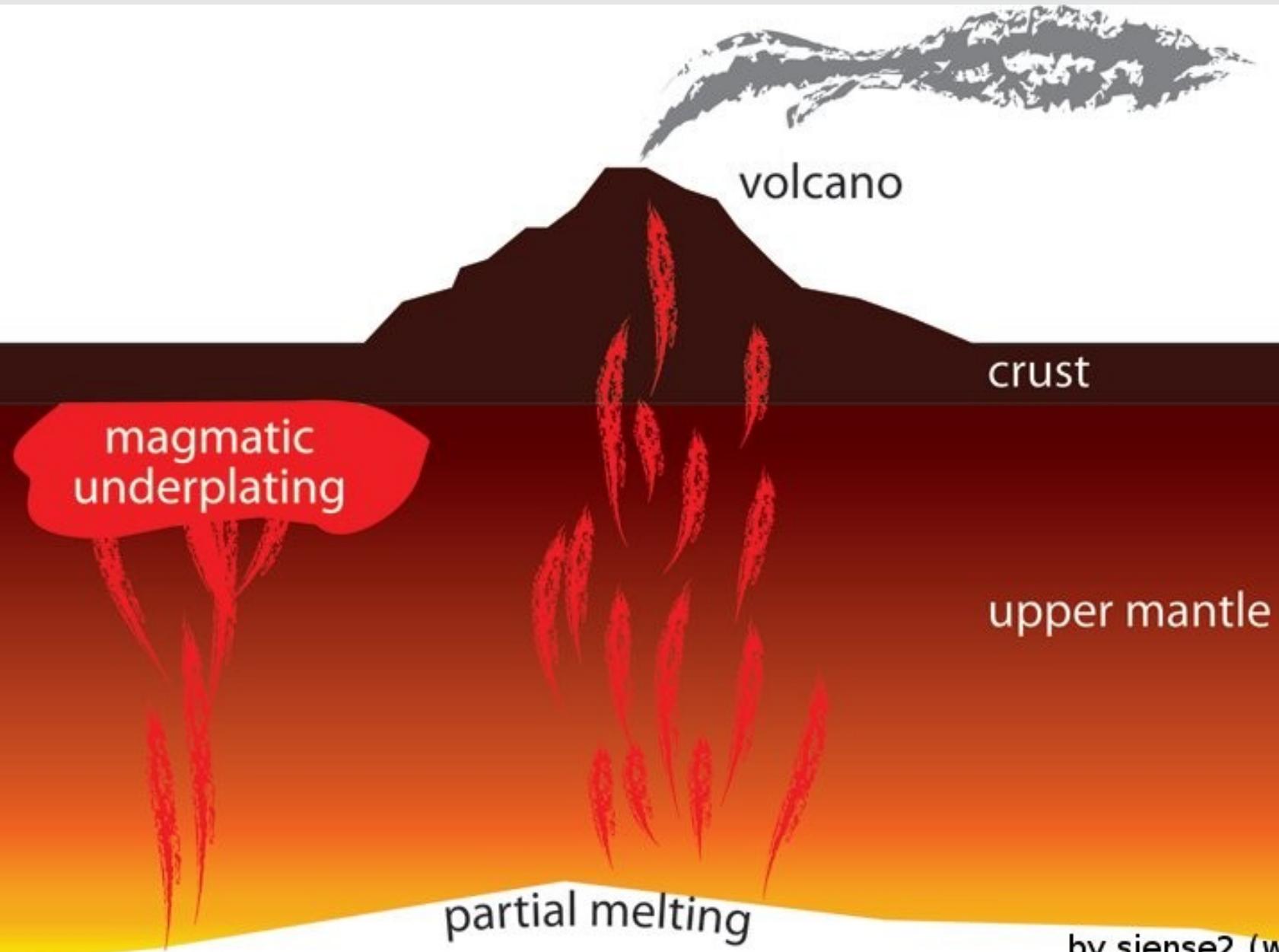






Não produz  
efeito gravitacional  
detectável

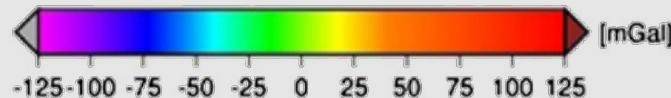
# Modelo 2: Underplating



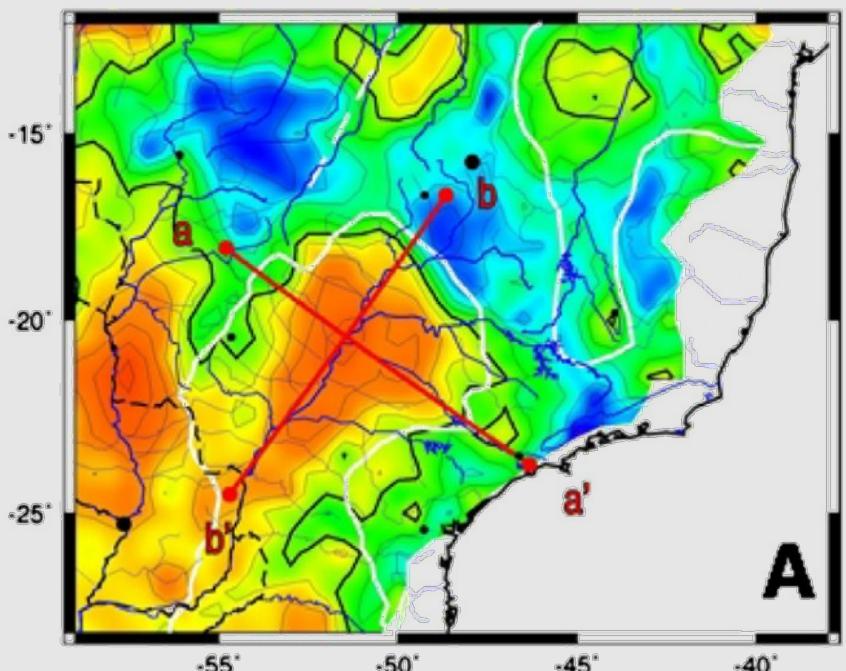
# Mariani et al. (2013)

Anomalia corrigida de:

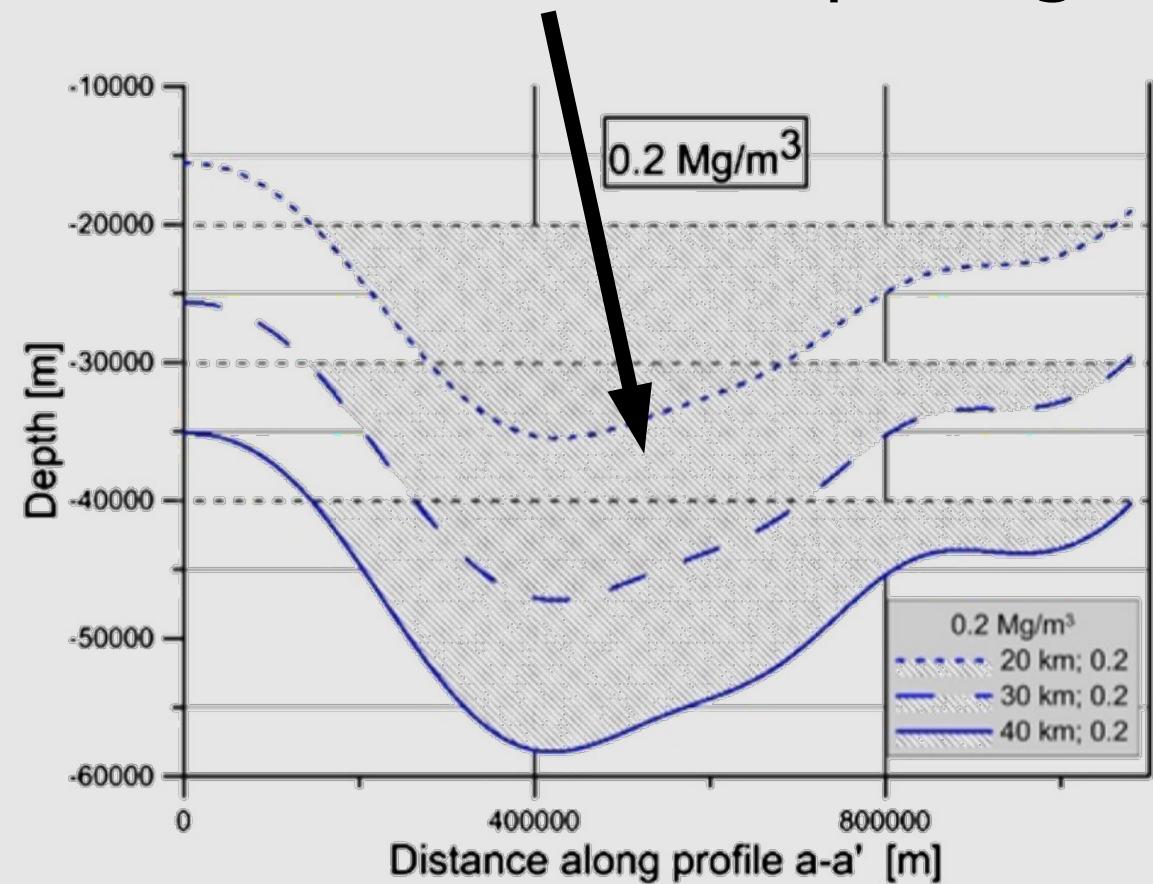
- Sedimentos
- Serra Geral
- Moho

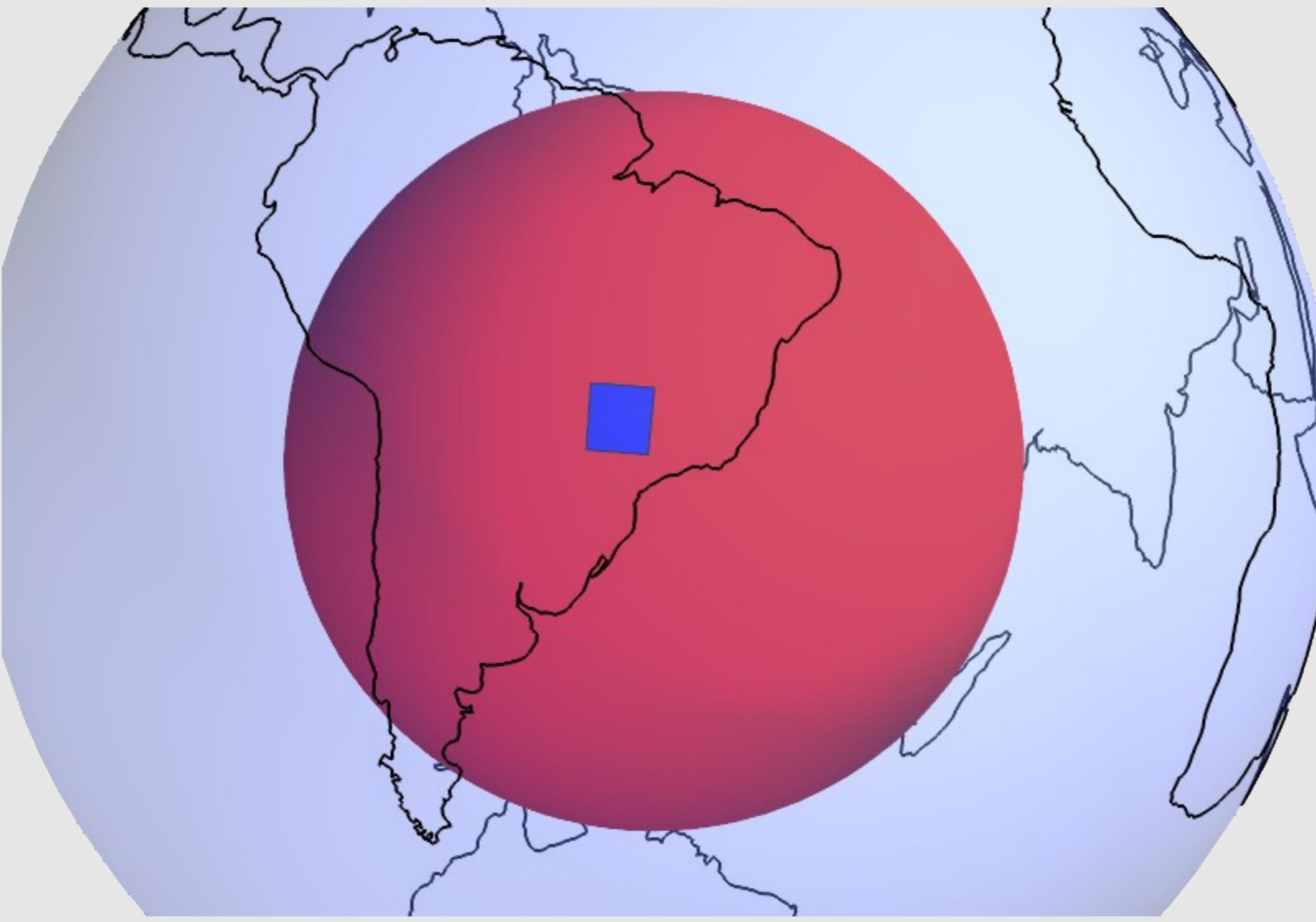


BOUGUER CORR. MOHO\_A\_0.3 & SED

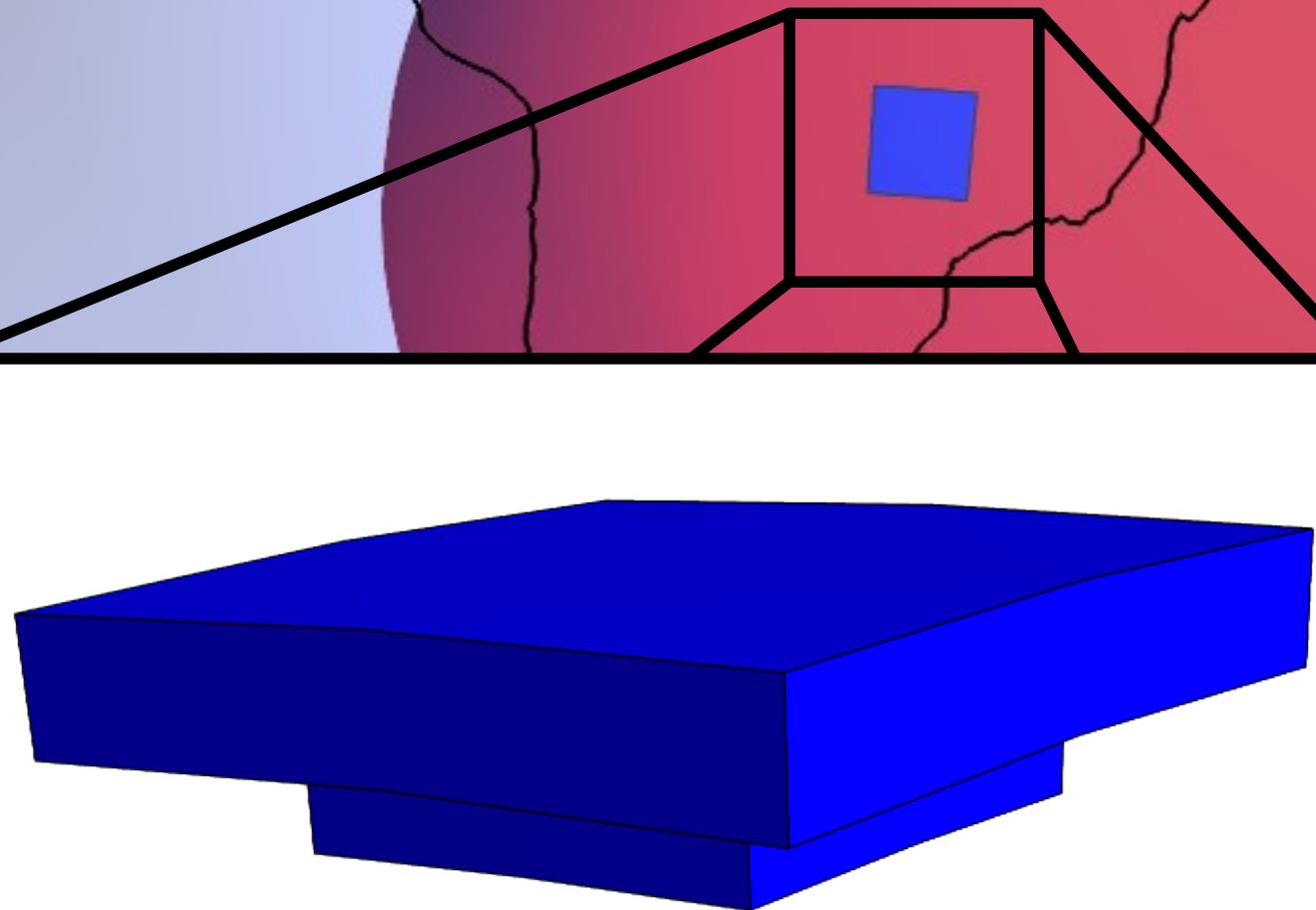


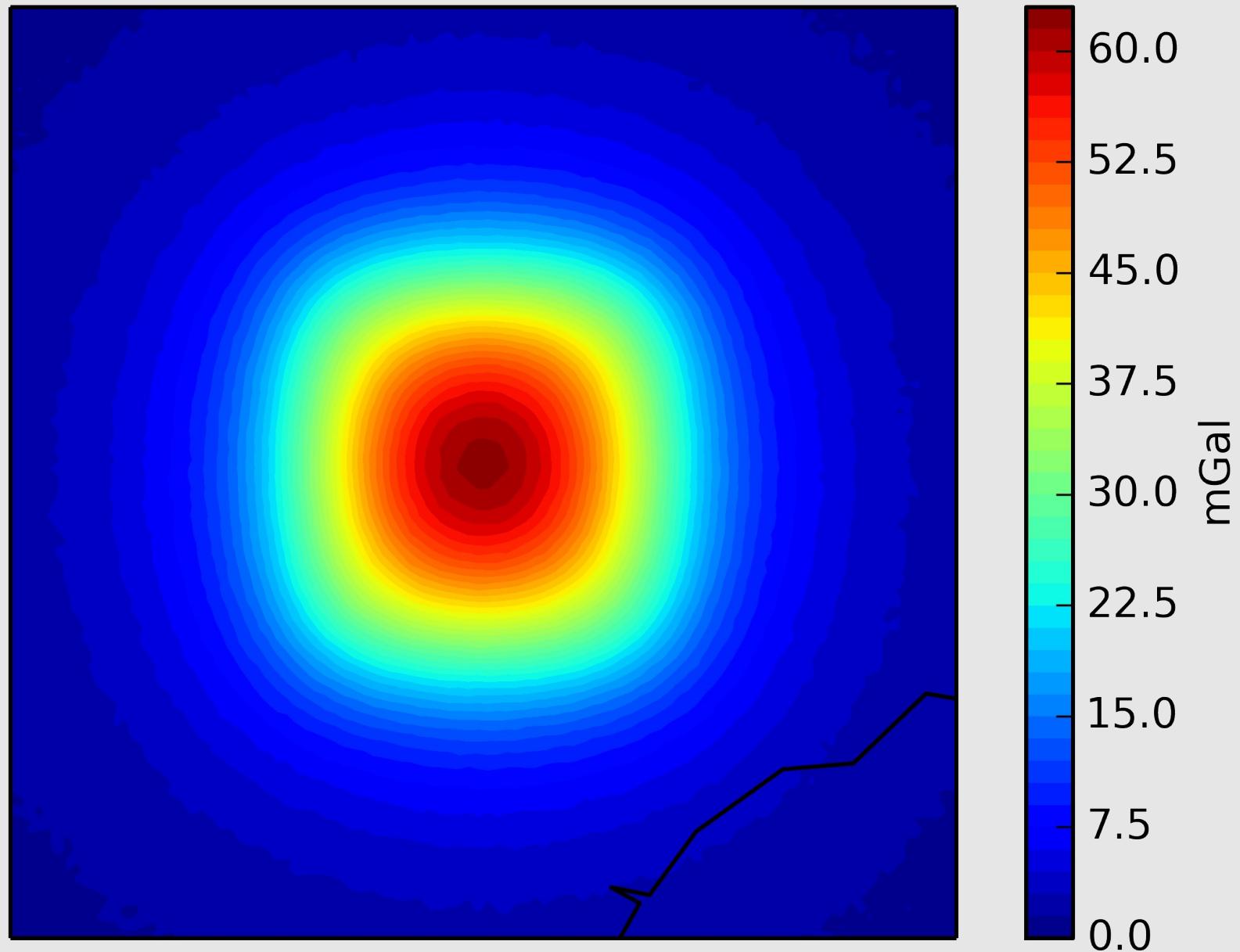
Modelo de underplating

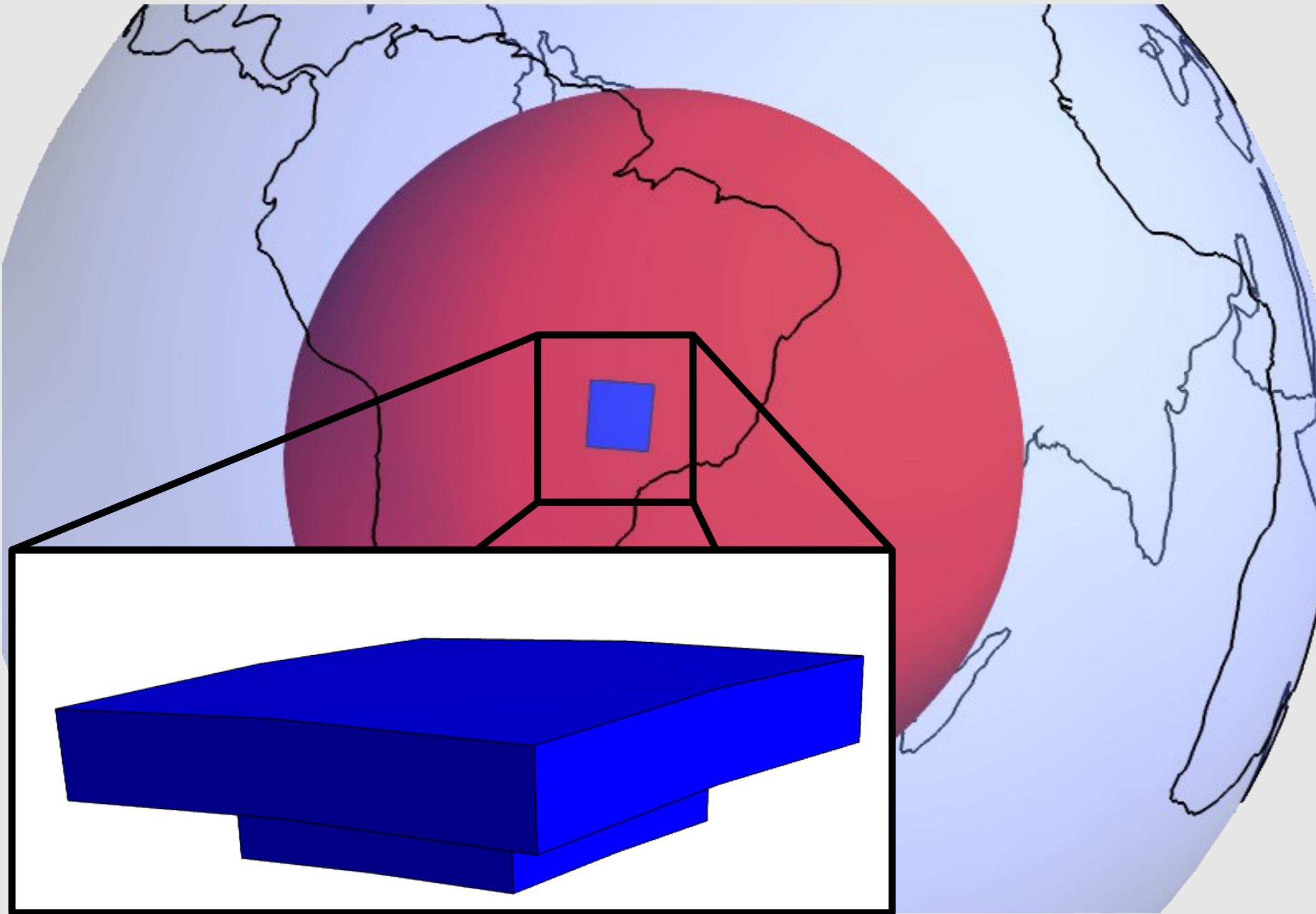


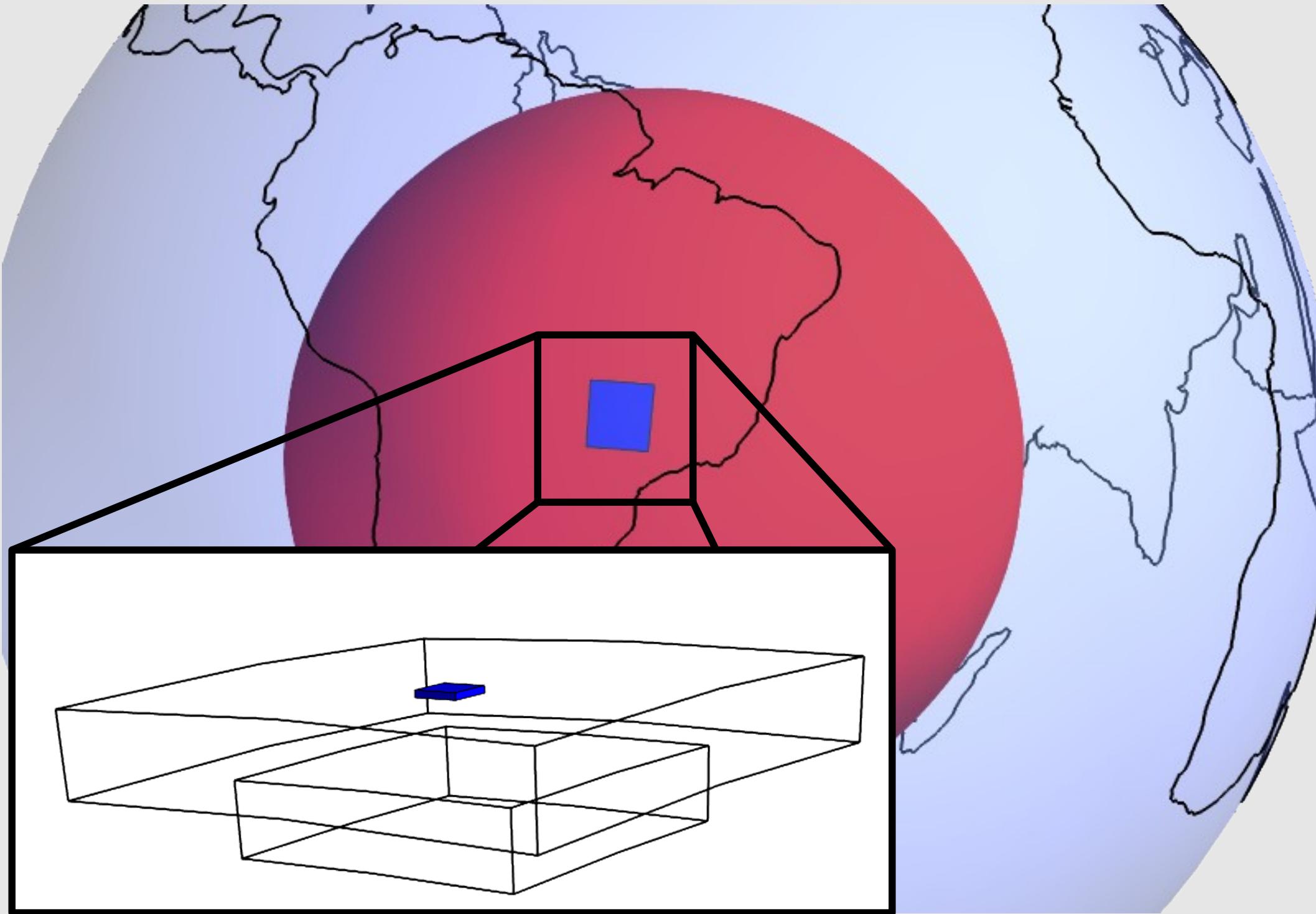


Dimensões e contraste de  
densidade de Mariani et al. (2013)





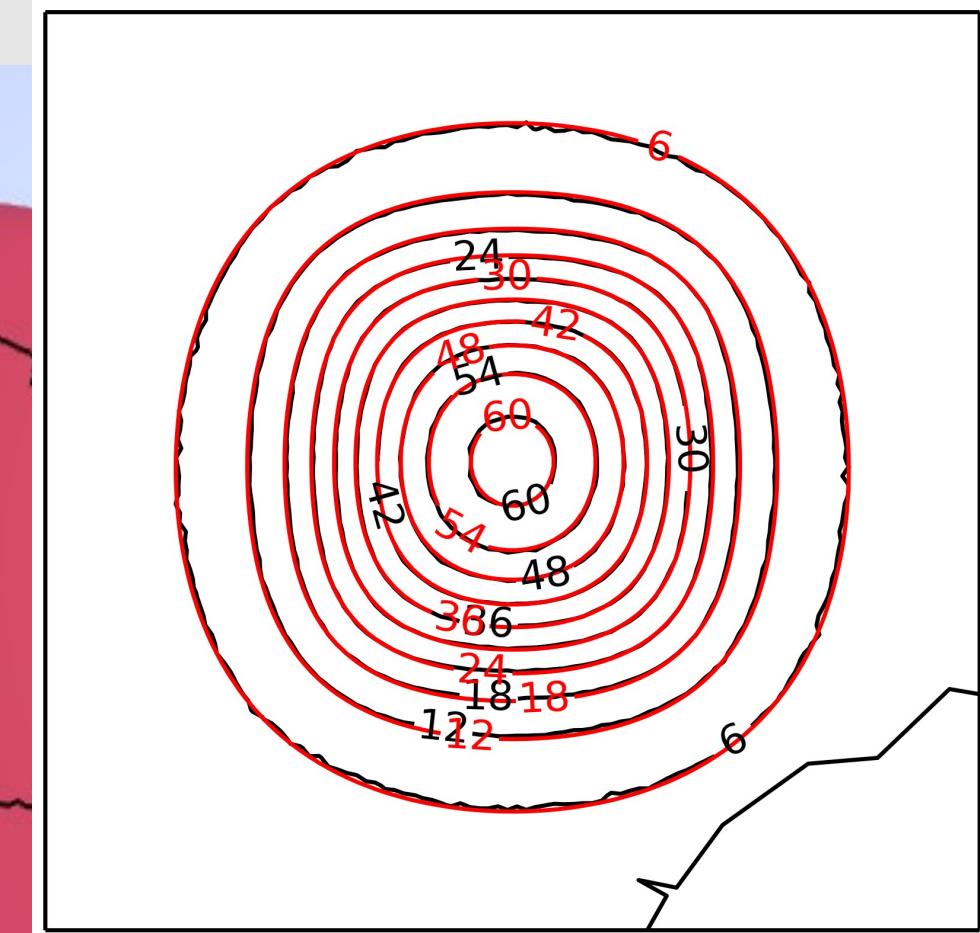




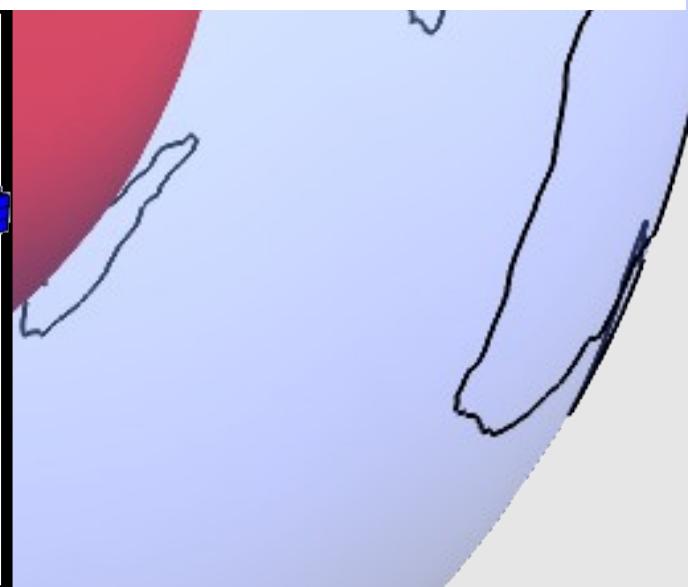
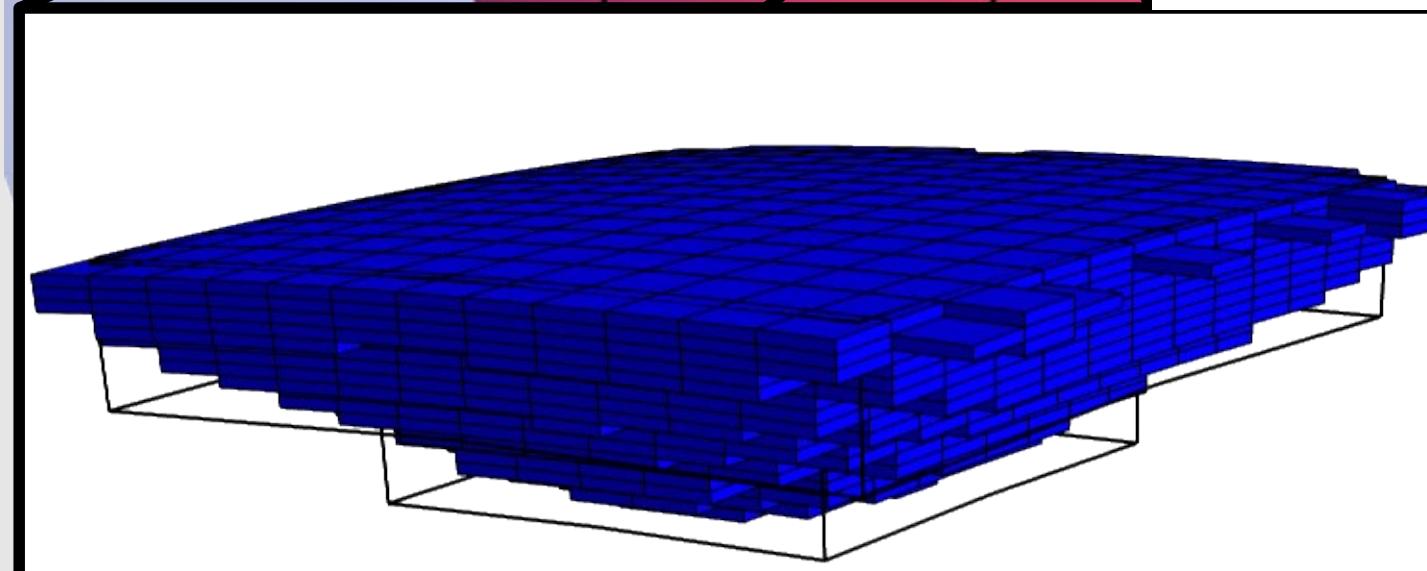
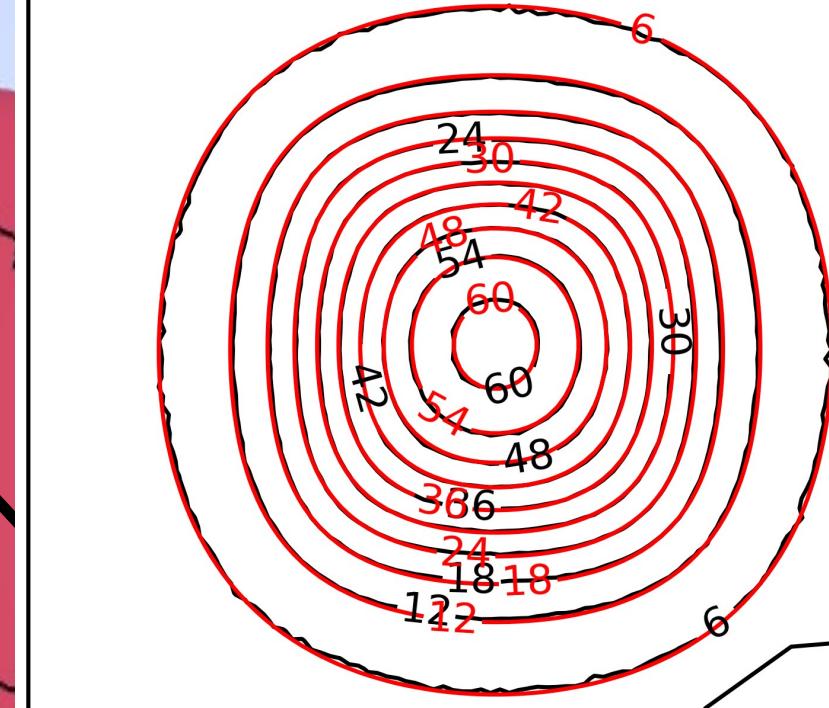
Resultado  
da inversão

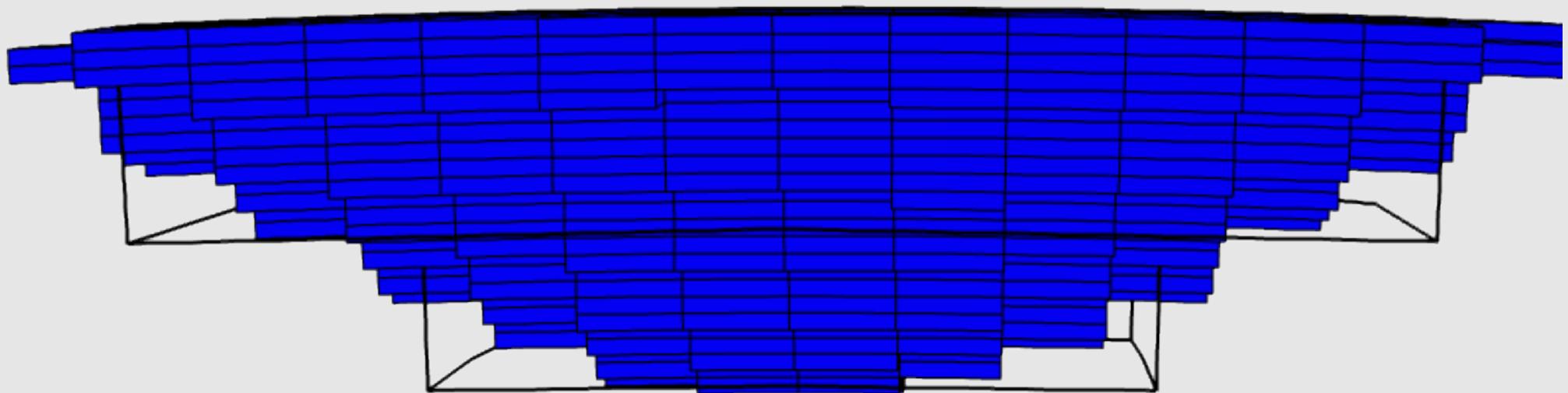
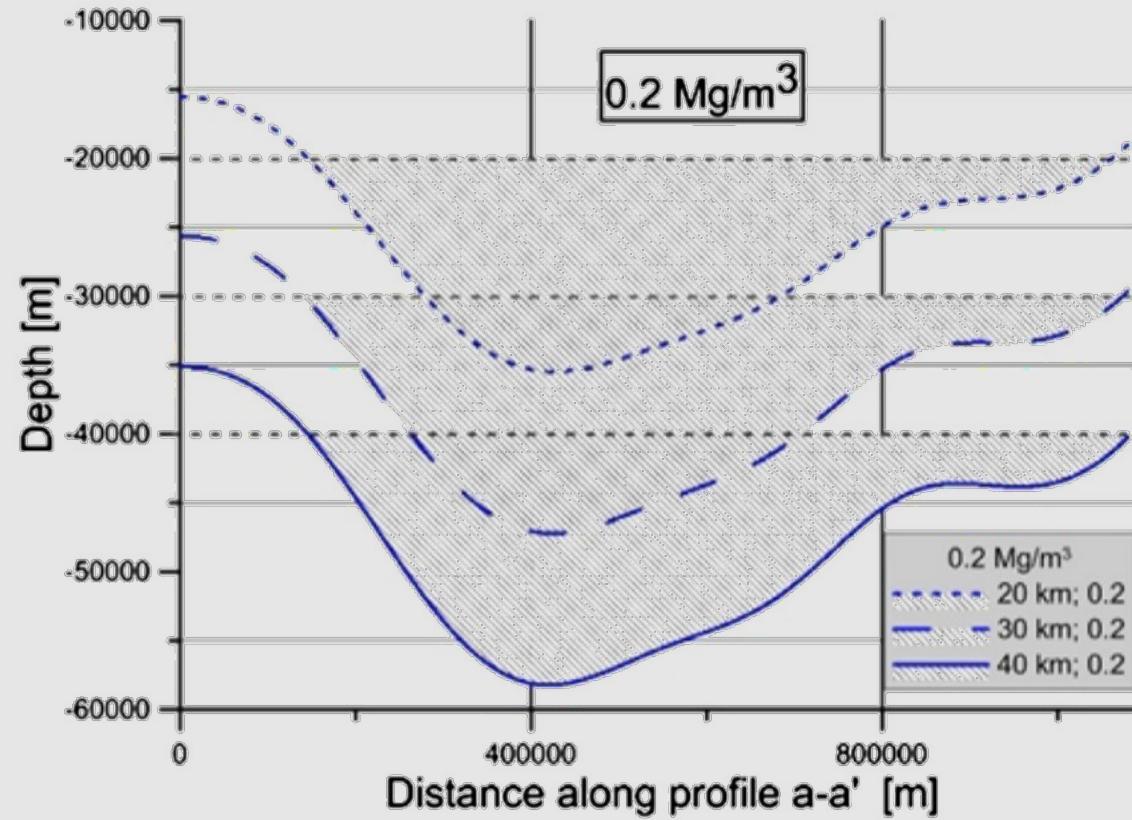


Resultado  
da inversão



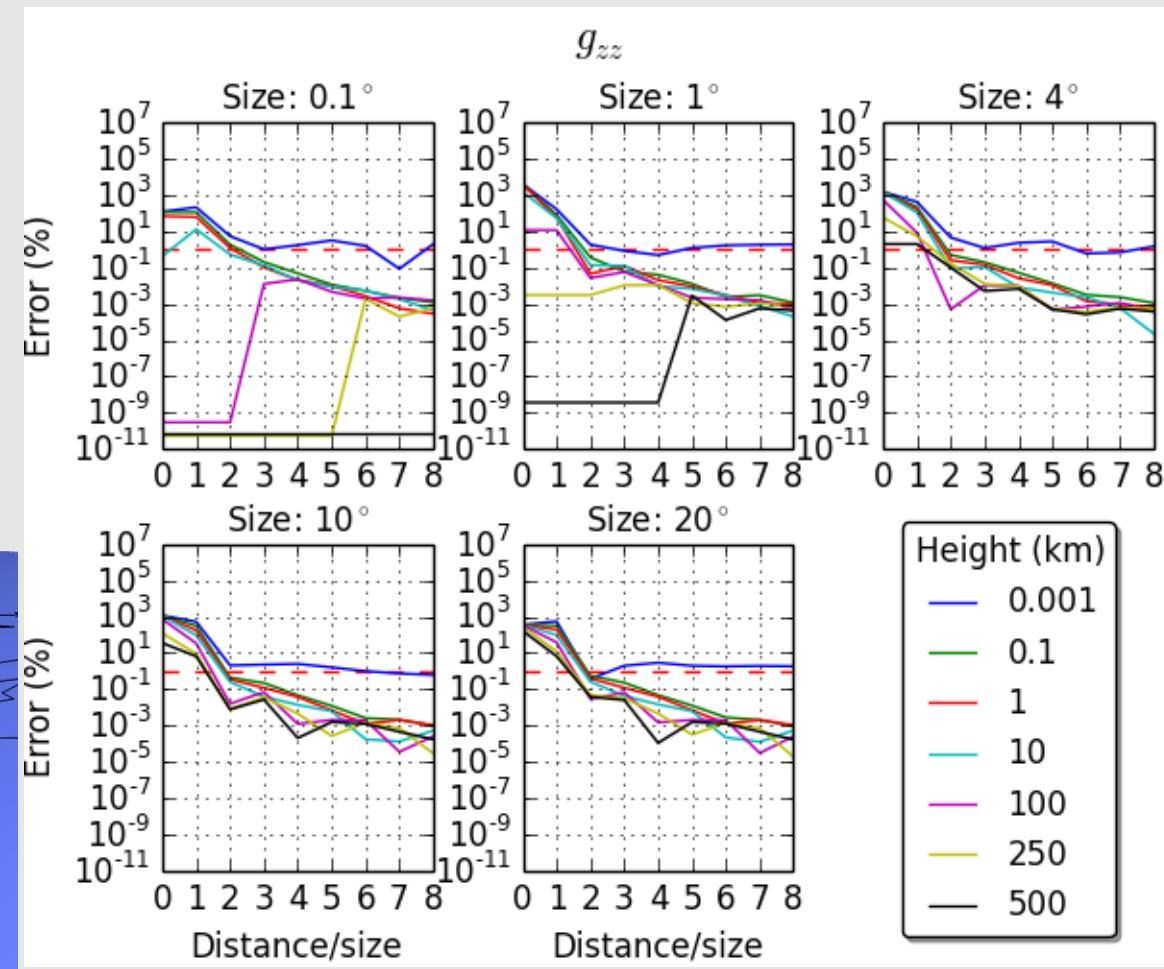
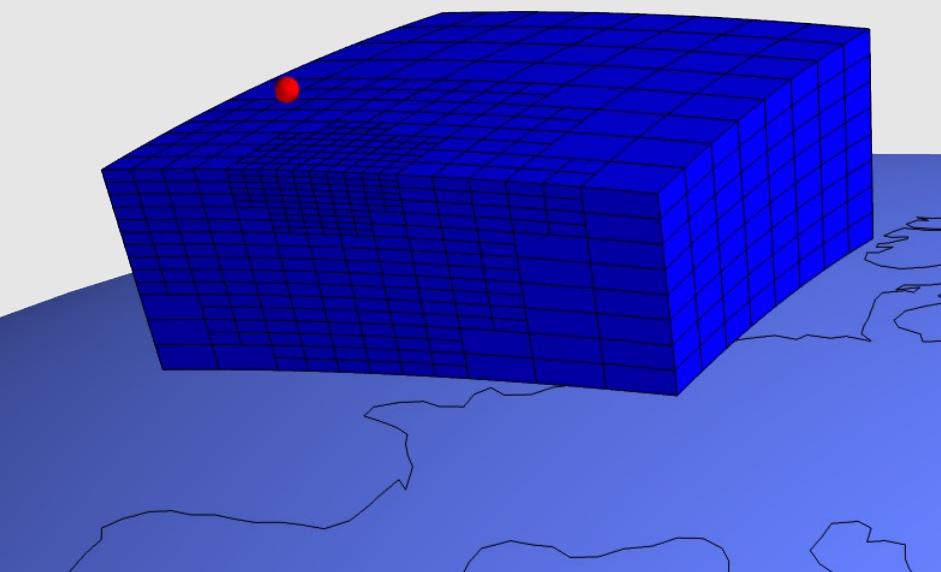
Resultado  
da inversão



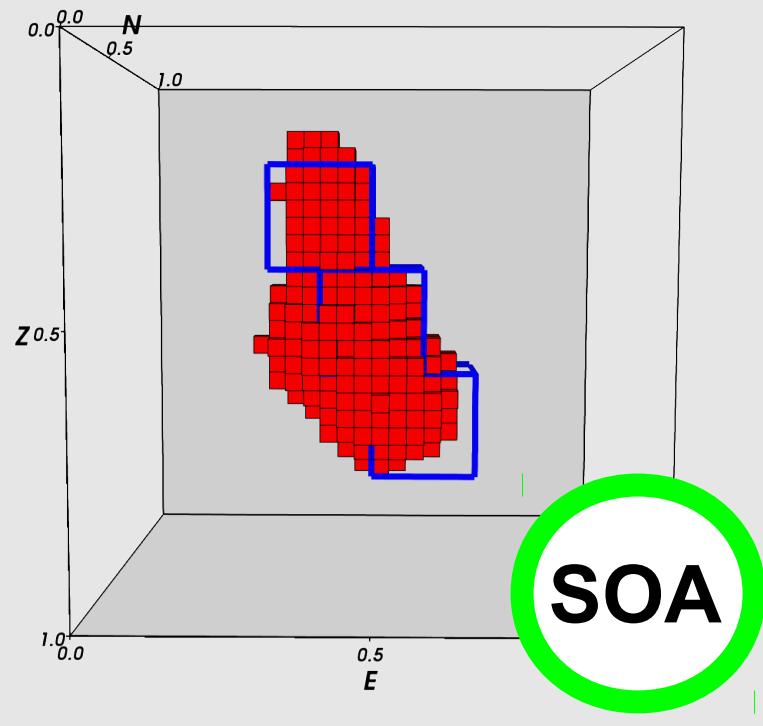
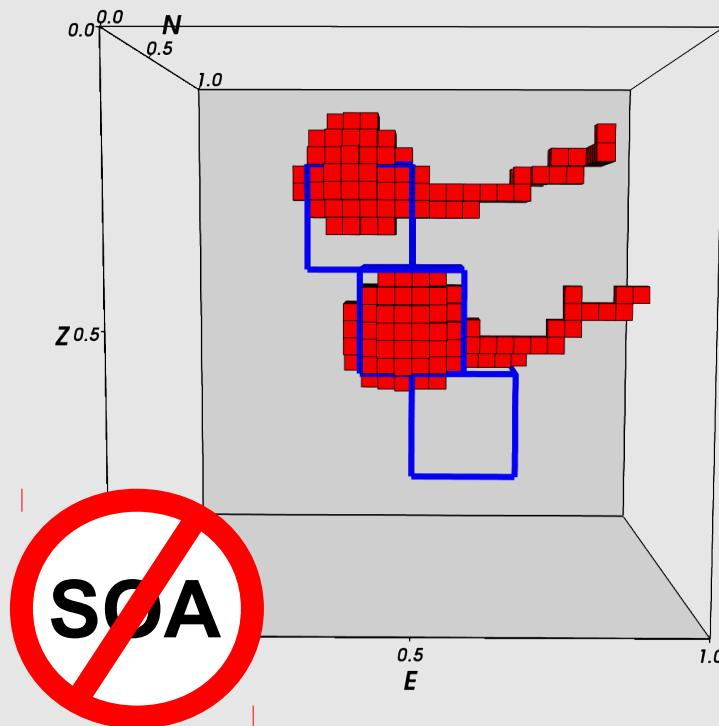


# Conclusões

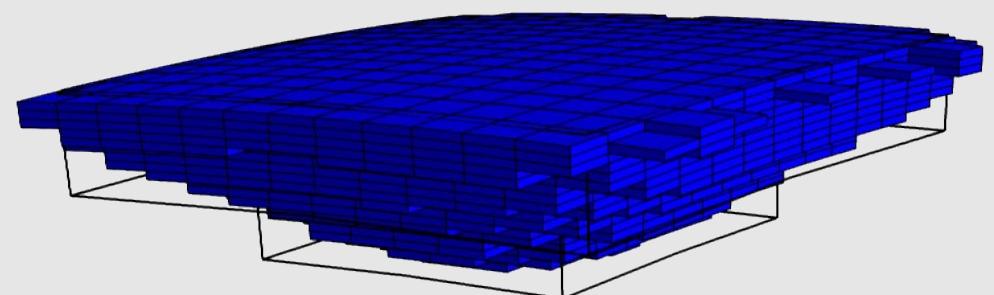
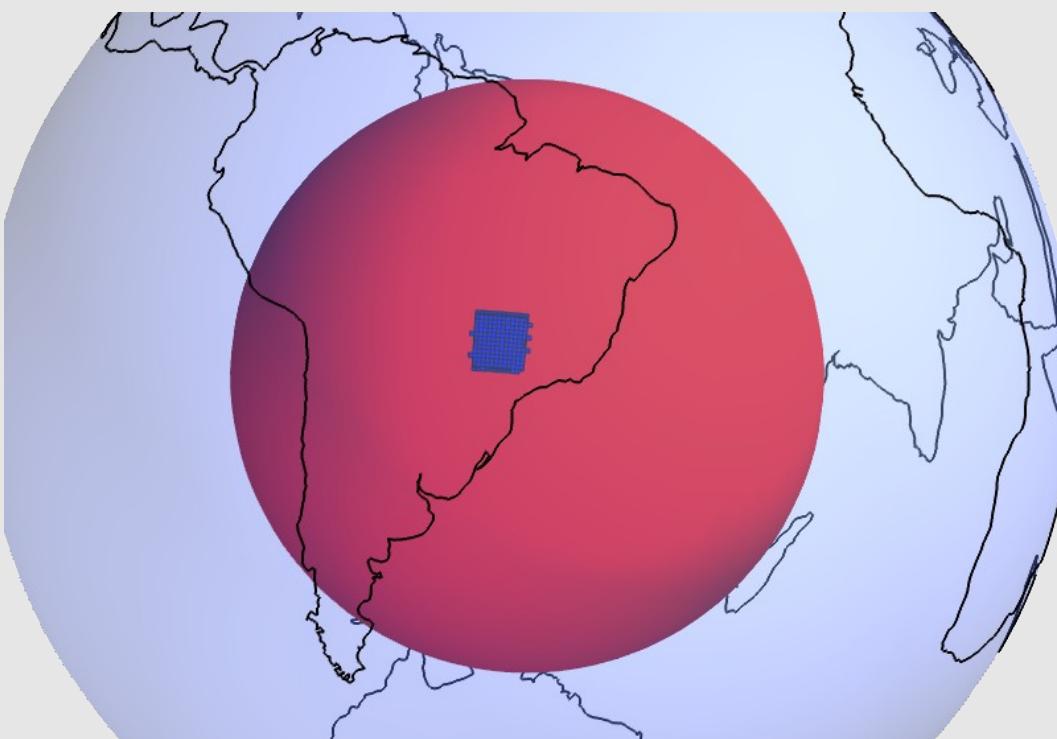
- Discretização adaptativa = erro de 1% na modelagem direta com “r”s diferentes



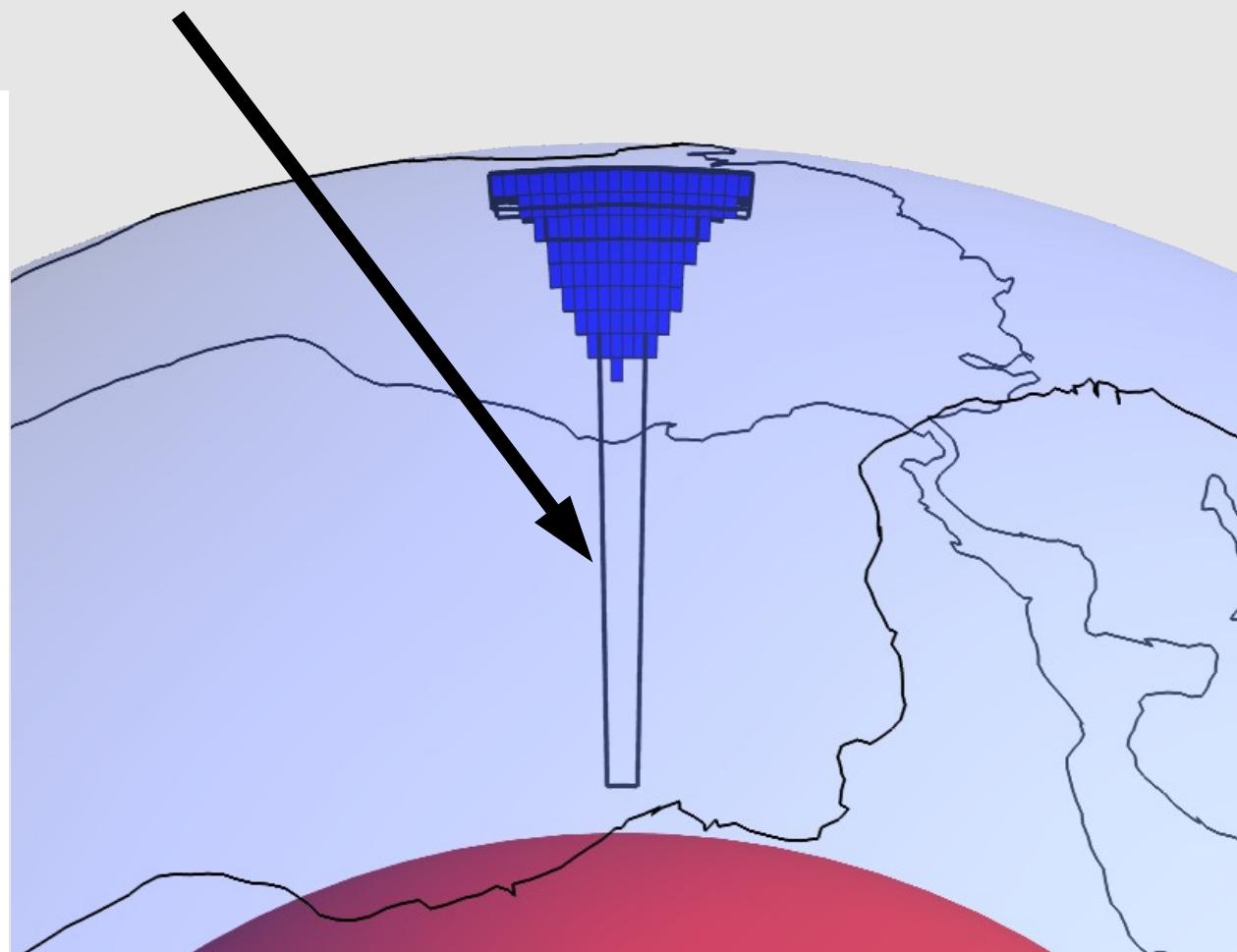
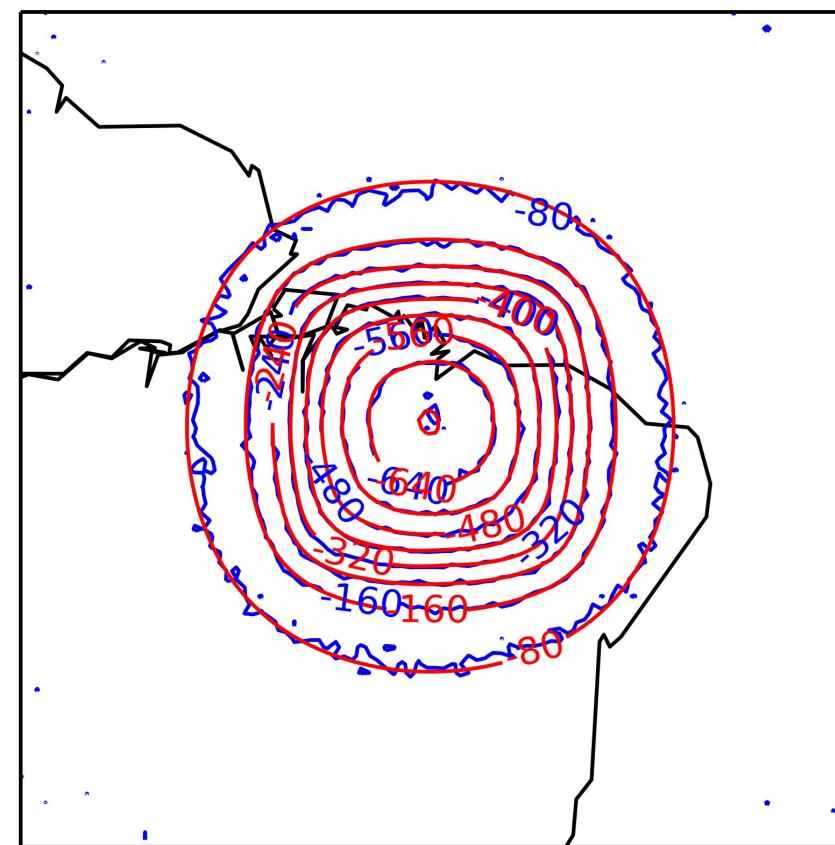
- Uso da “shape-of-anomaly” = mais robusto com relação a sementes



- Tesseroides + plantação = inversão de grandes estruturas



- Decaimento de campos potenciais limita a profundidade

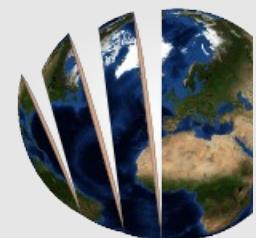


# Atividades (2012-2013)

- Disciplinas
- Apresentação oral de 5 trabalhos em congresso
- 3 resumos expandidos
- 2 artigos (terceiro autor)
- Implementação da metodologia

– Software livre: **Fatiando a Terra**

Geophysical modeling and inversion



[www.fatiando.org](http://www.fatiando.org)

# Cronograma

- 2013
  - Artigo sobre aprimoramentos do método de inversão
- 2014
  - Aplicação a dados reais
  - Artigo(s) sobre modelagem direta/inversa com tesseroides
  - Defesa

# Referências

- Braitenberg, C., P. Mariani, J. Ebbing, and M. Sprlak (2011), The enigmatic Chad lineament revisited with global gravity and gravity-gradient fields, Geological Society, London, Special Publications, 357(1), 329–341, doi:10.1144/SP357.18.
- Ku, C. C. (1977), A direct computation of gravity and magnetic anomalies caused by 2-and 3-dimensional bodies of arbitrary shape and arbitrary magnetic polarization by equivalent-point method and a simplified cubic spline, Geophysics, 42(3), 610–622, doi:10.1190/1.1440732.
- Li, Z., T. Hao, Y. Xu, and Y. Xu (2011), An efficient and adaptive approach for modeling gravity effects in spherical coordinates, Journal of Applied Geophysics, 73(3), 221–231, doi:10.1016/j.jappgeo.2011.01.004.
- Mariani, P., C. Braitenberg, and N. Ussami (2013), Explaining the thick crust in Paraná basin, Brazil, with satellite GOCE gravity observations, Journal of South American Earth Sciences, 45, 209–223, doi:10.1016/j.jsames.2013.03.008.
- Wild-Pfeiffer, F. (2008), A comparison of different mass elements for use in gravity gradiometry, Journal of Geodesy, 82(10), 637–653, doi:10.1007/s00190-008-0219-8.