

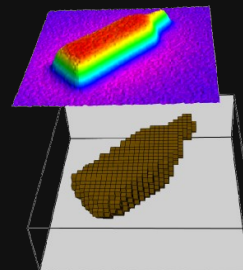
Modelagem e inversão em coordenadas esféricas na gravimetria

Leonardo Uieda

Valéria C. F. Barbosa (Orientadora)



Observatório
Nacional



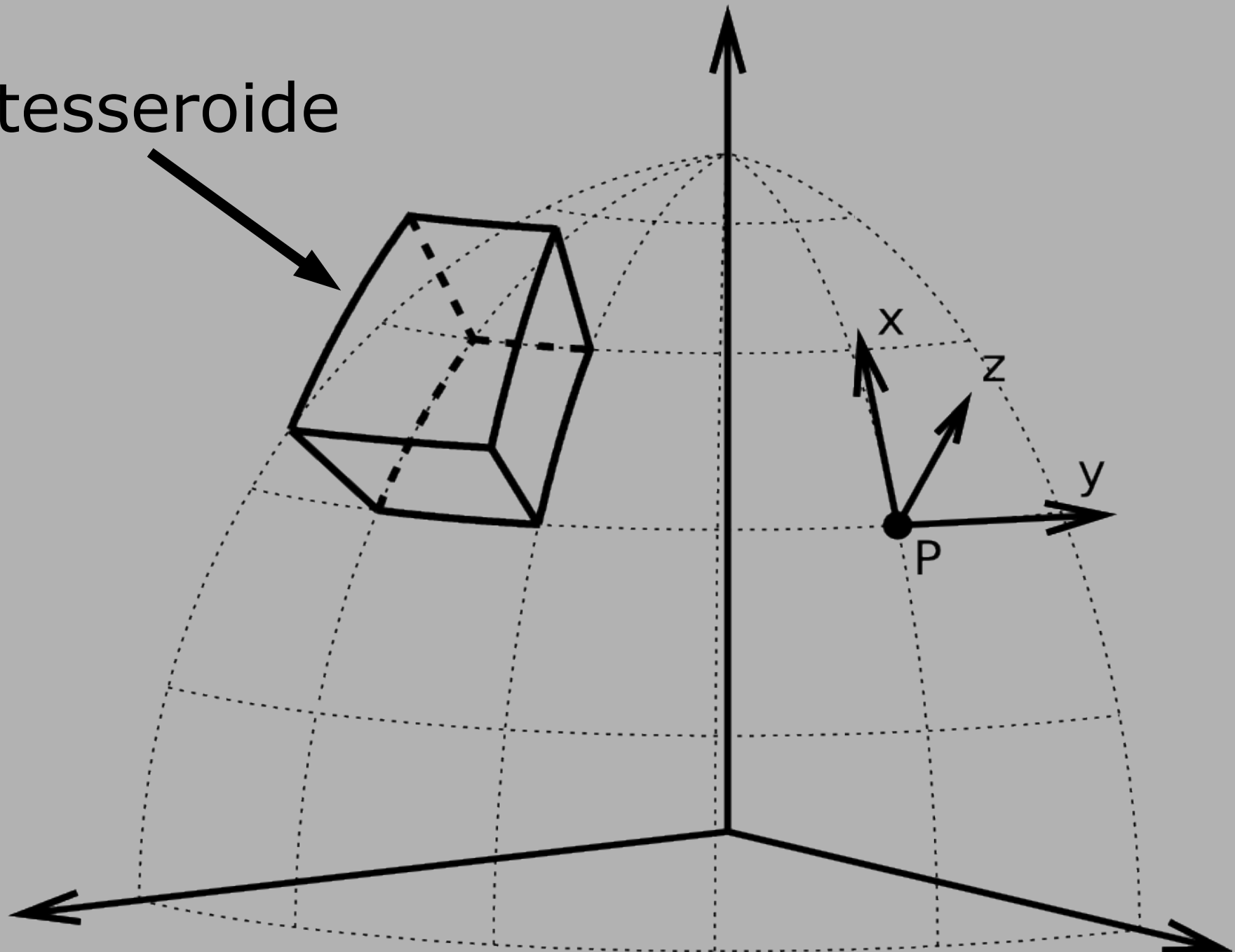
PInGa

Grupo de
Problemas Inversos
em Geofísica

1. Calcular grav
de um modelo (tesseroides)
2. Calcular modelo
a partir da gravidade
3. Software

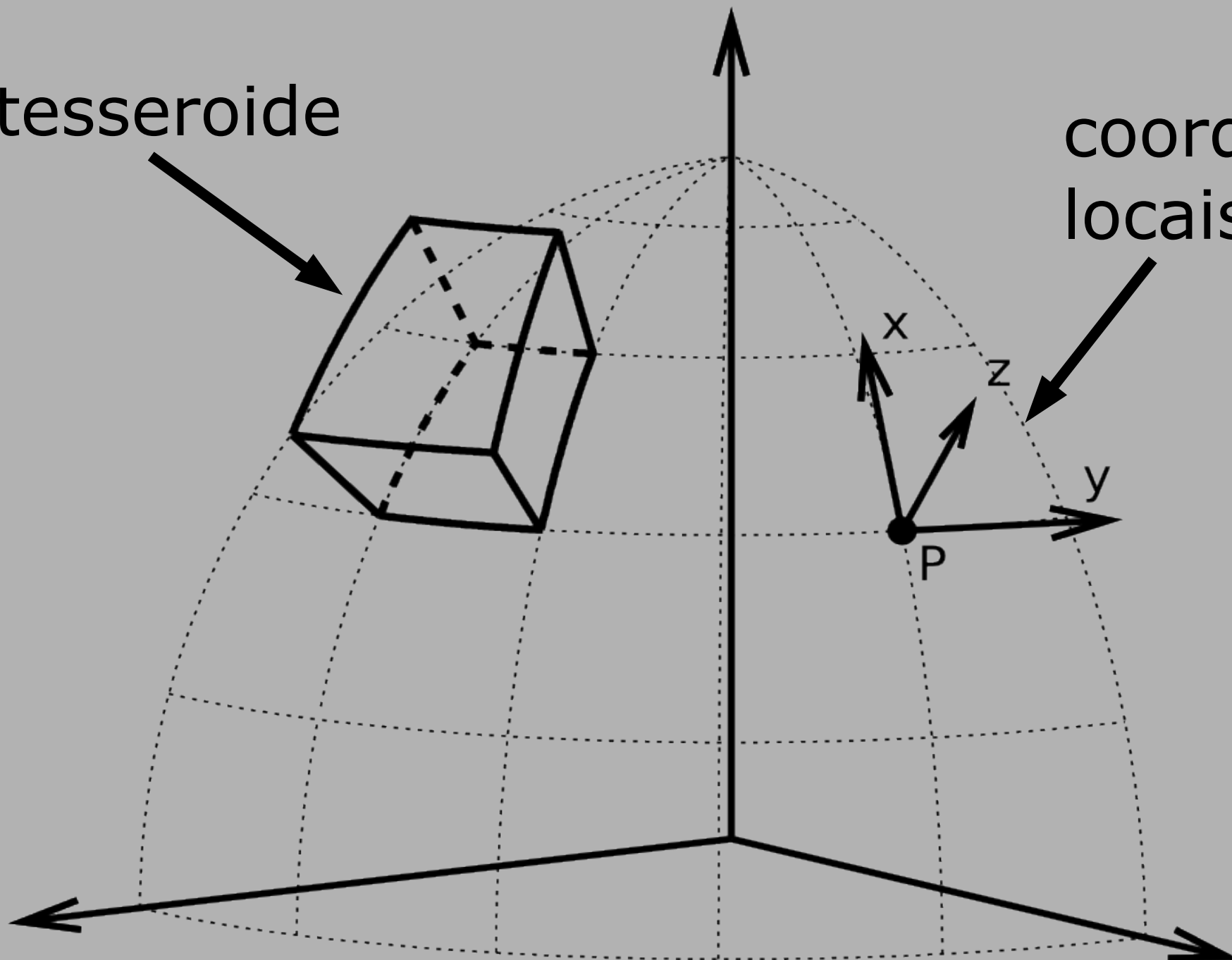
Grav de um modelo

tesseroide



tesseroide

coord.
locais



Integração numérica

Quadratura Gauss-Legendre

Integral



Soma de massas pontuais

Acurácia

Nº de massas pontuais

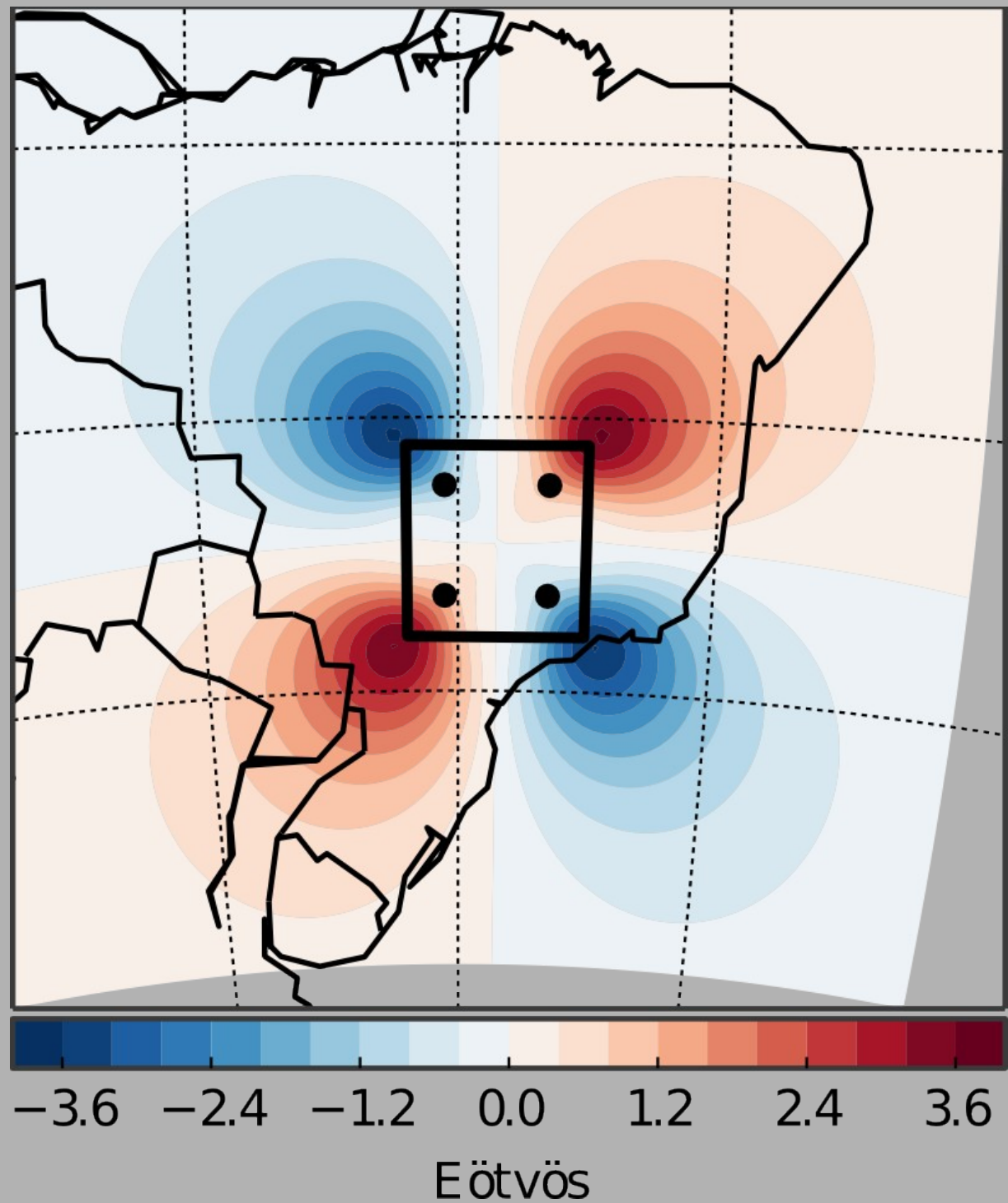
+

Distância massas / Distância obs.

gxy

$h = 400 \text{ km}$

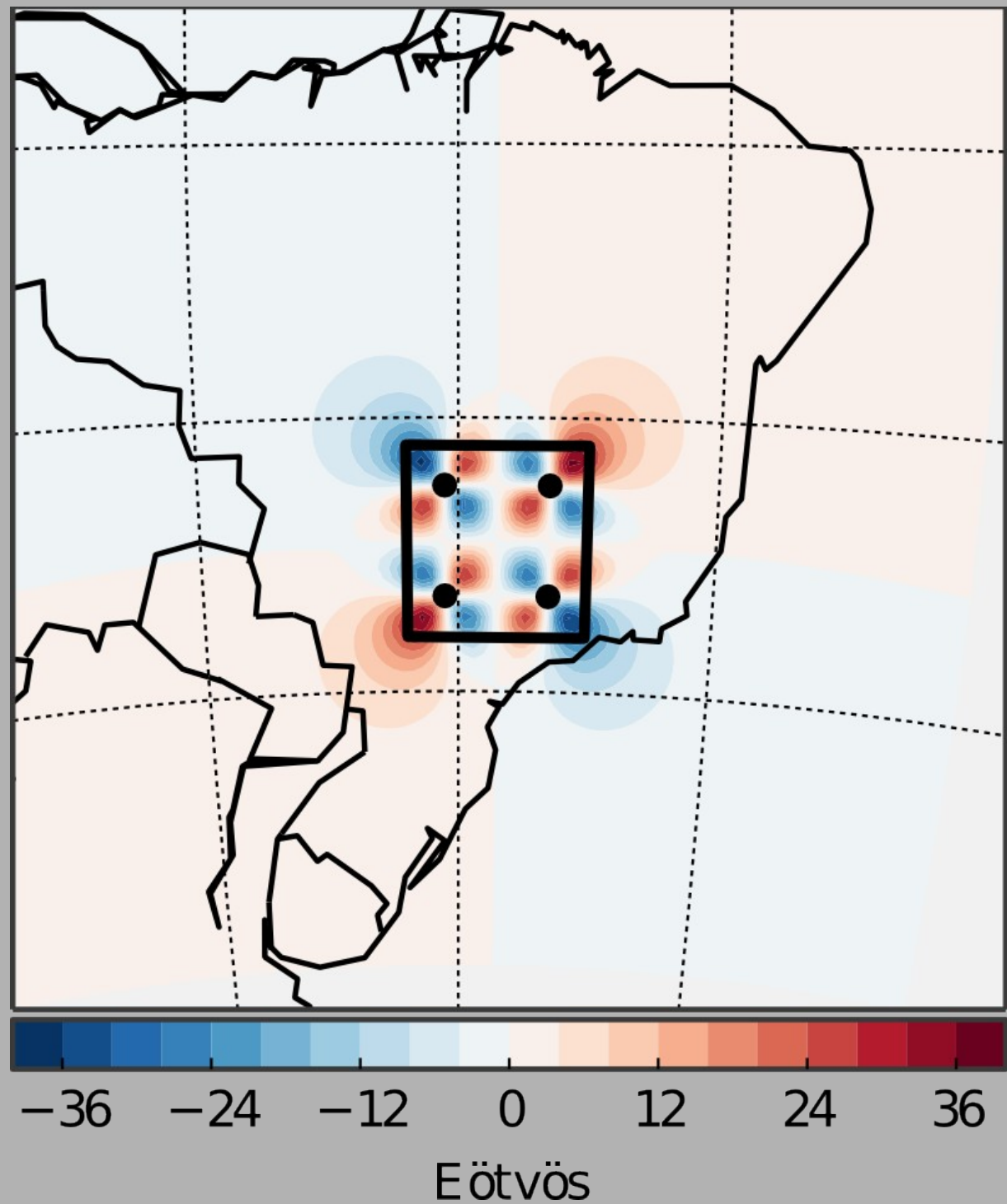
Massas:
 $2 \times 2 \times 2$



gxy

$h = 150 \text{ km}$

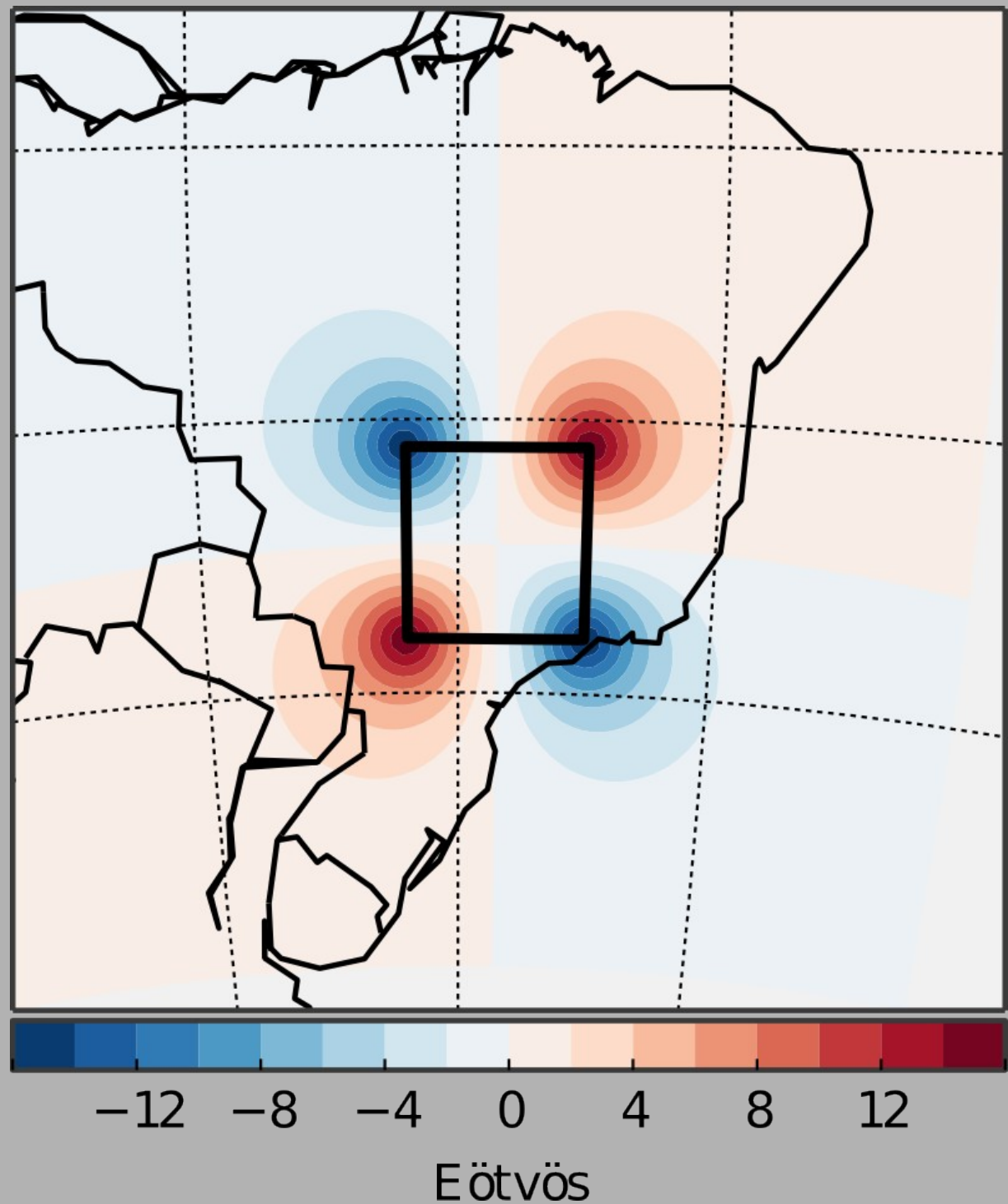
Massas:
 $2 \times 2 \times 2$



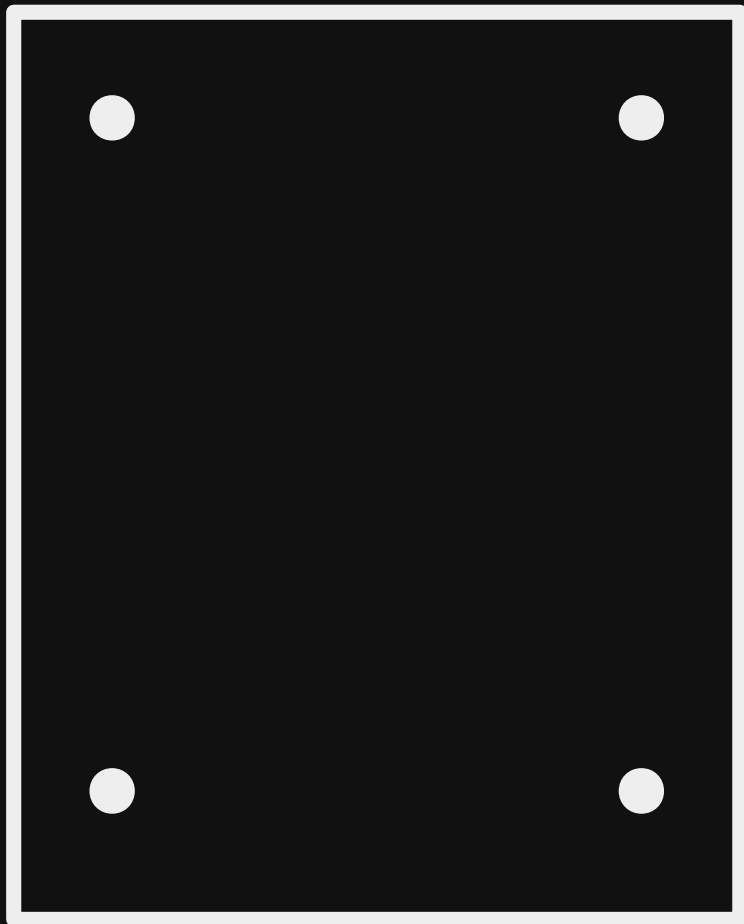
gxy

$h = 150 \text{ km}$

Massas:
30 x 30 x 30



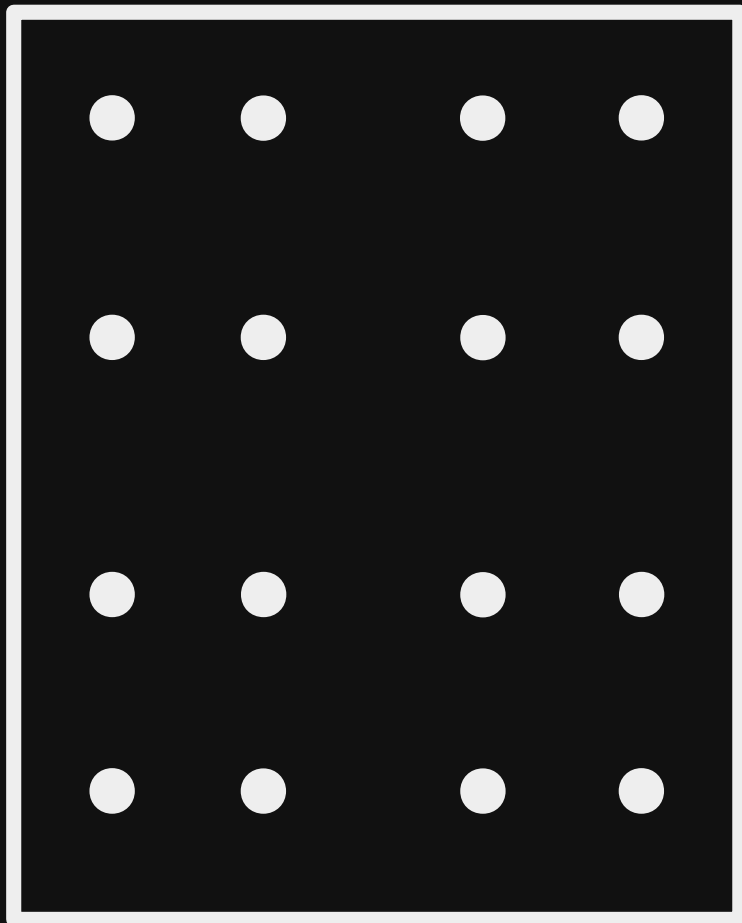
Diminuir o erro



Erro grande

Diminuir o erro

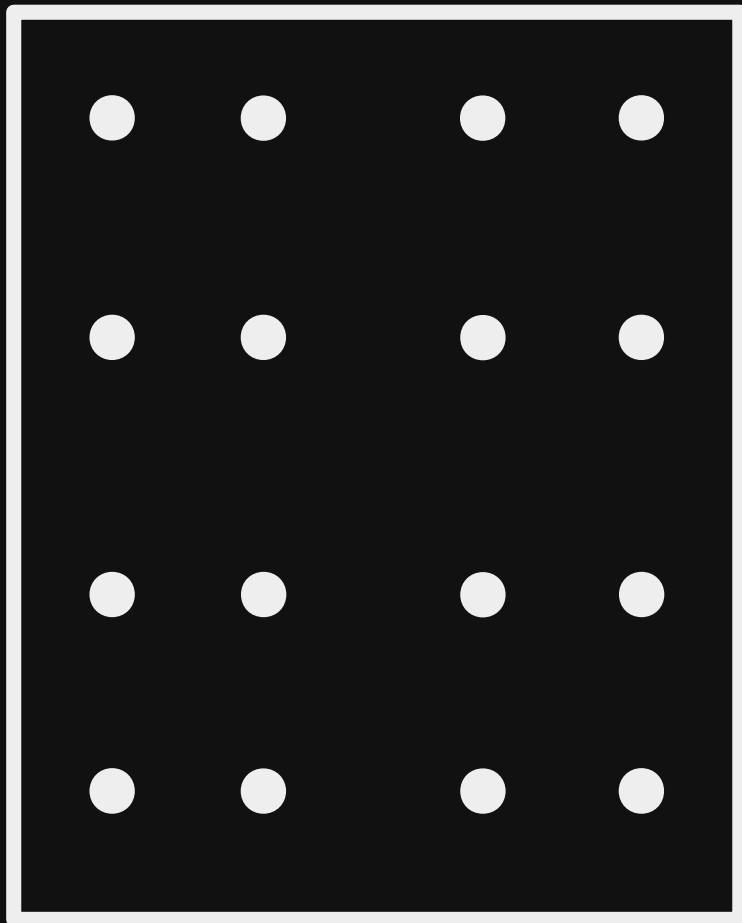
Mais massas



Erro **menor**

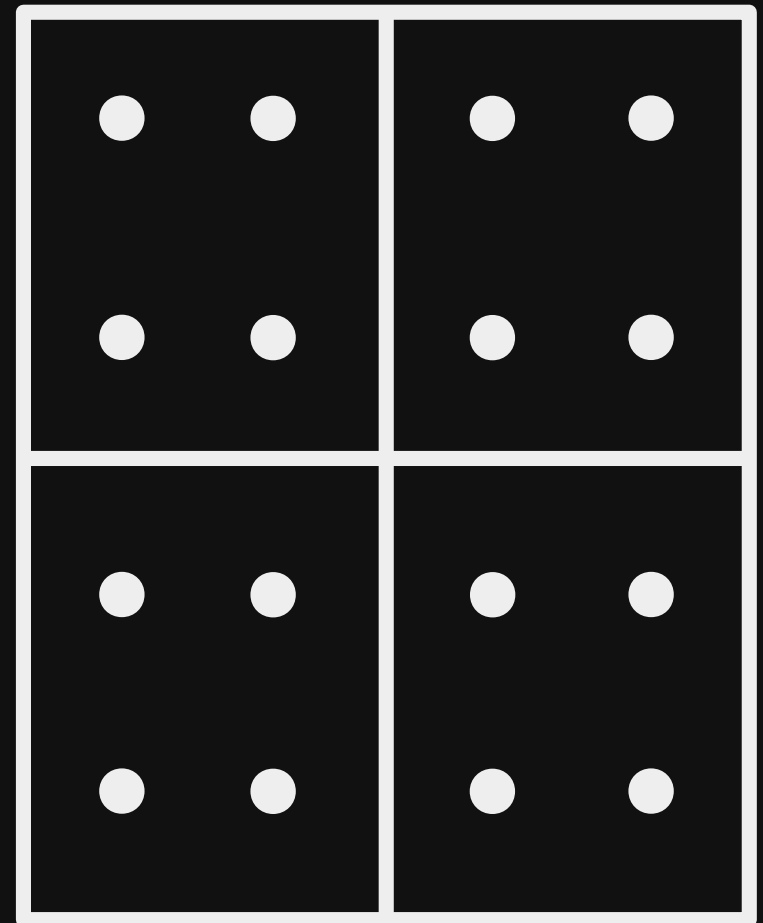
Diminuir o erro

Mais massas



ou

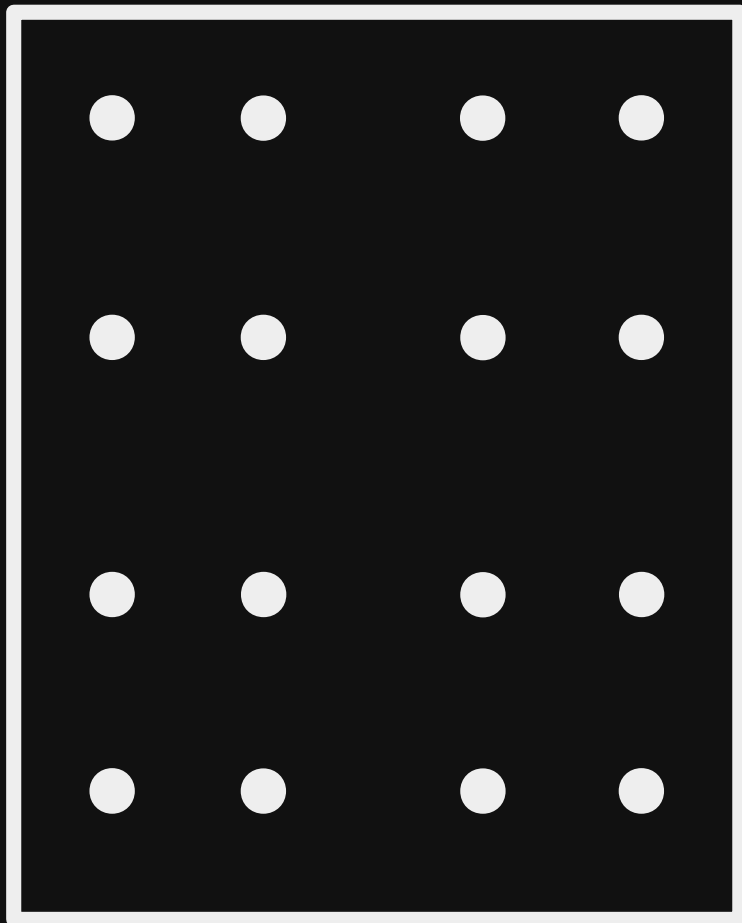
Mais tesseroides



Diminuir o erro

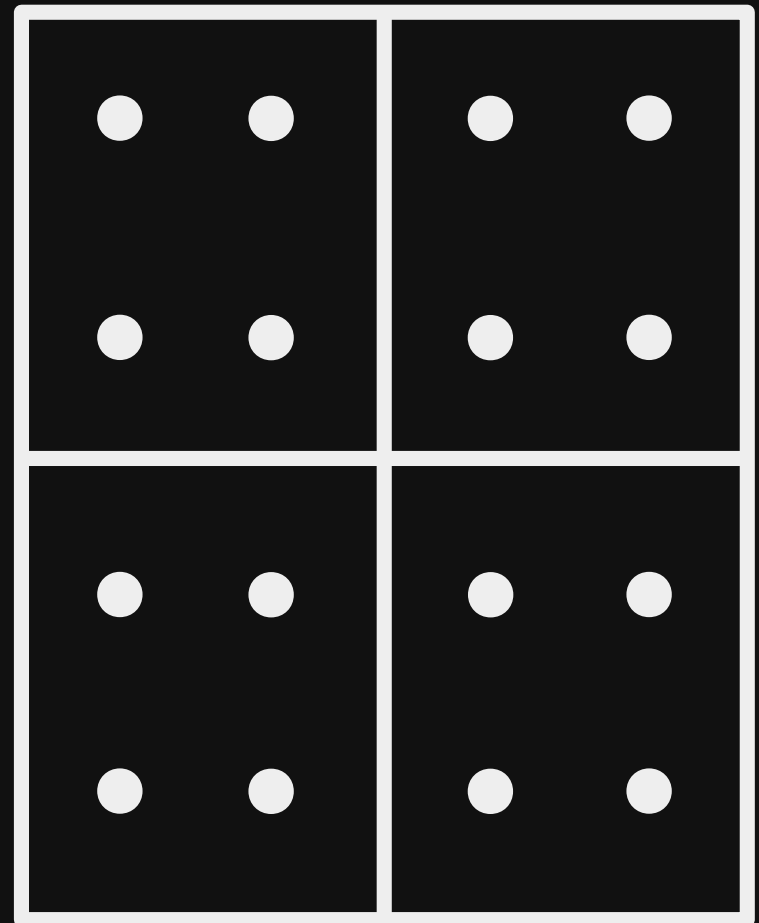


Mais massas



ou

Mais tesseroides



Algoritmo

modelo

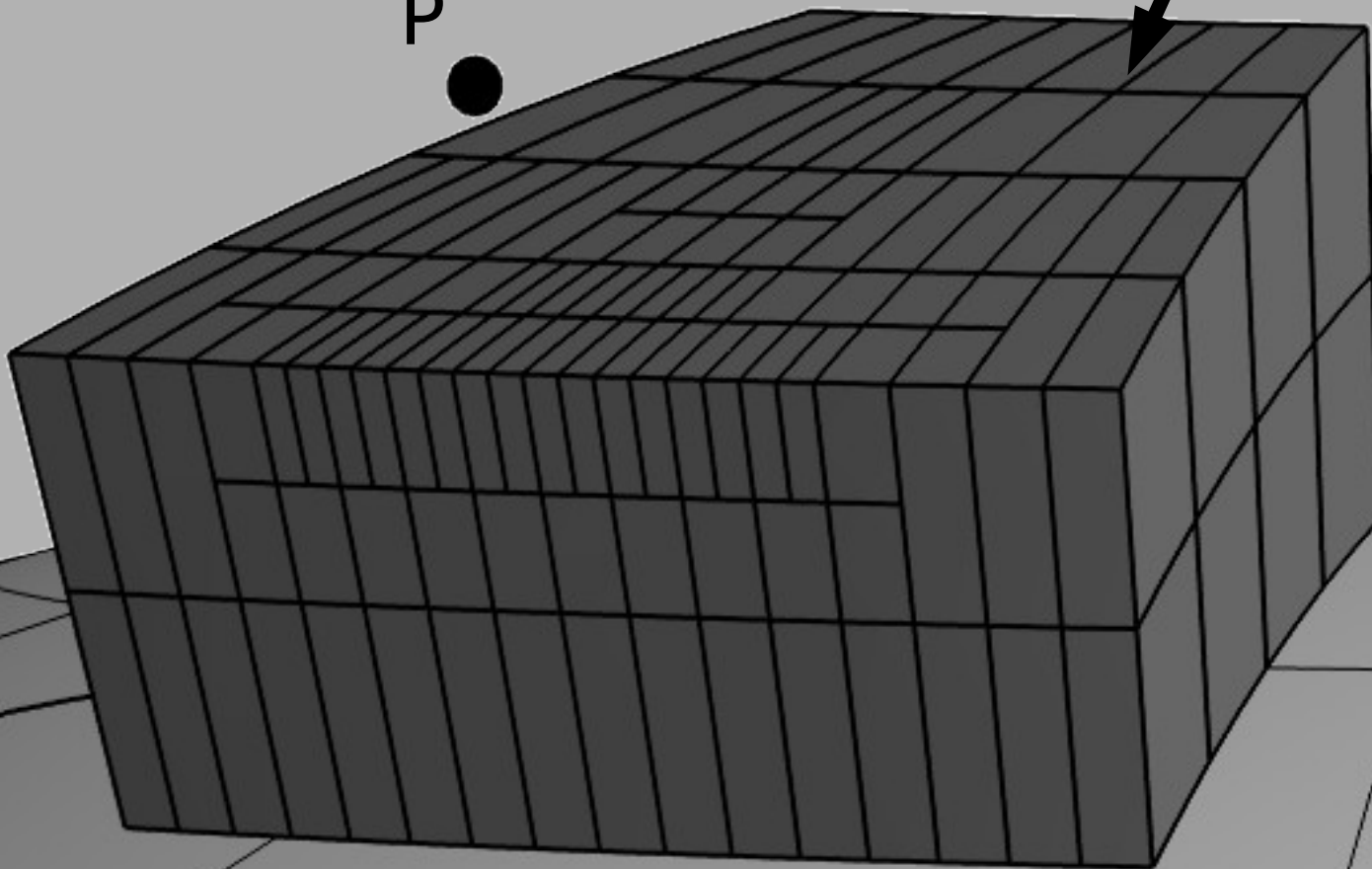
P



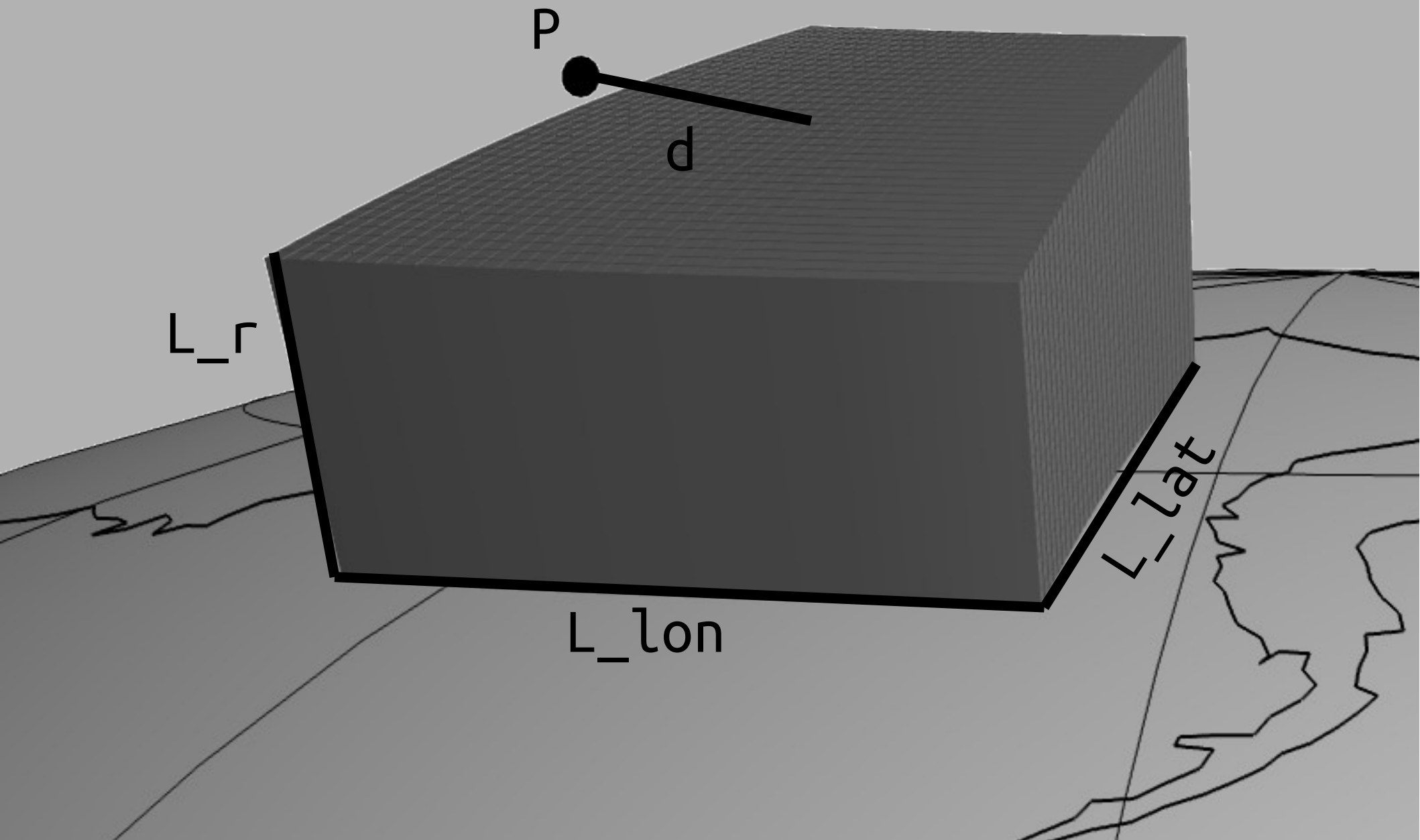
Algoritmo

modelo

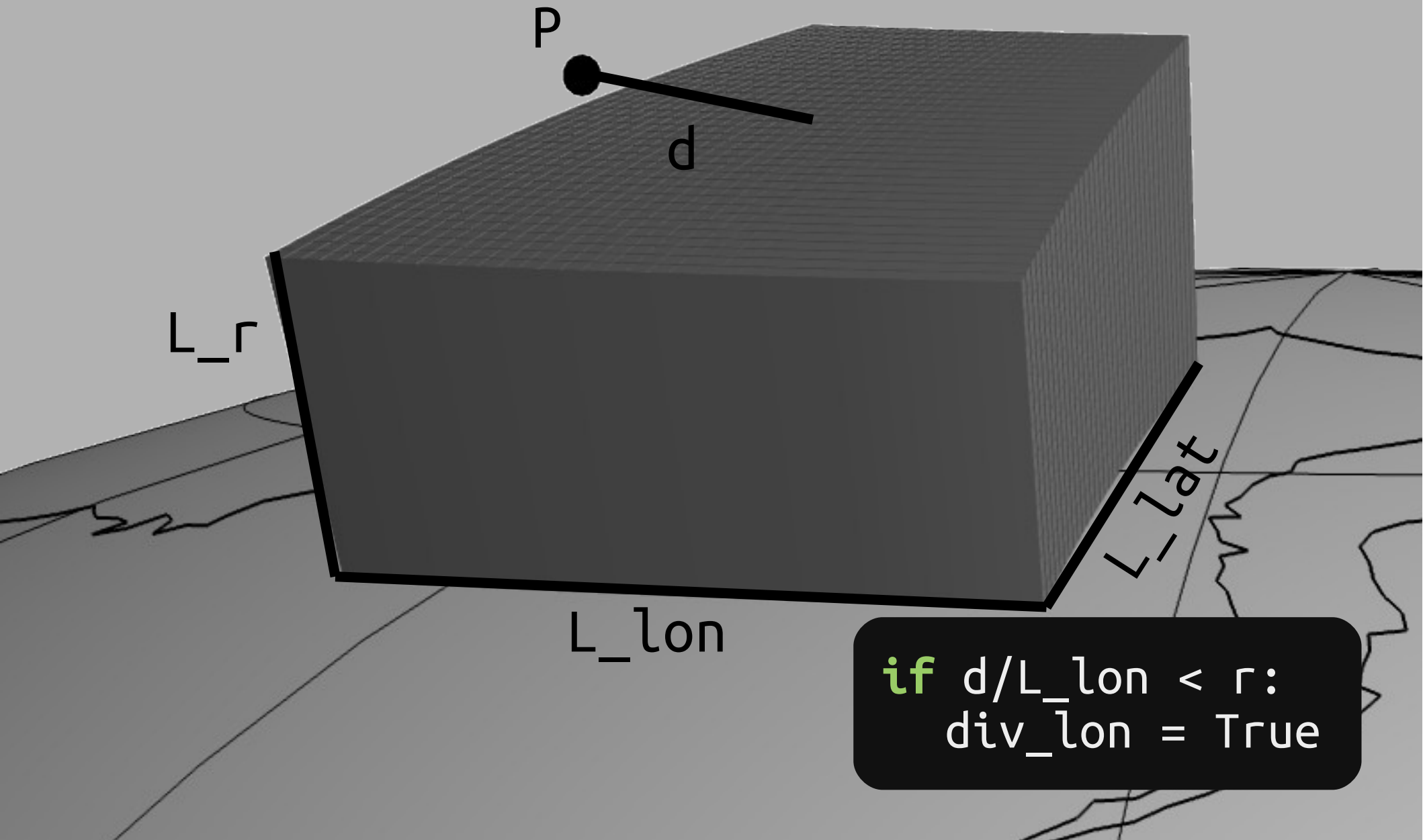
P



Algoritmo

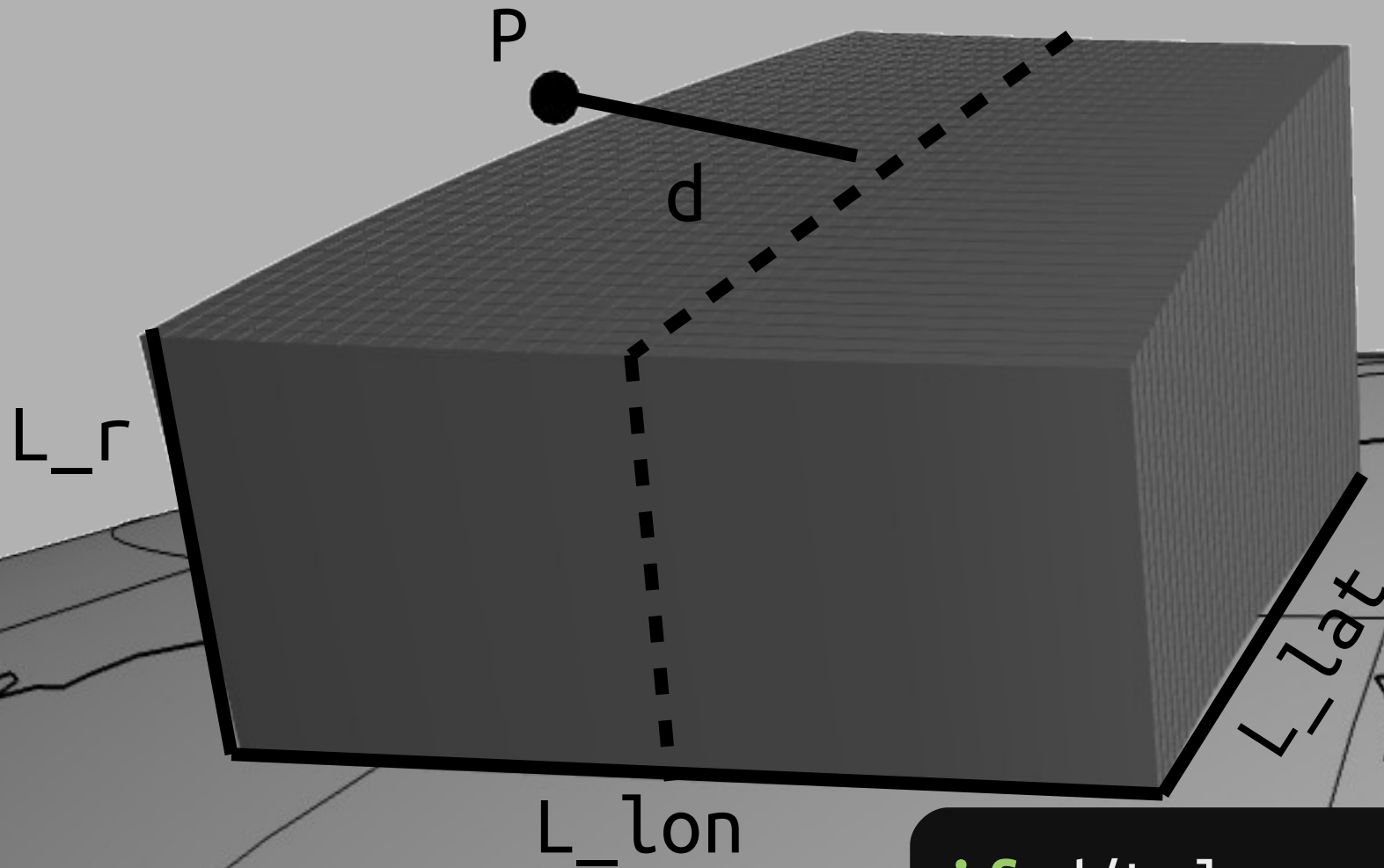


Algoritmo



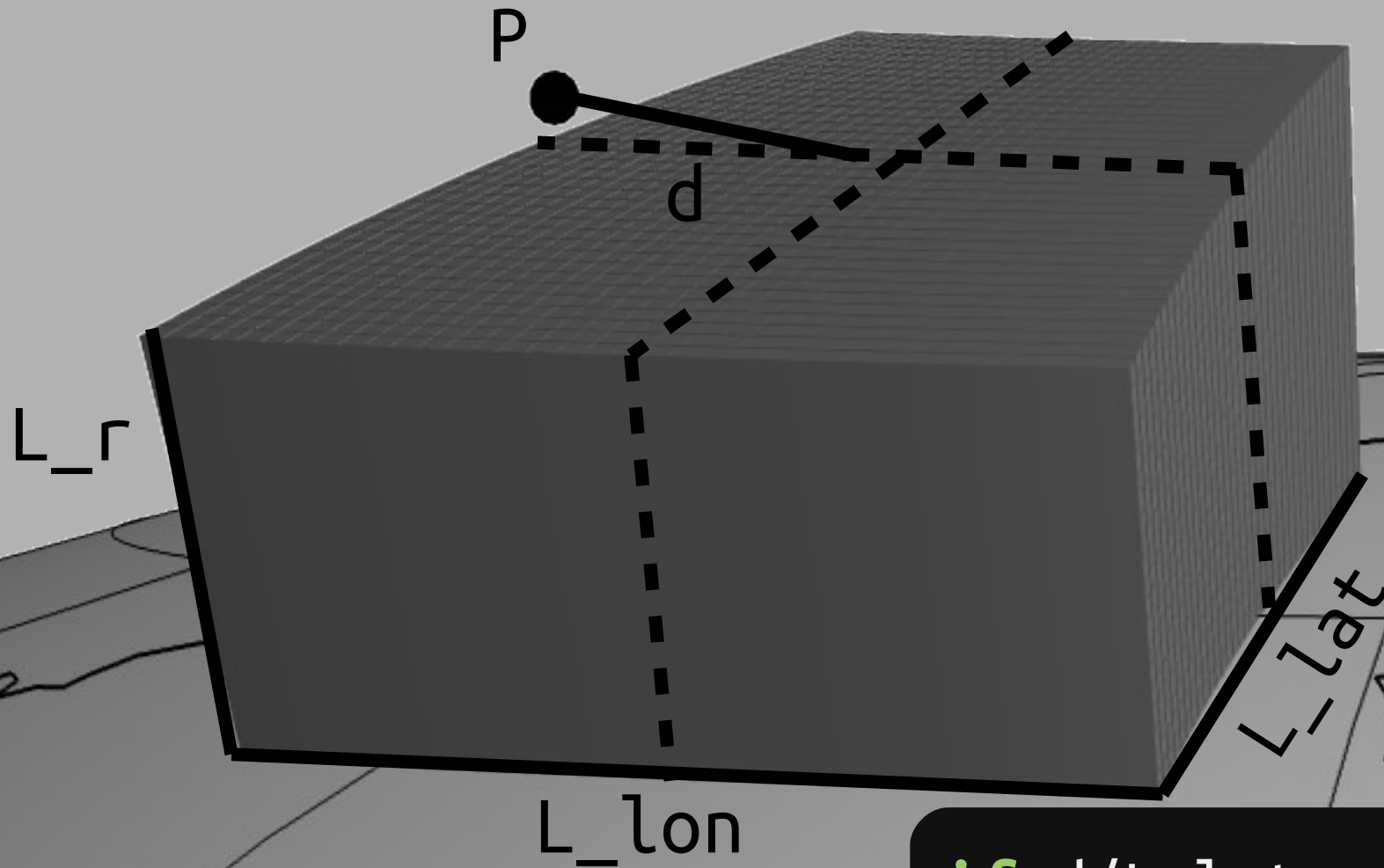
```
if  $d/L_{lon} < r$ :  
    div_lon = True
```

Algoritmo



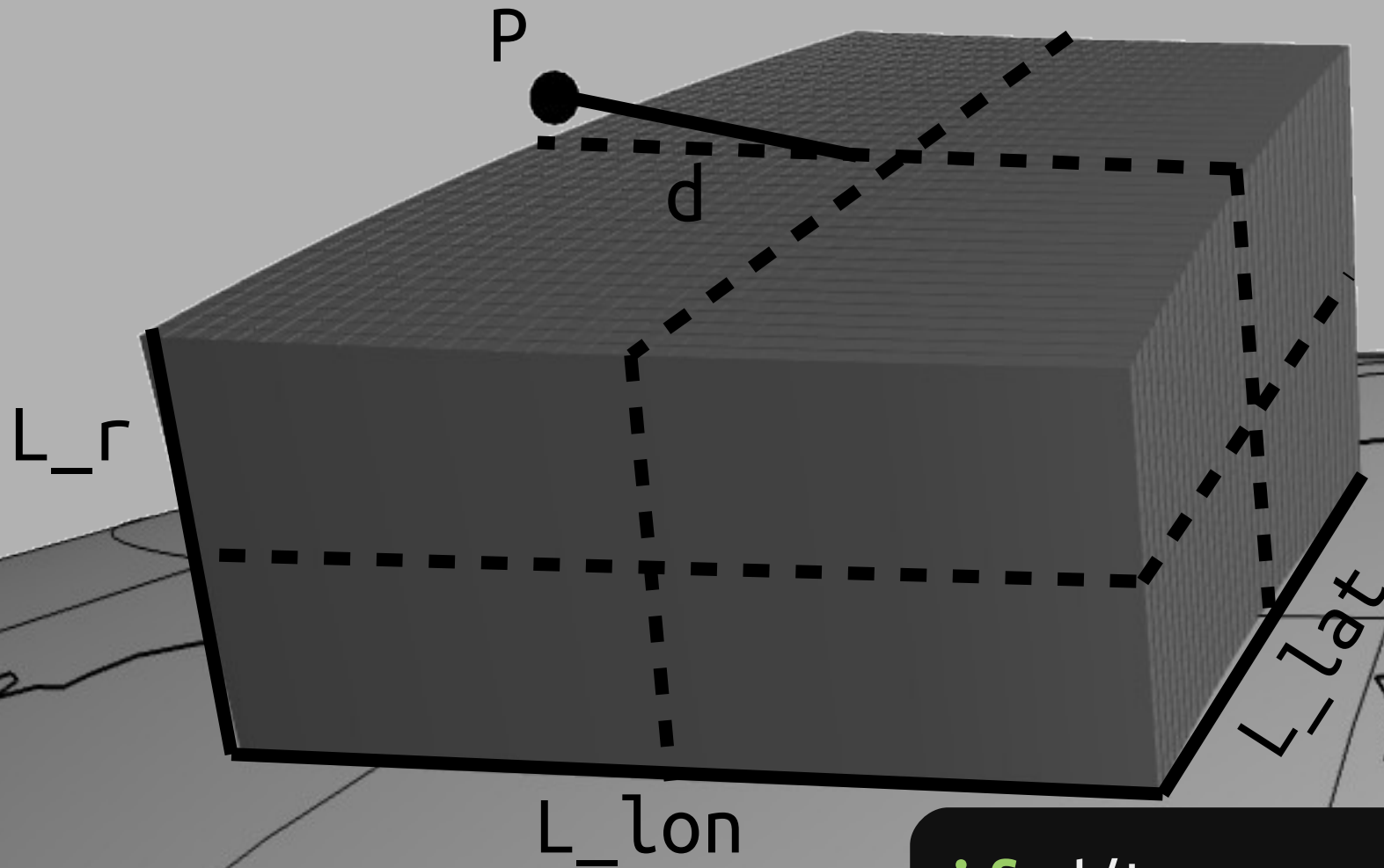
```
if  $d/L_{lon} < r$ :  
    div_lon = True
```

Algoritmo



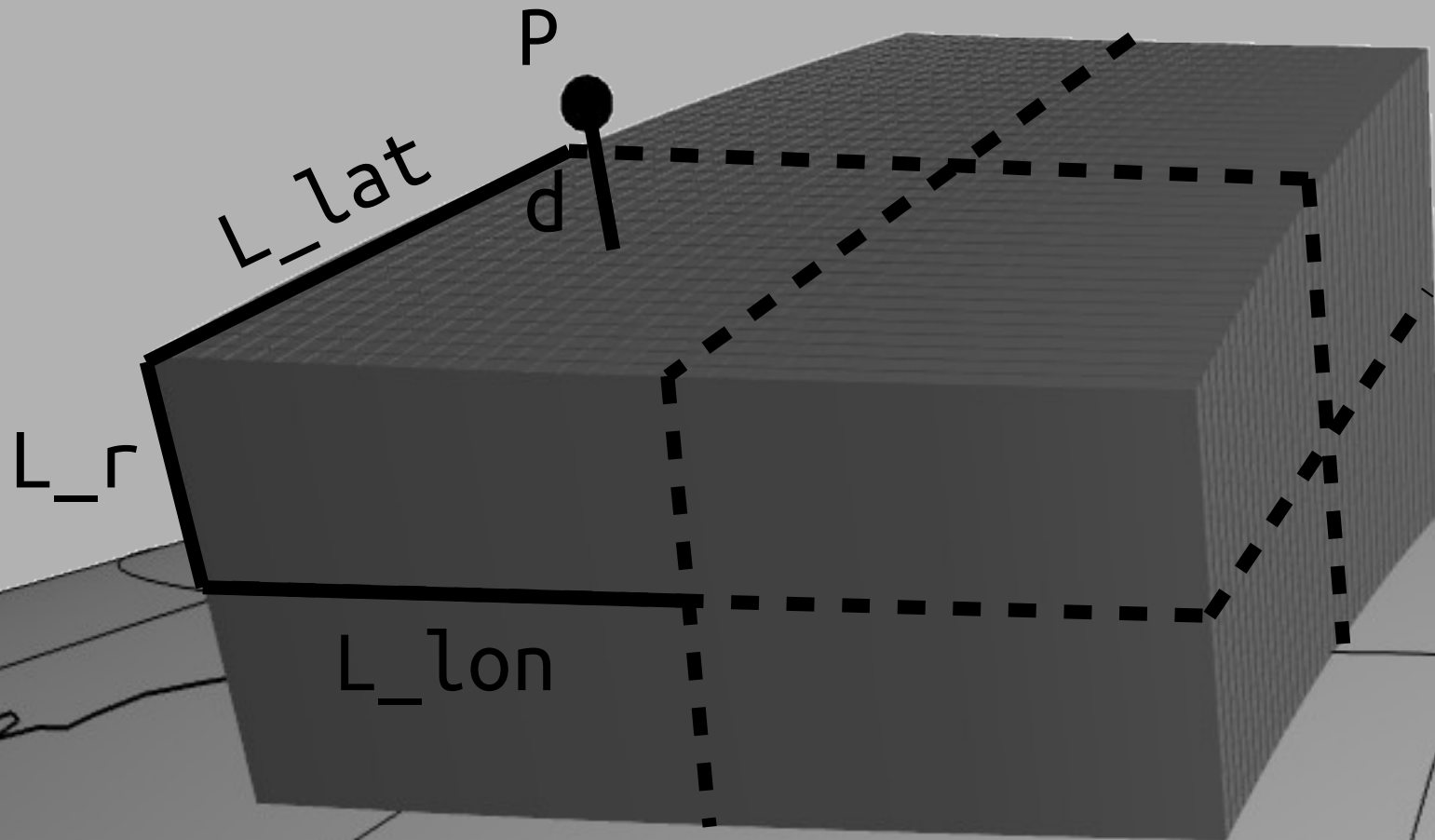
```
if  $d/L_{lat} < r$ :  
    div_lat = True
```

Algoritmo



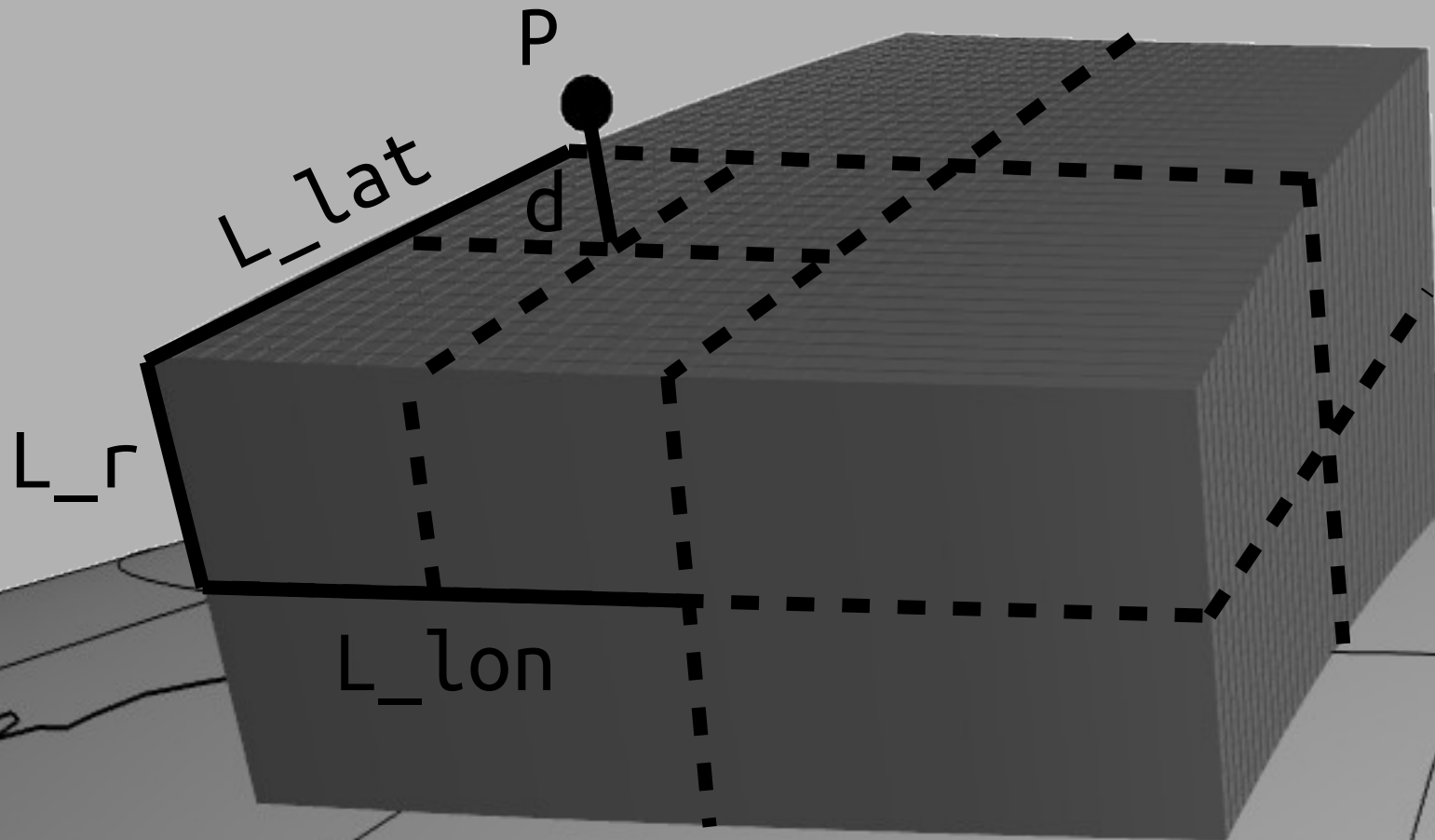
```
if  $d/L_r < r$ :  
    div_r = True
```

Algoritmo



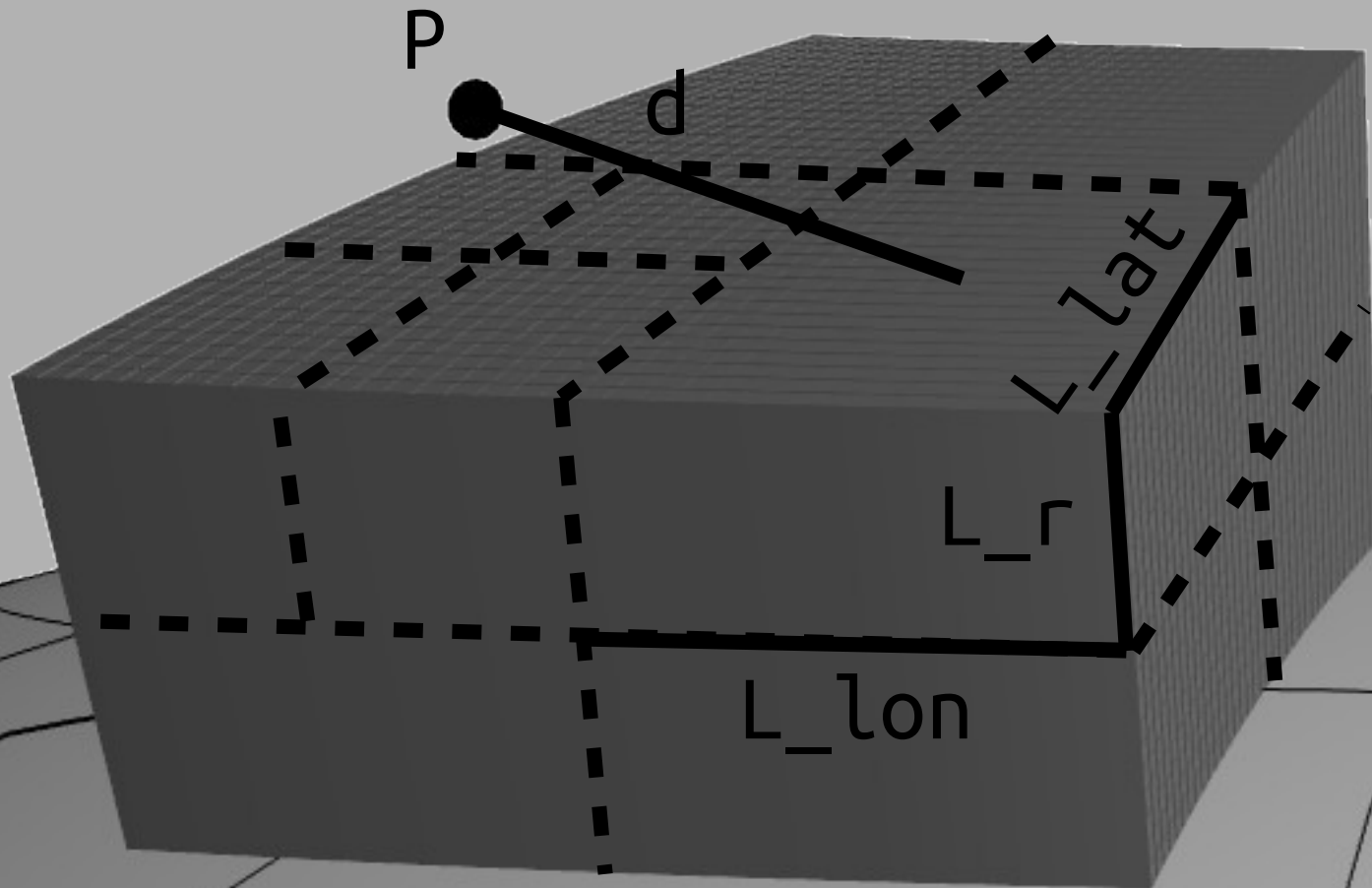
```
if  $d/L_{lon} < r$ :  
    div_lon = True
```

Algoritmo



```
if  $d/L_{lon} < r$ :  
    div_lon = True
```

Algoritmo



```
if  $d/L_{lon} < r$ :  
    div_lon = True
```

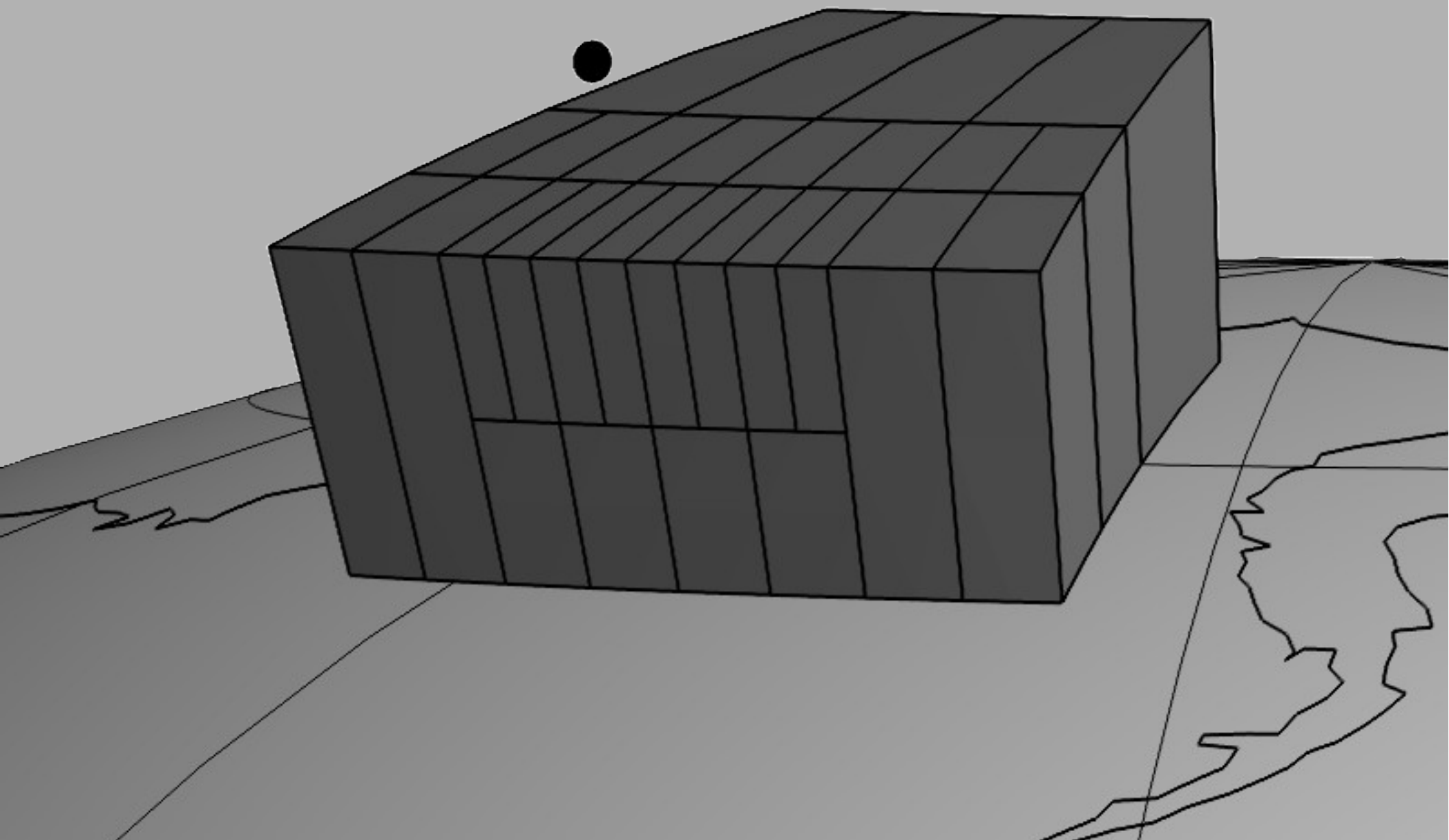

Algoritmo

r determina n° de divisões.

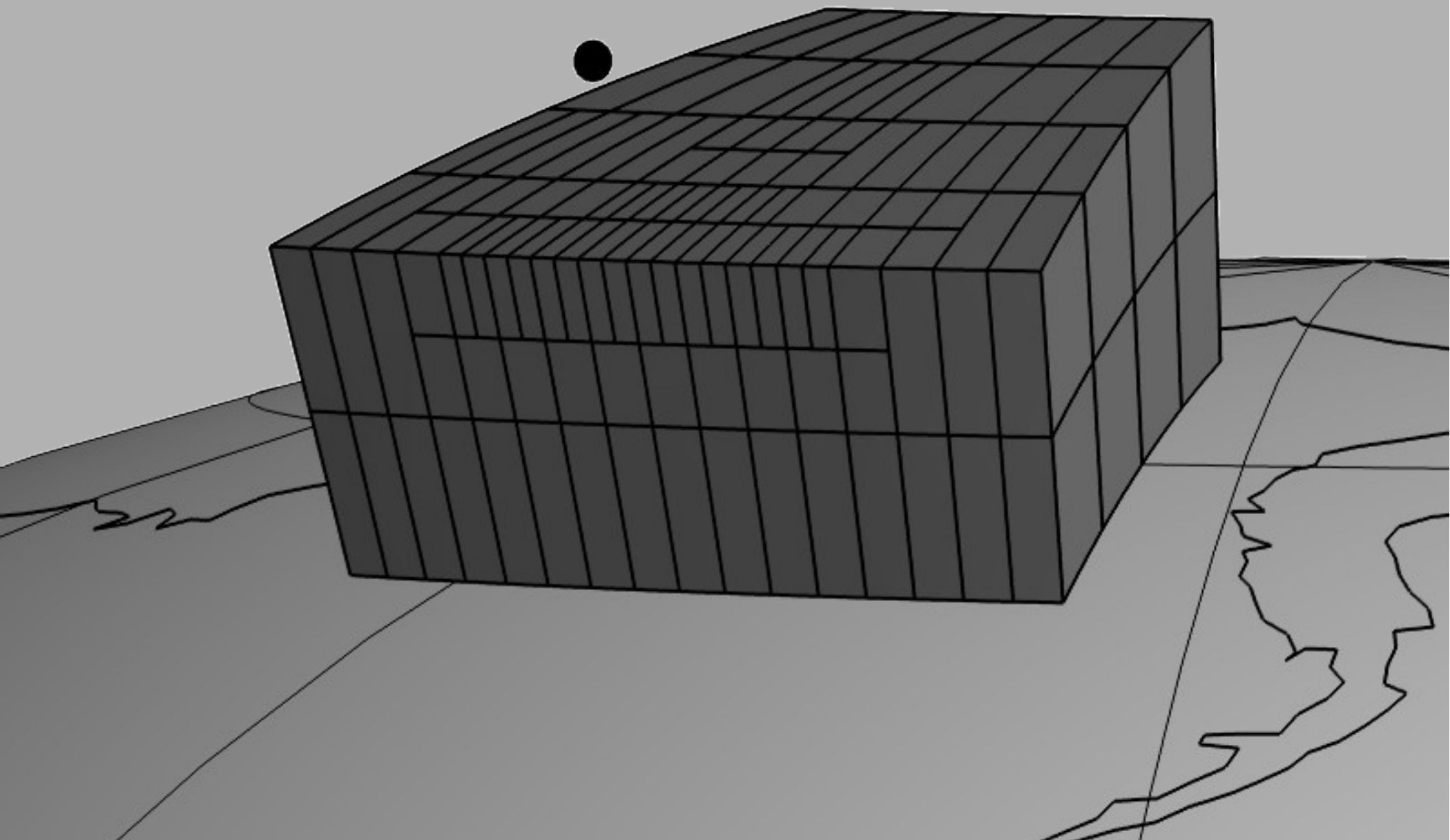


tempo de computação
+
acurácia

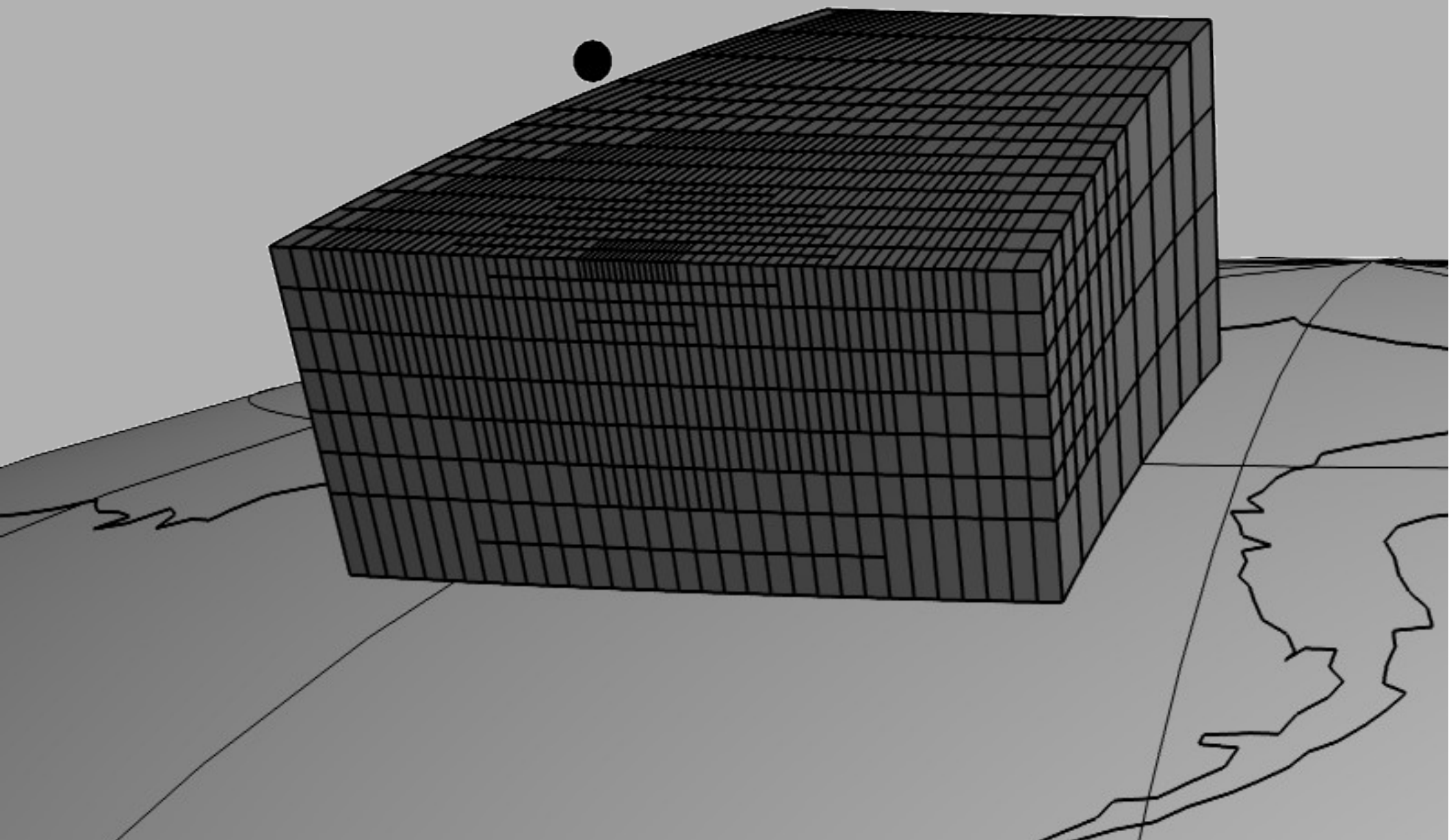
$$r = 1$$



$$r = 2$$



$$r = 6$$



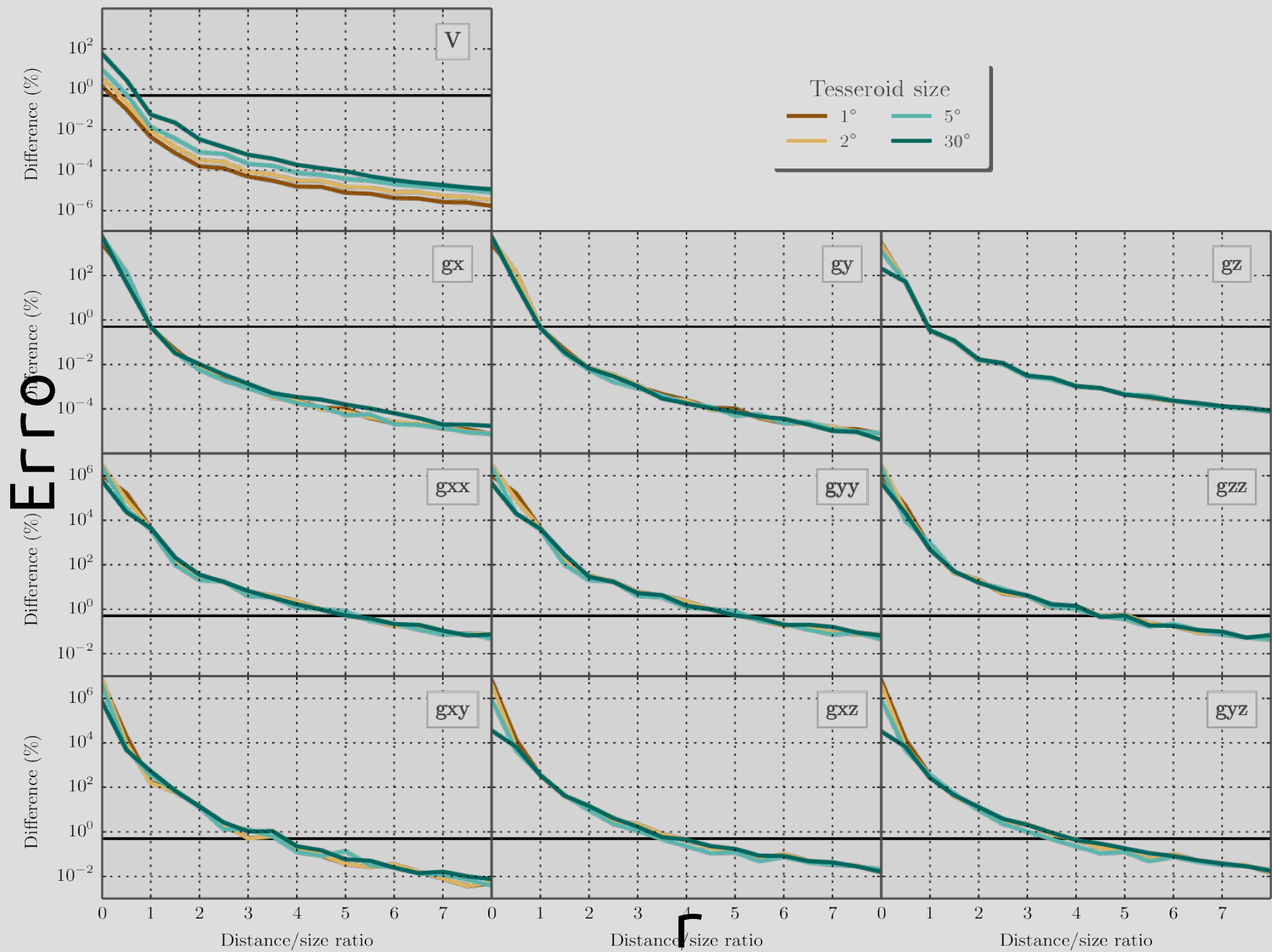
Casca esférica

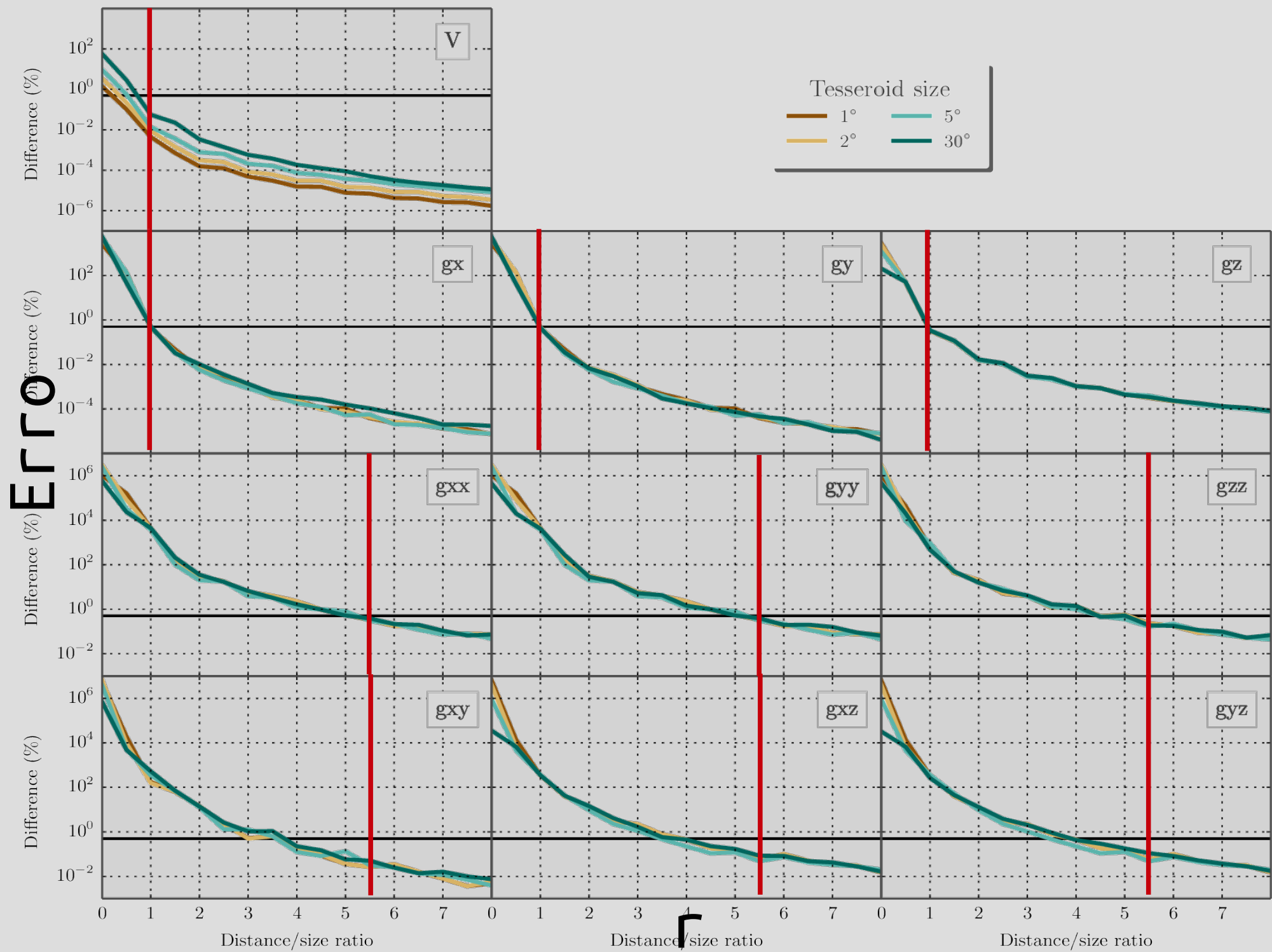
Solução analítica

Discretiza casca em tesseroides

Diferença entre resultados = **erro**

... para **vários** r





Conclusão

$$r = \begin{cases} 1 & - \text{potencial e } g \\ 6 & - \text{gradientes} \end{cases}$$

Garante erro **máximo** de 0.5%



1. Calcular grav
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**Calcular modelo
a partir da grav.**

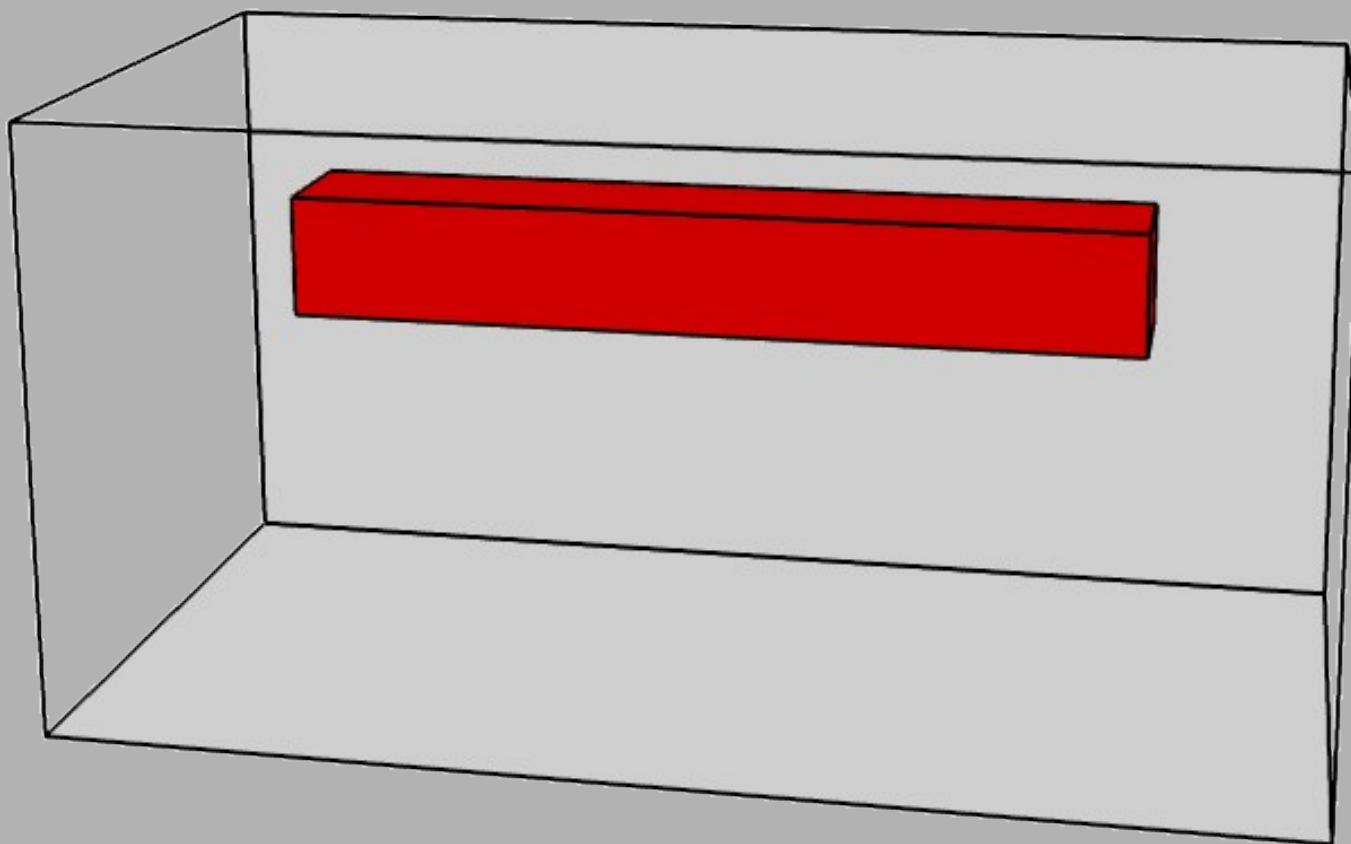
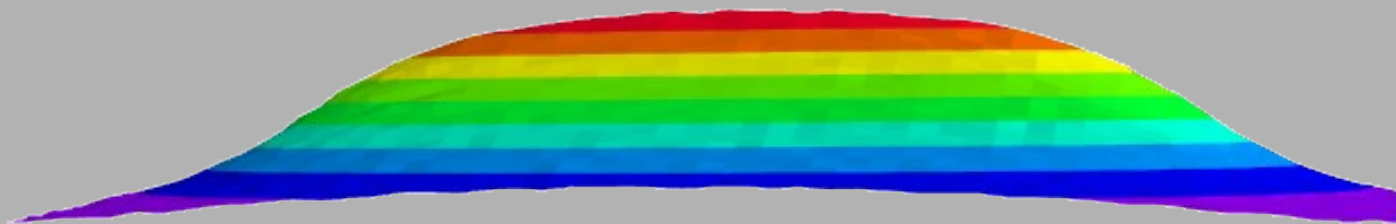
Algoritmo de plantação

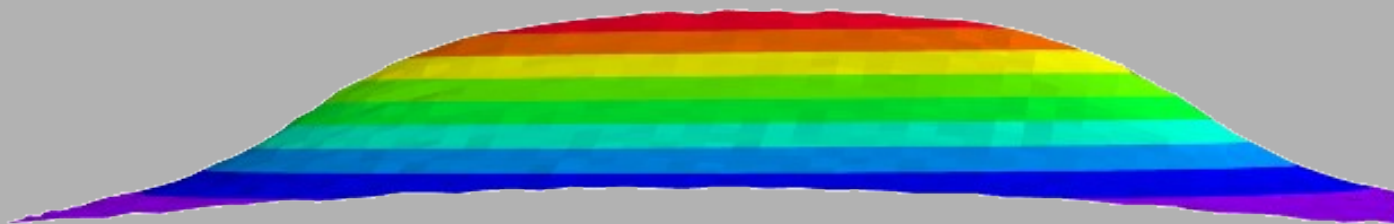
Gravidade + gradientes

Solução cresce em torno de sementes

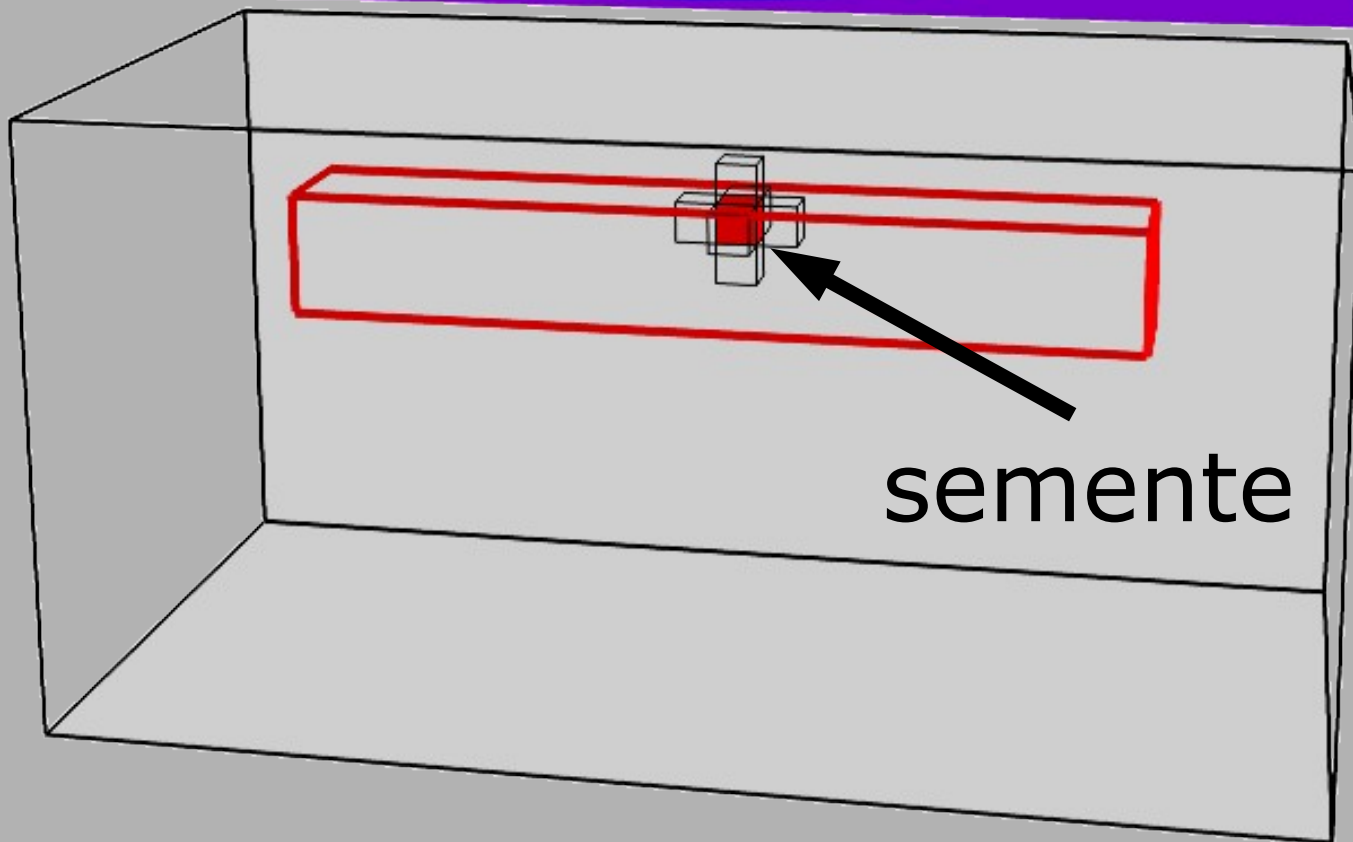
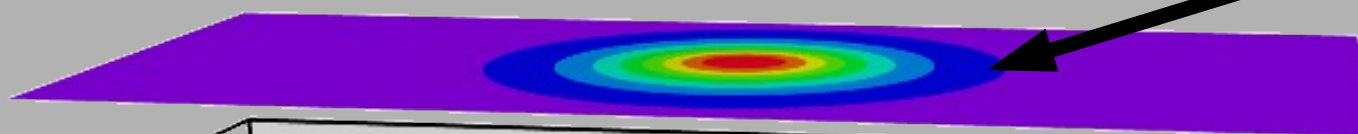
Não resolve sistemas lineares

Cálculo eficiente da Jacobiana

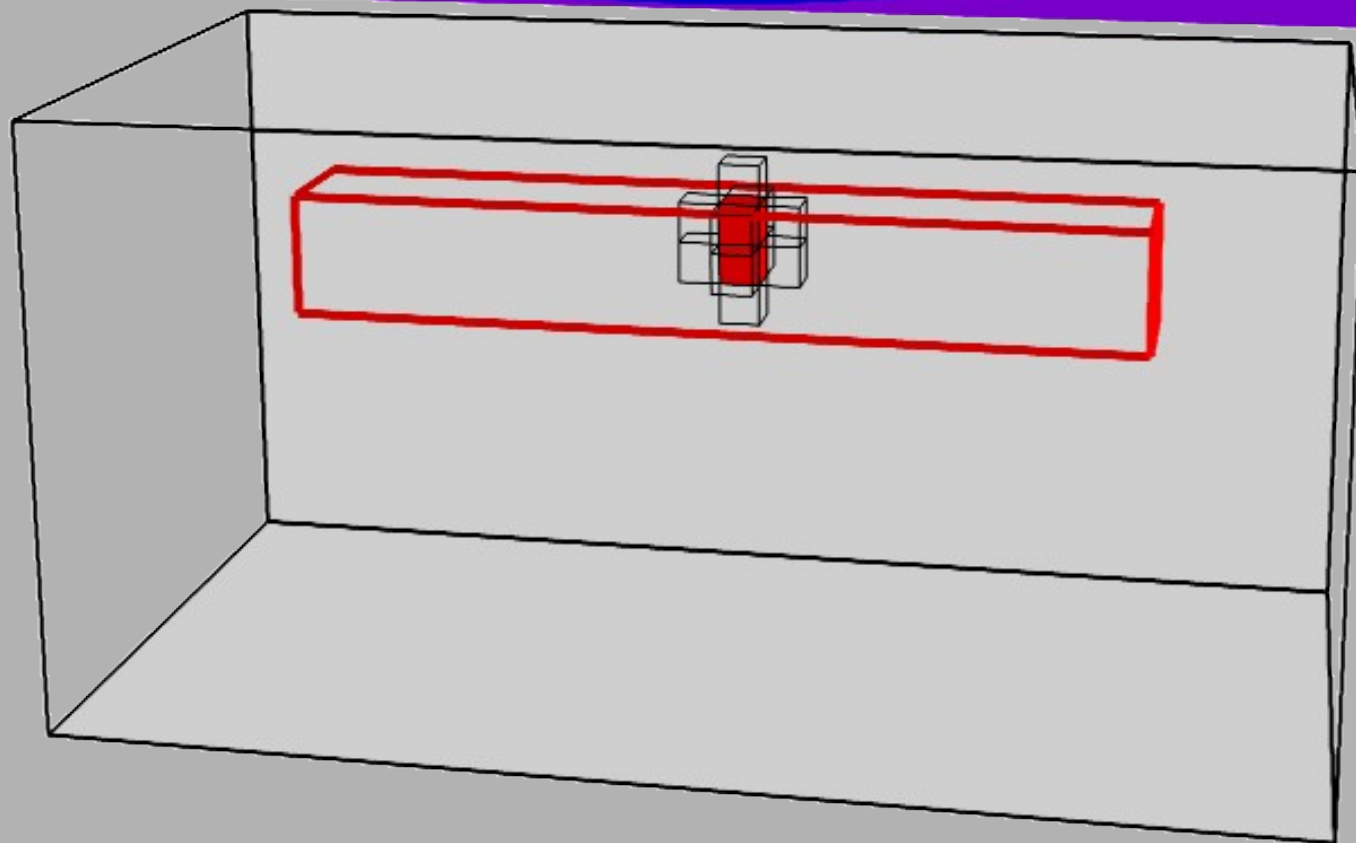
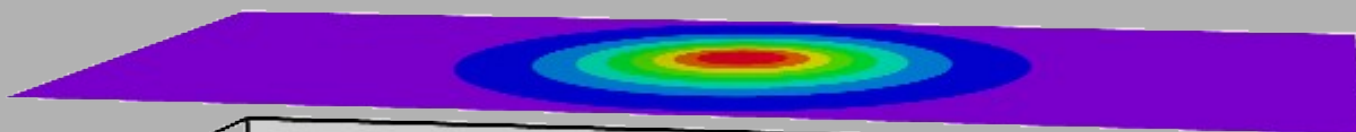


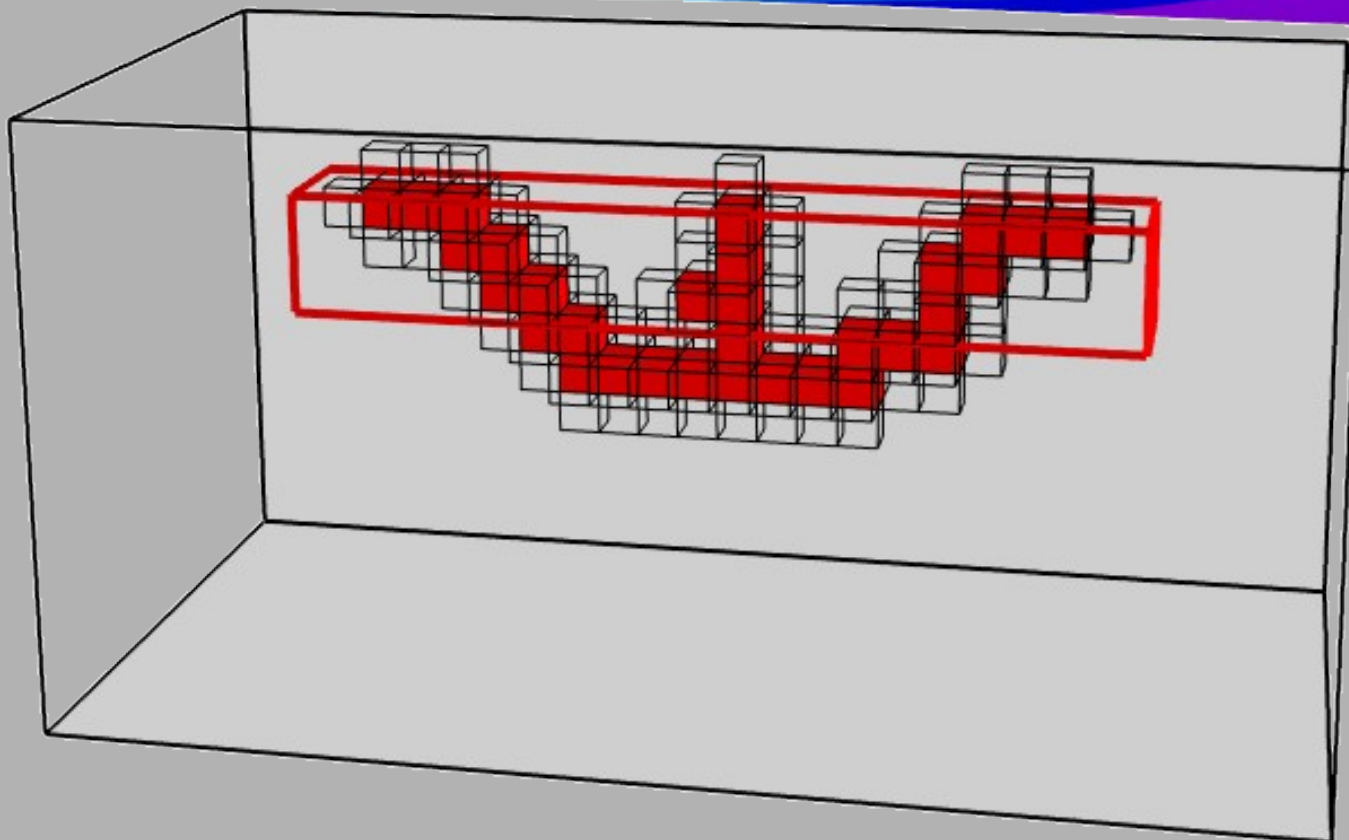
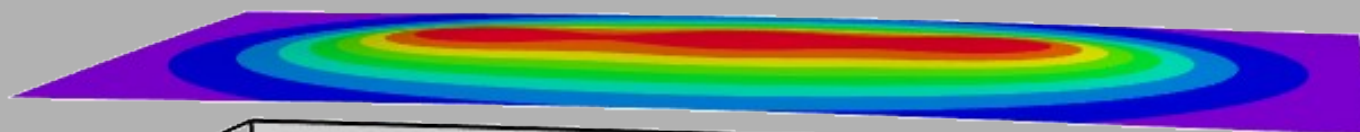
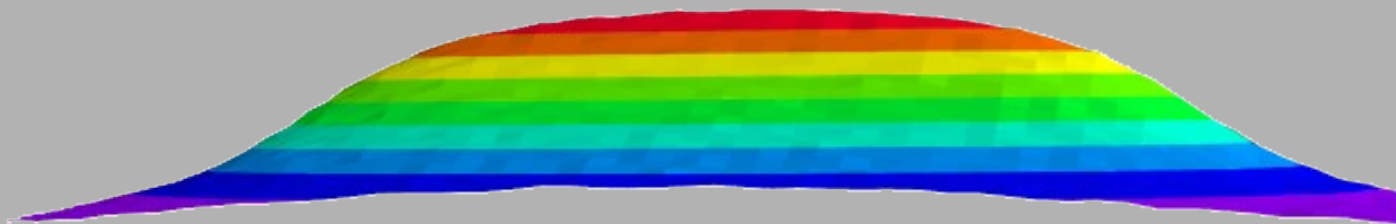


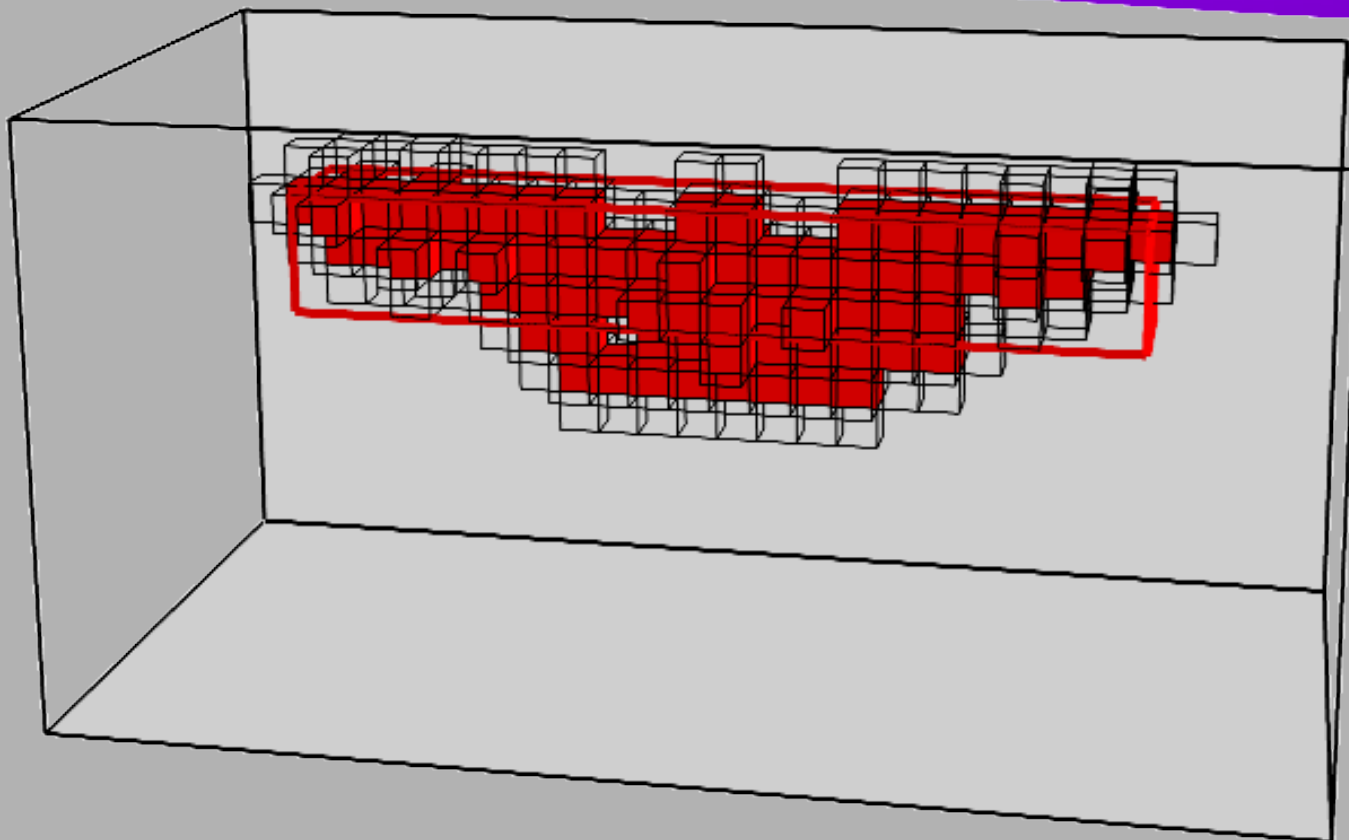
dado predito

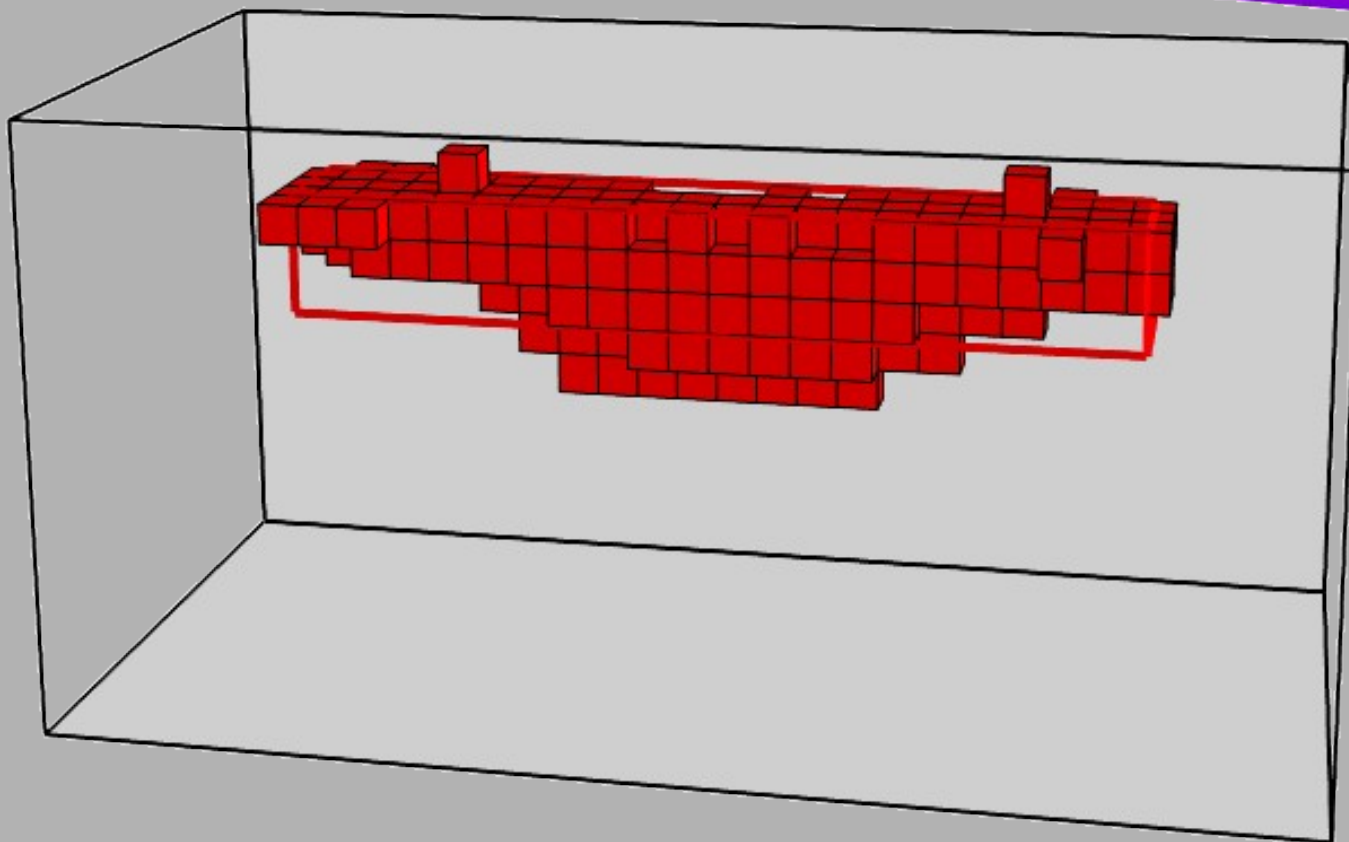
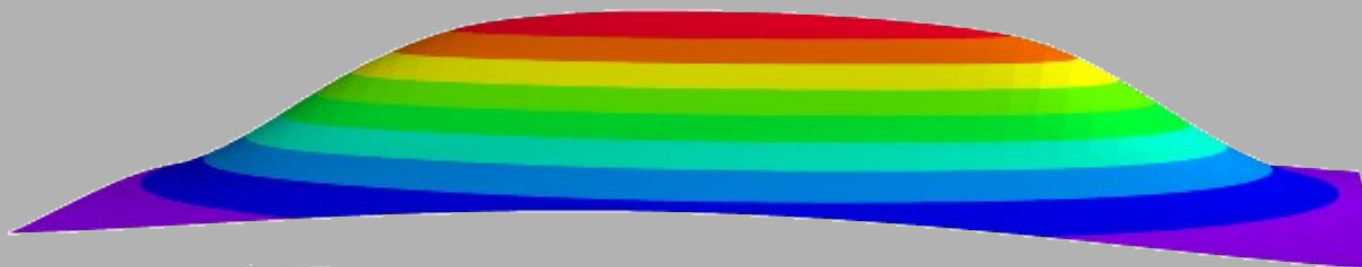


semente

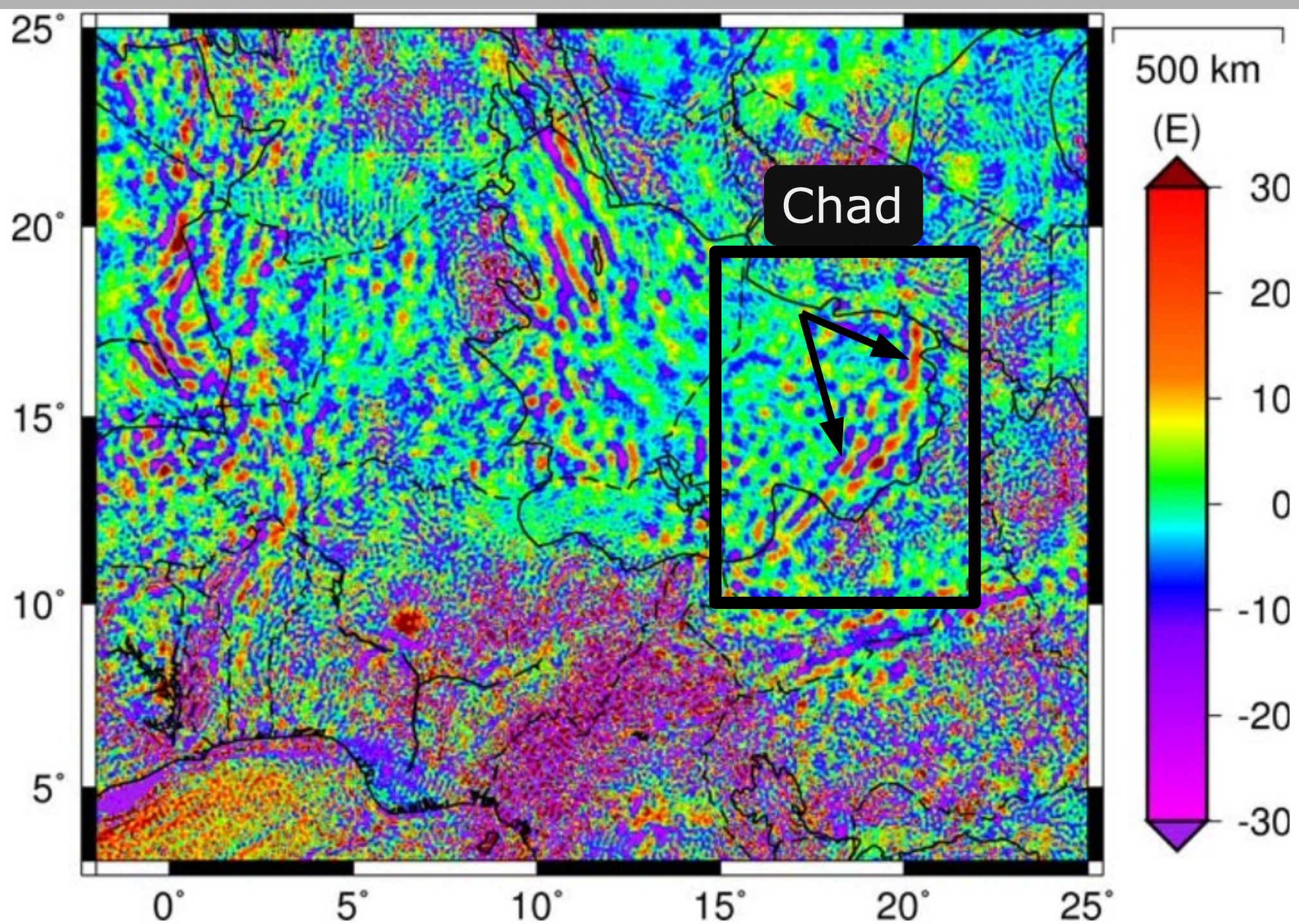




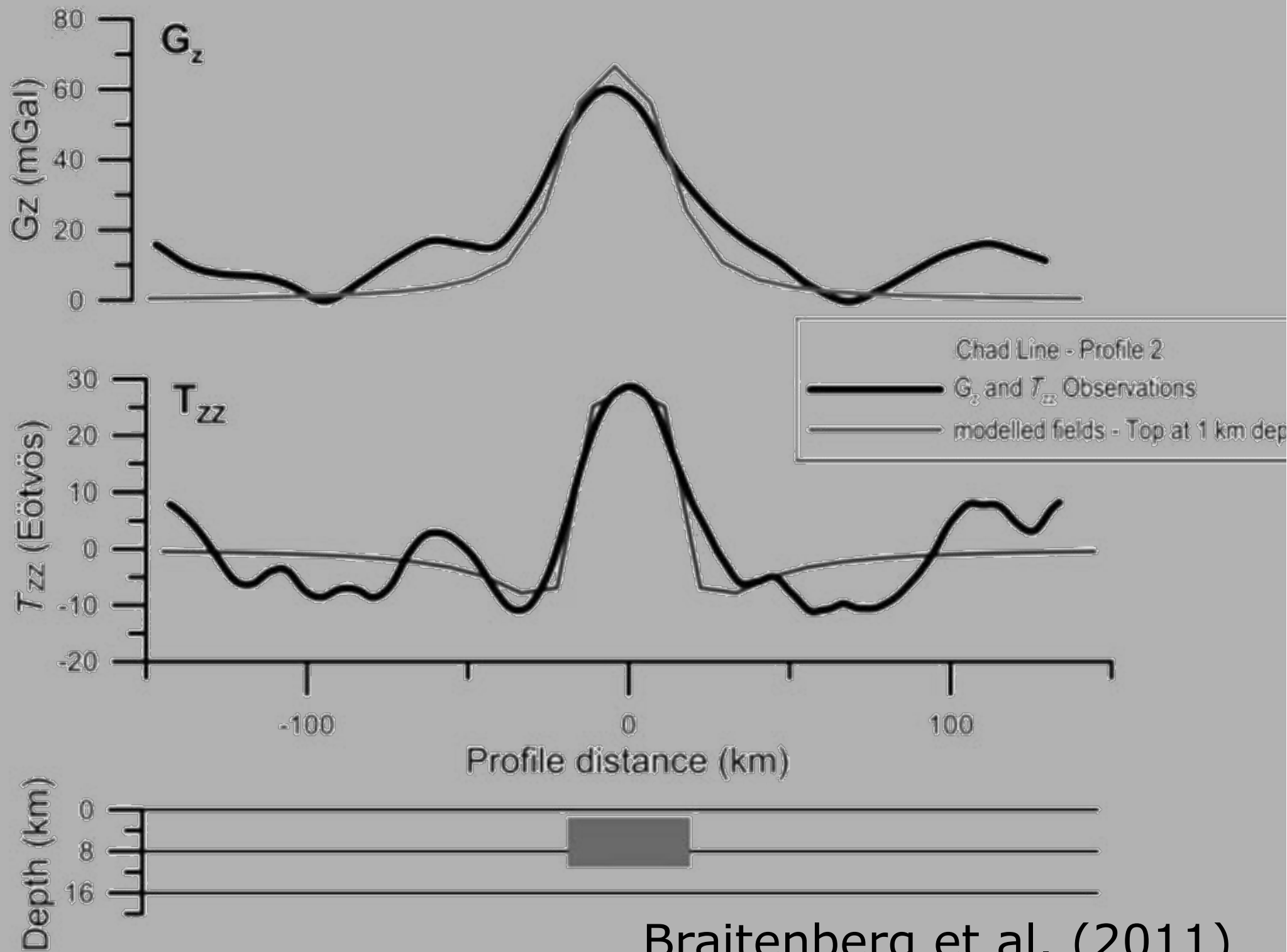




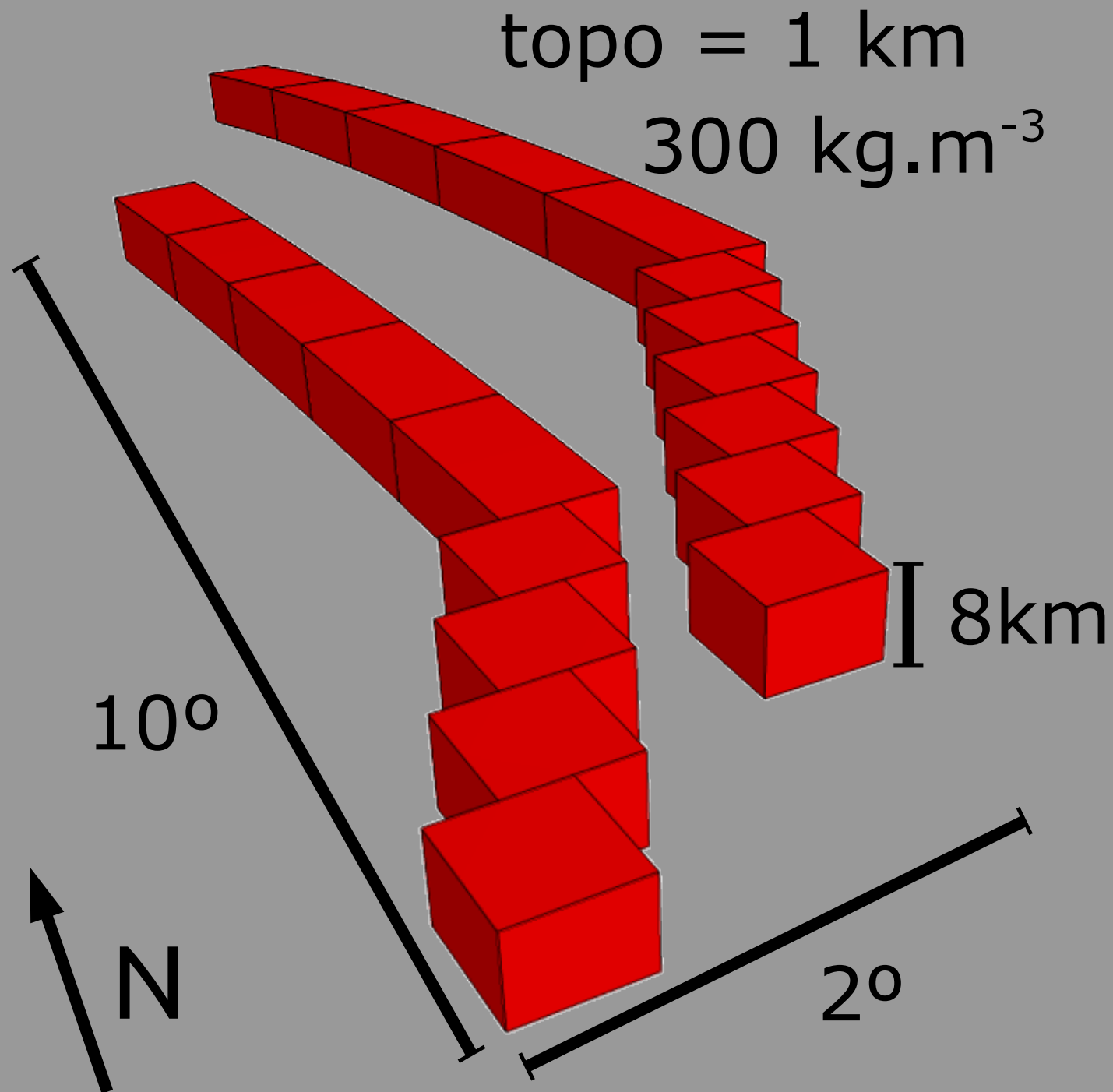
Sintético: lineamentos



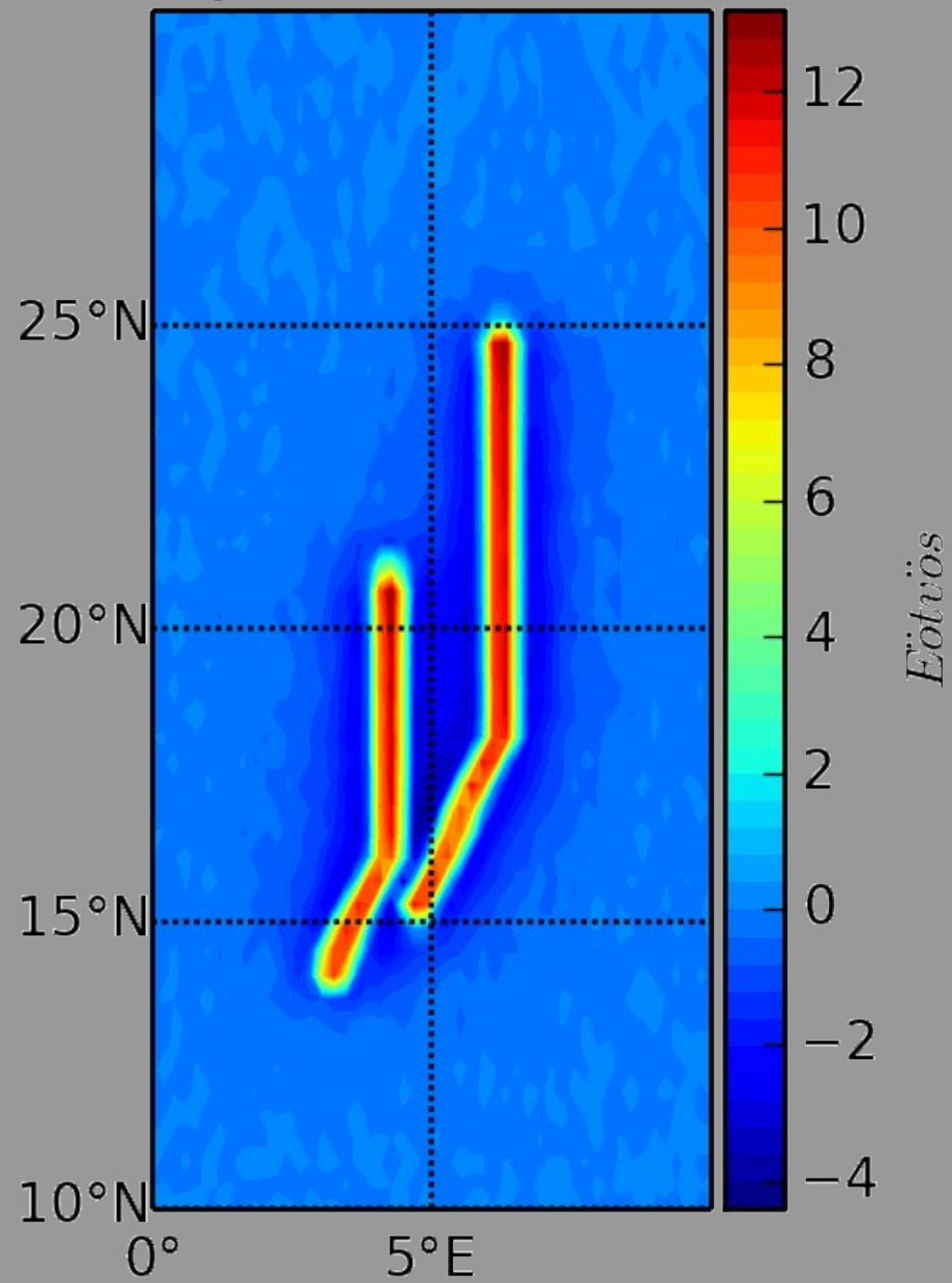
Braitenberg et al. (2011)



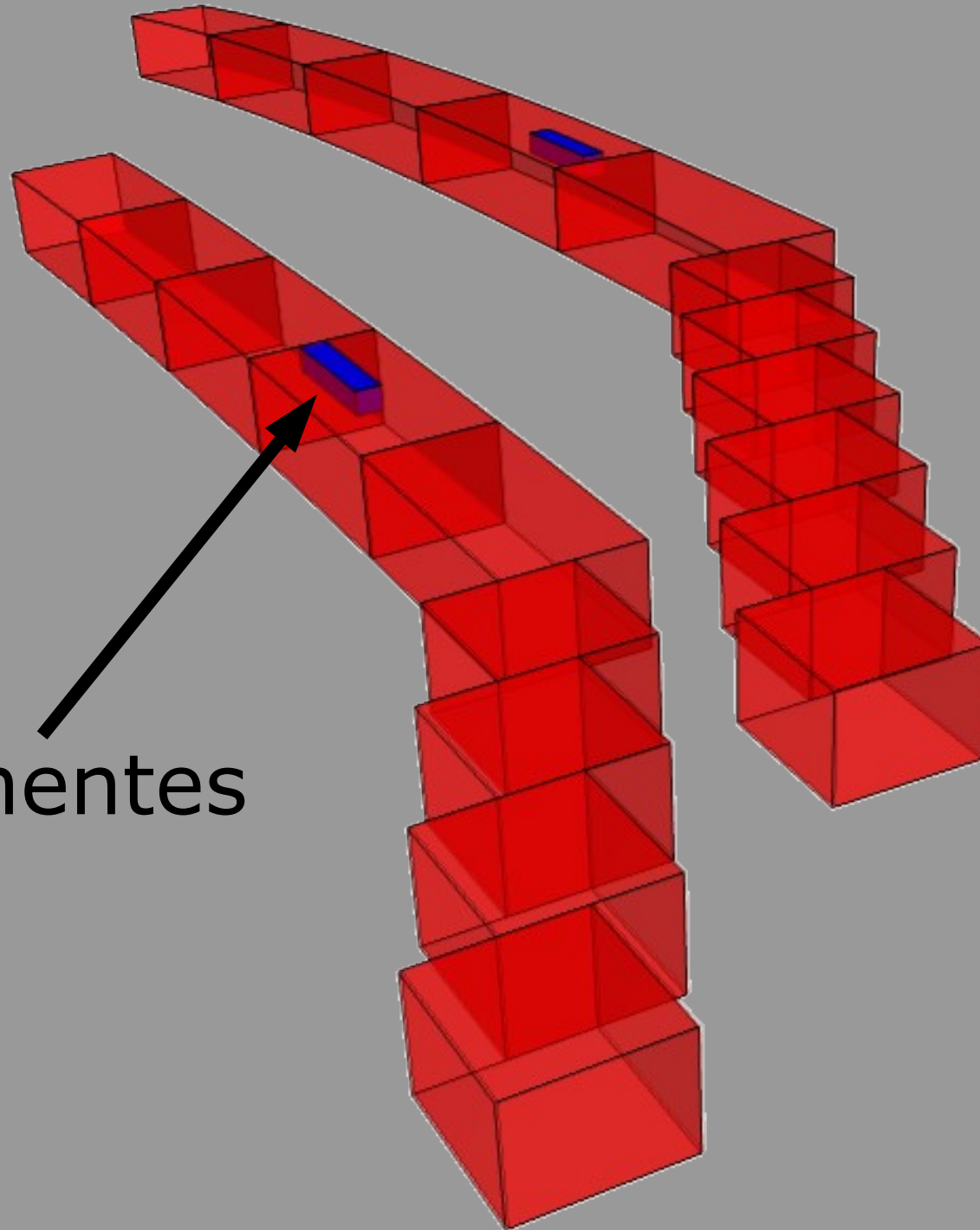
Braitenberg et al. (2011)



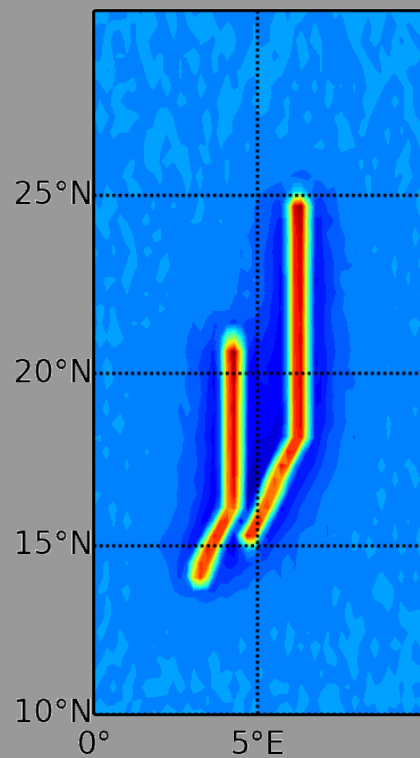
gzz a 20 km



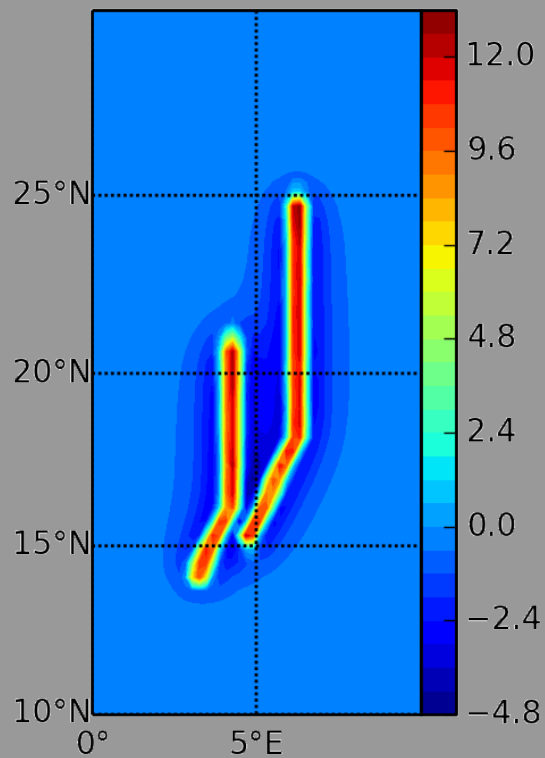
Sementes



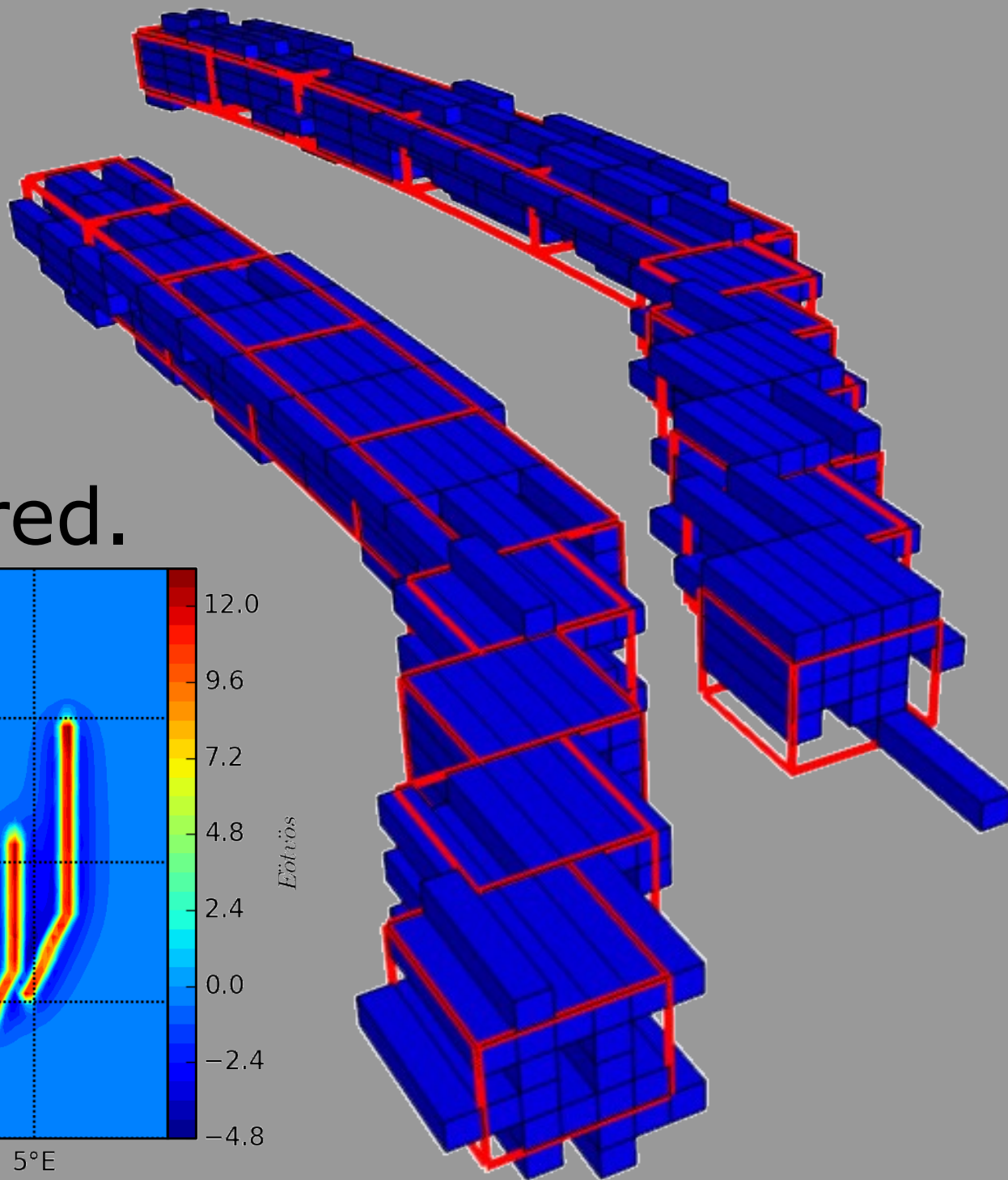
obs.



pred.



Eötvös



Conclusão

Capaz de recuperar lineamentos.

Investigando:

Geometria do mesh influencia o resultado.

Células alongadas – resultado alongado.

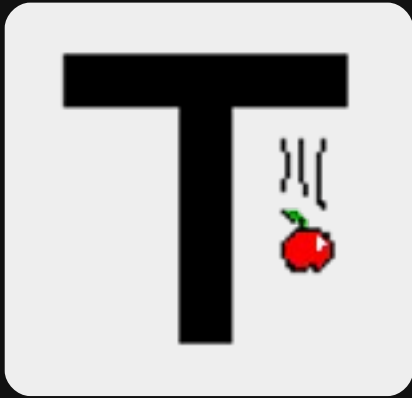
Células achatadas – resultado achatado.

Mesh - informação a priori.

- ✓ 1. Calcular grav
de um modelo (tesseroïdes)
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Software

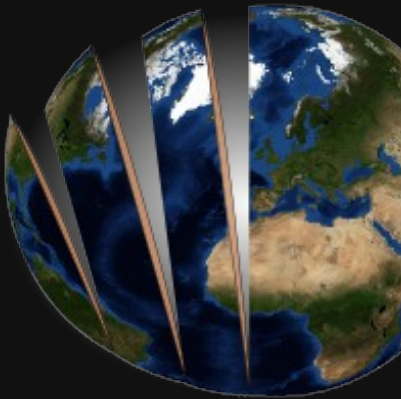
Software para modelagem



Tesseroids: leouieda.com/tesseroids

Modelagem direta

(tesseroides e prismas)

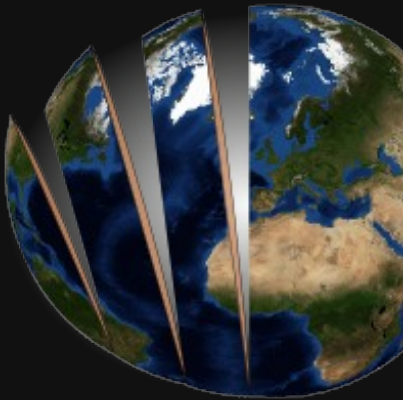


Fatiando a Terra: fatiando.org

*Modelagem direta (prisma, esfera,
tesseroide, prisma poligonal)*

Visualização

Software para inversão



`fatizando.inversion`

Automatizar construção de
problemas inversos.

Reutilização, simplicidade, flexibilidade

Software para inversão

$$\Gamma(\bar{p}) = \phi(\bar{p}) + \mu\theta(\bar{p})$$



```
gamma = Misfit(...) + 0.01*Smoothness(...)
```

Software para inversão

$$\Gamma(\bar{p}) = \phi(\bar{p}) + \mu\theta(\bar{p})$$



```
gamma = Misfit(...) + 0.01*Smoothness(...)
```



dados, modelo interpretativo, etc

Software para inversão

Minimizar Γ com método de Newton

$$\delta p = \left(A^T A + \mu W \right)^{-1} \left[A^T (d - f(p_0)) - \mu W p_0 \right]$$



```
gamma.config('newton', initial=p0).fit()
```


Software para inversão

Minimizar Γ com método de Newton

$$\delta p = (A^T A + \mu W)^{-1} [A^T (d - f(p_0)) - \mu W p_0]$$



```
gamma.config('newton', initial=p0).fit()
```

```
gamma.config('levmarq', initial=p0).fit()
```

Software para inversão

Minimizar Γ com método de Newton

$$\delta p = \left(A^T A + \mu W \right)^{-1} \left[A^T (d - f(p_0)) - \mu W p_0 \right]$$



```
gamma.config('newton', initial=p0).fit()
```

```
gamma.config('levmarq', initial=p0).fit()
```

```
gamma.config('acor', bounds=[-3, 4]).fit()
```

Conclusões

Igual para ajuste de reta e inversão 3D.

Vários algoritmos:

*Newton, Levenberg-Marquardt,
Steepest Descent, Ant Colony Optimization.*

Fácil de implementar.

Optimizar quando necessário.

Atividades

2013-2014

Artigos

- *The Leading Edge*

“Geophysical tutorial: Euler deconvolution of potential-field data”

[doi:10.1190/tle33040448.1](https://doi.org/10.1190/tle33040448.1)

- *Ore Geology Reviews (Dionísio)*

“Imaging iron ore from the Quadrilátero Ferrífero (Brazil) using geophysical inversion and drill hole data”

[doi:10.1016/j.oregeorev.2014.02.011](https://doi.org/10.1016/j.oregeorev.2014.02.011)

Congressos

- Oral: *EGU General Assembly*
“Gravity inversion in spherical coordinates using tesseroids”
github.com/leouieda/egu2014
- Poster: *Scipy 2014*
“Using Fatiando a Terra to solve inverse problems in geophysics”
github.com/leouieda/scipy2014

Cronograma

2014-2015

Resultados

- ✓ • Modelagem direta (refeitos e aprimorados)
- ✓ • Sintéticos inversão (apresentado na EGU)
 - ✓ – Lineamentos
 - ✓ – Underplating
 - Dado real inversão (GOCE)
- ✓ – Região: lineamento Chad, África
- ✓ – Baixar dados: TIM, EIGEN, EGG, ETOPO
 - Corrigir topografia
 - Inversão

Escrita

- Modelagem direta (**fazendo**): ~ 30/09
- Inversão: ~ 11/2014 – 01/2015
- Artigos sobre software

Todo material online

github.com/pinga-lab

github.com/leouieda