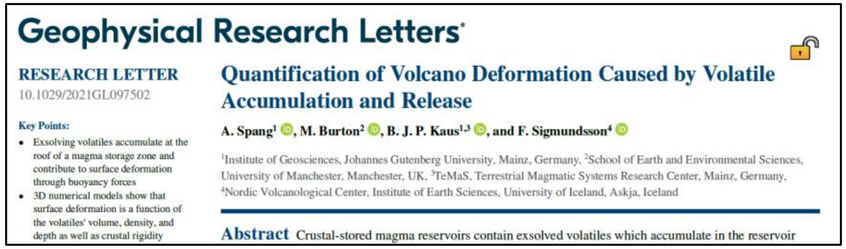
Quantification of Volcano Deformation caused by Volatile Accumulation and Release

Arne Spang[1], Mike Burton[2], Boris Kaus[1], Freysteinn Sigmundsson[3]

[1]Johannes Gutenberg-University Mainz
[2]University of Manchester
[3]University of Iceland

Full text available:
https://www.researchgate.net/publication/360762278_Quantification_of_Volcano_Deformation_Caused_by_Volatile_Accumulation_and_Release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Key Points:
- Exsolving volatiles accumulate at the roof of a magma storage zone and contribute to surface deformation through buoyancy forces
- 3D numerical models show that surface deformation is a function of the volatiles' volume, density, and depth as well as crustal rigidity

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A. Spang[1], M. Burton[2], B. J. P. Kaus[1,3], and F. Sigmundsson[4]

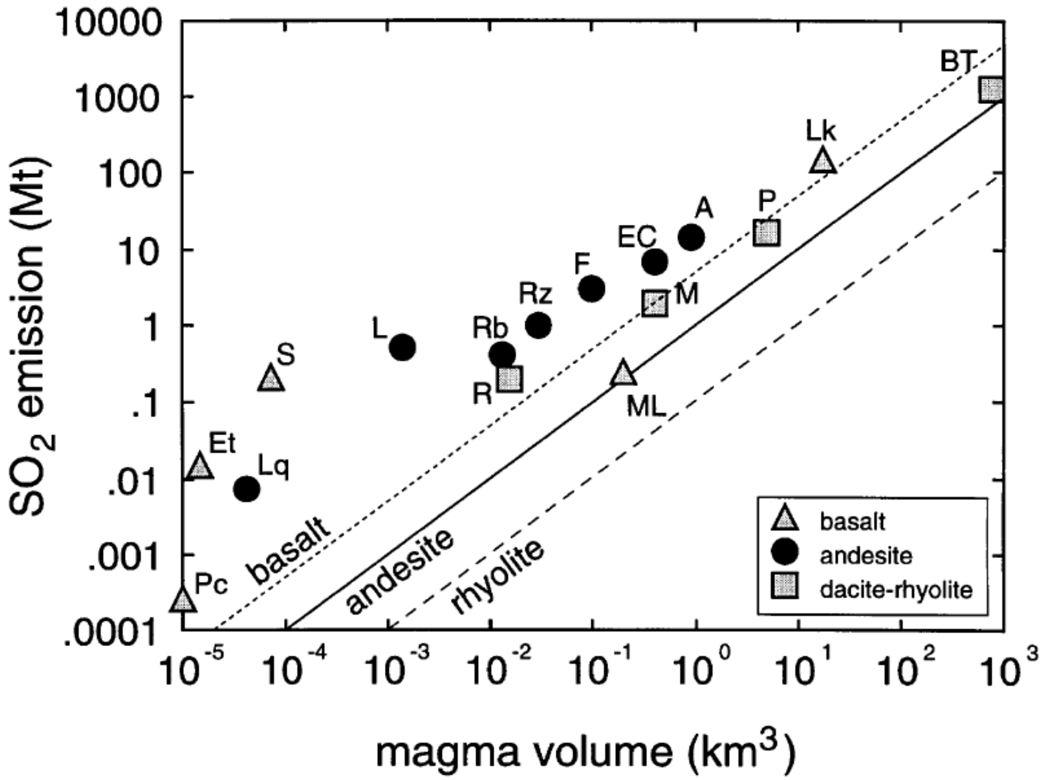
[1]Institute of Geosciences, Johannes Gutenberg University, Mainz, Germany, [2]School of Earth and Environmental Sciences, University of Manchester, Manchester, UK, [3]TeMaS, Terrestrial Magmatic Systems Research Center, Mainz, Germany, [4]Nordic Volcanological Center, Institute of Earth Sciences, University of Iceland, Askja, Iceland

Abstract Crustal-stored magma reservoirs contain exsolved volatiles which accumulate in the reservoir

accepted (GRL)

arspang@uni-mainz.de

Excess Gas

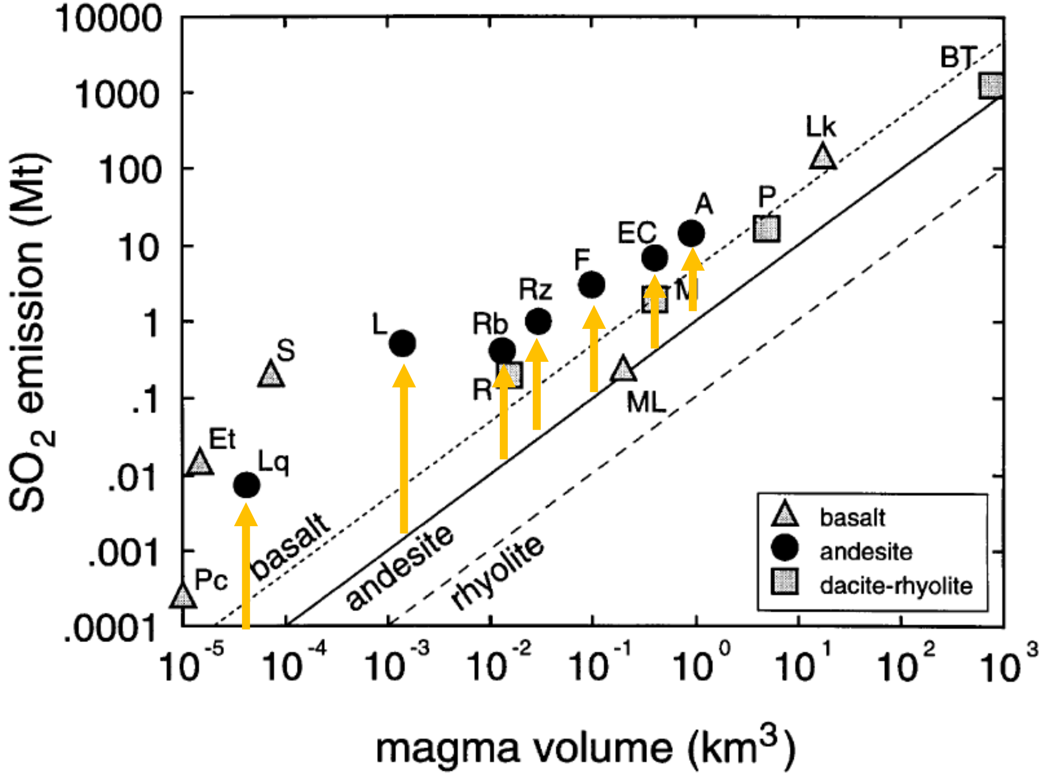


Magma contains:

- H_2O
- CO_2
- SO_2
- others

Wallace, 2001

Excess Gas



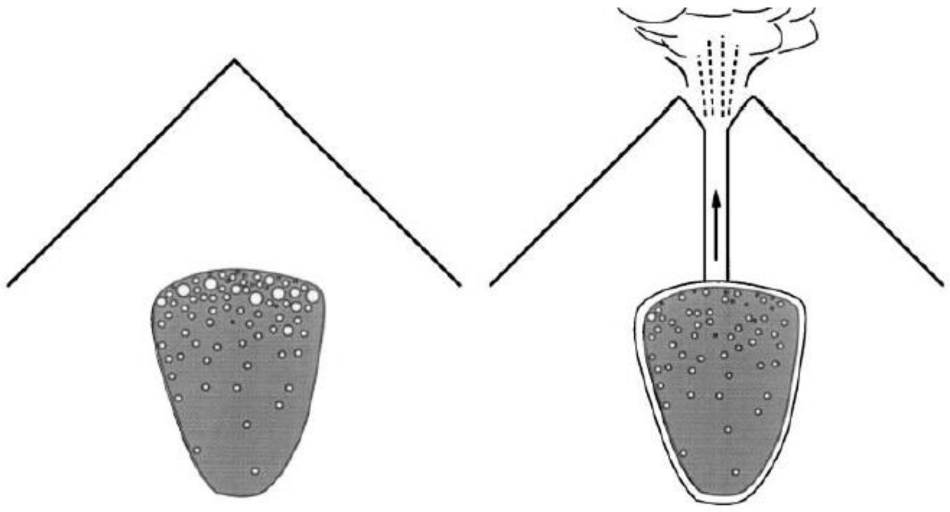
- Many eruptions emit 1 or 2 orders of magnitude more gas than they should
- Why? How?

Wallace, 2001

Excess Gas – pre-exsolved Volatiles?

Wallace 2001:

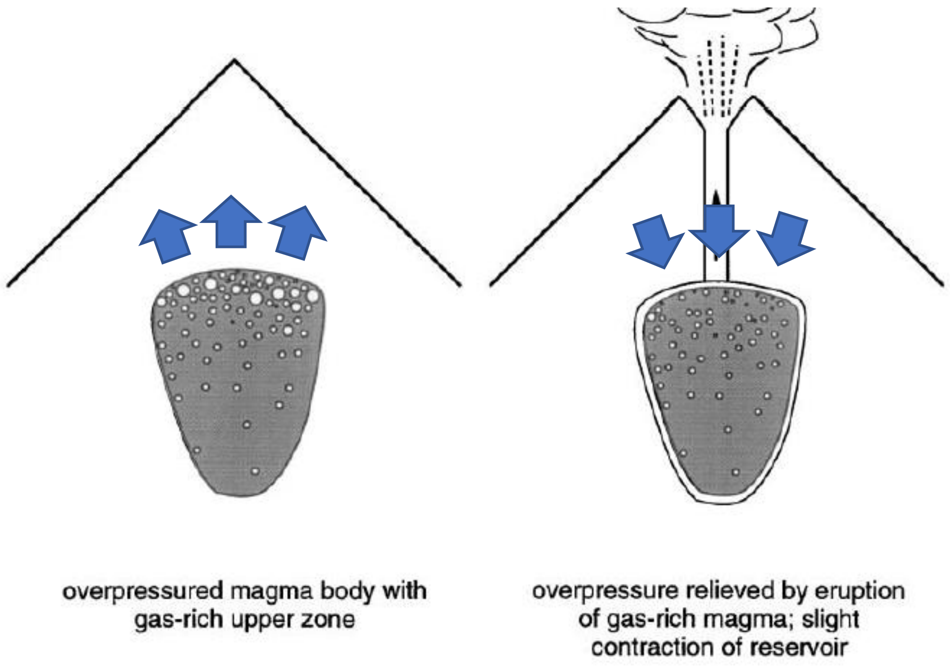
- Volatiles exsolve, rise to the top of the reservoir and create a volatile-rich, foamy layer
- During an eruption, all the volatiles and part of the magma escape
- Excess gas because the volcano erupts volatiles that exsolved from the magma that stayed in the crust



Wallace, 2001

Excess Gas – buoyancy forces?

- Volatile layer is low density, so it exerts buoyancy forces and causes uplift while it grows
- Upon eruption the buoyancy forces are instantly removed
- This causes subsidence



Wallace, 2001

Excess Gas – buoyancy forces?

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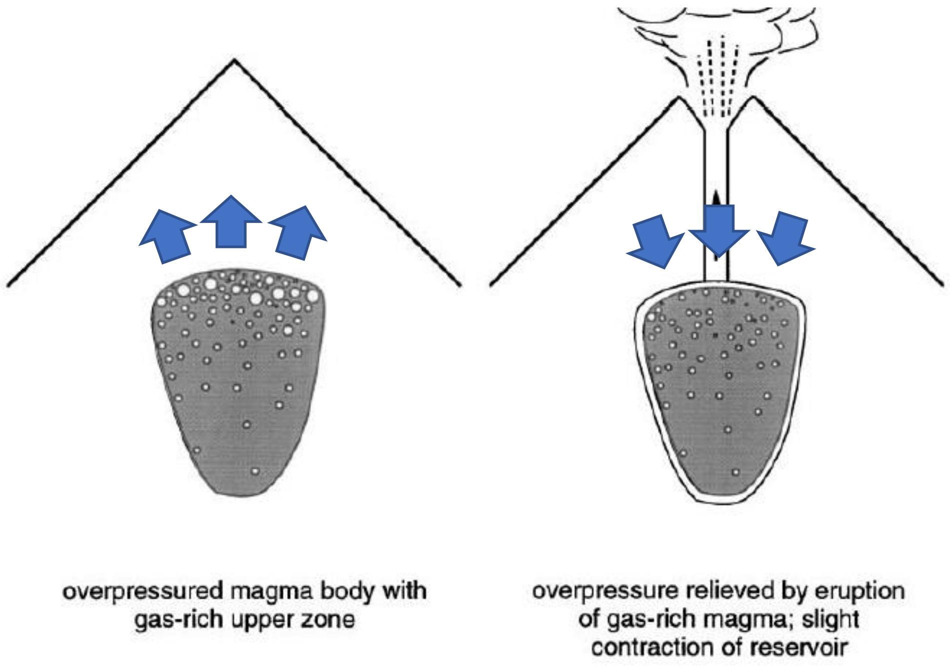
→ Magnitude of subsidence?



Wallace, 2001

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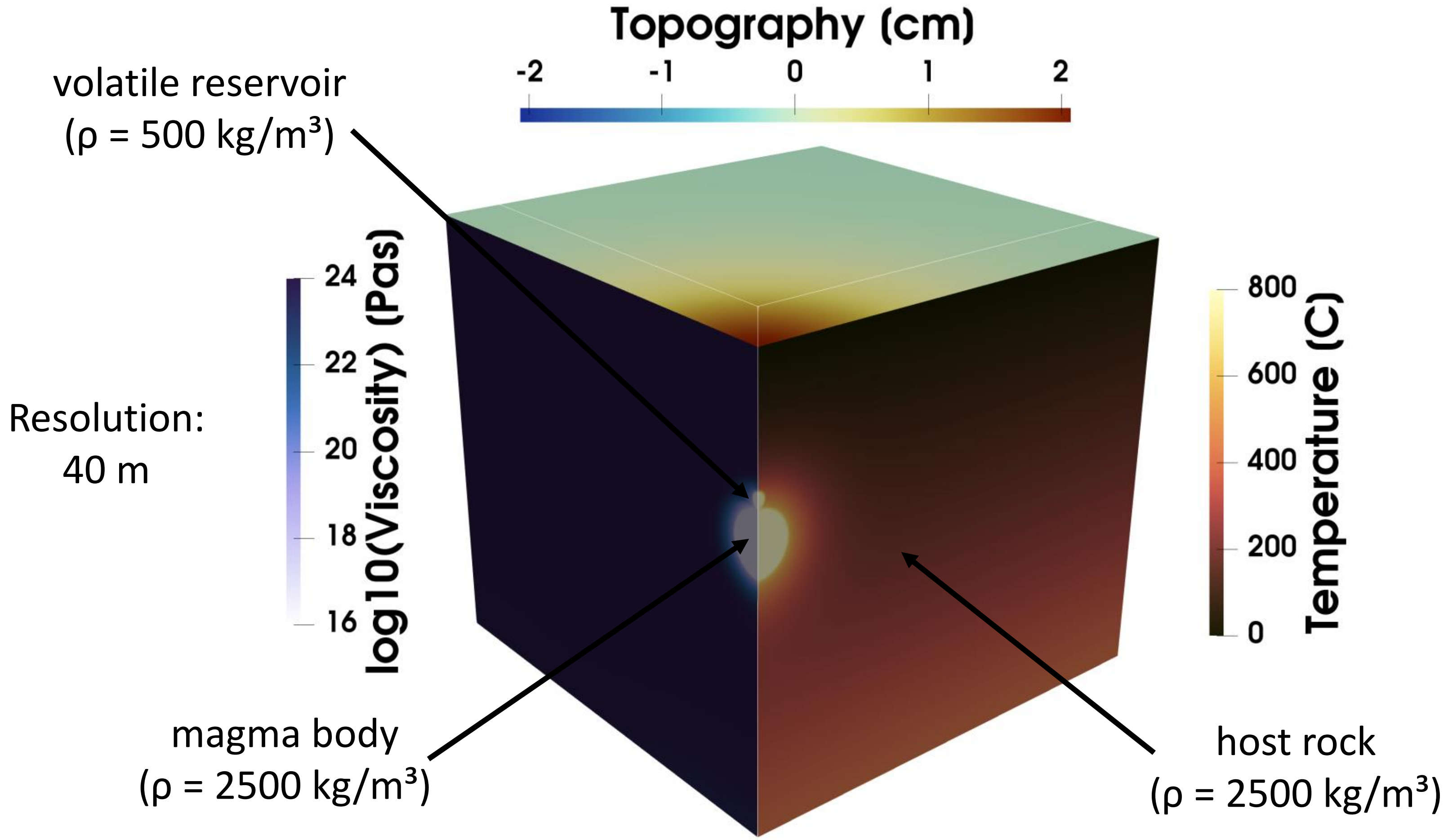
Model Setup



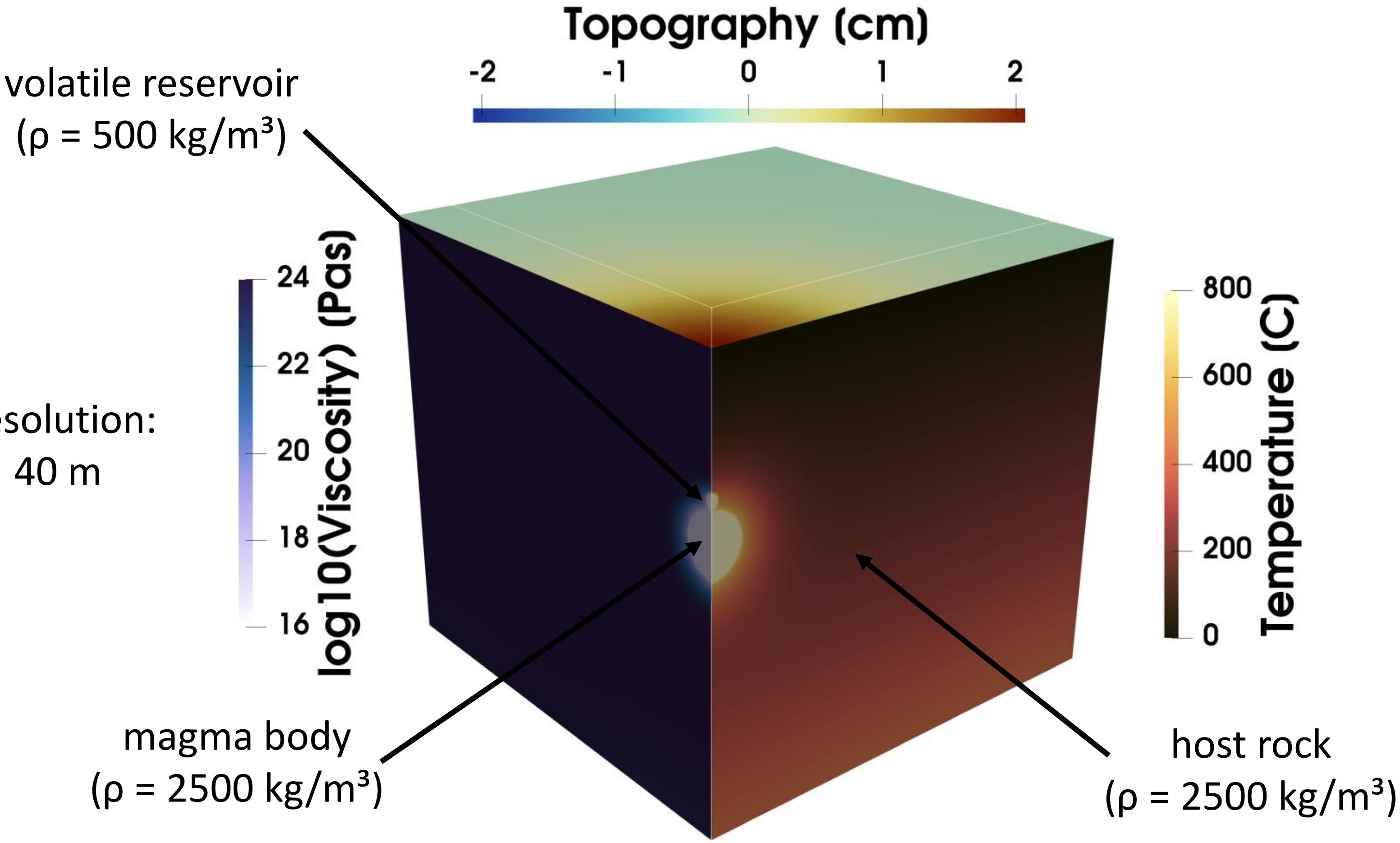
LaMEM[1]

- Density driven
- T- & $\dot{\epsilon}$-dependent visco-elasto-plastic rheology
- No additional pressure sources
- Resolution: 384^3

Spang et al., 2022 (accepted)

[1] Kaus et al., 2016

Model Approach



Resolution:
40 m

Eruption is approximated by instantly replacing buoyant volatiles with non-buoyant magma

Spang et al., 2022 (accepted)

[1] Kaus et al., 2016

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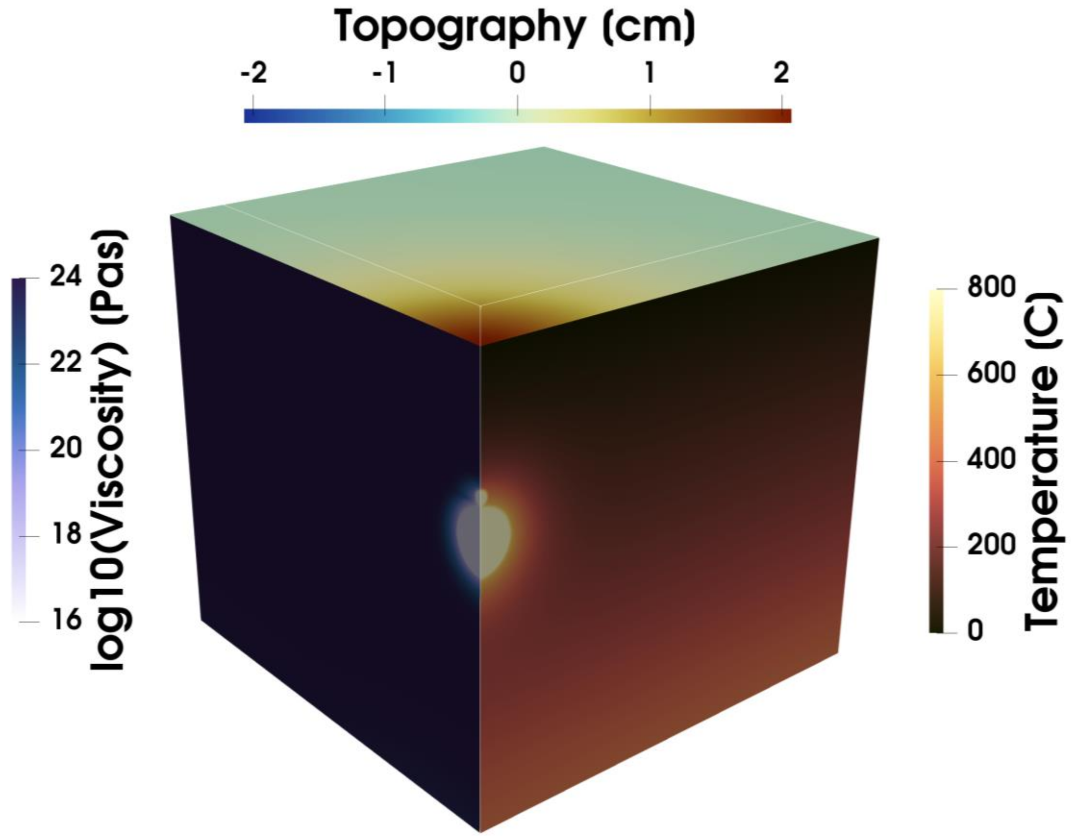
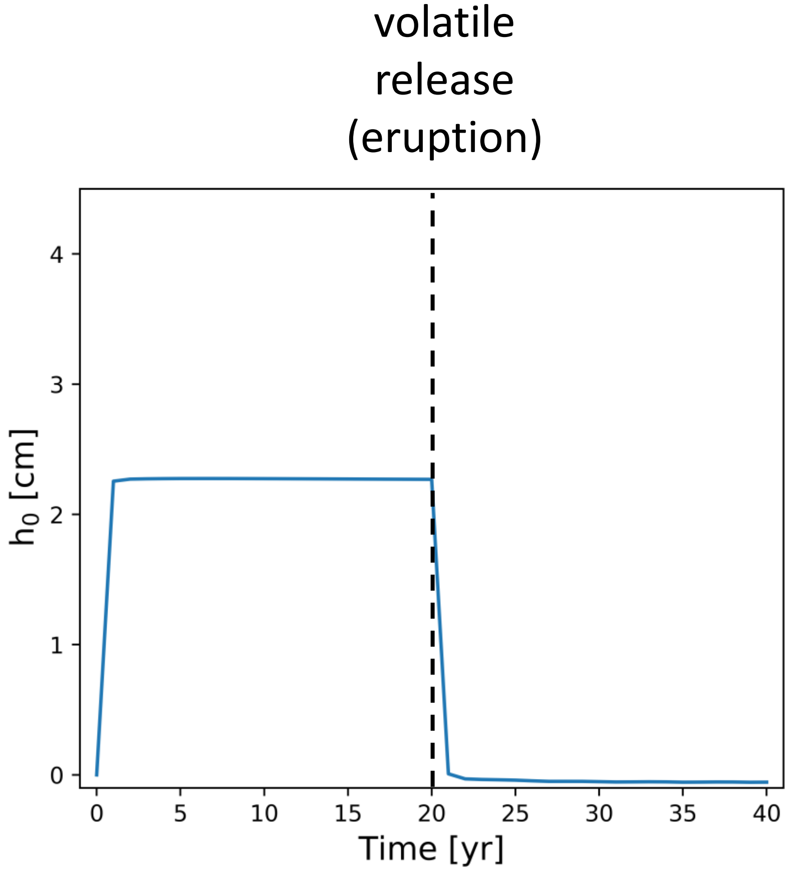
Results

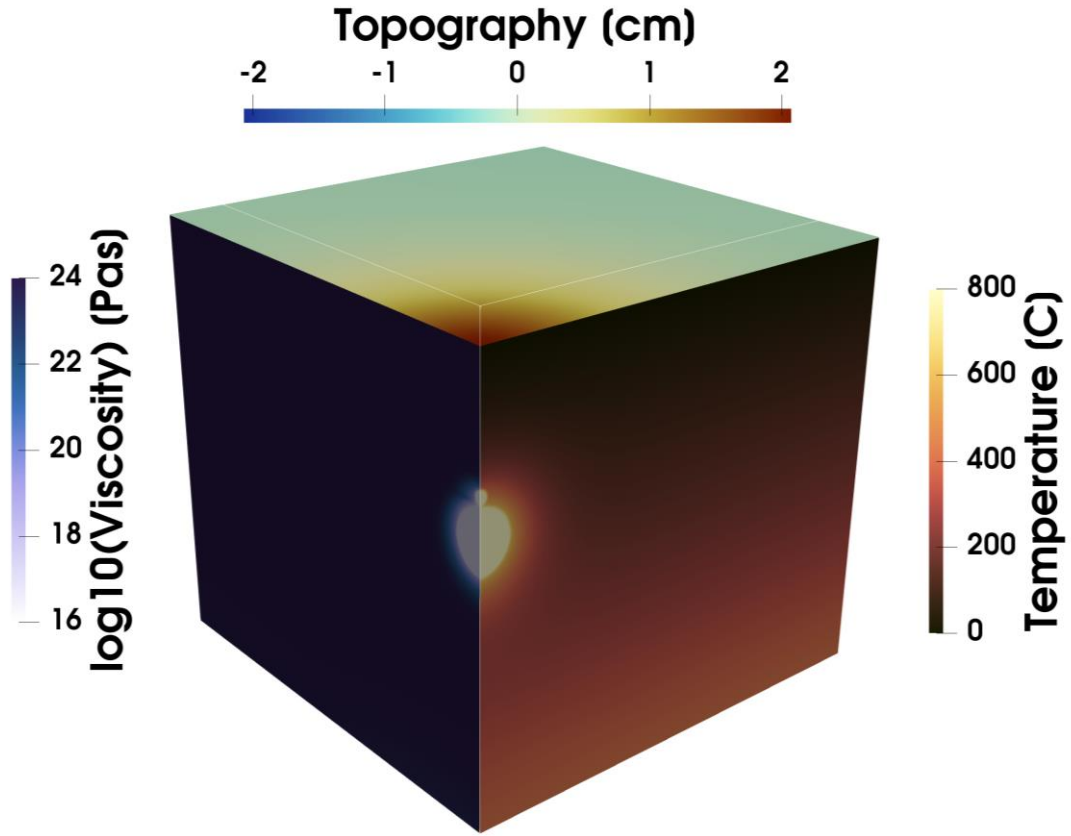




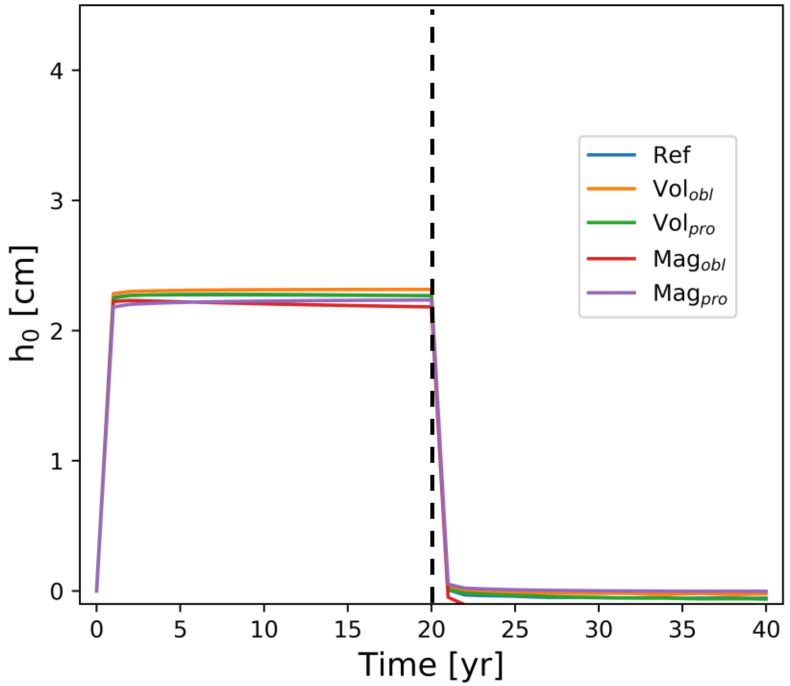
→ Removing buoyancy forces leads to subsidence

Spang et al., 2022 (accepted)

Results



volatile release (eruption)



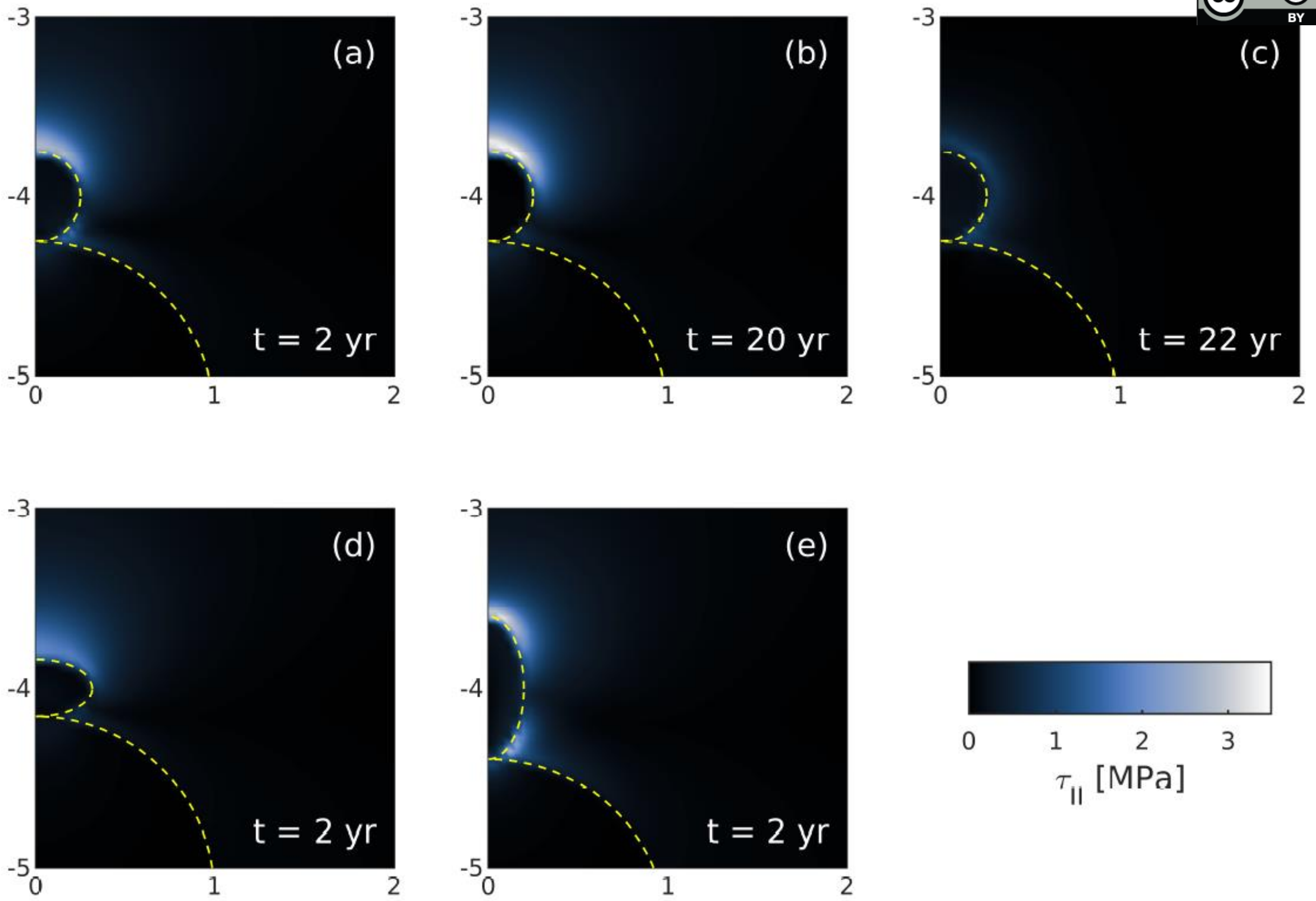
→ independent of magma/volatile shape

Spang et al., 2022 (accepted)

Stress evolution

- Compare a, d, e
- Lower stress for oblate but more surface area
- Higher stress for prolate but less surface area
- Integrated stresses are the same

→ Same uplift/subsidence



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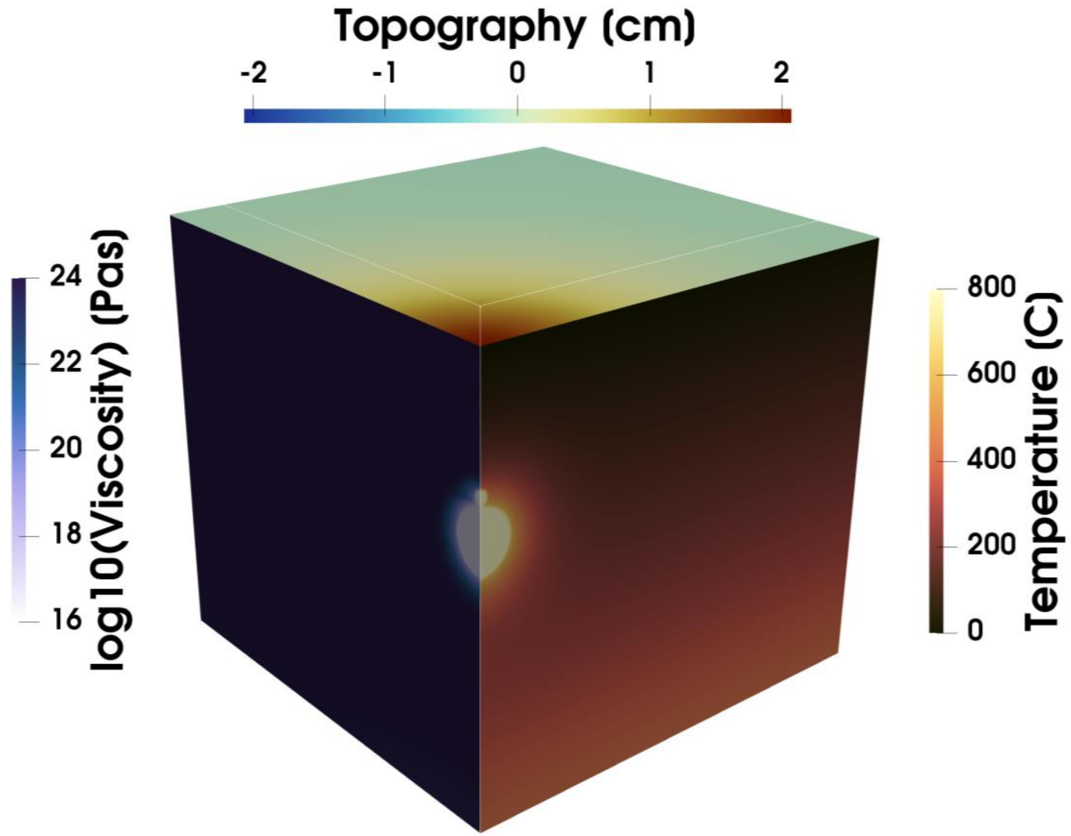
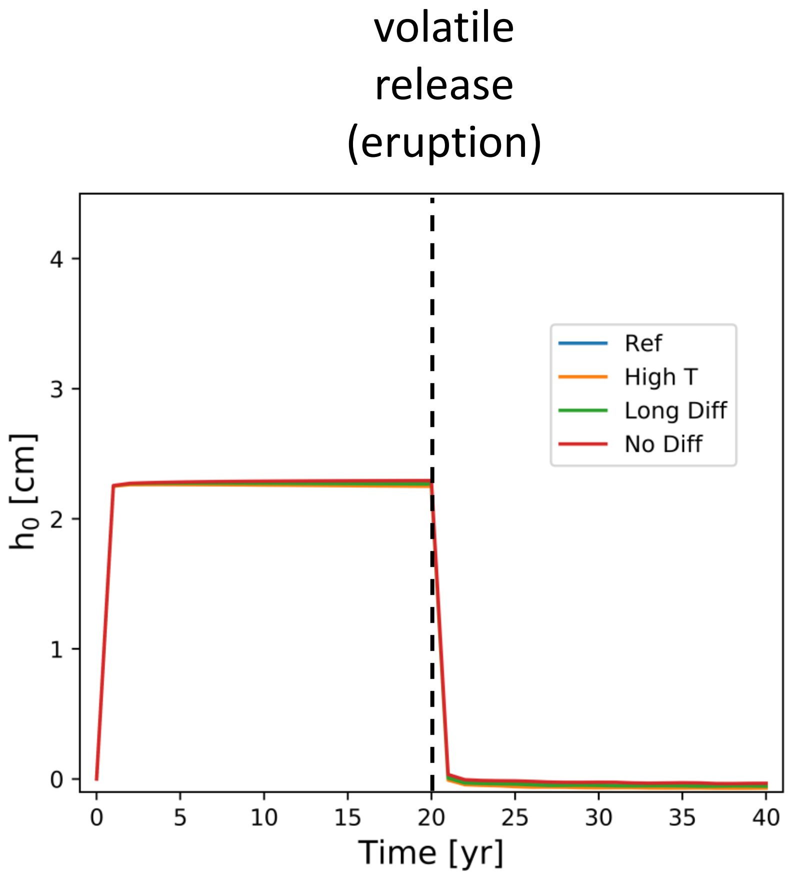
arspang@uni-mainz.de

Results





→ independent of temperature structure

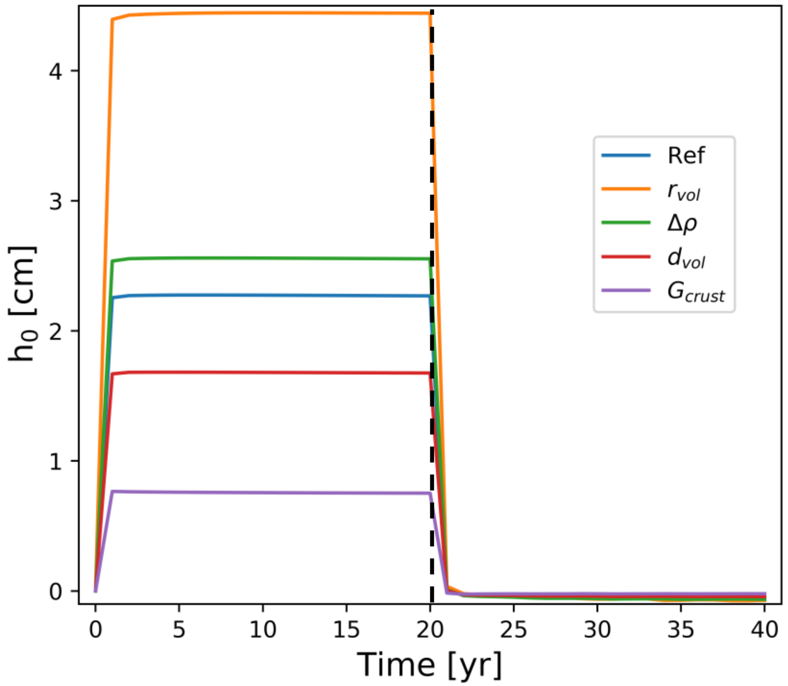
Spang et al., 2022 (accepted)

arspang@uni-mainz.de

Parameter Sensitivity

- Reservoir radius
- Reservoir depth
- Reservoir shape
- Magma shape
- Magma size
- Density contrast
- Host rock stiffness
- Host rock viscosity
- Temperature structure

volatile release (eruption)

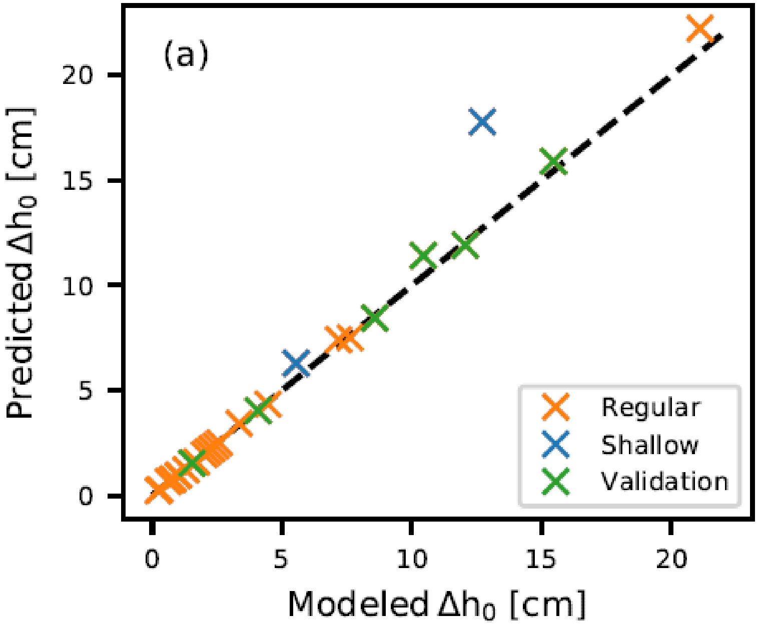


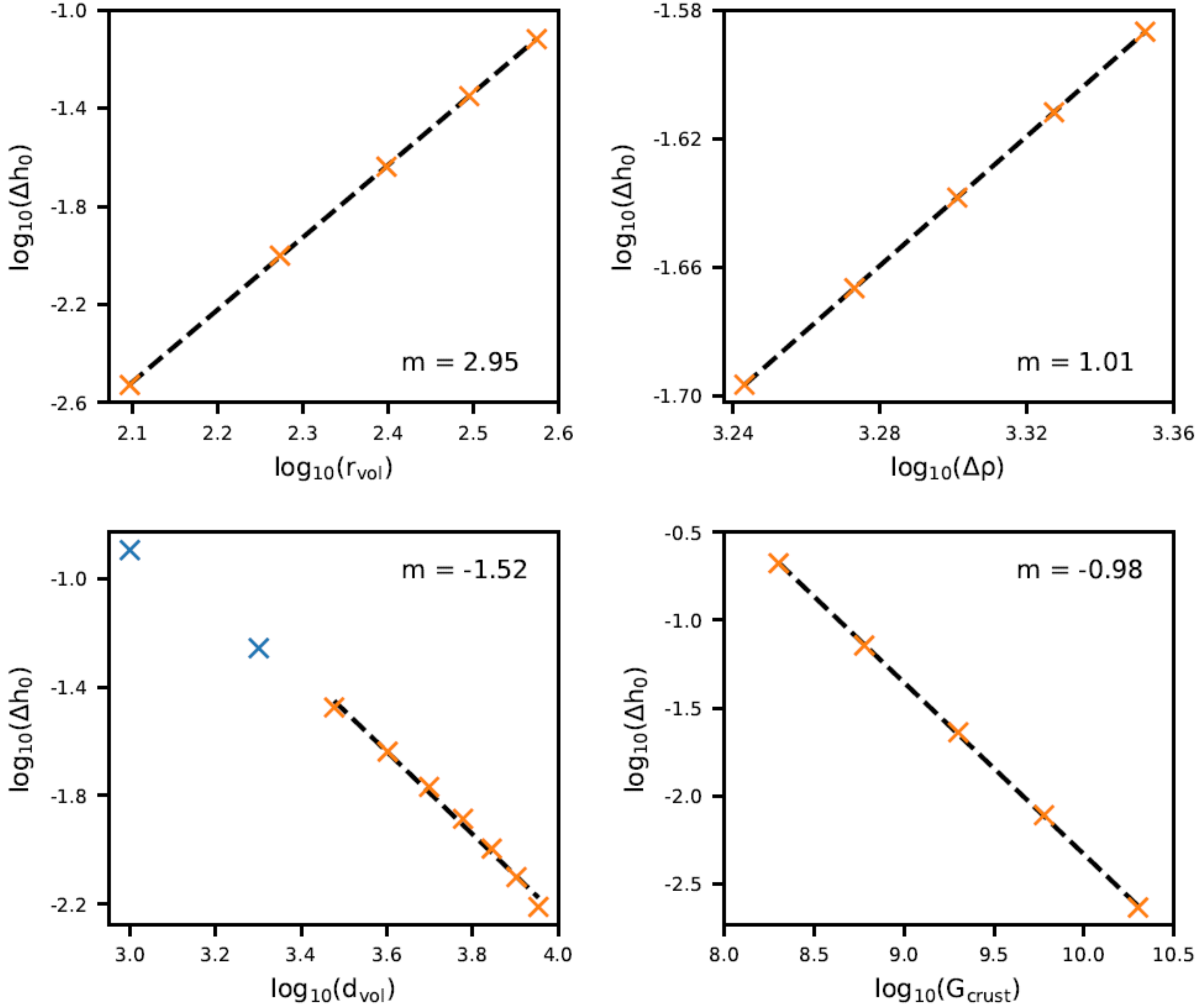
→ Derive a scaling law!

Spang et al., 2022 (accepted)

Results

$$\Delta h_0 = 12\,\pi\,\frac{r^3 \Delta\rho\, g}{G_{crust} d^{1.5}}$$





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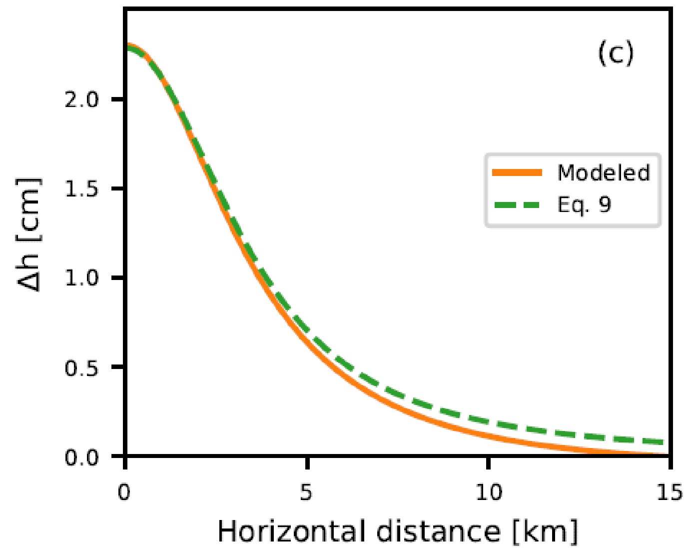
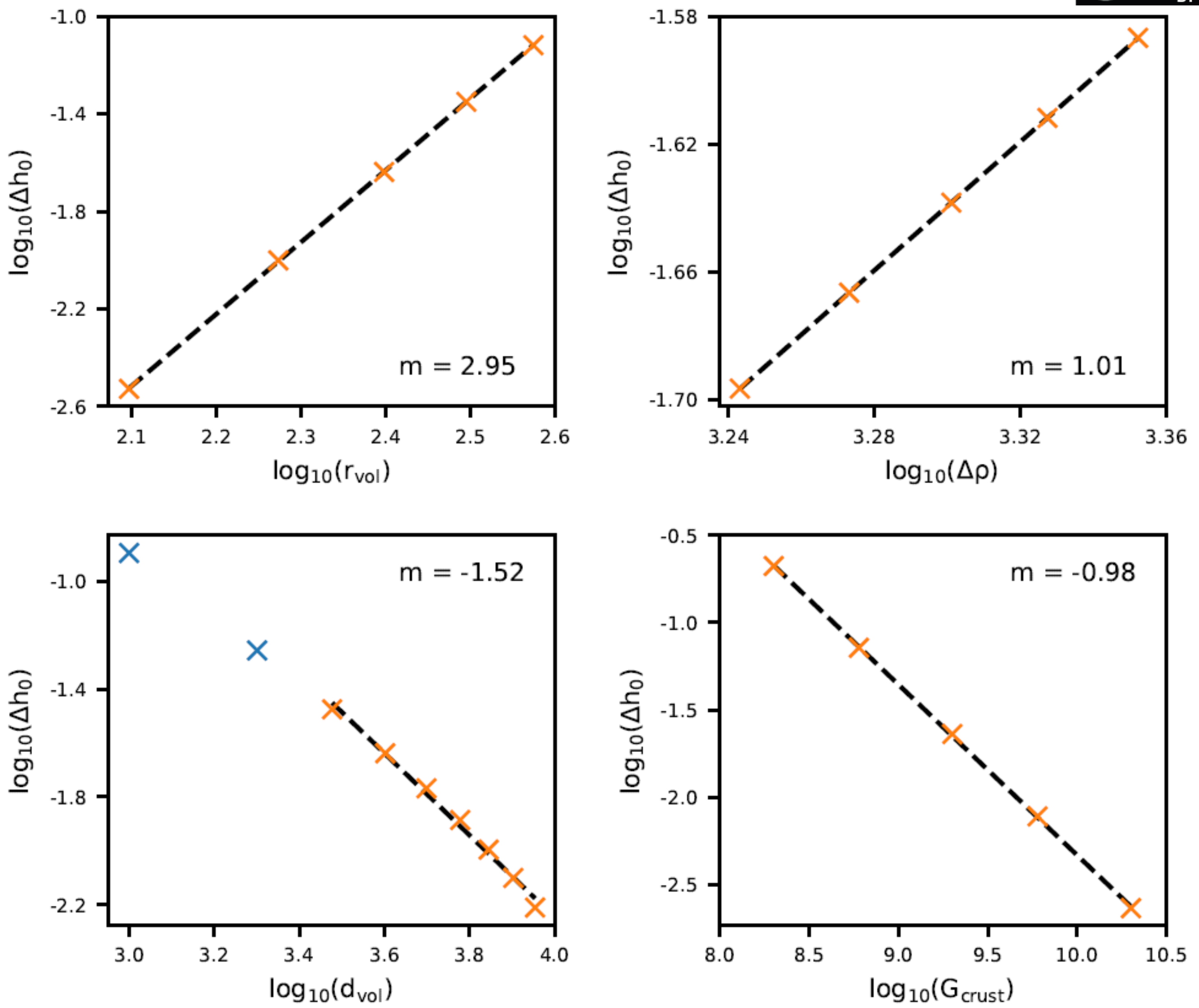
Decay with distance

$$\Delta h_0 = 12\,\pi\,\frac{r^3 \Delta\rho\, g}{G_{crust}\, d^{1.5}}$$

$$\Delta h(x) = 12\,\pi\,\frac{r^3 \Delta\rho\, g}{G_{crust}}\,\frac{d}{(d^2 + x^2)^{5/4}}$$





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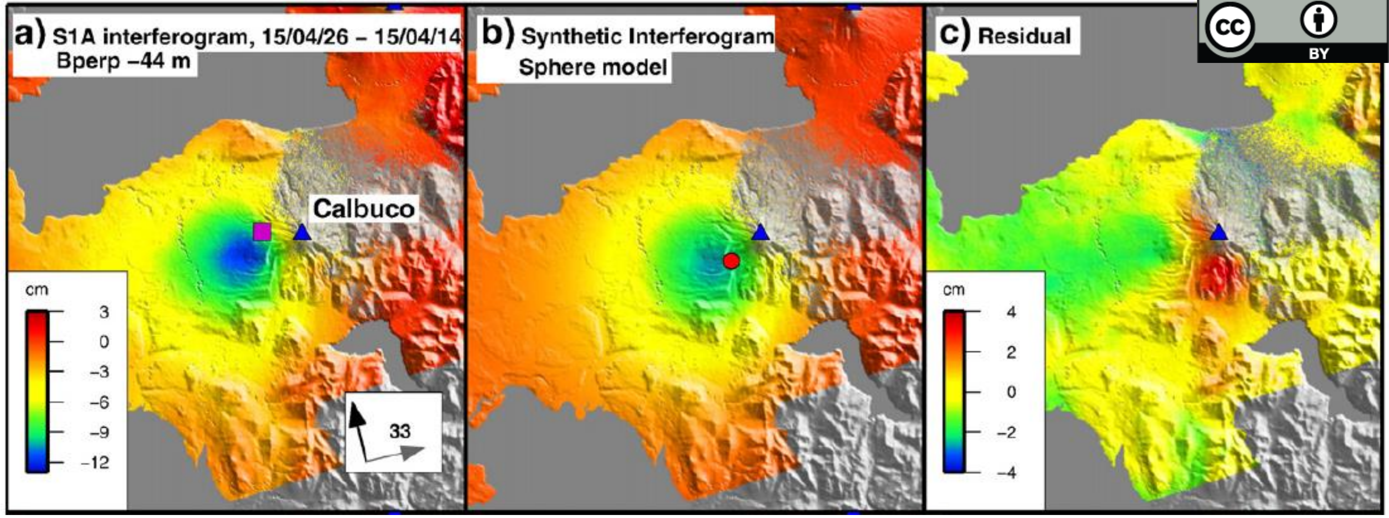
Application - Calbuco

$$\Delta h_0 = 12\,\pi\,\frac{r^3 \Delta\rho\ g}{G_{crust} d^{1.5}}$$



Delgado et al., 2017

volcano.si.edu

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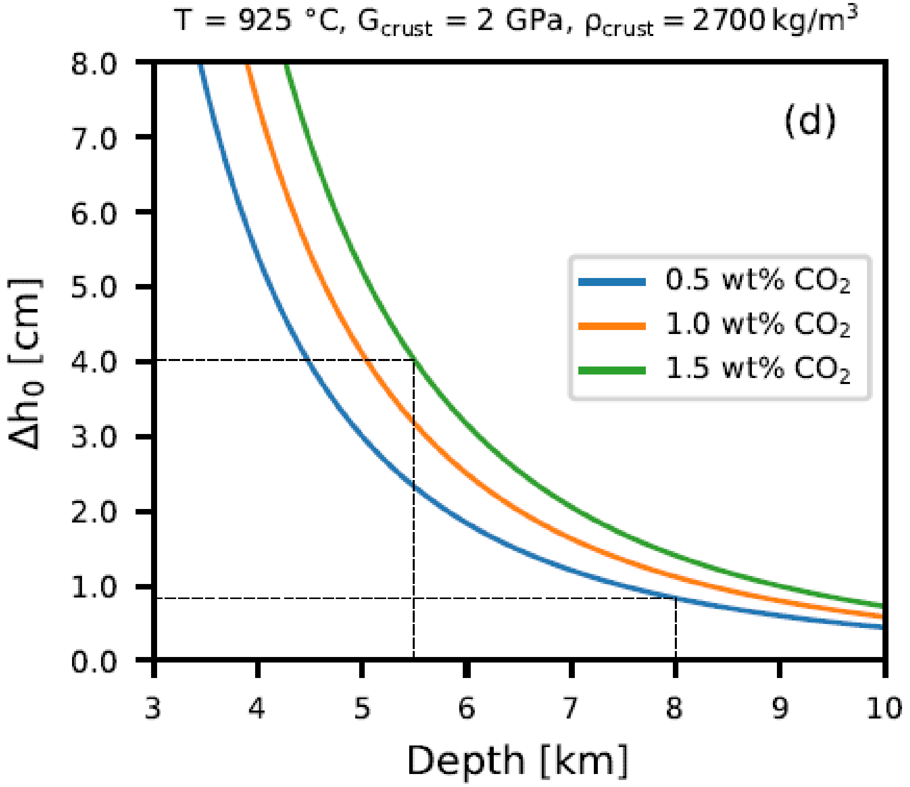
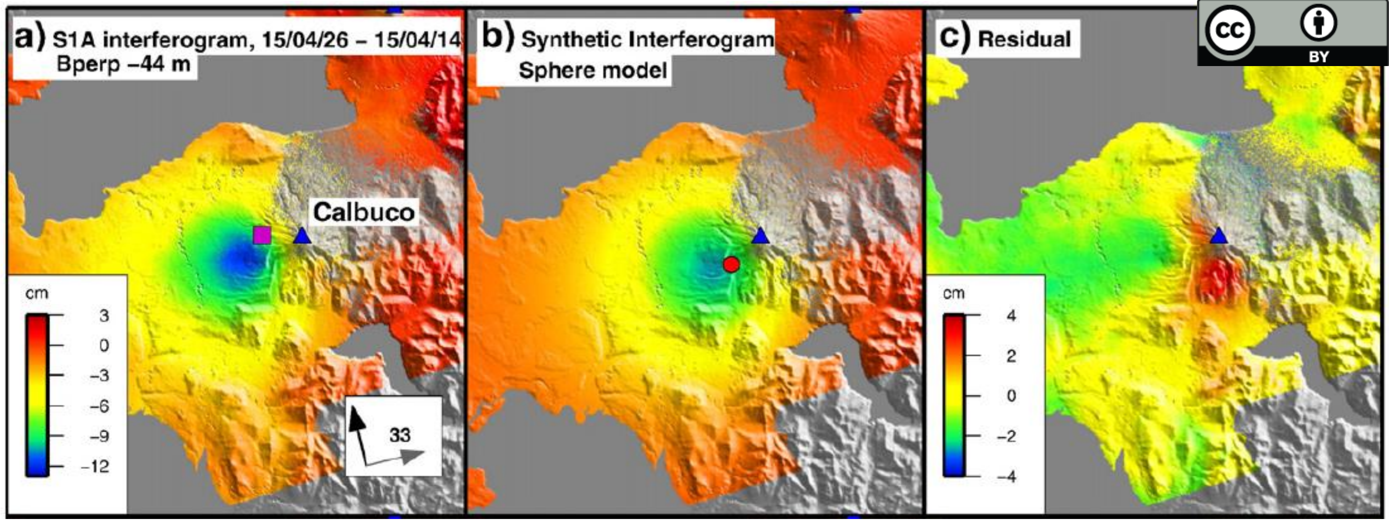




Delgado et al., 2017

→ **1-4 cm** syn-eruptive subsidence

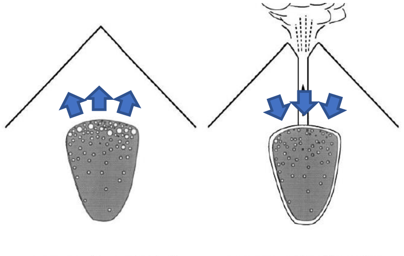
→ **~20%** of observed signal could come from the volatile reservoir (rest due to volume loss)

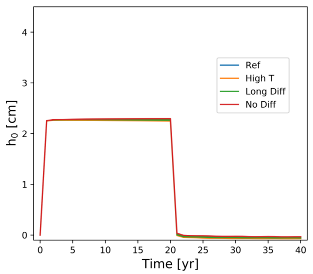
→ Could be added to **improve** the fit of **existing models**

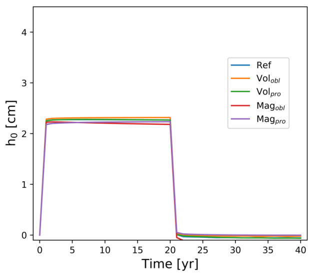
Spang et al., 2022 (accepted)

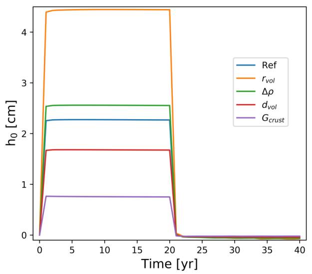
Summary

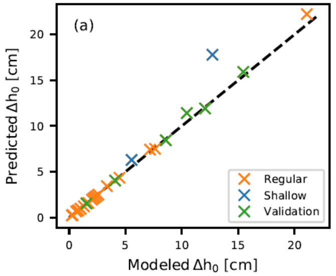
- Release of a volatile reservoir leads to syn-eruptive subsidence (Δh)
- $\Delta h = f(V_{vol}, \rho_{vol}, d_{vol}, G_{crust})$
- Application to Calbuco: contribution can be ~20%
- Not always: uplift/subsidence = inflation/deflation at depth
- Potentially: uplift/subsidence = volatile accumulation/release
- Improve inflation models by adding the effects of volatile buoyancy

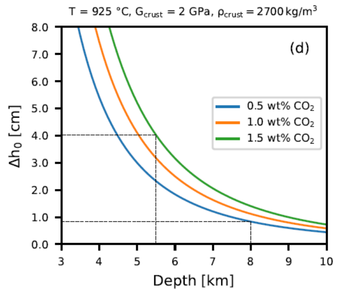










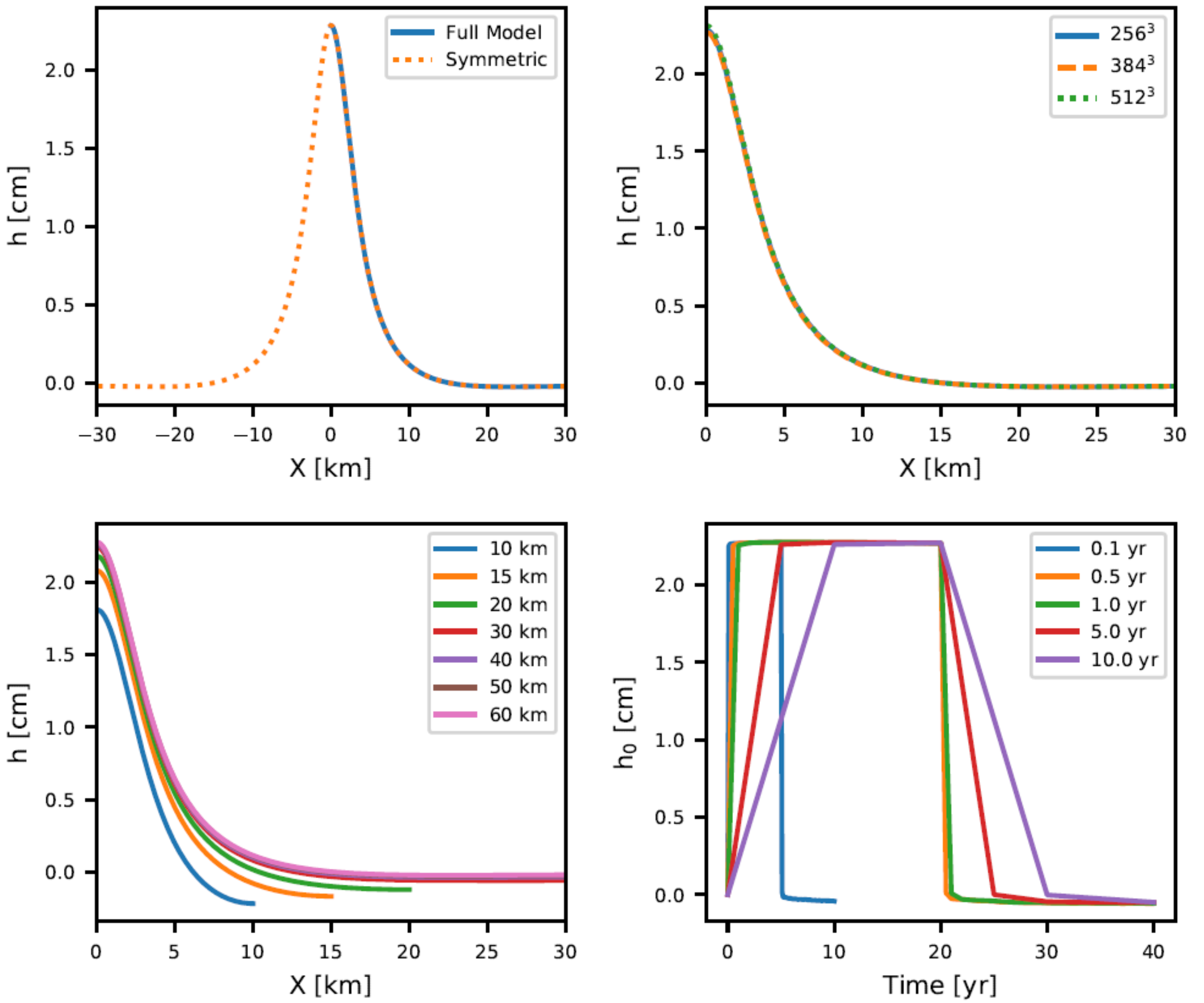


arspang@uni-mainz.de

JOHANNES GUTENBERG UNIVERSITÄT MAINZ
MAGMA Consolidator Grant Project
European Research Council

Resolution, Width, Timestep

- We tested for dependencies on model resolution, model width and timestep
- Resolution: 384^3
- Width: 50 km
- Timestep: 1 yr
  (new equilibrium is always reached after 2 steps)



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Questions?

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