TECTONIC STRESSES AS THE CAUSE OF ASYMMETRY AND SHAPE DEVIATION OF SUBSIDENCE PROFILES

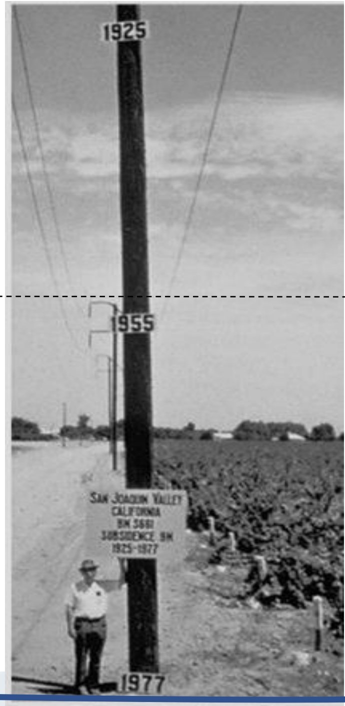
A numerical study and the new empirical subsidence prediction model

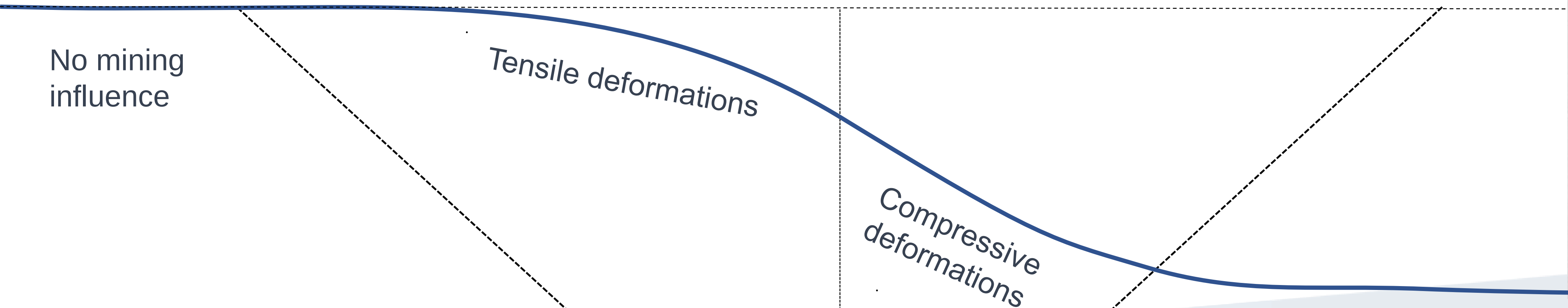
- Aleksandra Babaryka,
- Senior Scientist
- Babaryka.a.s@gmail.com
- Montanuniversität Leoben

- Prof. Dr.-Ing. Jörg Benndorf,
- Institut Director
- TU Bergakademie Freiberg,
- Institut für Markscheidewesen und Geodäsie

Introduction

Ground subsidence refers to the gradual sinking or settling of the Earth's surface caused by underground mining activities





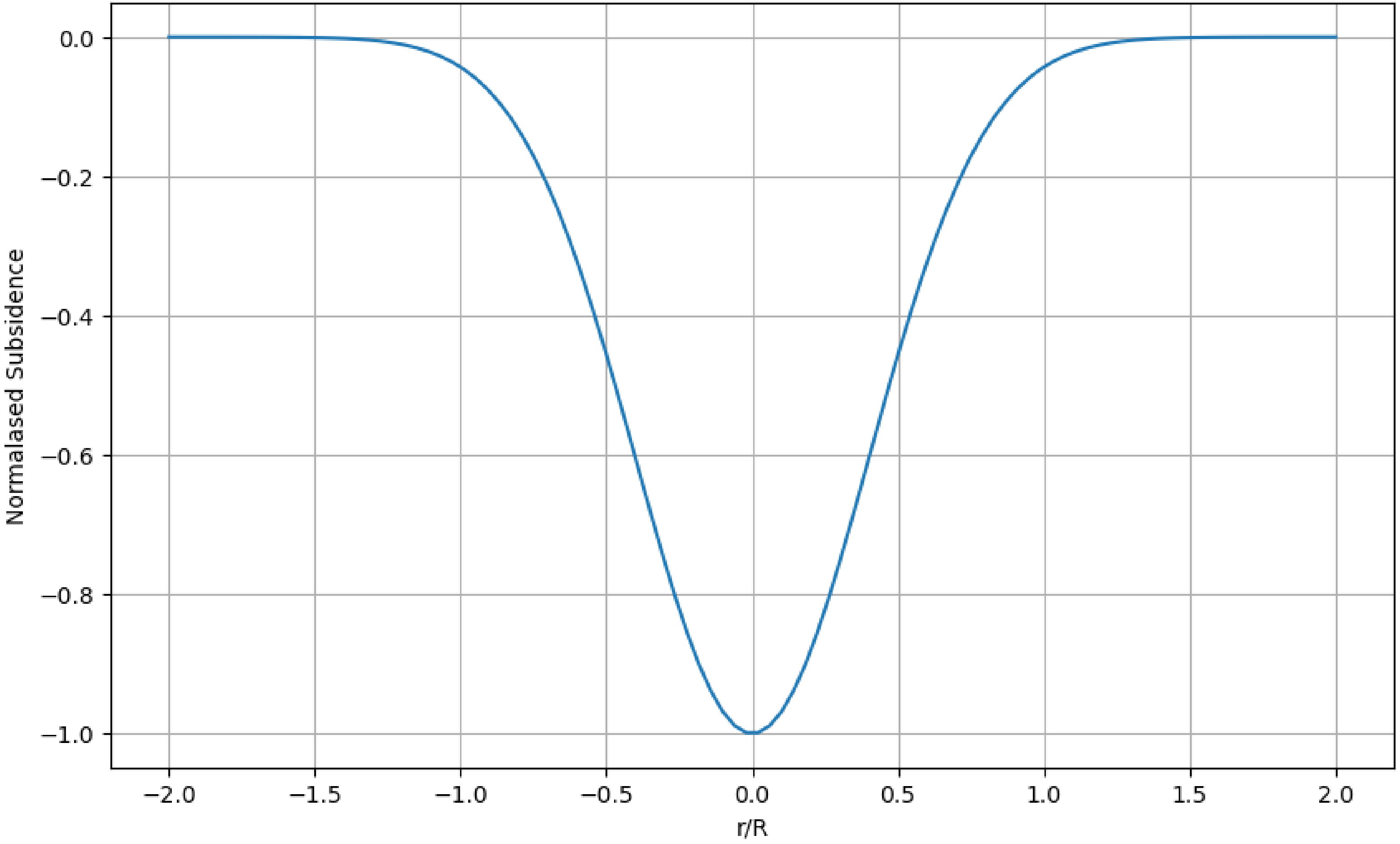
Surface settlement

[01]https://upload.wikimedia.org/wikipedia/commons/8/81/Gwsanjoaquin.jpg
[02]https://cdn.mos.cms.futurecdn.net/oB2WhdJMkuBBF2ixxzG5FW-1280-80.jpg.webp
[03] Wit, Kim & Lexmond, Bente & Stouthamer, Esther & Neussner, Olaf & Dörr, Nils & Schenk, Andreas & Minderhoud, Philip. (2021). Identifying Causes of Urban Differential Subsidence in the Vietnamese Mekong Delta by Combining InSAR and Field Observations. Remote Sensing. 13. 189. 10.3390/rs13020189.
[04]https://img.derwesten.de/img/incoming/crop7753192/0973054635-w1200-cv1_1-q85/Bergschaeden-Bergschaeden-0-656x240.jpg#
[05] A.H. Cooper (2008) Quarterly Journal of Engineering Geology and Hydrogeology, 41, 409-424, 13 August 2008, https://doi.org/10.1144/1470-9236/07-223

Subsidence prediction method

Classic subsidence prediction:
(Sroka and Shober 1982)

$$S(r) = \frac{\Delta V}{R^2} exp\left(-\pi \left(\frac{r}{R}\right)^2\right)$$



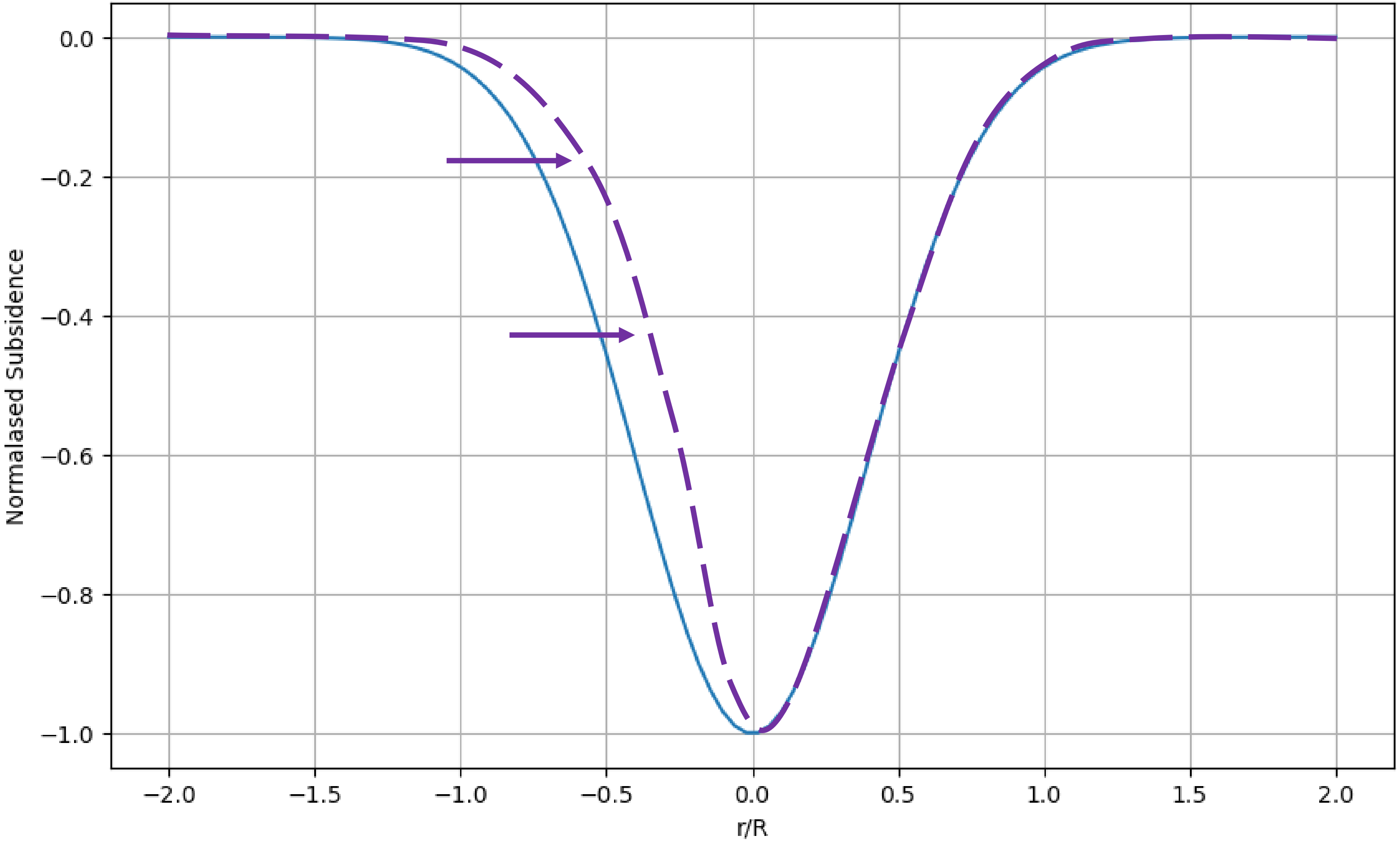
Aleksandra Babaryka and Prof. Dr.-Ing. Jörg Benndorf

MONTAN UNIVERSITÄT
WWW.UNILEOBEN.AC.AT
TU BERGAKADEMIE FREIBERG

Asymmetry deviation

Classic subsidence prediction:
(Sroka and Shober 1982)

$$S(r) = \frac{\Delta V}{R^2} exp\left(-\pi\left(\frac{r}{R}\right)^2\right)$$



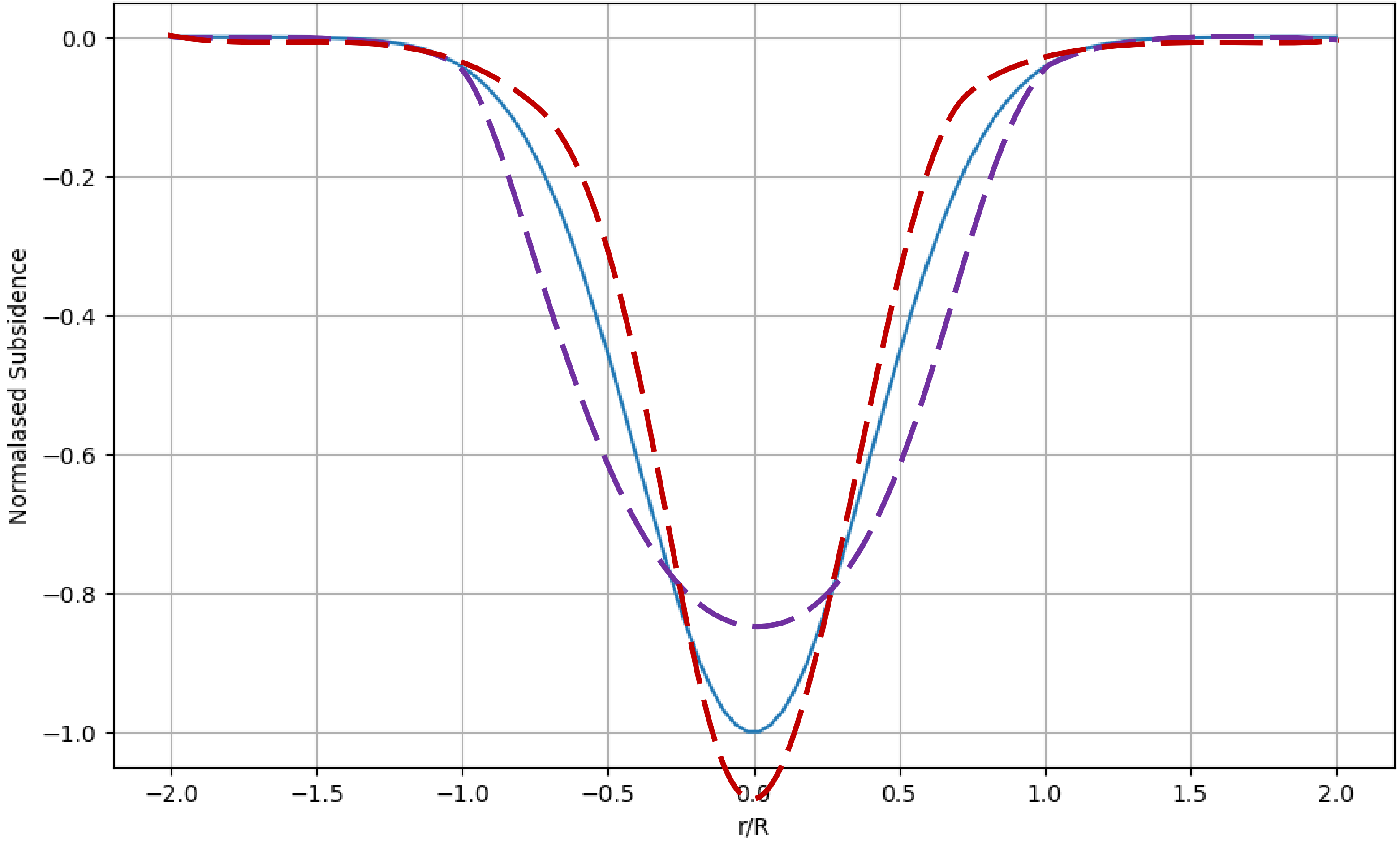
Aleksandra Babaryka and Prof. Dr.-Ing. Jörg Benndorf

MONTAN UNIVERSITÄT
WWW.UNILEOBEN.AC.AT
TU BERGAKADEMIE FREIBERG

Shape deviation

Classic subsidence prediction:
(Sroka and Shober 1982)

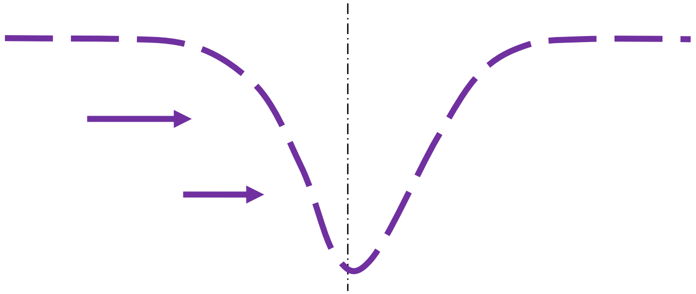
$$S(r) = \frac{\Delta V}{R^2} exp\left(-\pi \left(\frac{r}{R}\right)^2\right)$$



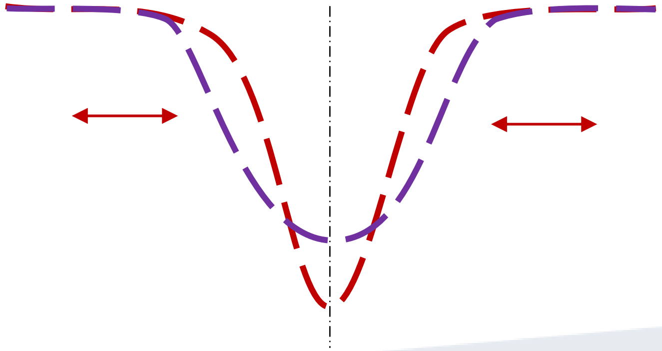
Aleksandra Babaryka and Prof. Dr.-Ing. Jörg Benndorf

Subsidence anomalies

Asymmetry



Shape



WHERE:
Sweden (Jones et al., 2019), the USA (Favorito & Seedorff, 2020), Great Britain (Speck & Bruhn, 1995), China (Khanal et al., 2022; Xia et al., 2016), Spain (Sanmiquel et al., 2018), Canada (Sepehri et al., 2017), Alaska, Bagdad, Andina, Athens, and Miami (Woo et al., 2013) etc.

REASONS:
Faults,
Stress conditions,
Stress release activities,
Topography,
Geological structure

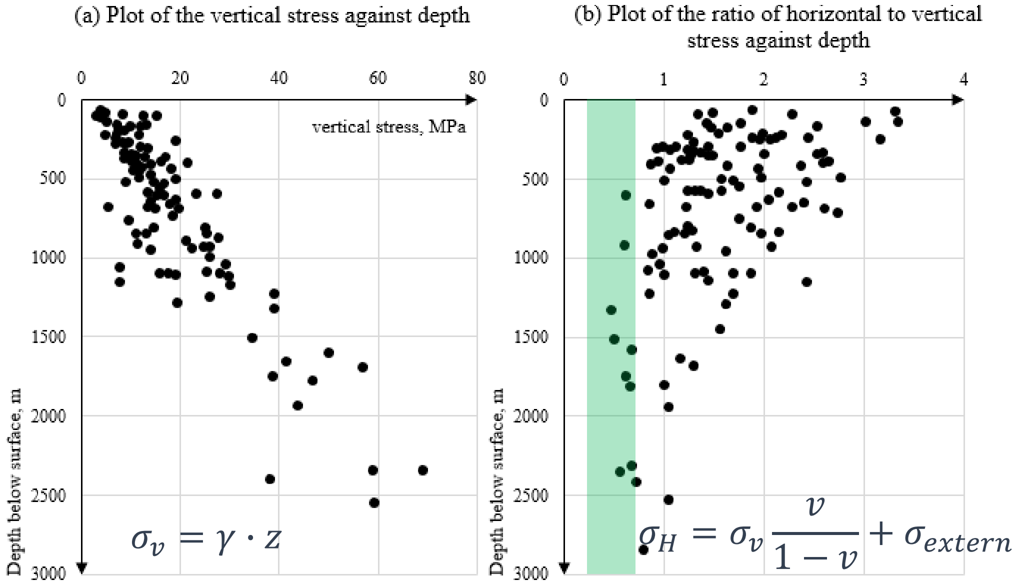
Higher horizontal stress

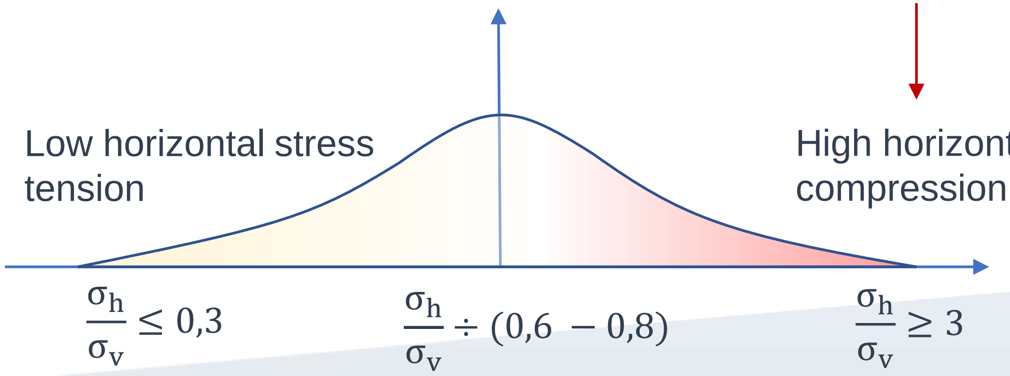
Aleksandra Babaryka and Prof. Dr.-Ing. Jörg Benndorf

MONTAN UNIVERSITÄT WWW.UNILEOBEN.AC.AT
TU BERGAKADEMIE FREIBERG

Goal

Investigation of the stress influence on the subsidence



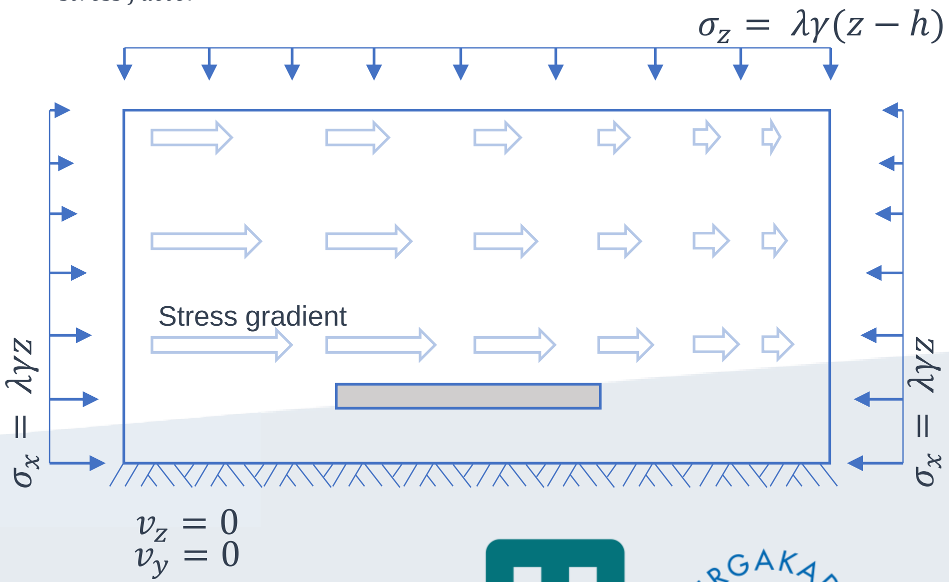


Numerical modeling:

Constitutive model: Hoek-Brown

$$Sress\ gradient = \frac{\lambda\, \gamma\, z\, n_{stress\ factor}}{2h}$$

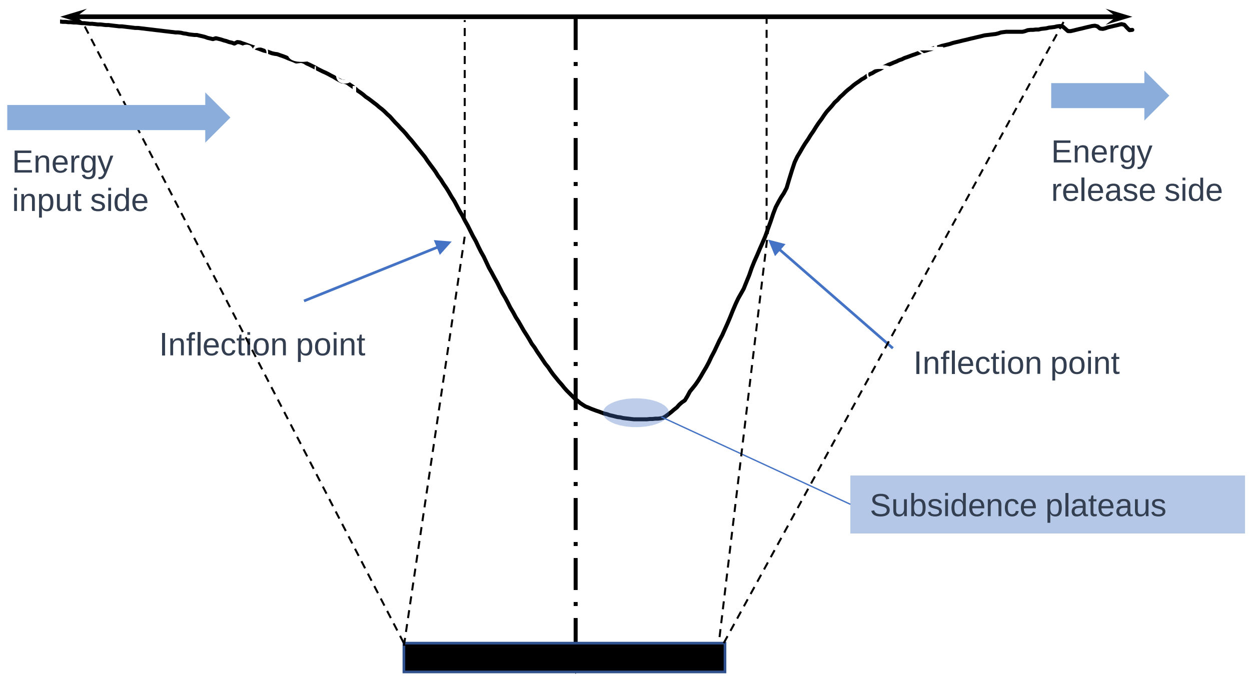
$$n_{stress\ factor} \in 1 \div 14$$

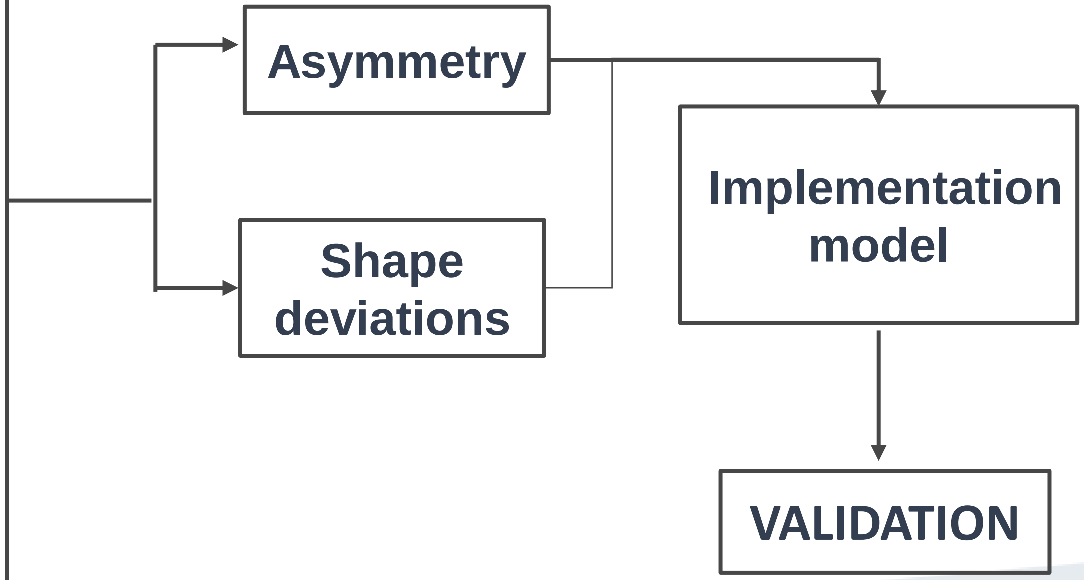


Aleksandra Babaryka and Prof. Dr.-Ing. Jörg Benndorf

Numerical results

Asymmetrical subsidence profile (Sandstones):



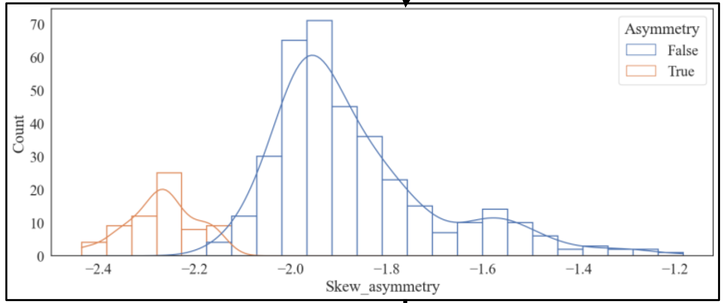


Aleksandra Babaryka and Prof. Dr.-Ing. Jörg Benndorf

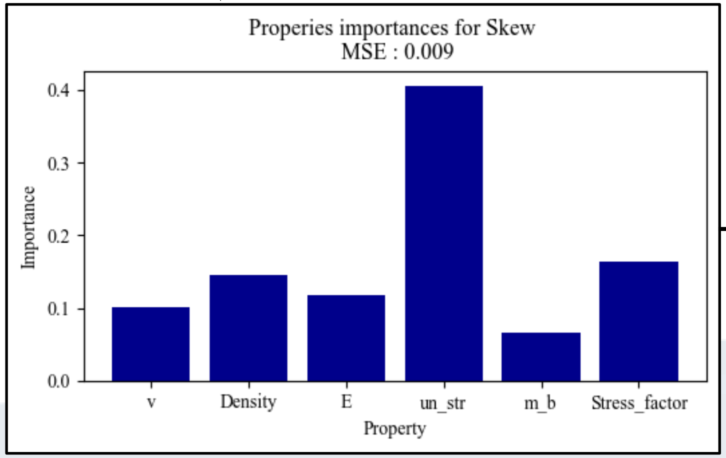
Numerical results

Asymmetry

Hystogram of skewness



Sensitivity analysis

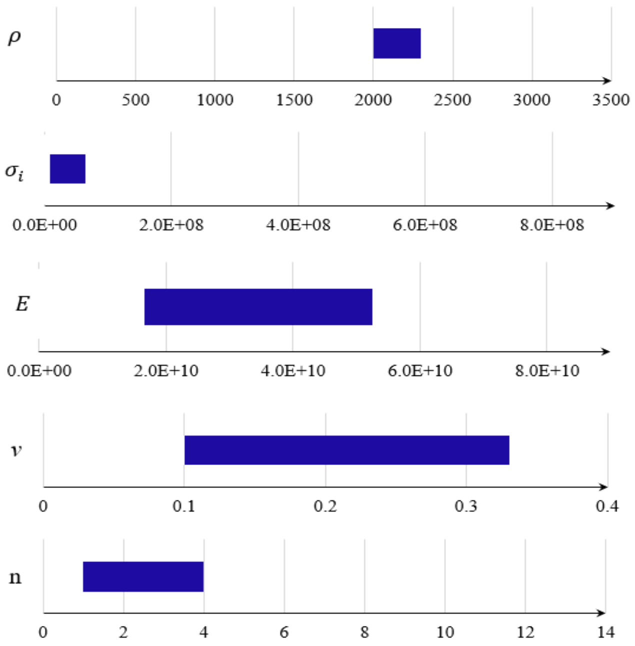


Decision Tree Classifier to Define Rock Property Ranges

Asymmetry:

$[\sigma_i \leq 7.9 \cdot 10^7 \,\&\, \rho \leq 2400 \,\&\, n < 5]$

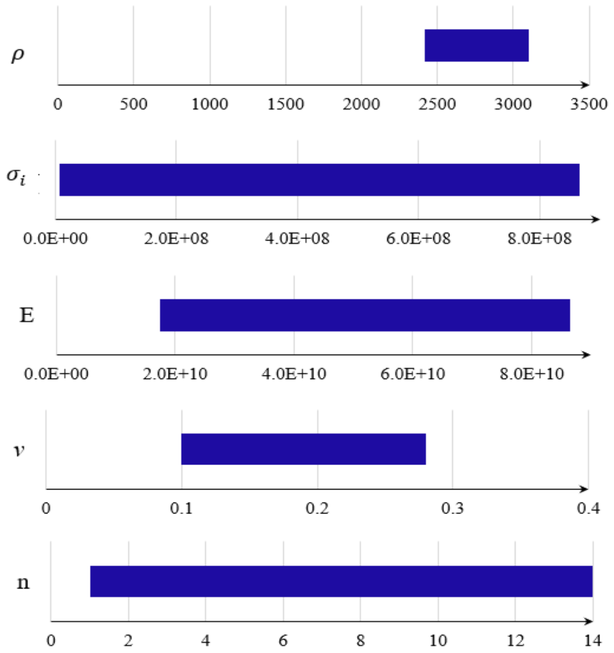
(a) Asymmetrical cases' properties



Symmetry:

$[\rho > 2400]$

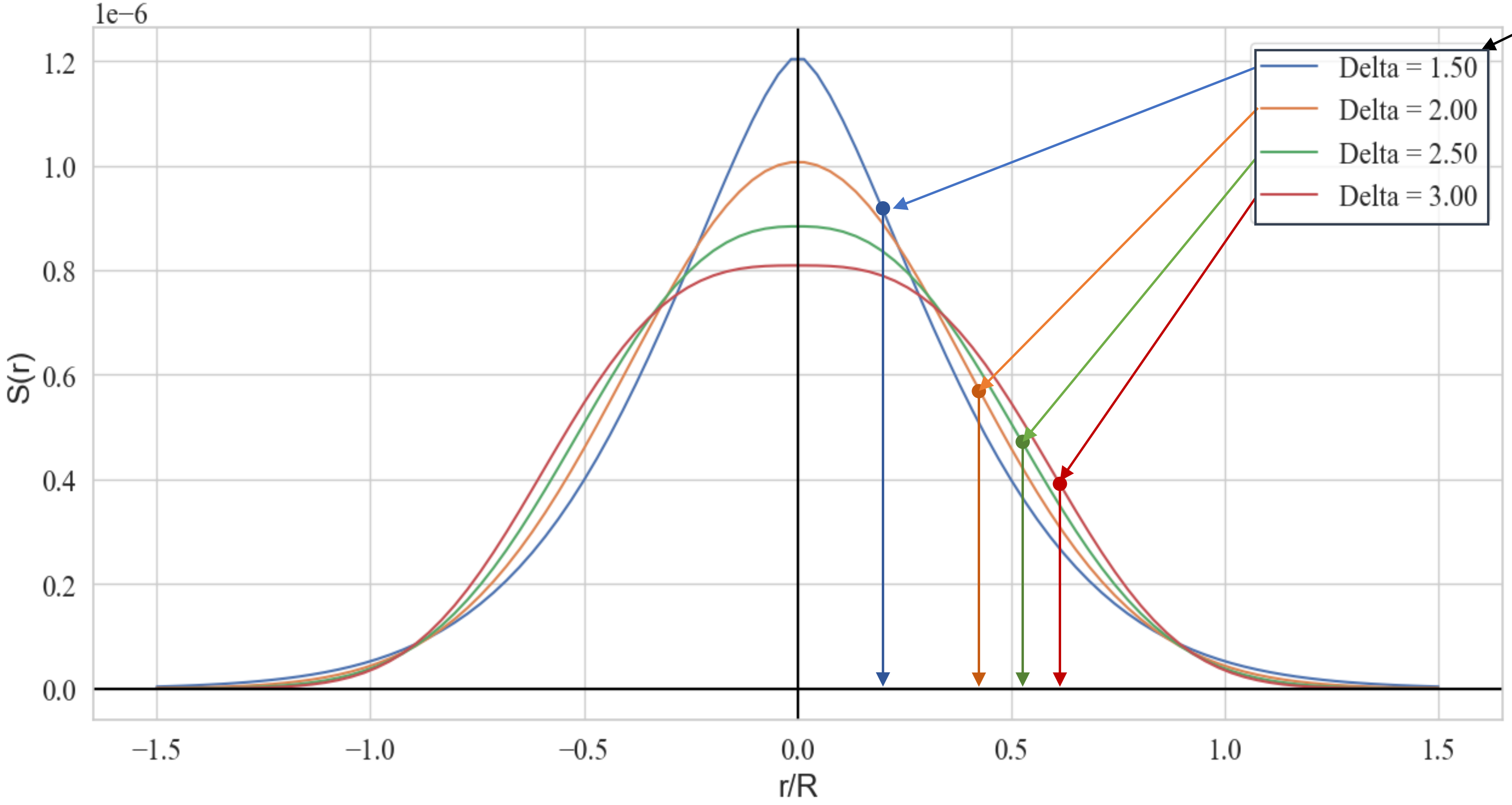
(b) Symmetrical cases' properties



Theory

Shape or an inflection point position

$$f(r) = \frac{2.3165568 \cdot e^{-\delta} + 0.6937466}{R^2} exp\left(-\pi \left(\frac{r}{R}\right)^{\delta}\right)$$

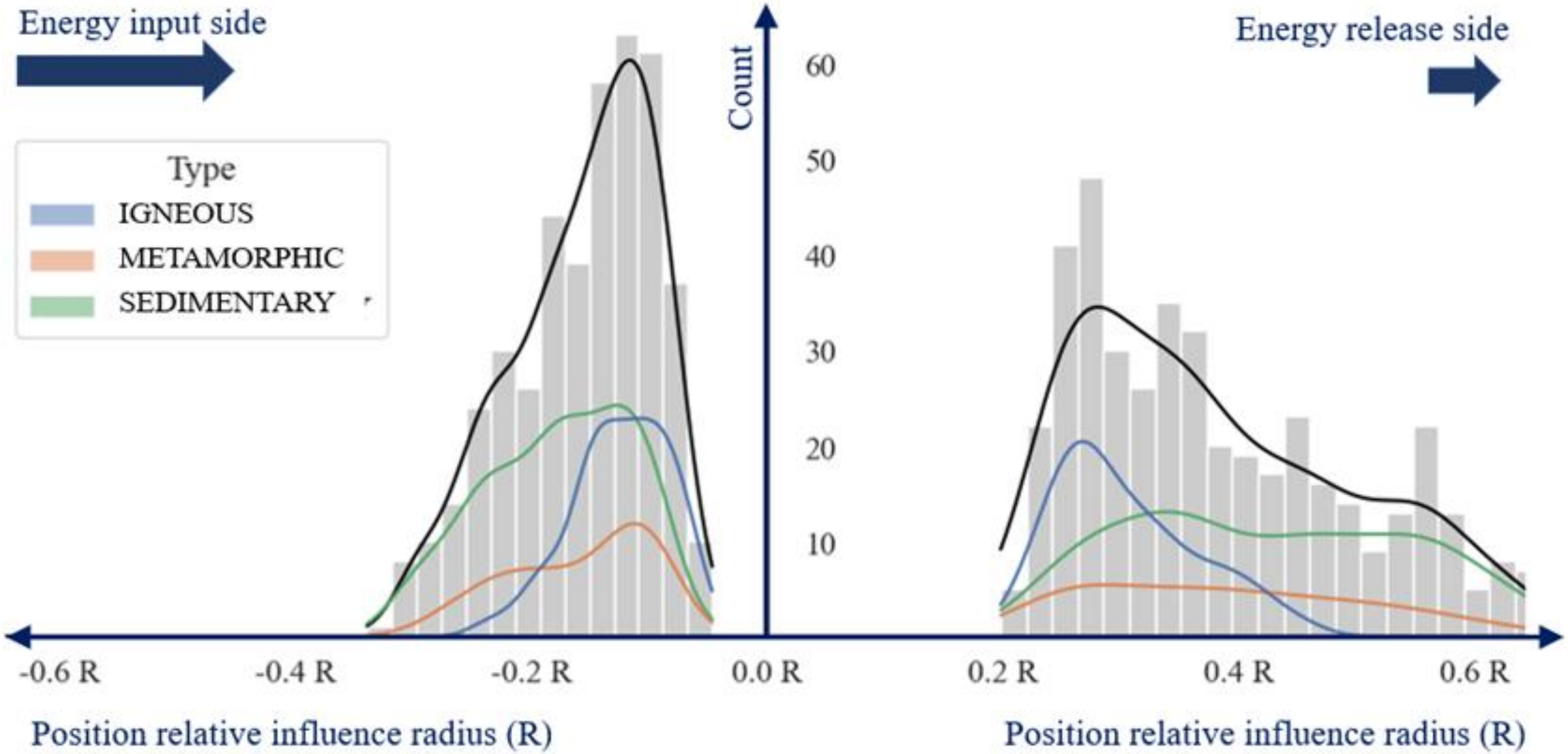


Aleksandra Babaryka and Prof. Dr.-Ing. Jörg Benndorf

Numerical results

Shape or an inflection point position

$$f(r) = exp\left(-\pi\left(\frac{r}{R}\right)^{\delta}\right)$$



Validation
(Cavern Storage Field in Northern Germany)

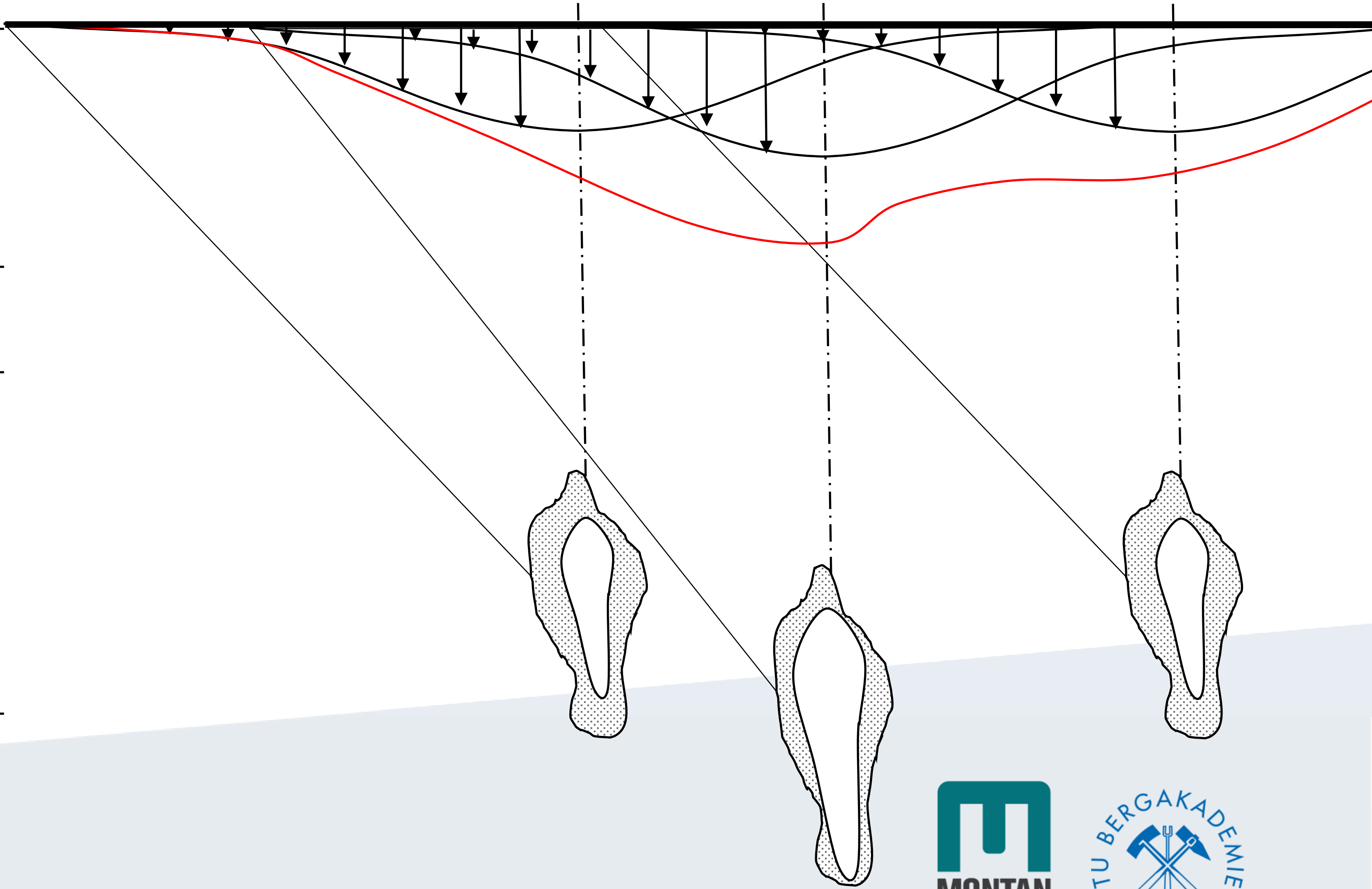
Caverns data:

Name	Xc	Yc	Zr	Zf	V	t	Type
102	925566	427317	848	1500	488736	1977	oil
103	925652	426824	855	1500	641162	1978	gas
104	925514	427557	855	1500	668584	1978	oil

In summary, there are 89 caverns...

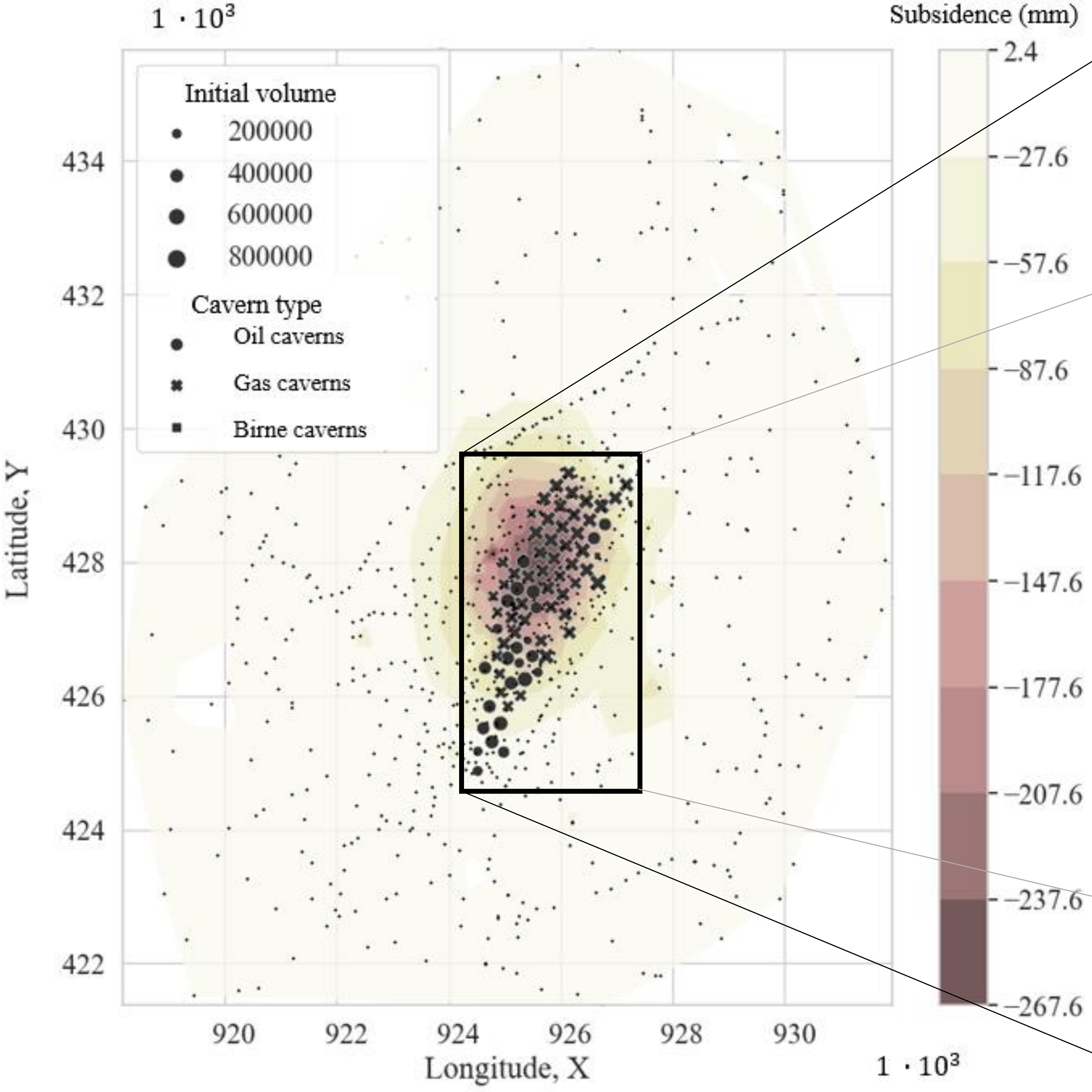
Leveling data:

Number	Subsidence (2017 - 2022)	X	Y
1	-7,4	921987	427274
2	-8,3	922283	426886
3	-7,94	922292	427102
4	-9,15	922432	427153
5	-9,74	922568	427216
	...		
731	-17,41	923035	427230

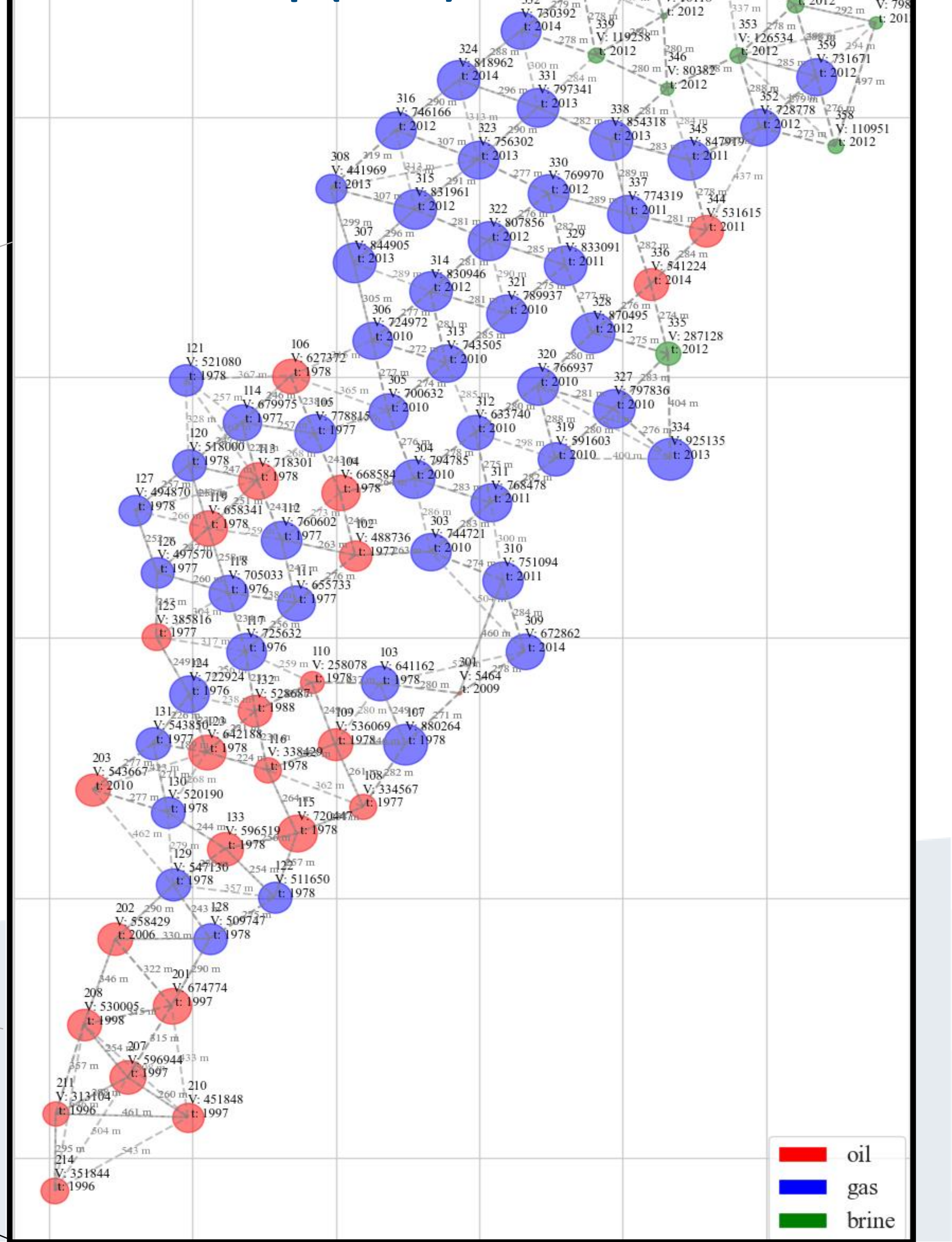


Aleksandra Babaryka and Prof. Dr.-Ing. Jörg Benndorf

Leveling (2017 - 2022)

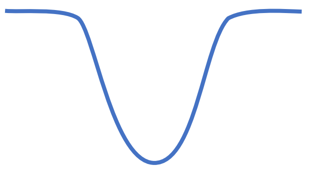
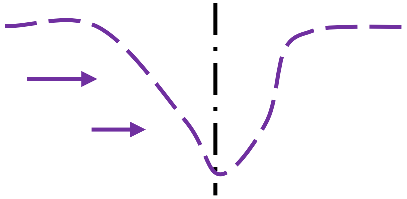
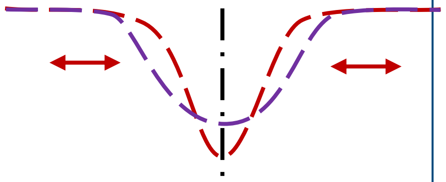
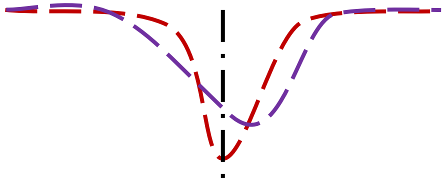


Cavern map (2022)



Model adaptation and results

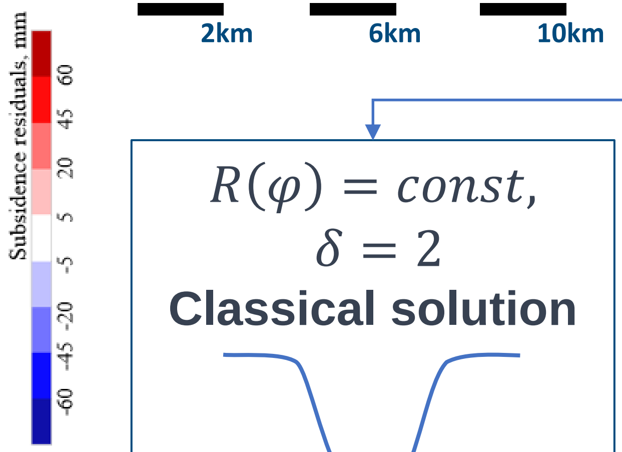
$$S(r,\varphi) = \frac{\Delta V}{\int_0^{2\pi}\int_0^{\infty} exp\left(-\pi \frac{r^2}{R(\varphi)^2}\right) r\,dr\,d\varphi} \cdot exp\left(-\pi\left(\frac{r}{R(\varphi)}\right)^{\delta}\right)$$

	$R(\varphi) = const,$ $\delta = 2$ **Classical solution**	$R(\varphi) = R(1+\sin(\varphi + \varphi_0)),$ $\delta = 2$ **Asymmetry adopted**	$R(\varphi) = const,$ $\delta = 0.99$ **Shape adopted**	$R(\varphi) = R(1+\sin(\varphi + \varphi_0)),$ $\delta = 1.5$ **Unifying solution**
				
MSE	**133**	**105**	**116**	**91**
MAE	**7,4**	**6,4**	**6,1**	**5,5**
R2	**0,968**	**0,972**	**0,975**	**0,978**
BIC	**5693**	**5599**	**5532**	**5435**

Aleksandra Babaryka and Prof. Dr.-Ing. Jörg Benndorf

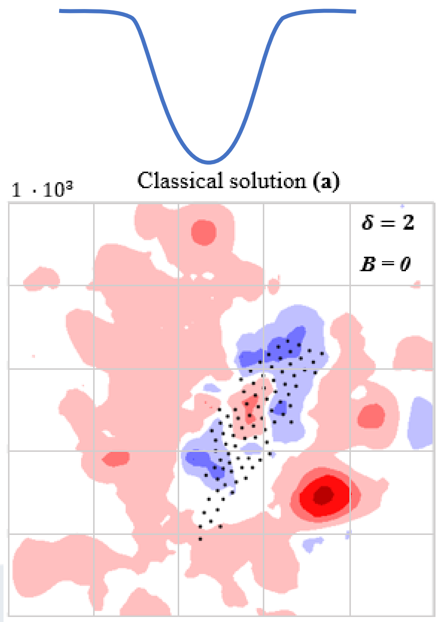
Model adaptation and residual maps

$$S(r,\varphi) = \frac{\Delta V}{\int_0^{2\pi}\int_0^{\infty} exp\left(-\pi \frac{r^2}{R(\varphi)^2}\right) r\,dr\,d\varphi} \cdot exp\left(-\pi\left(\frac{r}{R(\varphi)}\right)^{\delta}\right)$$



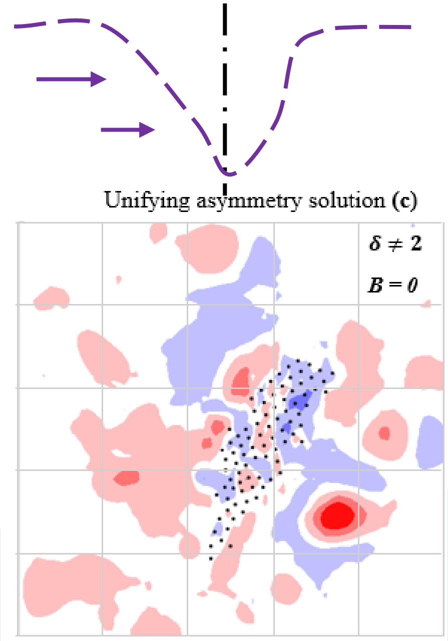
$$R(\varphi) = const,$$
$$\delta = 2$$

Classical solution



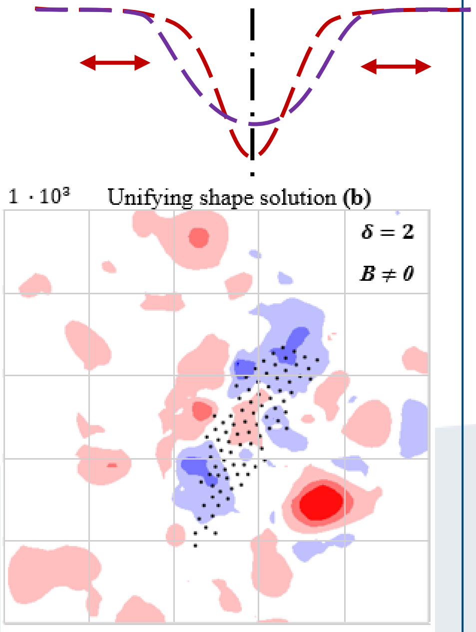
$$R(\varphi) = R(1 + \sin(\varphi + \varphi_0)),$$
$$\delta = 2$$

Asymmetry adopted



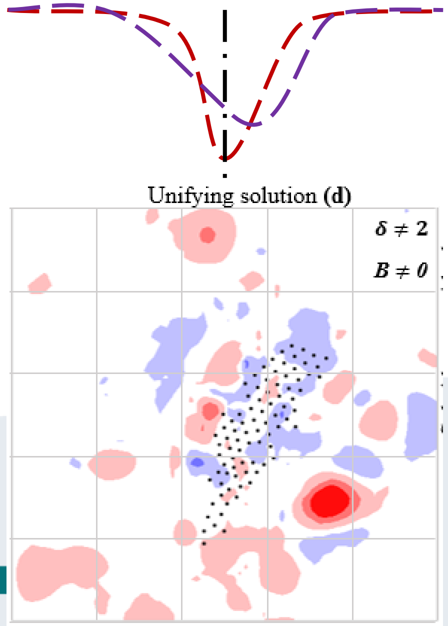
$$R(\varphi) = const,$$
$$\delta = 0.99$$

Shape adopted



$$R(\varphi) = R(1 + \sin(\varphi + \varphi_0)),$$
$$\delta = 1.5$$

Unifying solution

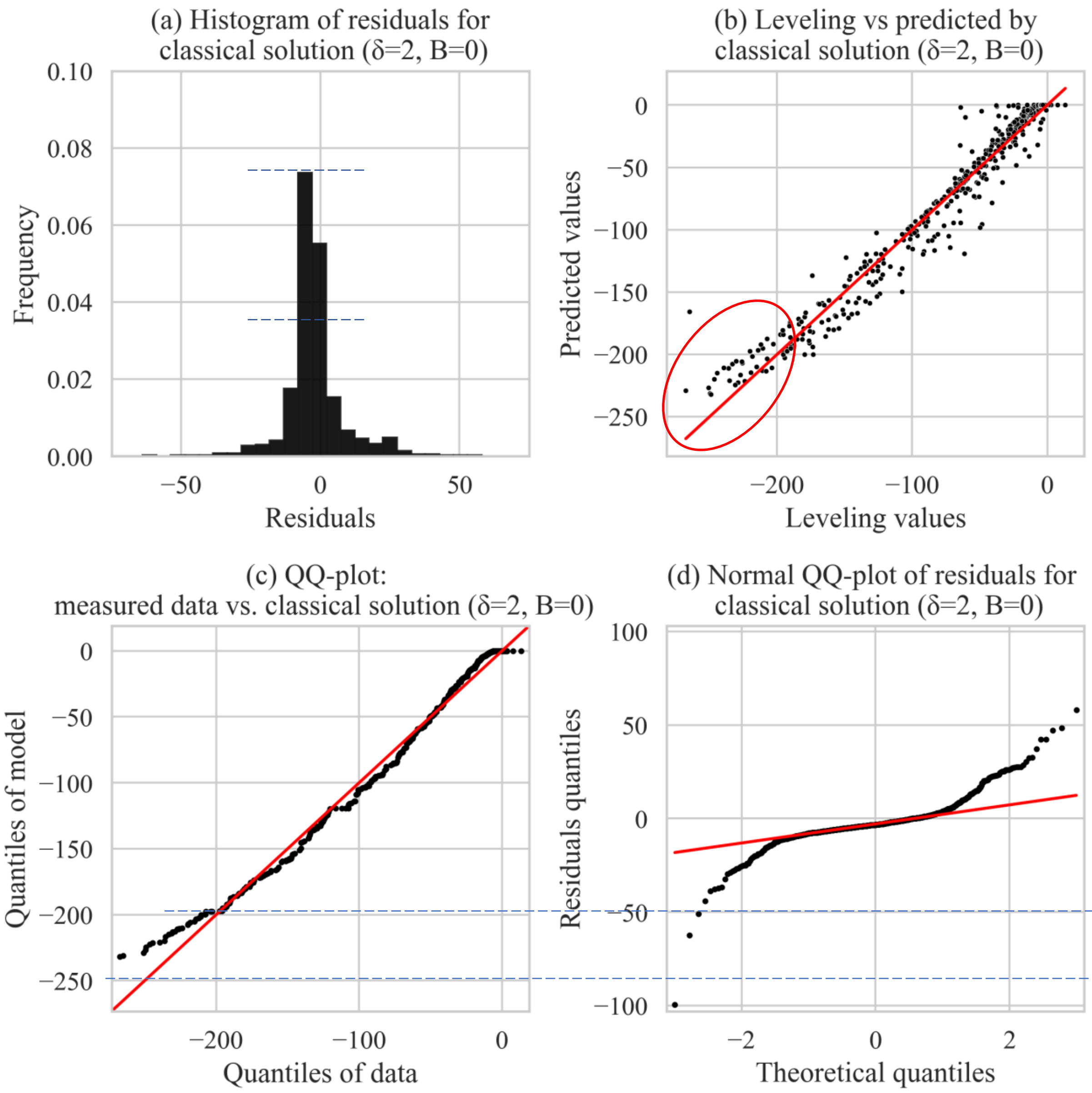


Aleksandra Babaryka and Prof. Dr.-Ing. Jörg Benndorf

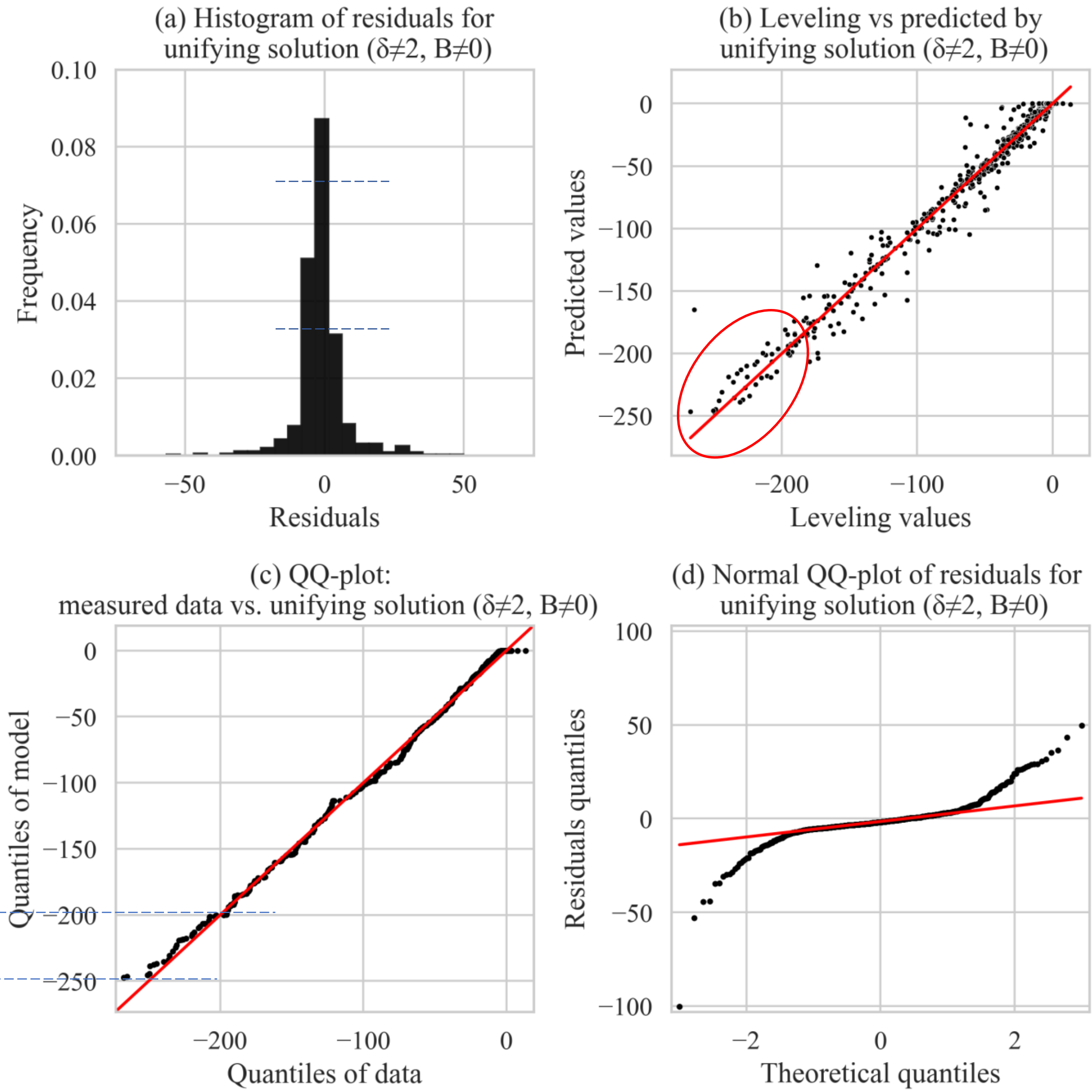
MONTAN UNIVERSITÄT WWW.UNILEOBEN.AC.AT
TU BERGAKADEMIE FREIBERG

Statistical interpretation of results

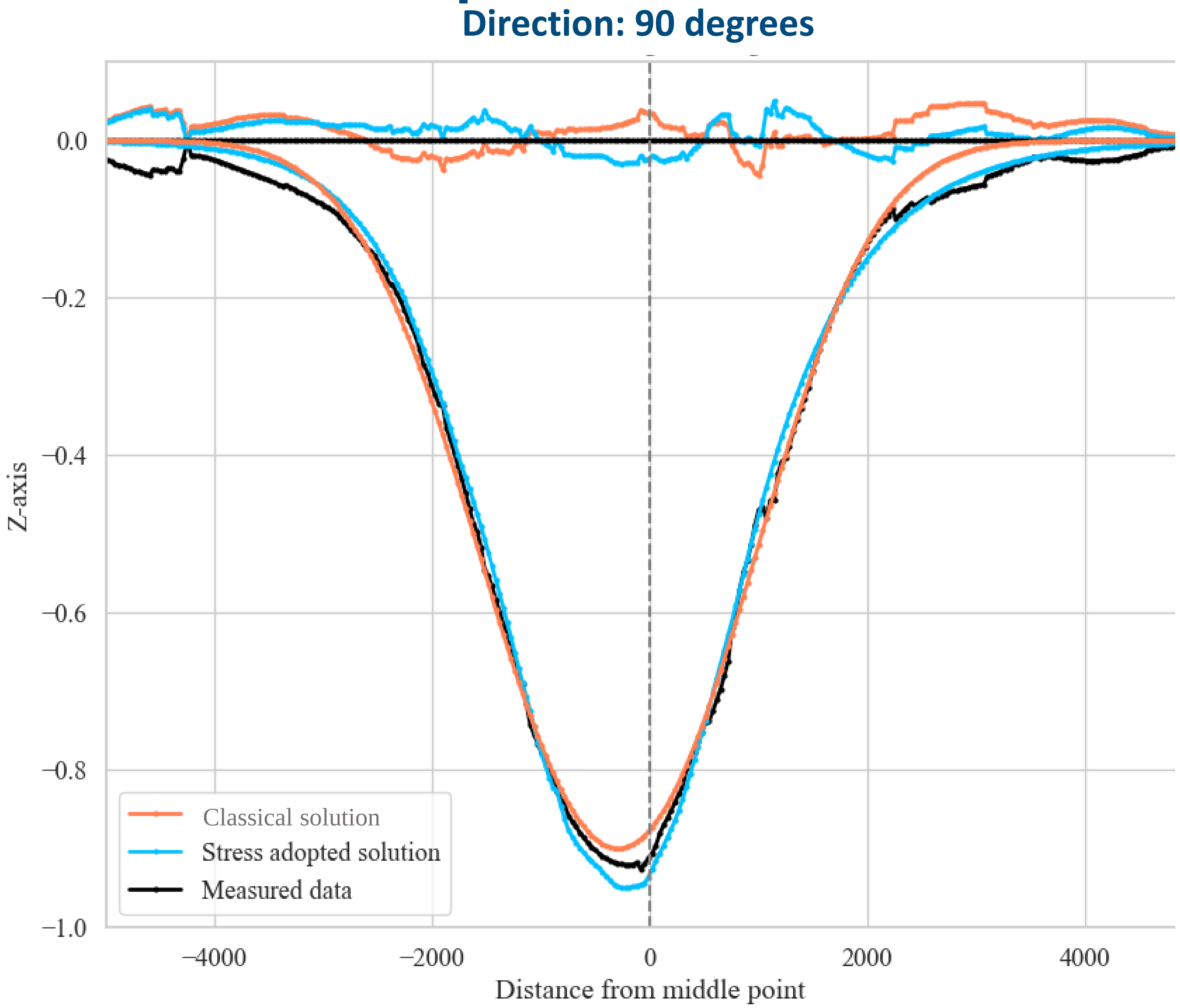
Classical model

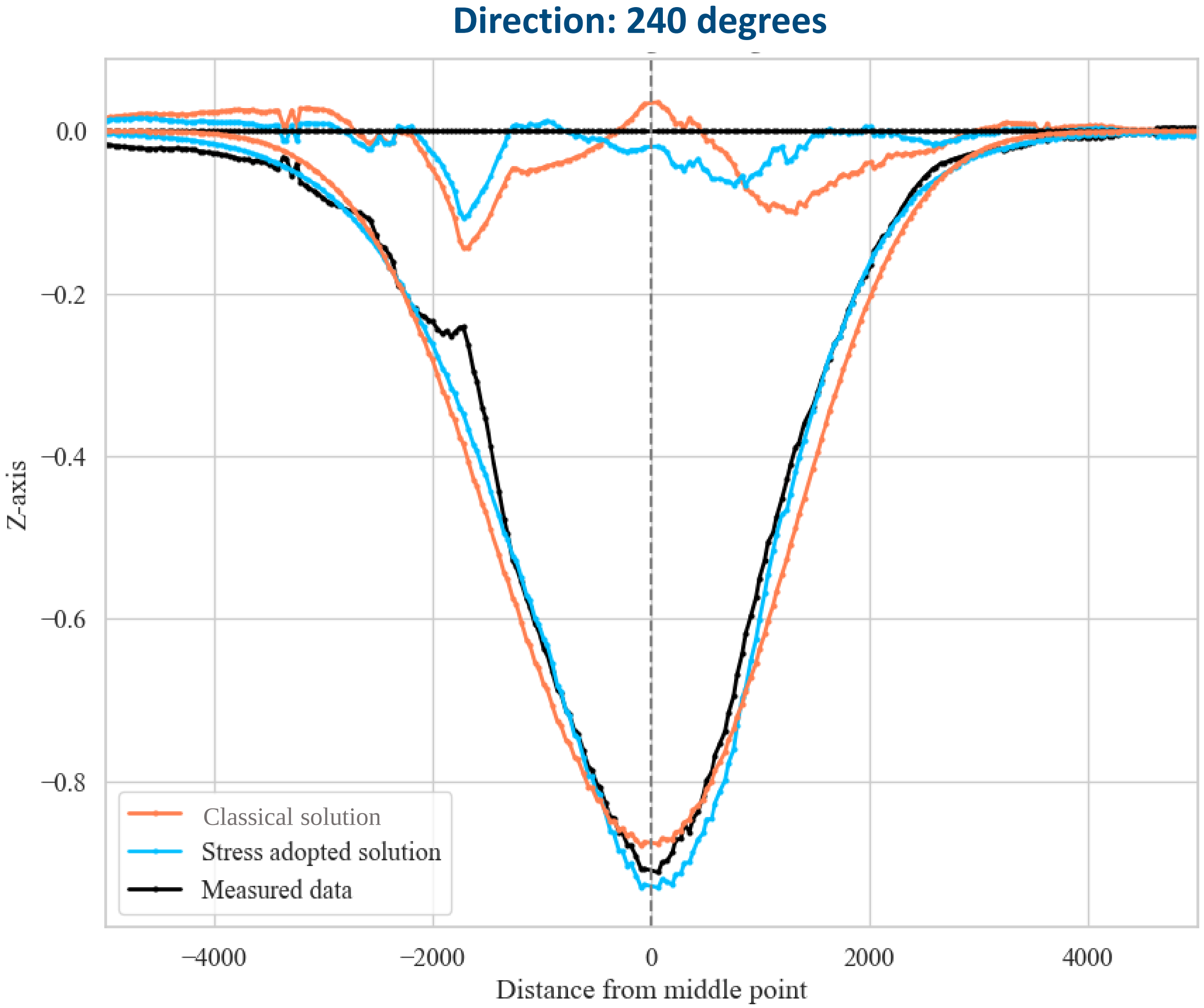


Stress adopted model



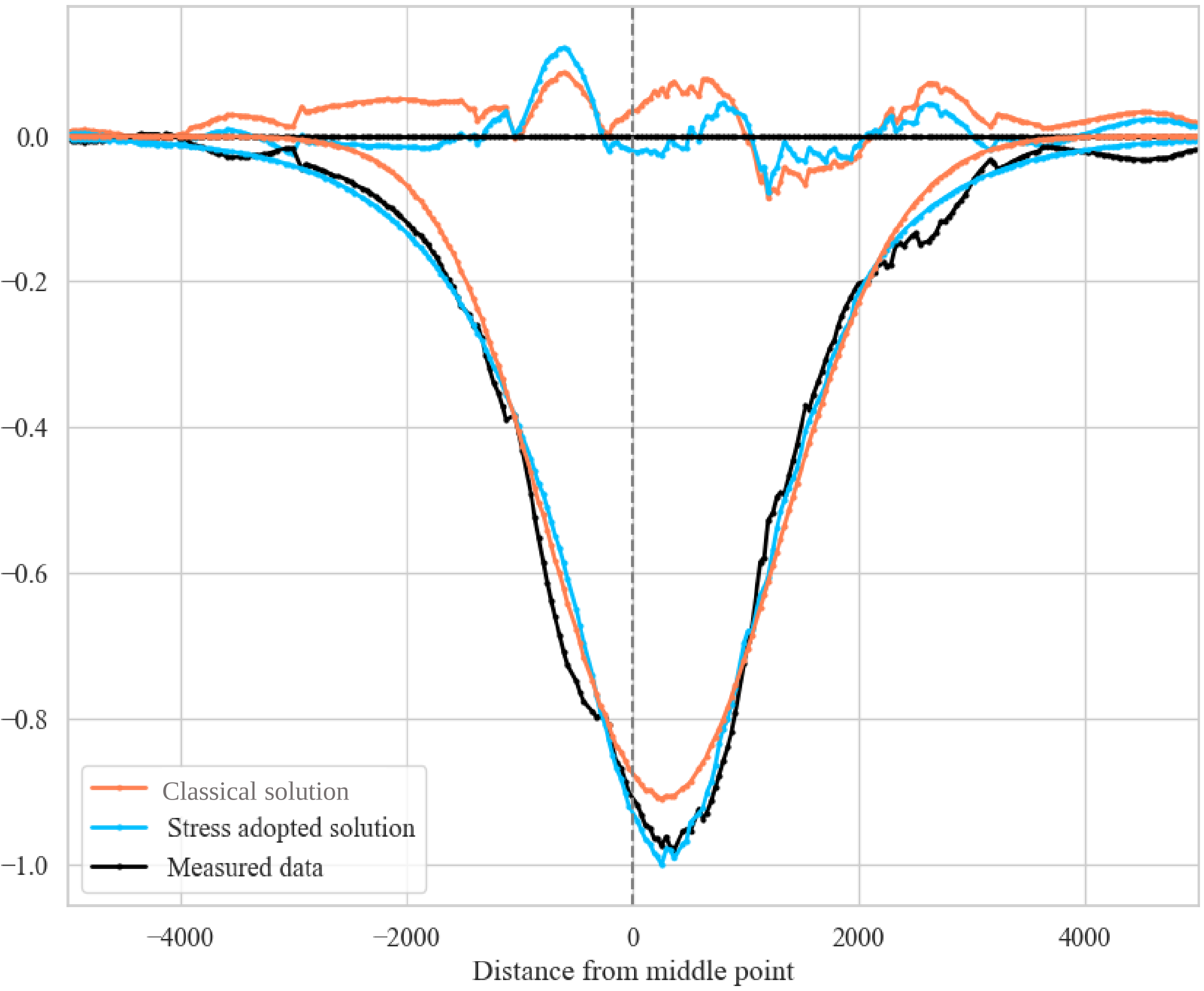
Subsidence profiles in different directions



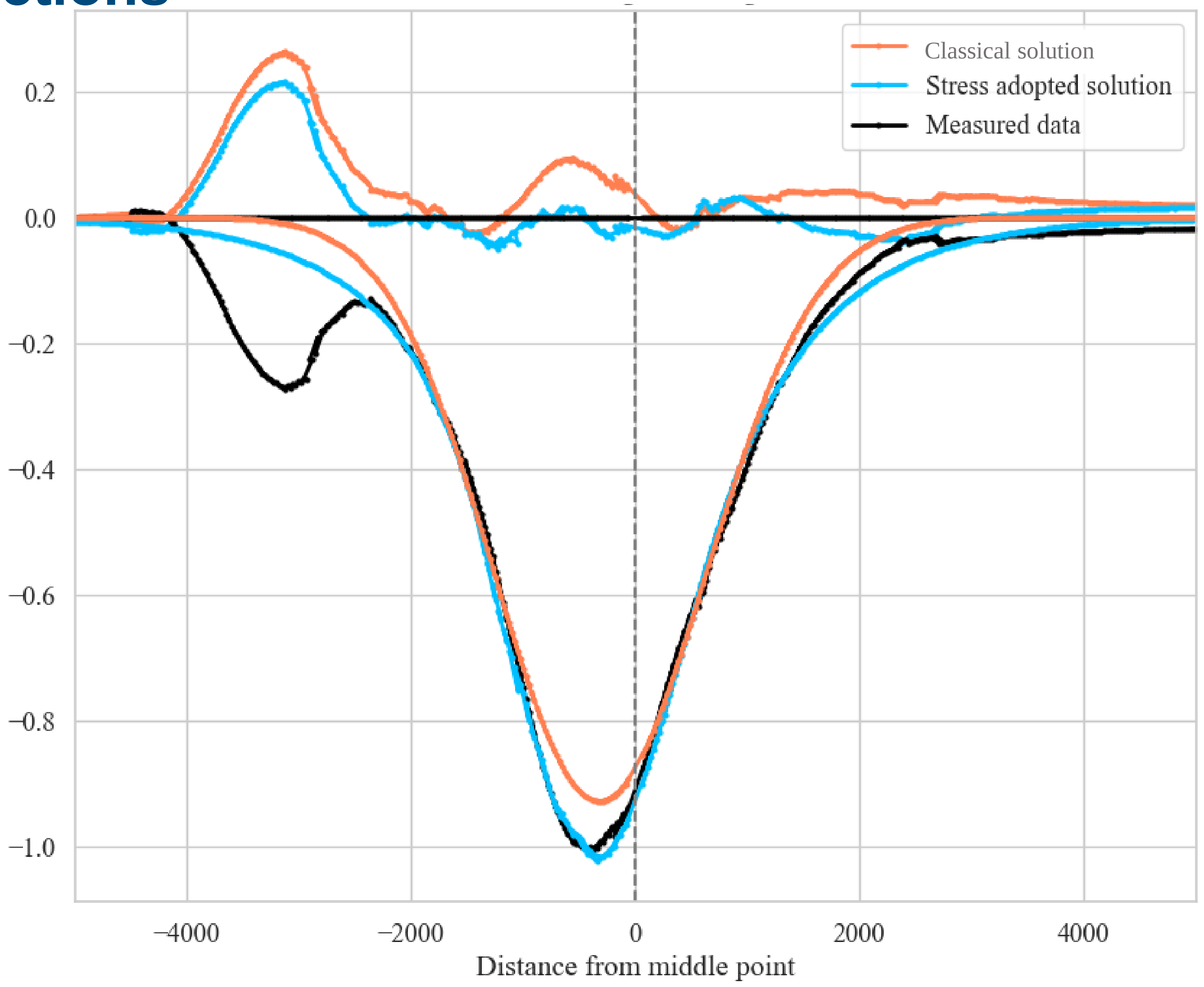


Subsidence profiles in different directions

Direction: 205 degrees

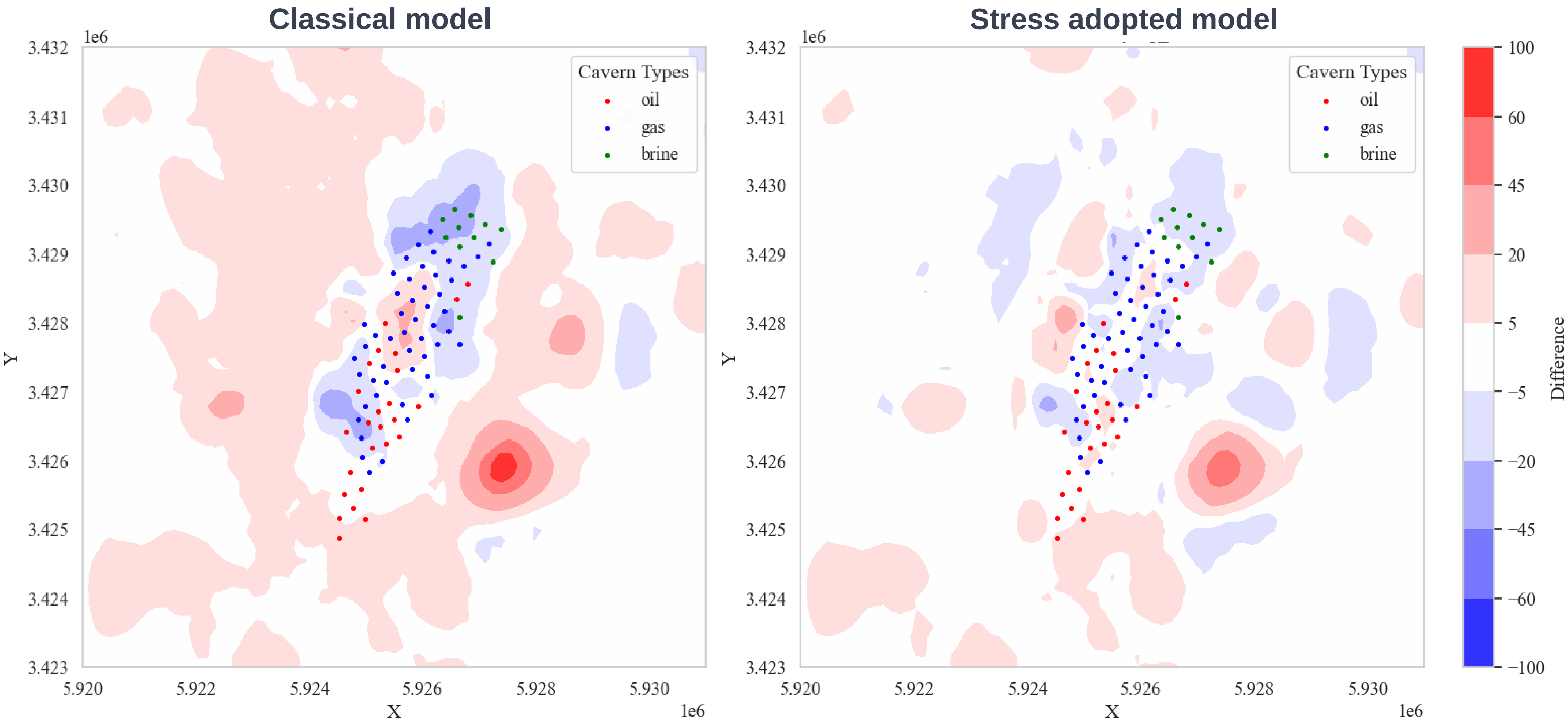


Direction: 315 degrees



Aleksandra Babaryka and Prof. Dr.-Ing. Jörg Benndorf

Residuals maps



Aleksandra Babaryka and Prof. Dr.-Ing. Jörg Benndorf

CONLUSIONS

The stress conditions influence the shape of the distribution and the angular properties of the subsidence profile.

The non-uniform distribution leads to asymmetry.

By incorporating stress conditions into the developed method for subsidence prediction, the quality of the prediction is improved compared to the classical solution:

- Shape adaptation: **up to 12%.** Most improvements occur in the periphery;
- Asymmetry adaptation : **up to 21%.** Most improvements occur in the middle part.
- Shape and Symmetry adaptation: **up to 31%**

Aleksandra Babaryka and Prof. Dr.-Ing. Jörg Benndorf

MONTAN UNIVERSITÄT
WWW.UNILEOBEN.AC.AT

TU BERGAKADEMIE · FREIBERG ·

GET IN TOUCH

The presentation and other relative publications are available in free access on ResearchGate. Accessing them is made easy by scanning QR-Code

Aleksandra Babaryka,

Babaryka.a.s@gmail.com

Montanuniversität Leoben

Prof. Dr.-Ing. Jörg Benndorf,

TU Bergakademie Freiberg

References

Jones T, Nordlund E, Wettainen T. Mining-Induced Deformation in the Malmberget Mine. Rock Mech Rock Eng. 2019;52:1903-1916. doi:10.1007/s00603-018-1716-6

Favorito DA, Seedorff E. Laramide Uplift near the Ray and Resolution Porphyry Copper Deposits, Southeastern Arizona: Insights into Regional Shortening Style, Magnitude of Uplift, and Implications for Exploration. Econ Geol. 2020;115(1):153-175. doi:10.5382/econgeo.4697

Speck, R. C., & Bruhn, R. W. (1995). Non-Uniform Mine Subsidence Ground Movement and Resulting Surface-Structure Damage. Environmental & Engineering Geoscience, 1(1), 61-74. https://doi.org/10.2113/gseegeosci.I.1.61

Sroka A, Schober F. Die Berechnung der maximalen Bodenbewegungen über kavernenartigen Hohlräumen unter Berücksichtigung der Hohlraumgeometrie. [Calculation of maximum ground movements above cavern-like voids considering cavity geometry]. Kali u. Steinsalz. 1982;8:273-277.

Khanal, M., Qu, Q., Zhu, Y., Xie, J., Zhu, W., Hou, T., & Song, S. (2022). Characterization of Overburden Deformation and Subsidence Behavior in a Kilometer Deep Longwall Mine. Minerals, 12(5), 543. https://doi.org/10.3390/min12050543

Xia, K., Chen, C., Liu, X. et al. (2016). Mining-induced ground movement in tectonic stress metal mines: a case study. Bulletin of Engineering Geology and the Environment, 75, 1089–1115. https://doi.org/10.1007/s10064-016-0886-2

Sanmiquel, L., Bascompta, M., Vintró, C., & Yubero, T. (2018). Subsidence Management System for Underground Mining. Minerals, 8(6), 243. https://doi.org/10.3390/min8060243

Sepehri M, Apel D, Hall R. Prediction of mining-induced surface subsidence and ground movements at a Canadian diamond mine using an elastoplastic finite element model. Int J Rock Mech Min Sci. 2017;100:73-82. doi:10.1016/j.ijrmms.2017.10.006

Woo, K.-S., Eberhardt, E., Elmo, D., & Stead, D. (2013). Empirical investigation and characterization of surface subsidence related to block cave mining. International Journal of Rock Mechanics and Mining Sciences, 61, 31-42. ISSN 1365-1609. https://doi.org/10.1016/j.ijrmms.2013.01.015.