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Exploring the inner structure of the Esztramos Mountain using muographic measurements

Bence Rábóczki^{1,2}, Gergely Surányi¹, Gergő Hamar¹, László Balázs^{1,2}

1: HUN-REN Wigner RCP, High-Energy Physics Department

2: Eötvös Loránd University, Department of Geophysics

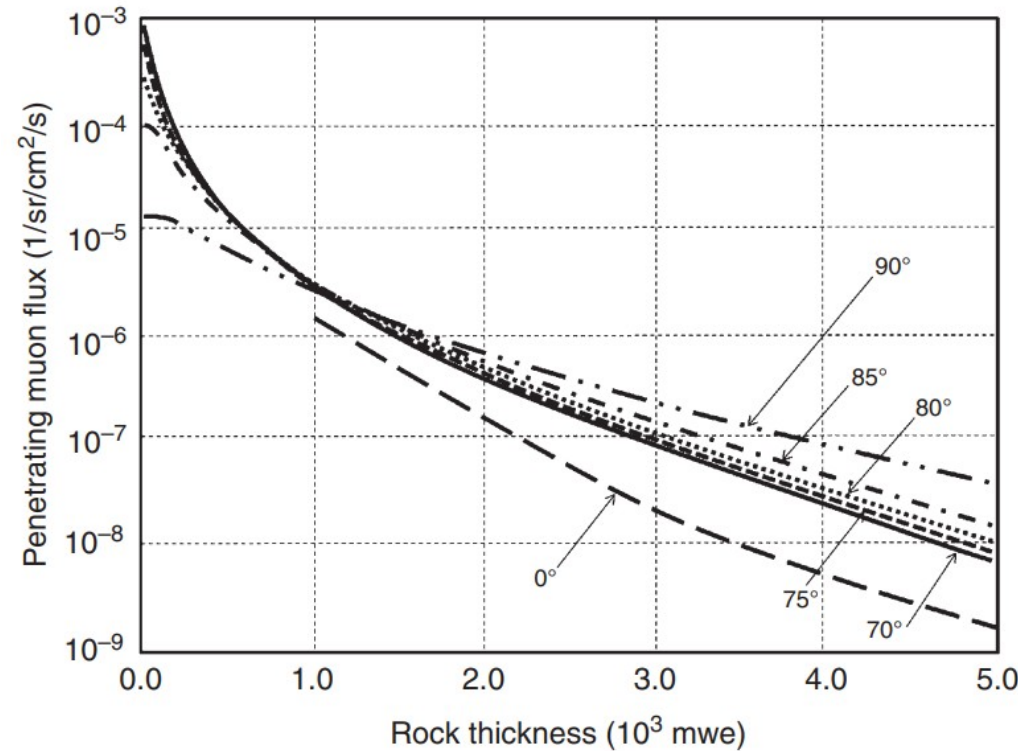
Meeting of Young Geoscientists 2024 - Eger

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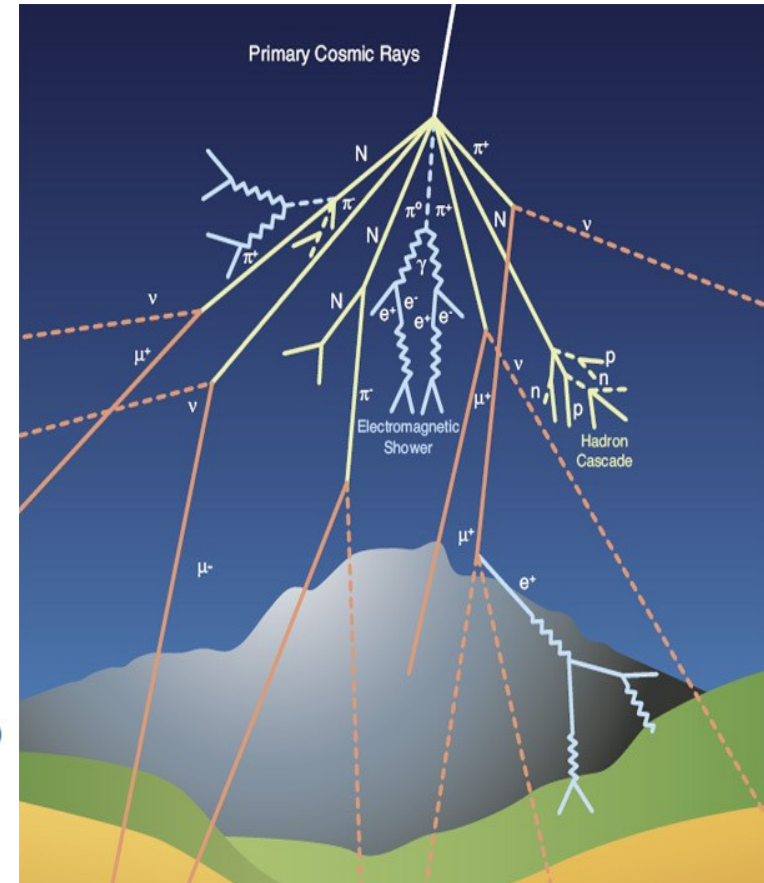
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 - b. Detecting the particles
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Principles of muography – Cosmic radiation and muons

- Muons are part of the **secondary cosmic radiation**
- They have a **steady**, angle dependent **flux** on the surface
- They can **penetrate** hundreds of meters of **rock** (~4 GeV mean energy)
- A number of them are **absorbed** in the process
- The number of absorbed muons depends on the **density of the rock along their trajectories**



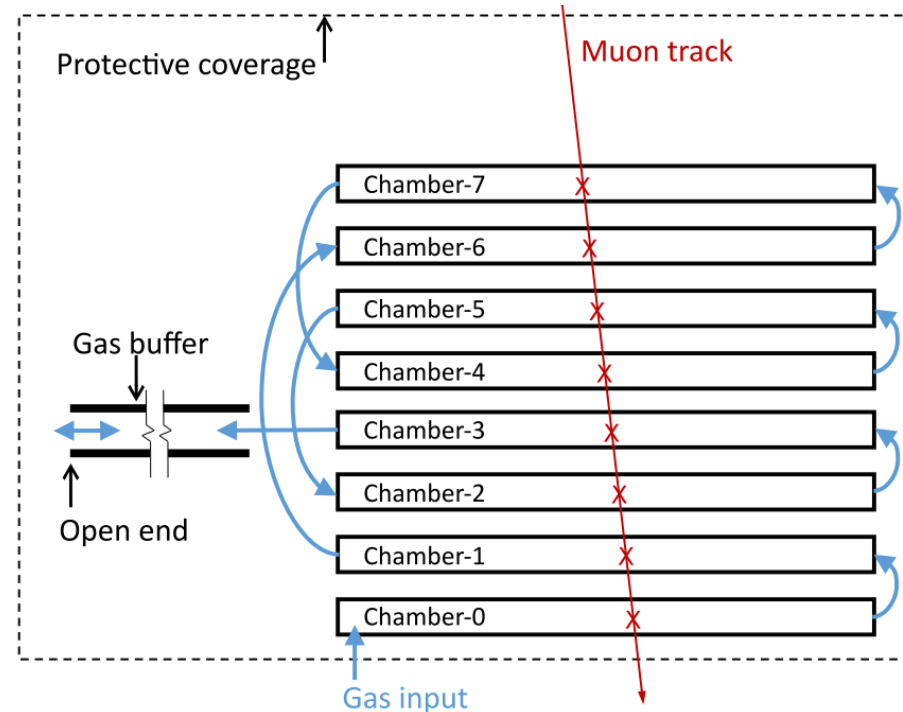
Penetrating muon flux as a function of rock thickness and zenith angle [1]



Cosmic radiation visualised [2]

Principles of muography – Detecting the particles

- Muons have the same charge as an electron → detection possible by **electron multiplication in ionised gas** (proportional chamber)
- Electron multiplication takes place **in the vicinity of high voltage wires** (MWPC)
- Perpendicular **wires** record **X** and **Y** coordinates, **stacking** of chambers records **Z**
- **Tracking algorithms** filter out noise and other low energy particles



Schematic 2D drawing of a muograph [3] on the left, and the „Mtl1” detector inside the Esztramos Mountain on the

right
Meeting of Young
Geoscientists - Eger

Principles of muography - Creating a muogram

Flux: calculated from the number of recorded muons, detector area, zenith angle, detector efficiency and time **OR** taken from a *flux model* [4]

$$\phi = \frac{N}{A \cdot \alpha \cdot \varepsilon \cdot t} \quad [\phi] = \frac{1}{m^2 \cdot sr \cdot s}$$

Density length: The product of the average density and length of the rock. Calculated from the measured flux and the *geoinformatic model* of the explored area **OR** an assumed average density & the GI model through rock length

$$DL = \rho_{avg} \cdot RL \quad [DL] = \frac{kg}{m^2}$$

Rock length: The length of the rock above the detector. Calculated from the measured flux through density length and an assumed average density **OR** taken from the geoinformatic model

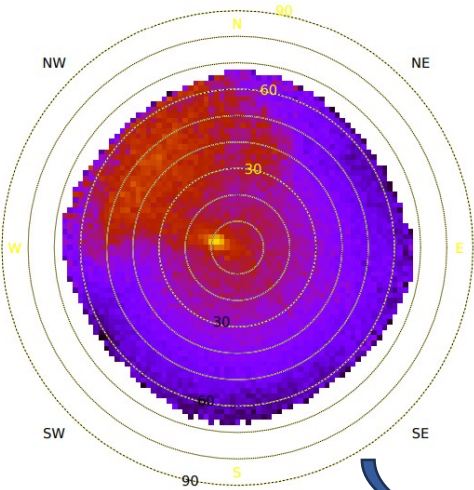
$$RL = \frac{DL}{\rho_{avg}} \quad [RL] = m$$

Missing rock: The difference between the modeled and the measured rock lengths → anomalies

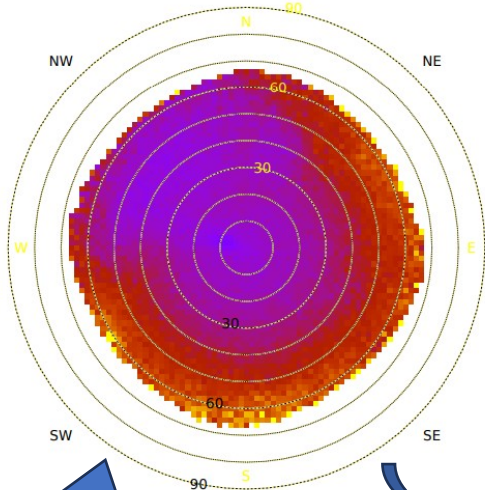
$$MR = RL_{modeled} - RL_{measured} \quad [MR] = m$$



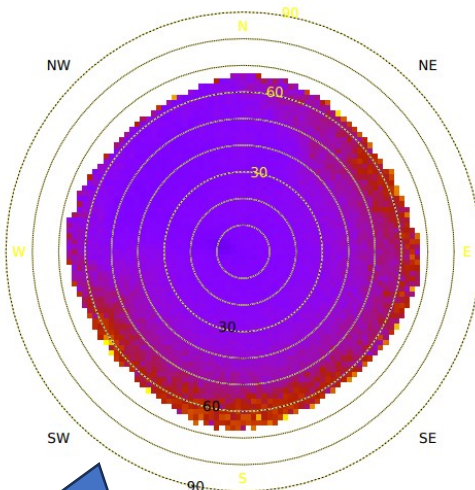
Measured Flux



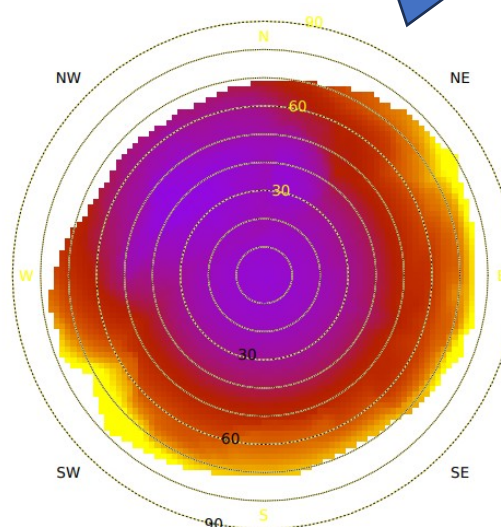
Measured DL



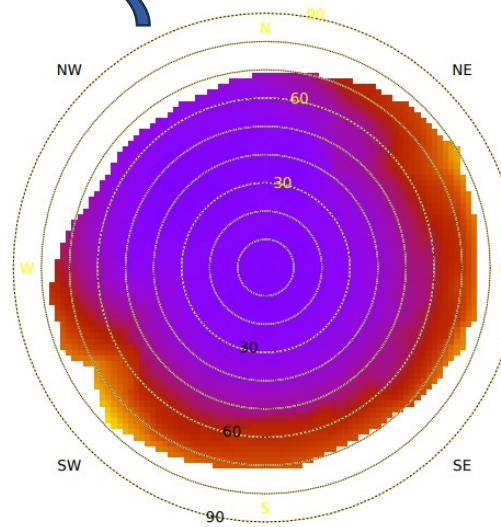
Measured RL



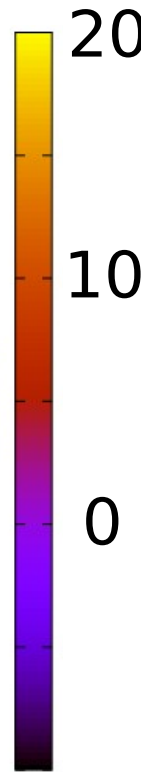
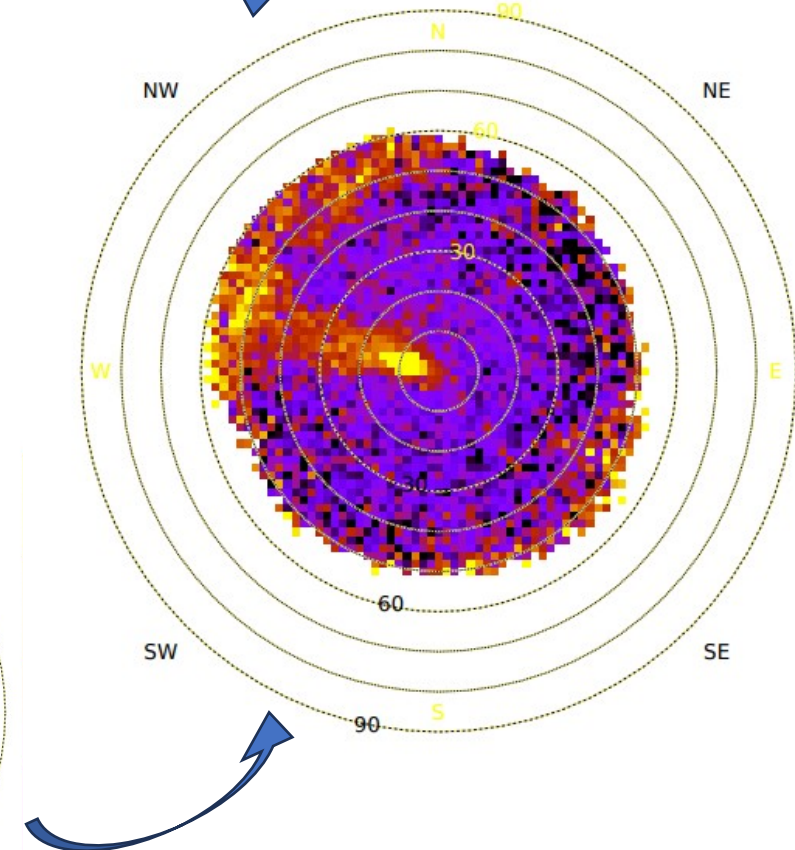
Modeled DL



Modeled RL



Missing Rock [m]

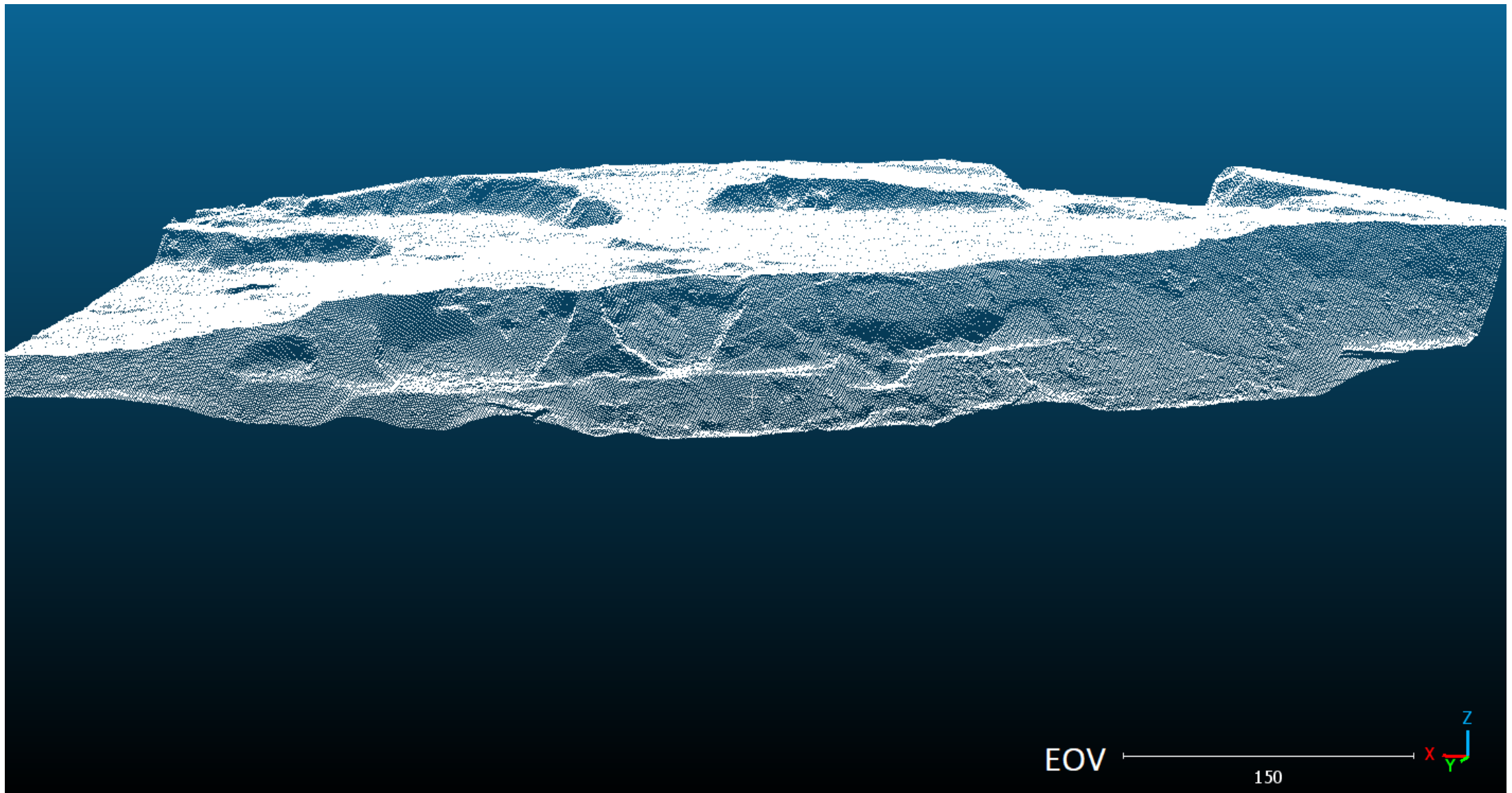


$$\rho = 2.65 \frac{g}{cm^3}$$

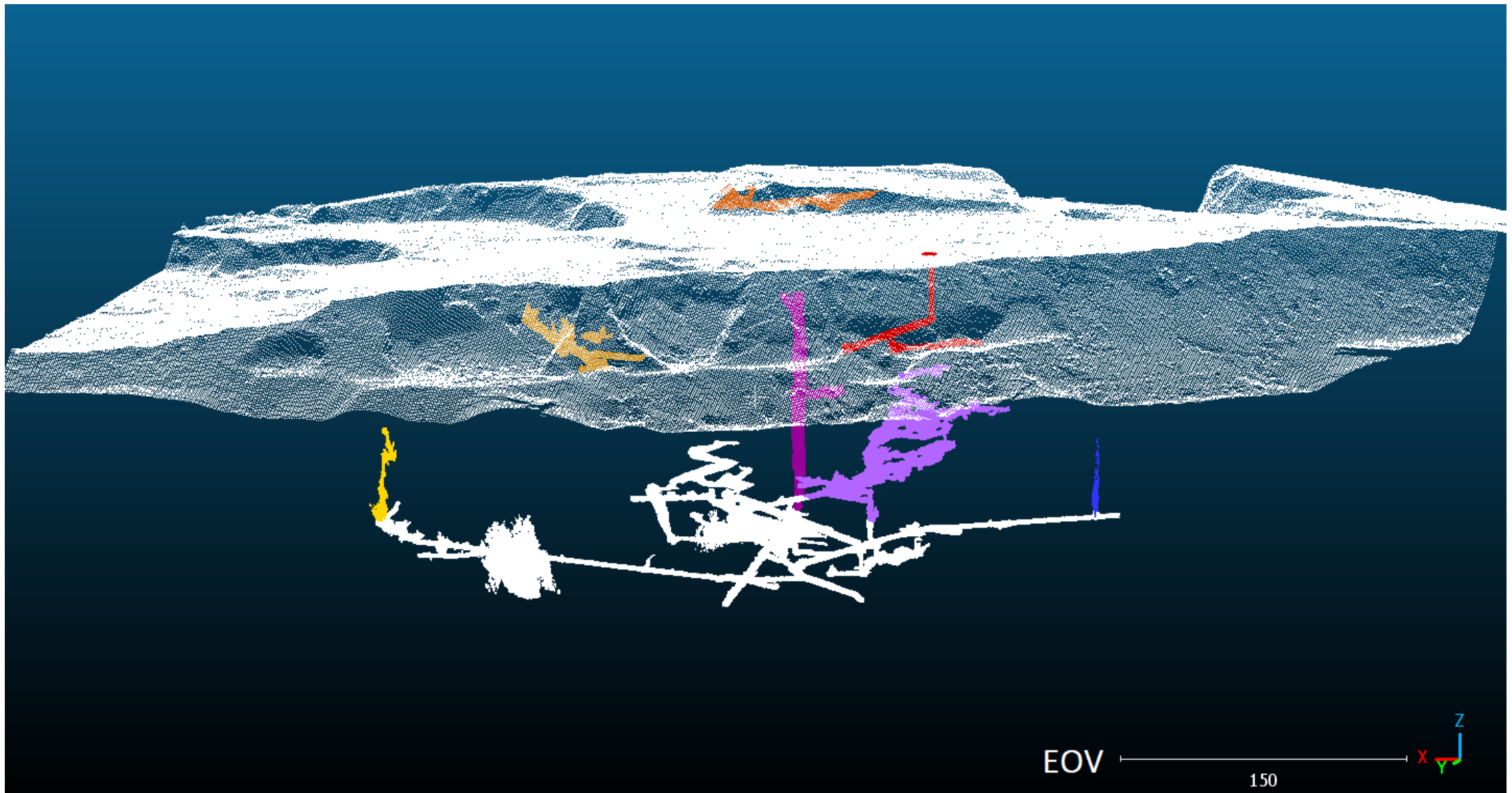
*average density
was used for all
calculations in
the campaign*

Overview of the Esztramos Mountain

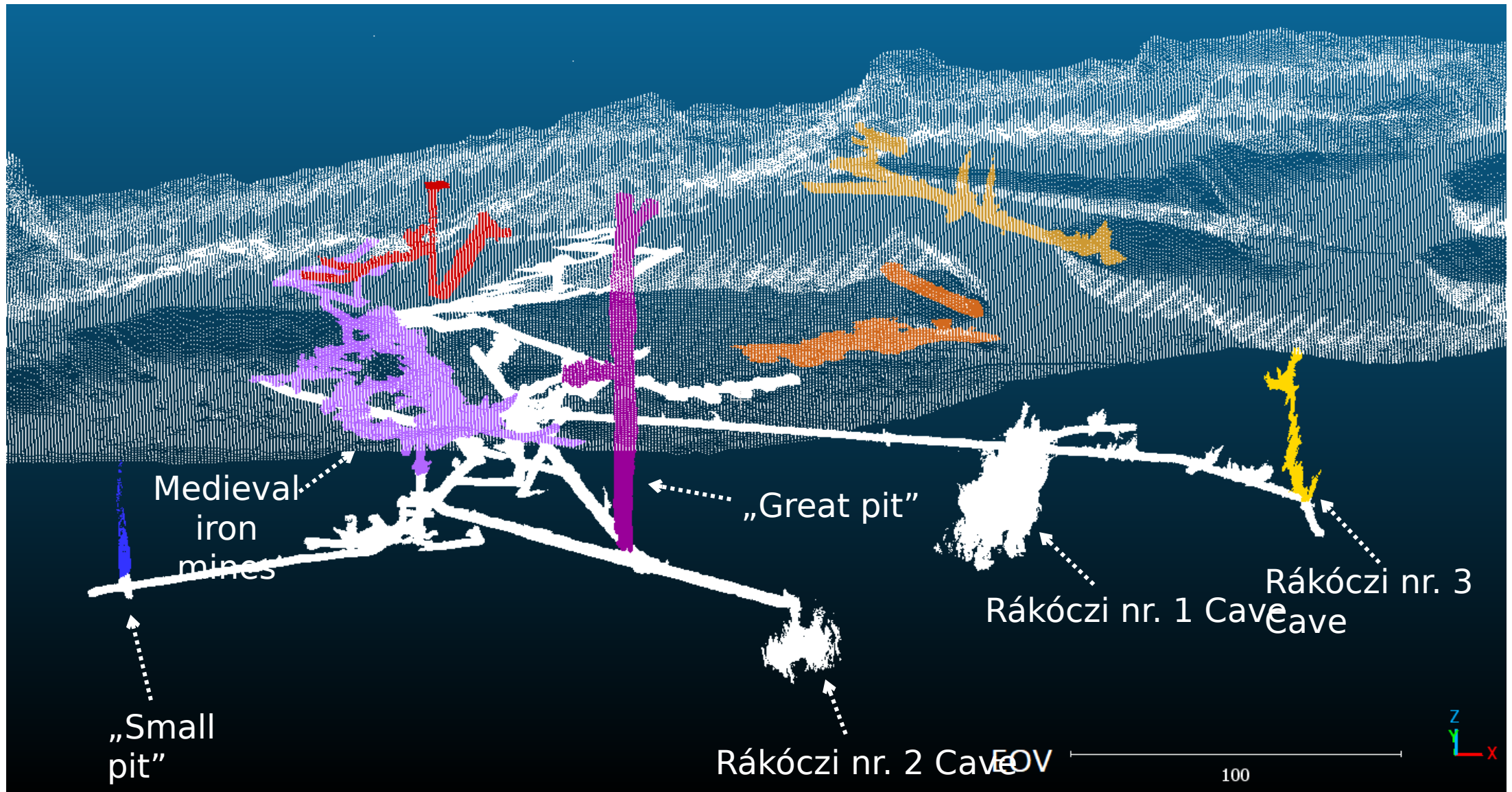




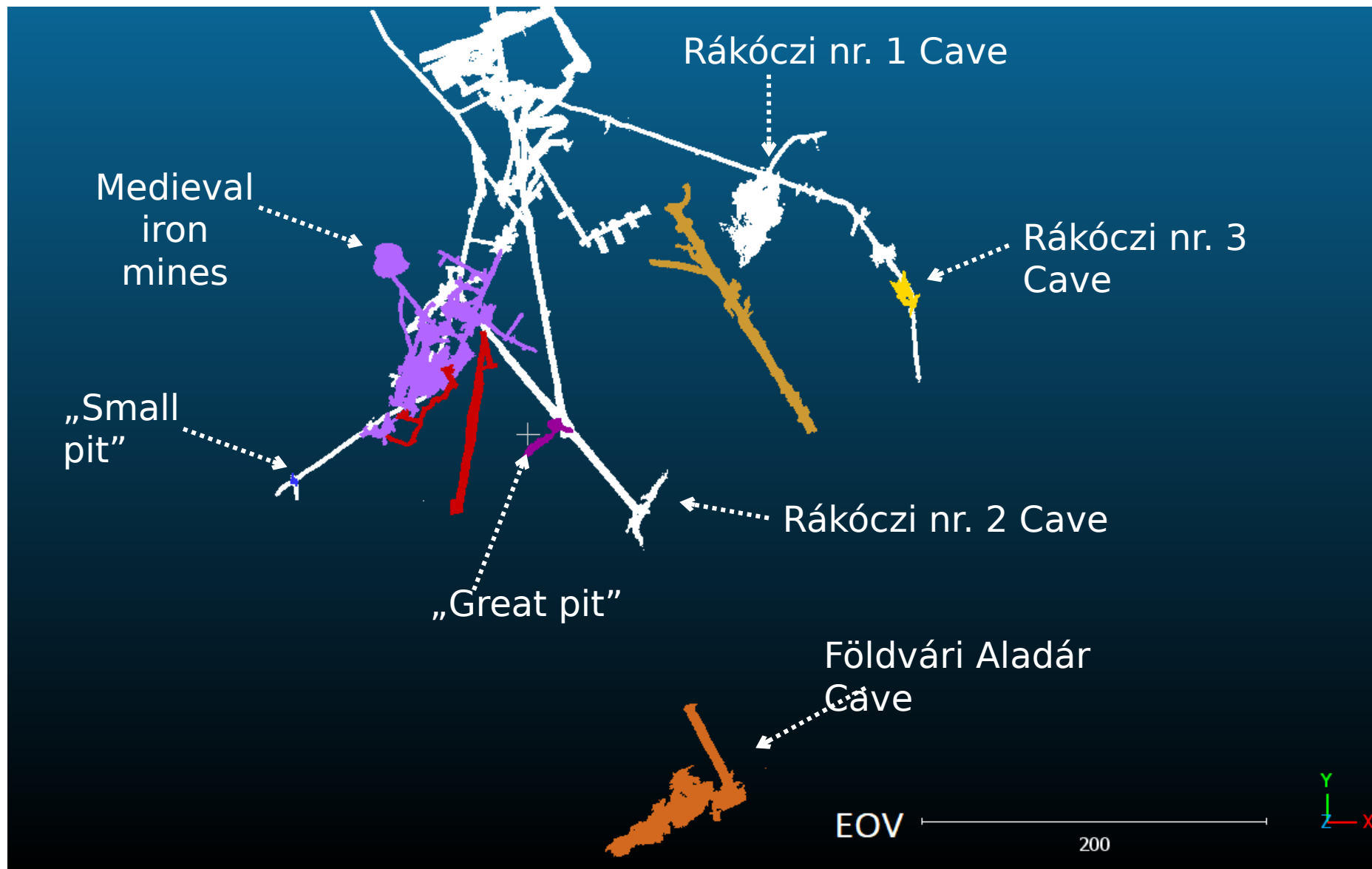
Northern view of the surface model



Northern view of the surface model and known cavities

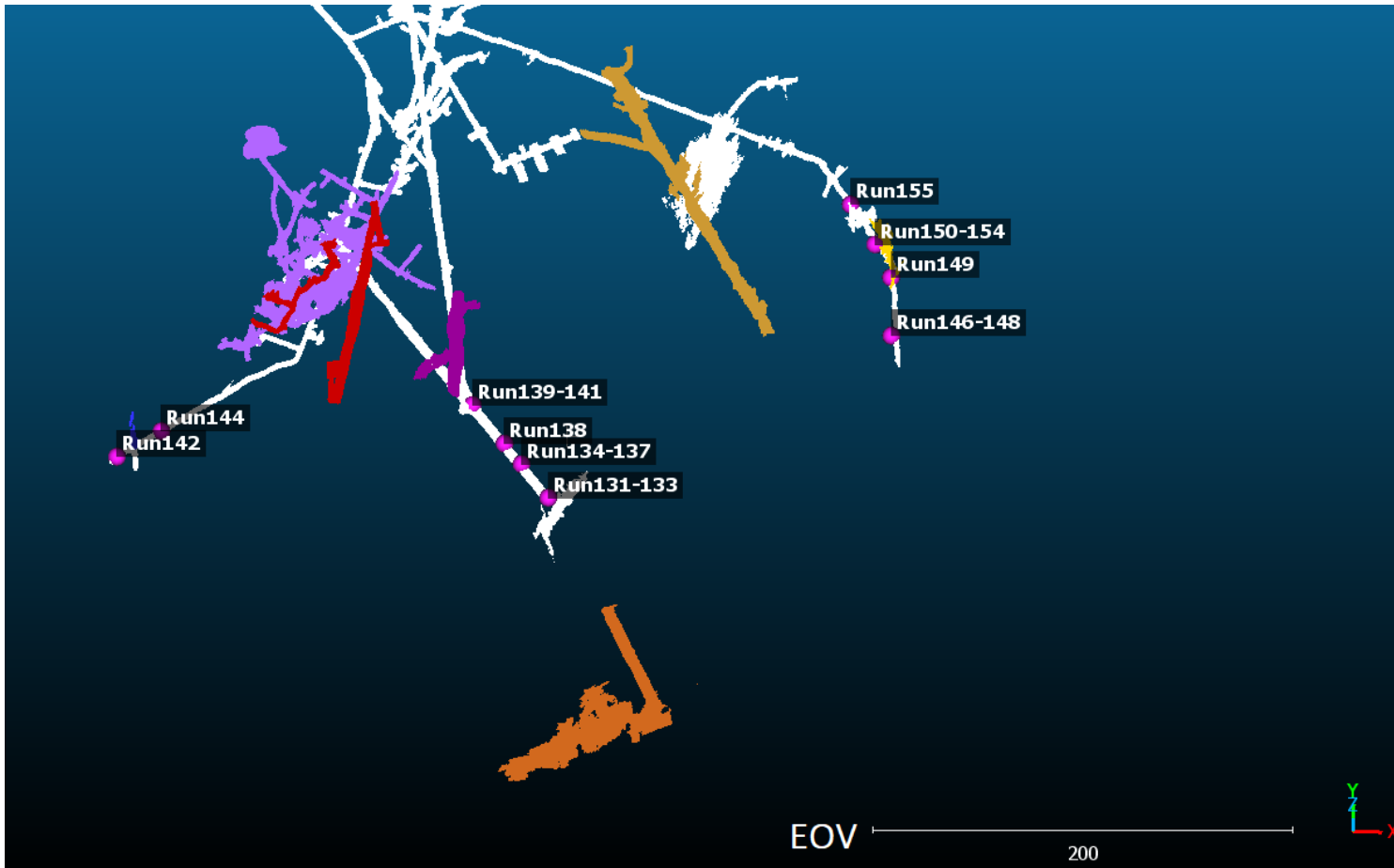


Southern view of the surface model and known cavities



Top view of the known cavities

Showcasing the conducted measurements

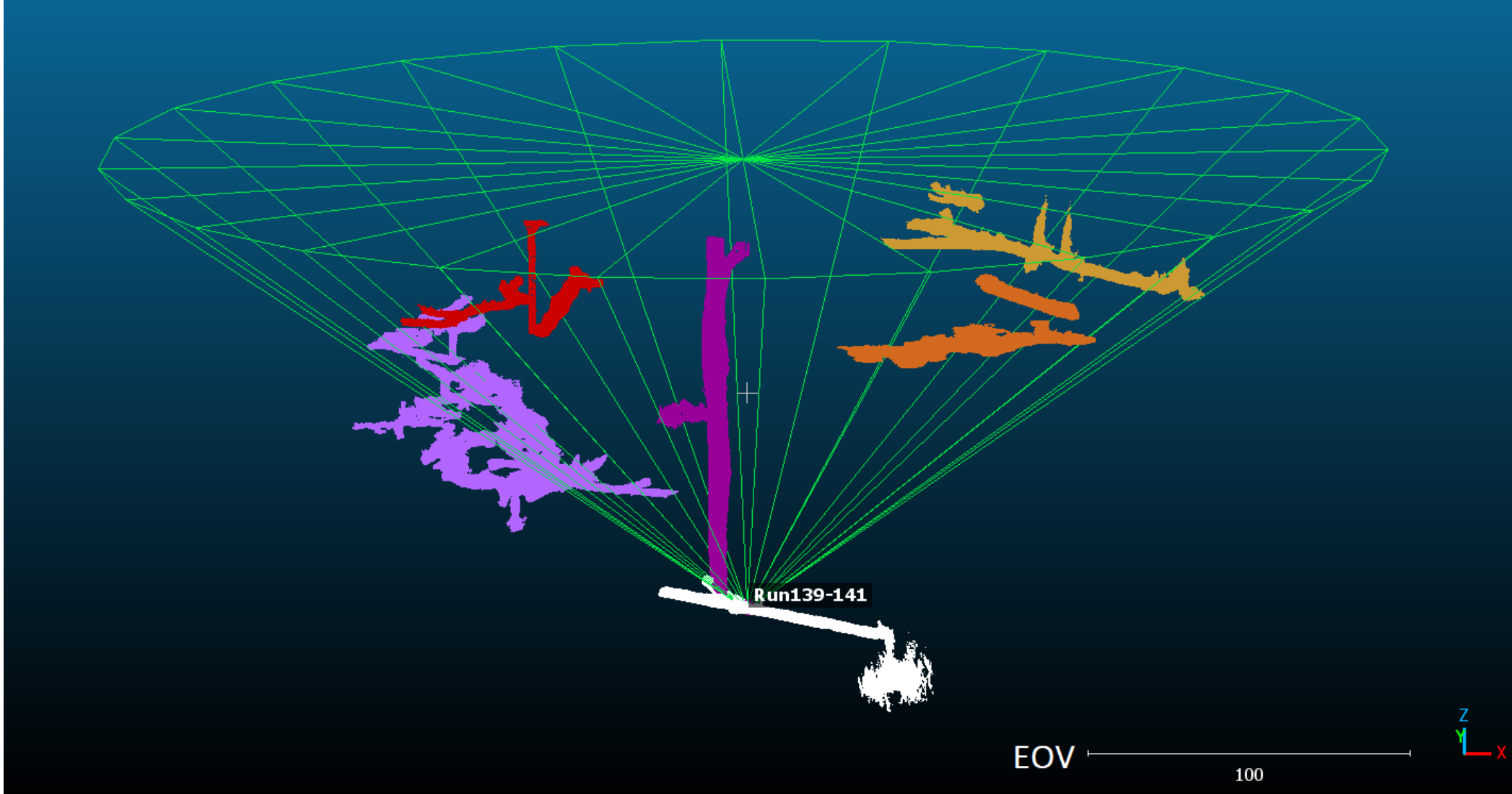


What are the goals and questions of the campaign?

- Measurements on the west: *Does the small shaft connect with the mines?*
- Measurements on the middle: *Exploration and validation*
- Measurements on the east: *Are the Rákóczi Caves a part of a larger system?*

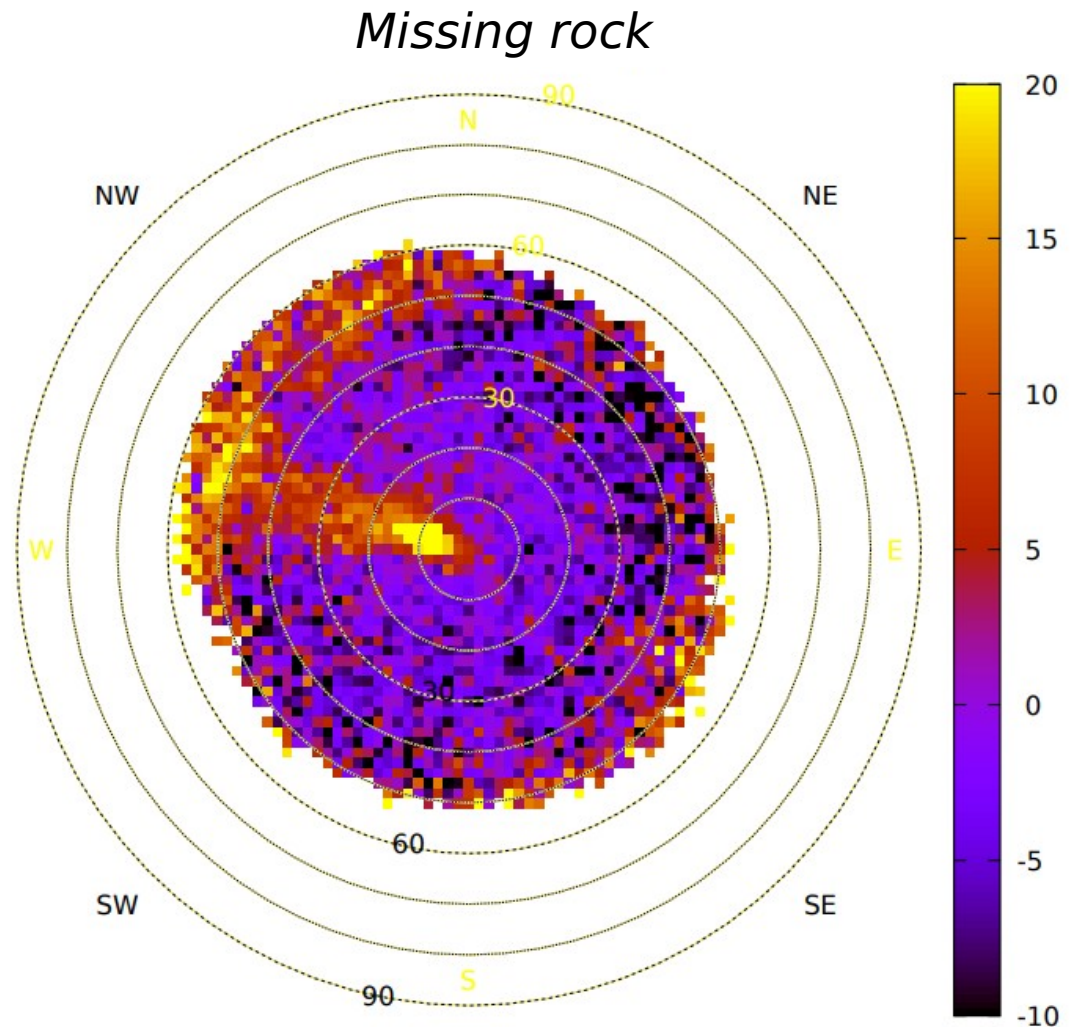
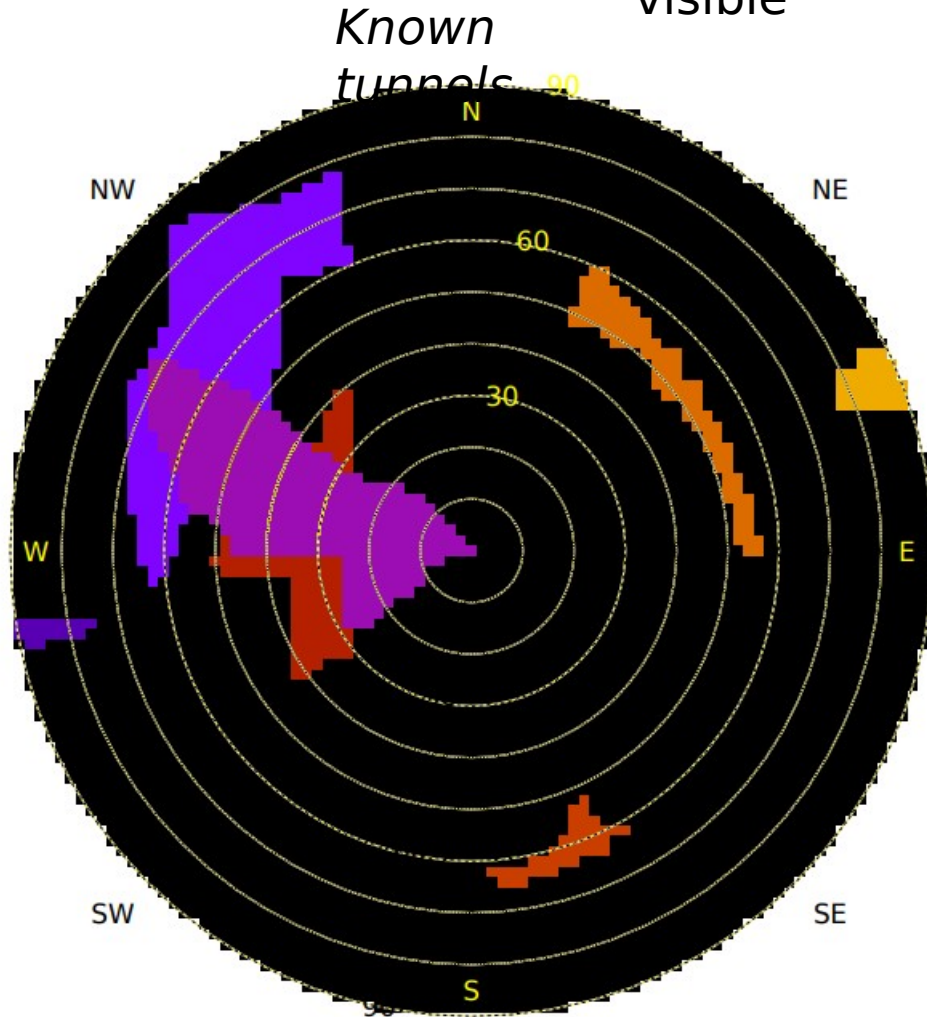
Results

- You will be presented with the measurements that gave the **most spectacular results**
- **First** you will see the what **areas** of the mountain were **explored** by the measurements
- **Second** you will see on the where the **known tunnels** and caves would appear on the muogram and on the the **muograms** themselves

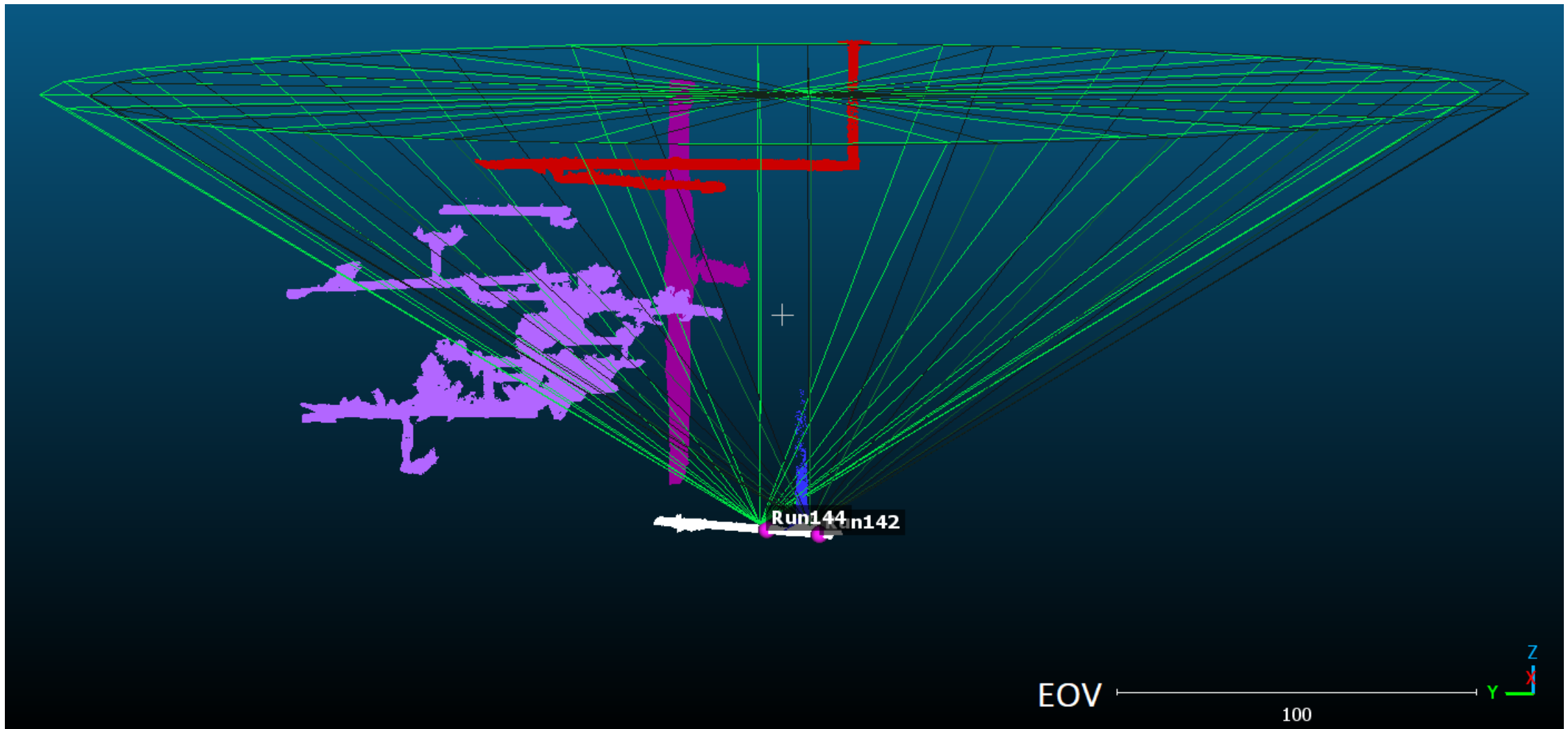


Southern view of the explored areas by Run-139

The pit and the mines are clearly visible



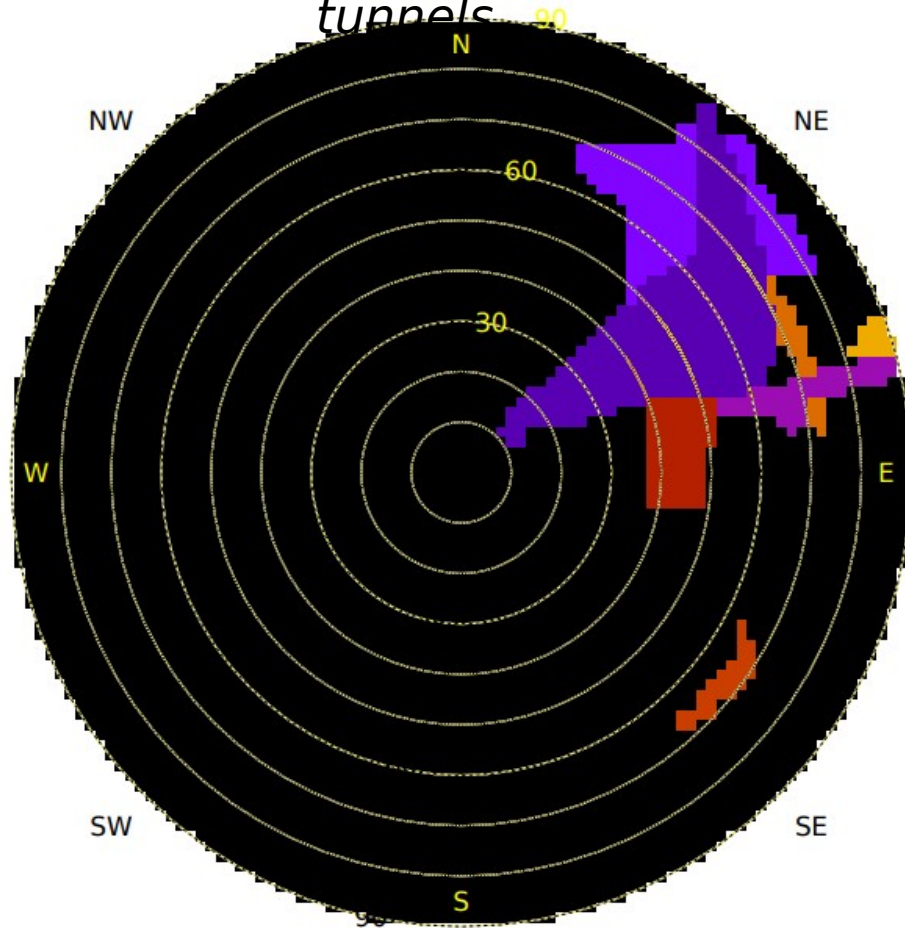
MtI1
Run139



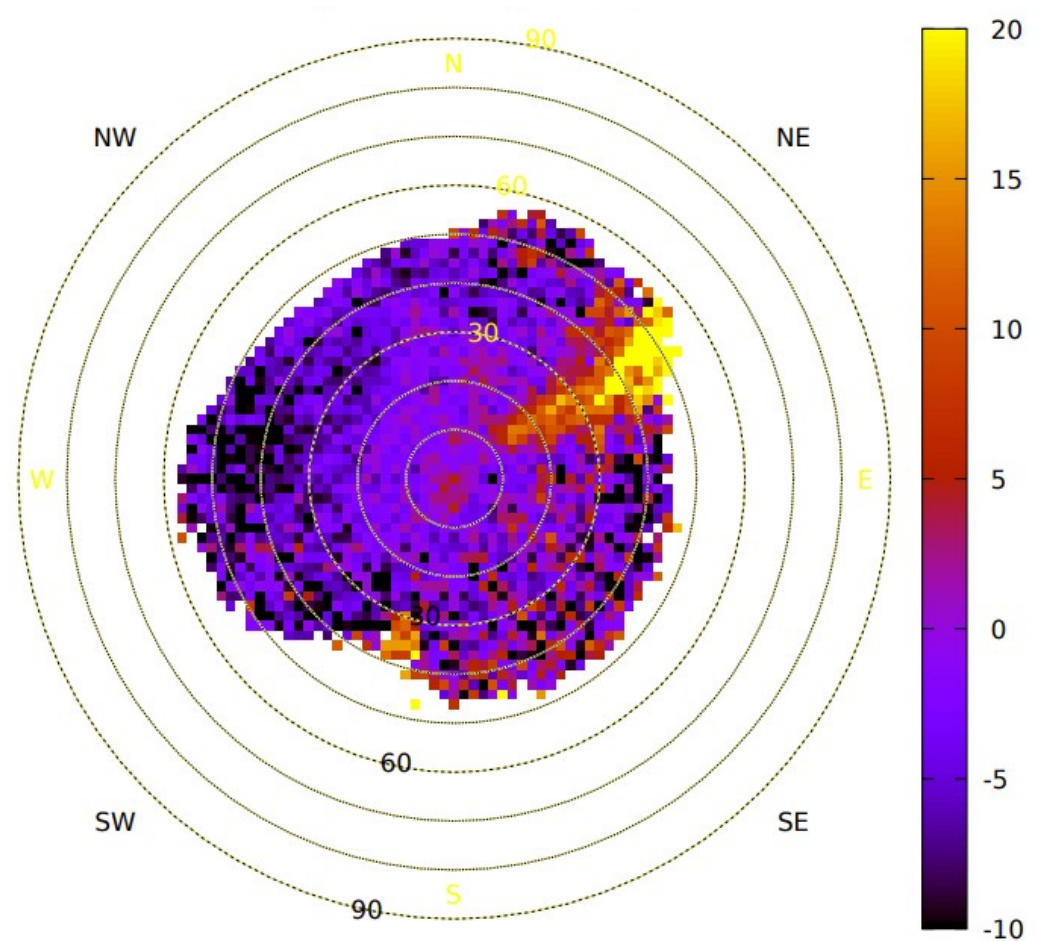
Western view of the explored areas by Run142 and Run144

The known cavities can be seen clearly, with no indication of further ones in the southwestern direction

*Known
tunnels*

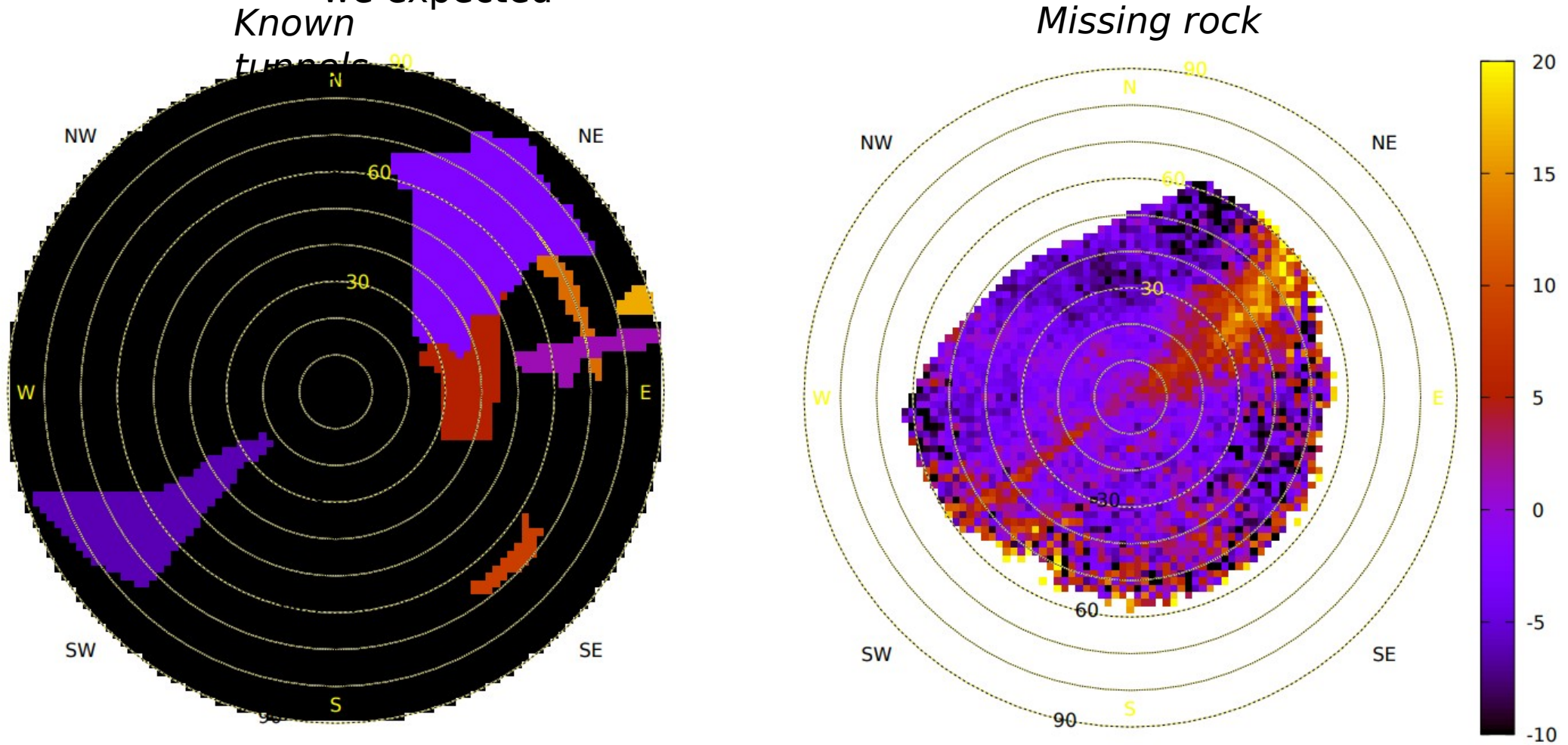


Missing rock

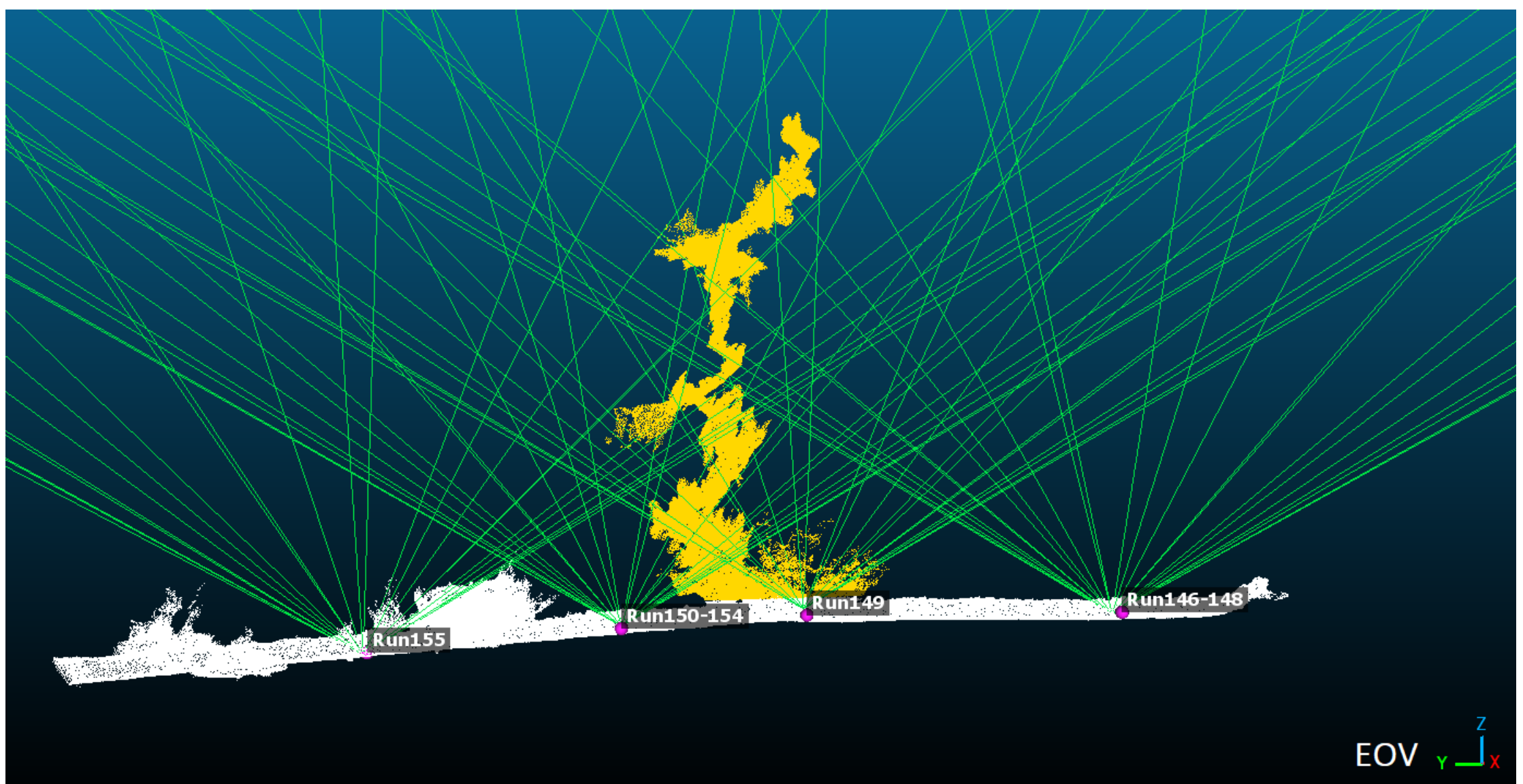


MtI1
Run142

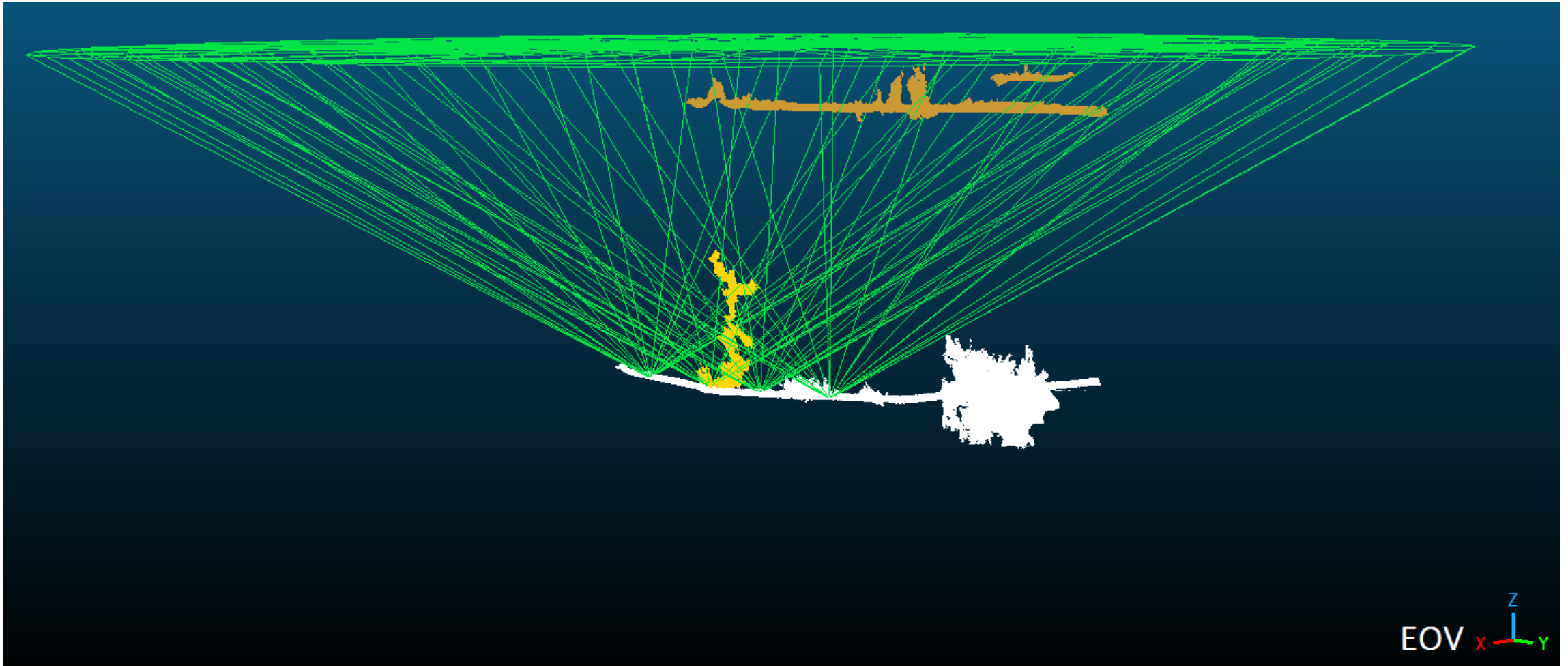
The small pit and the mines are connected, as we expected



MtI1
Run144

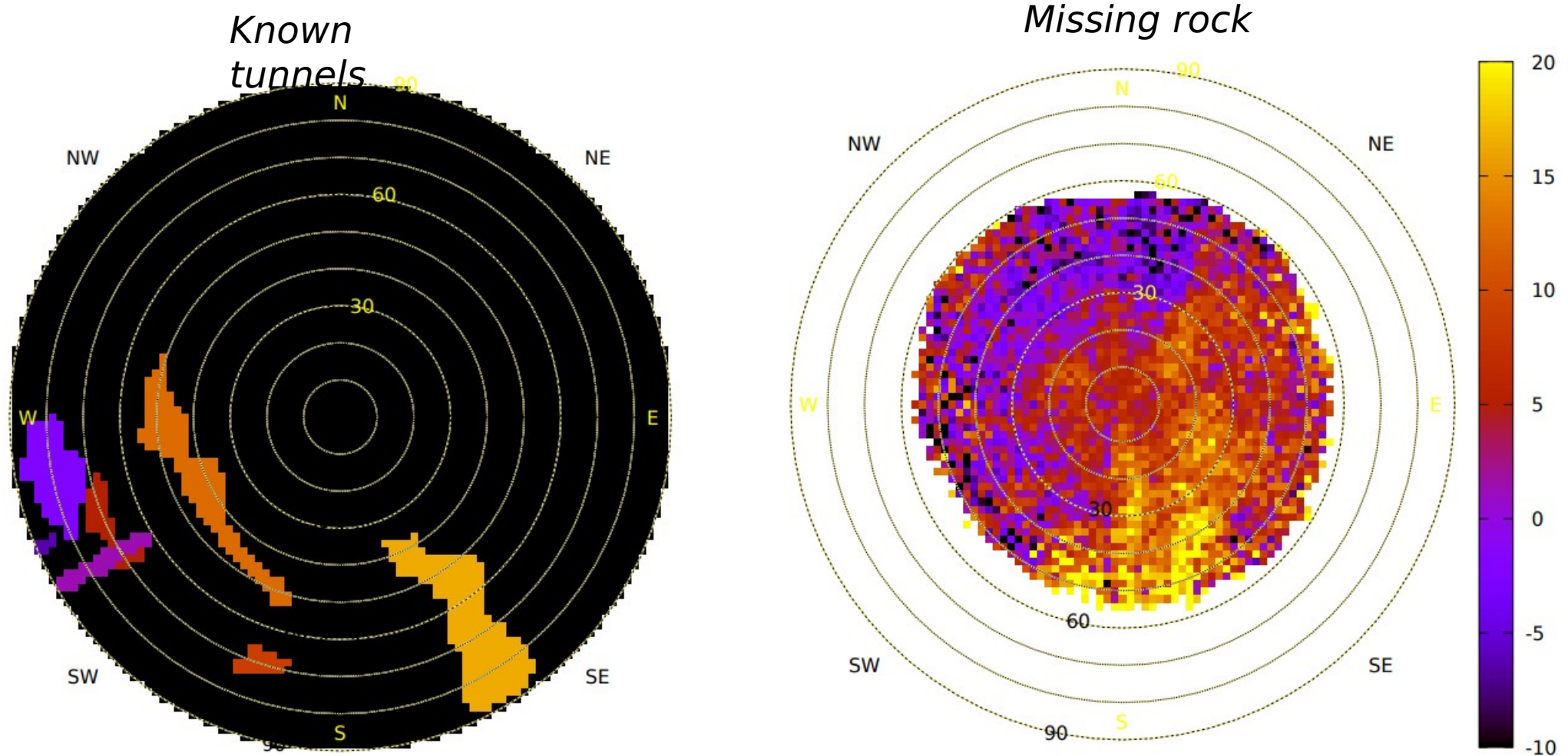


Western view of the explored areas by the eastern runs



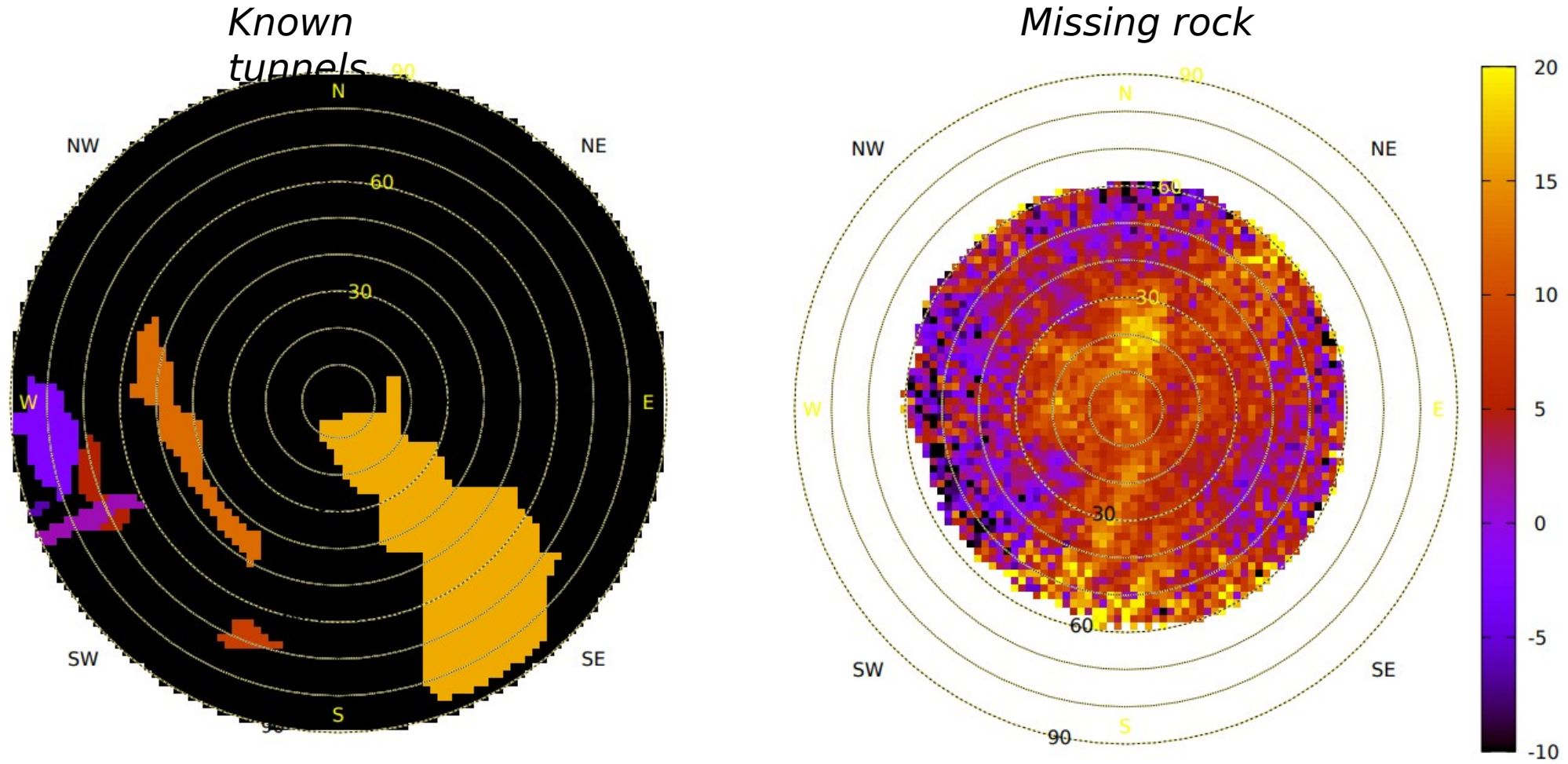
Northeastern view of the explored areas by the eastern runs

Huge density anomalies appear in eastern, northeastern and southern directions



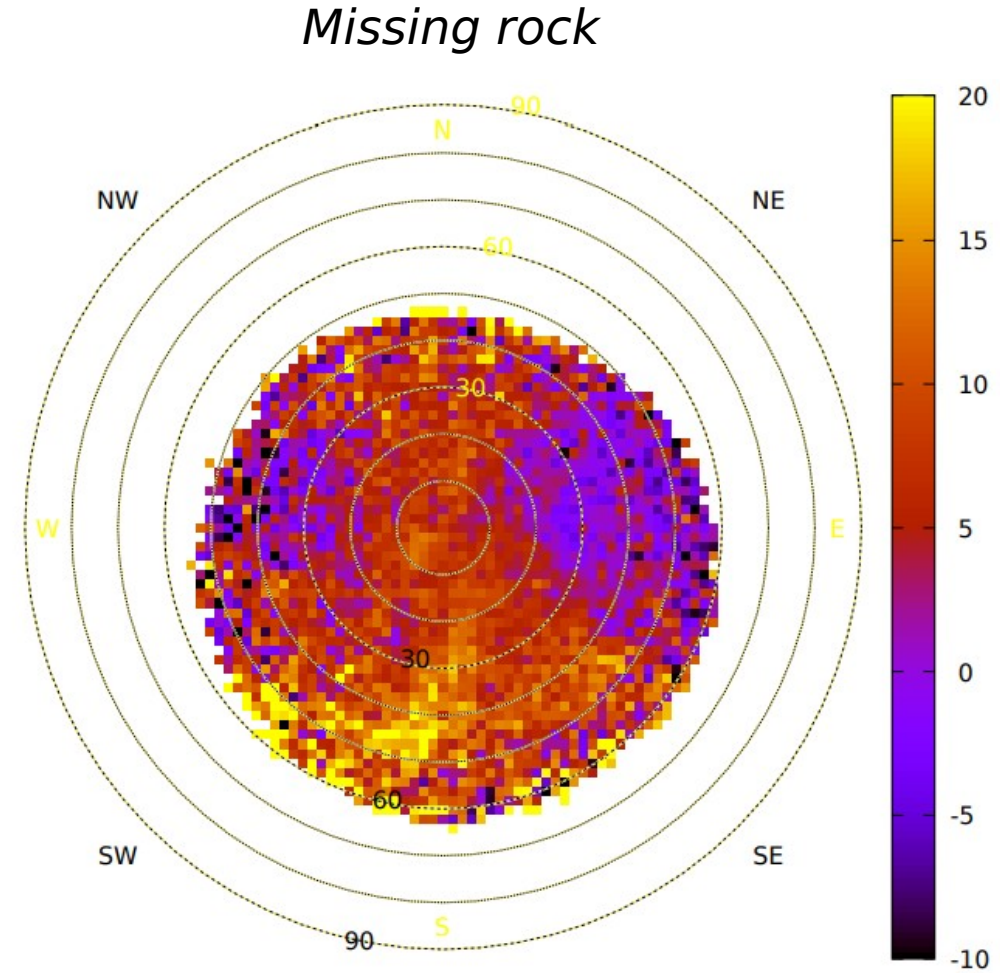
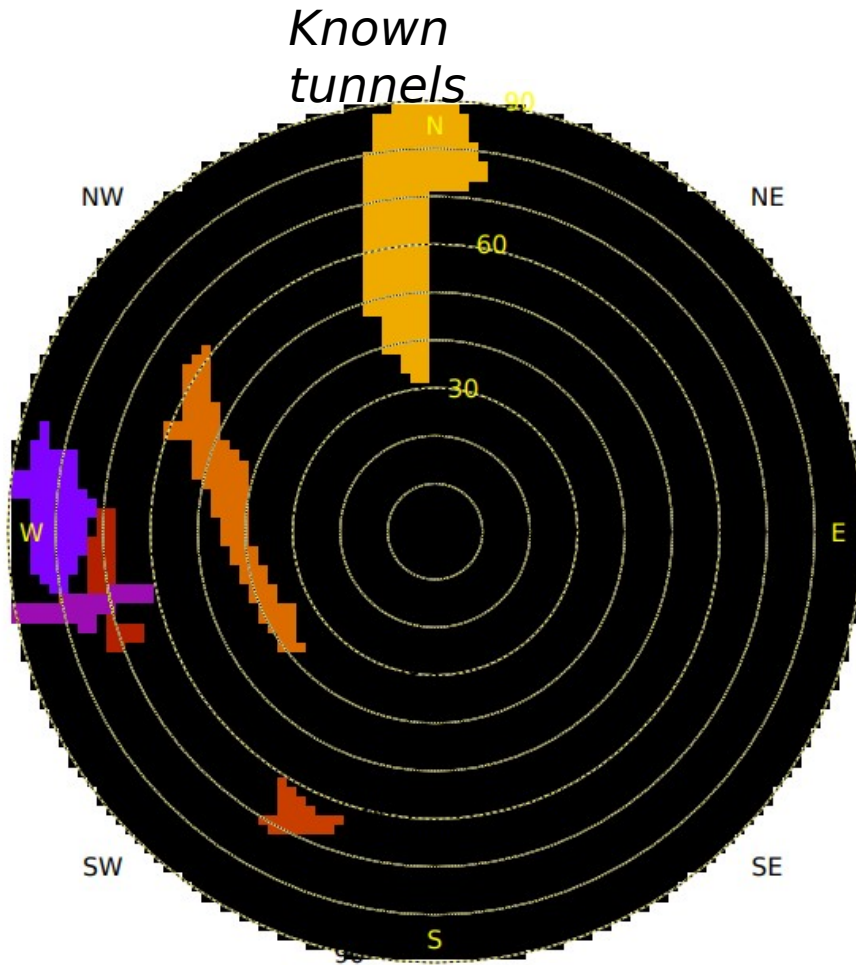
Mtl1 Run155

The caves seem to spread out to many previously unknown branches



Mtl1 Run150-154

Anomalies continue in the southern direction



MtI1
Run148

Conclusion

Questions

Answers

Western
measurements

*Does the small shaft
connect with the mines?*

*Yes, they are connected and
the mines do not span beyond
the connection*

Measurements on the
middle

Exploration and validation

*Our measurements are valid,
we detected the known
anomalies and no missing rock
was indicated in the areas with
no cavities*

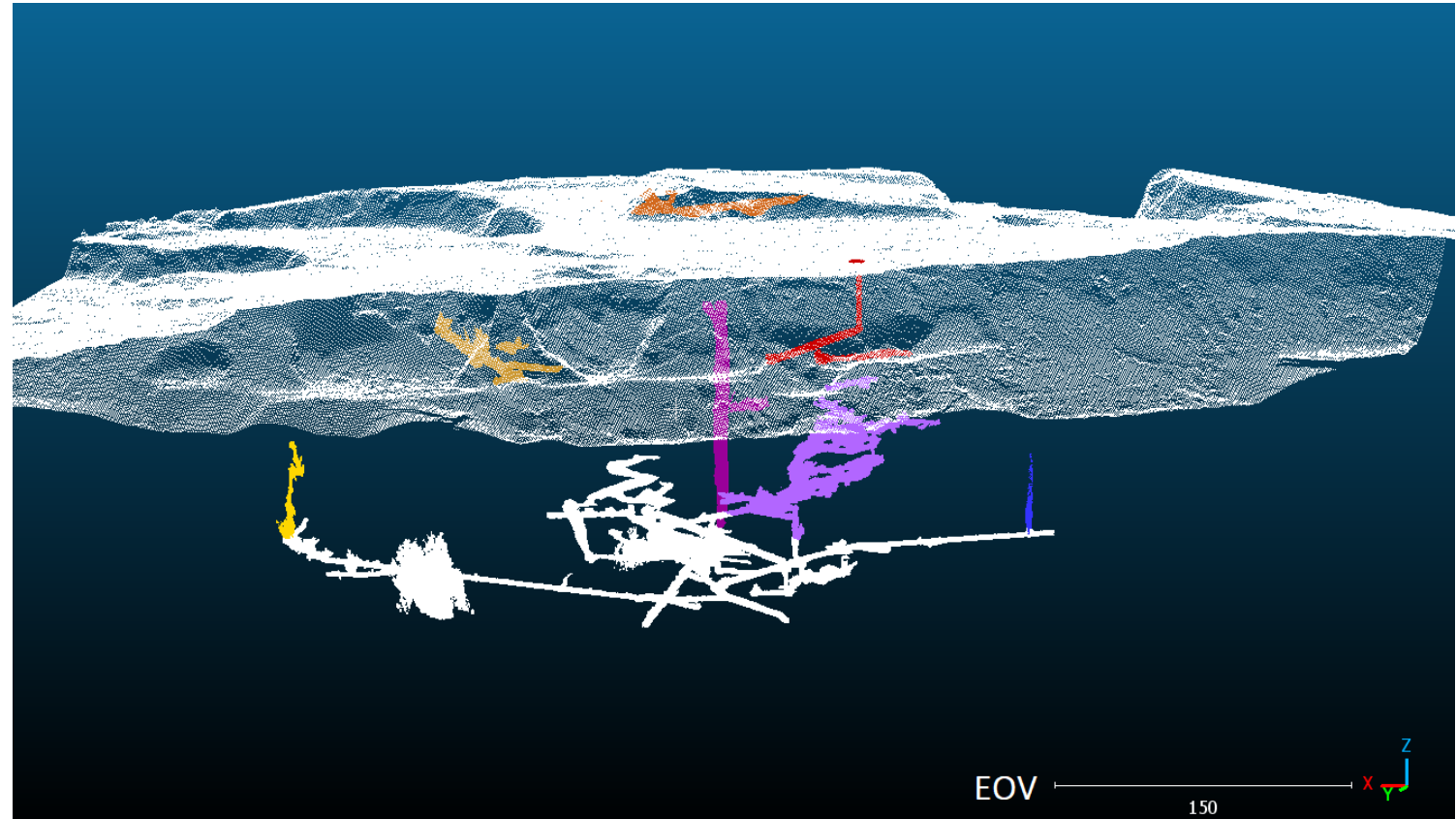
Eastern
measurements

*Are the Rákóczi Caves a
part of a larger system?*

*Yes, the Rákóczi nr. 3 cave
appears to be part of a larger
system, that is north-south
oriented*

Further plans

- Muographic **inversion** of the Rákóczi nr. 3 cave and it's surroundings
- **Expand measurements** with inclined detectors to see further inside the mountain
- Use drilling or other geophysical methods to further **confirm** our **results**





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Thank you for your attention!

Contact: Bence Rábóczki

Research Assistant at HUN-REN Wigner RCP, High-Energy Geophysics Research Group

raboczki.bence@hun-ren.wigner.hu

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- *Vesztergombi Nagyenergiás Fizikai Laboratórium (VLAB)*

References

- 1) L. Oláh, H.K.M. Tanaka, D. Varga - Muography: Exploring Earth's Subsurface with Elementary Particles, American Geophysical Union 2022, p. 5
- 2) <https://cds.cern.ch/images/CMS-PHO-GEN-2017-008-1>
- 3) Nyitrai, Gábor & Hamar, Gergő & Varga, Dezső. (2021) - Towards low gas consumption of muographic tracking detectors in field applications
- 4) Guan, Mengyun & Chu, Ming-Chung & Cao, Jun & Luk, Kam-Biu & Yang, Changgen. (2015). A parametrization of the cosmic-ray muon flux at sea-level.

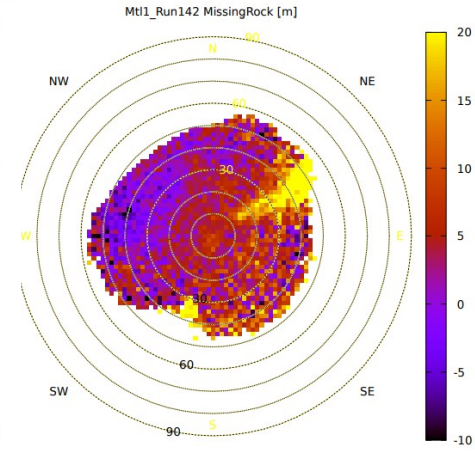
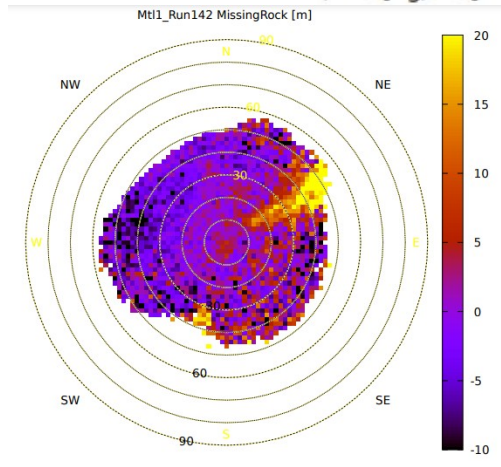
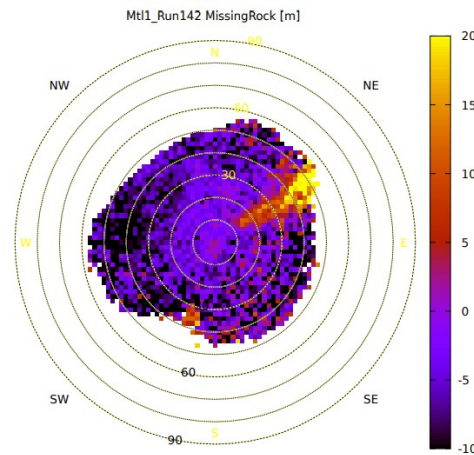
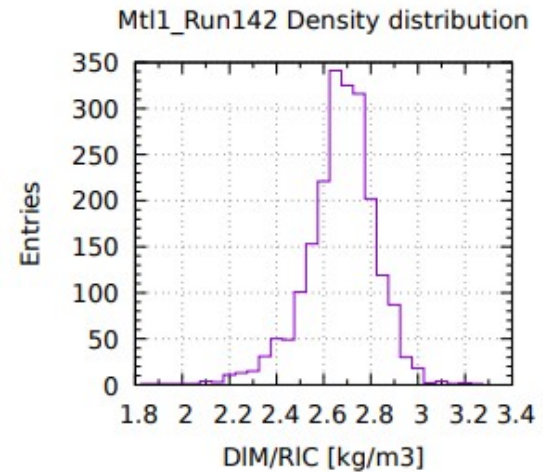
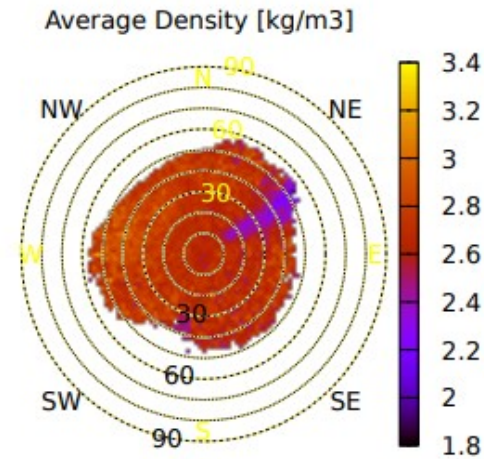
Extra slides and figures

In case of further questions

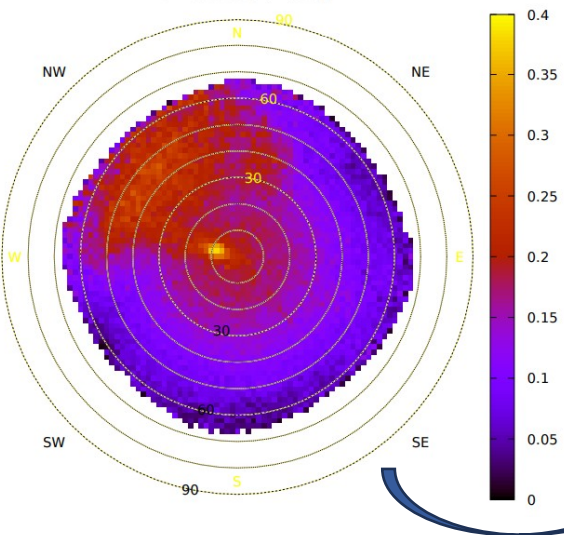
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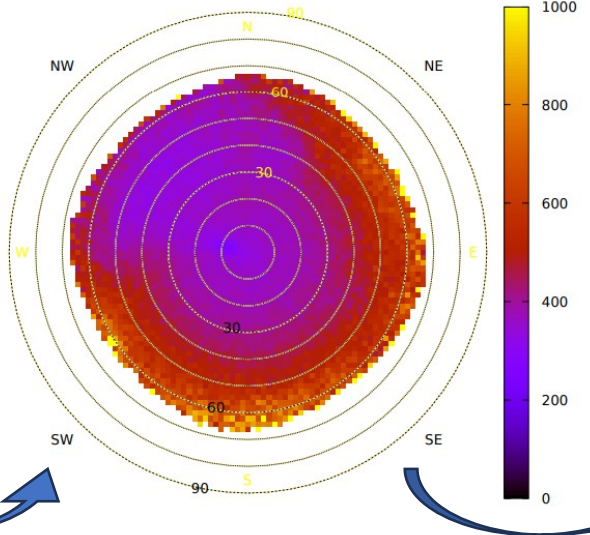
2.6 → 2.7 → 2.8



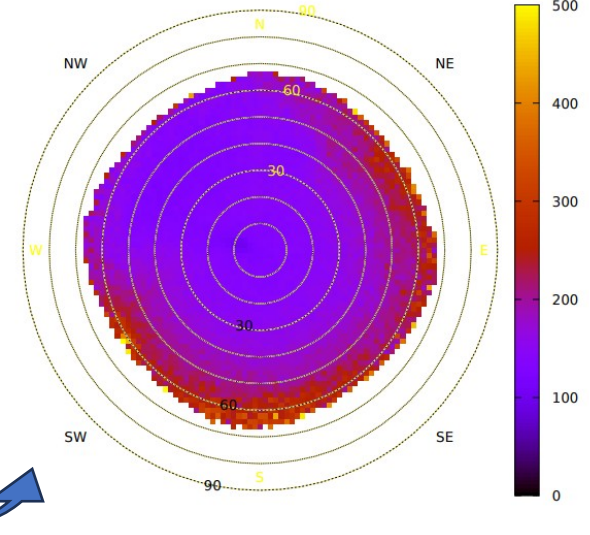
Measured Flux



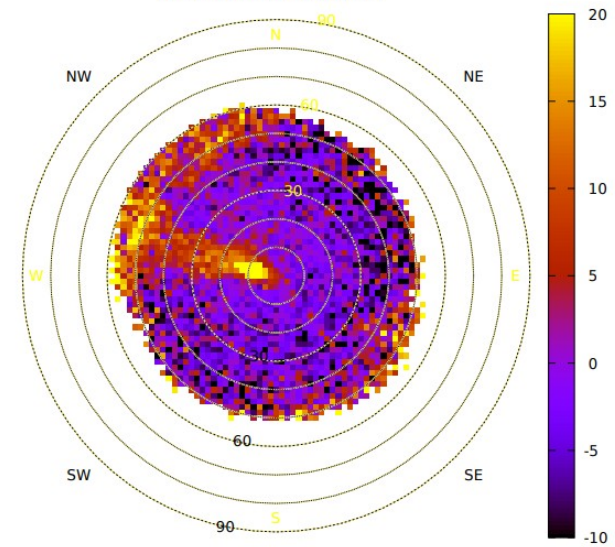
Measured DL



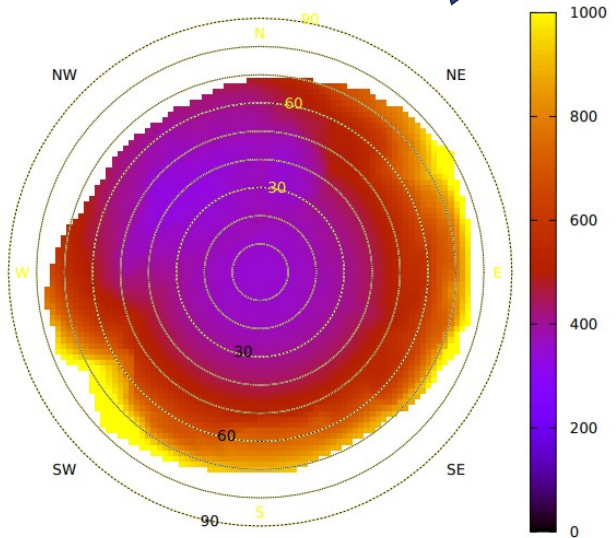
Measured RL



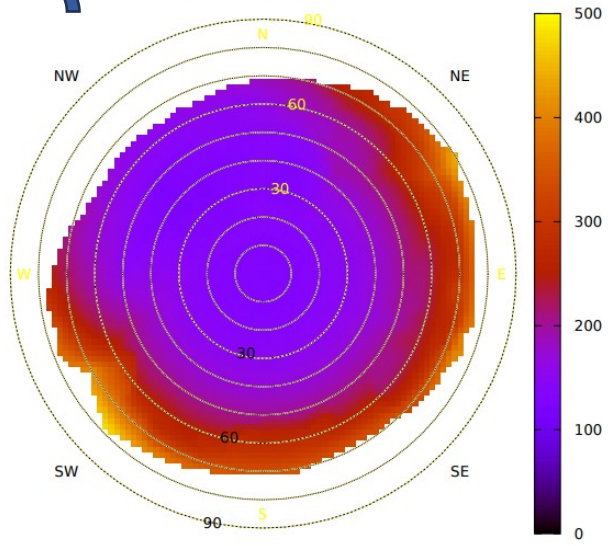
Missing Rock



Modeled DL



Modeled RL



Scalebars are visible here