Muography of Debris Dams

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Outline

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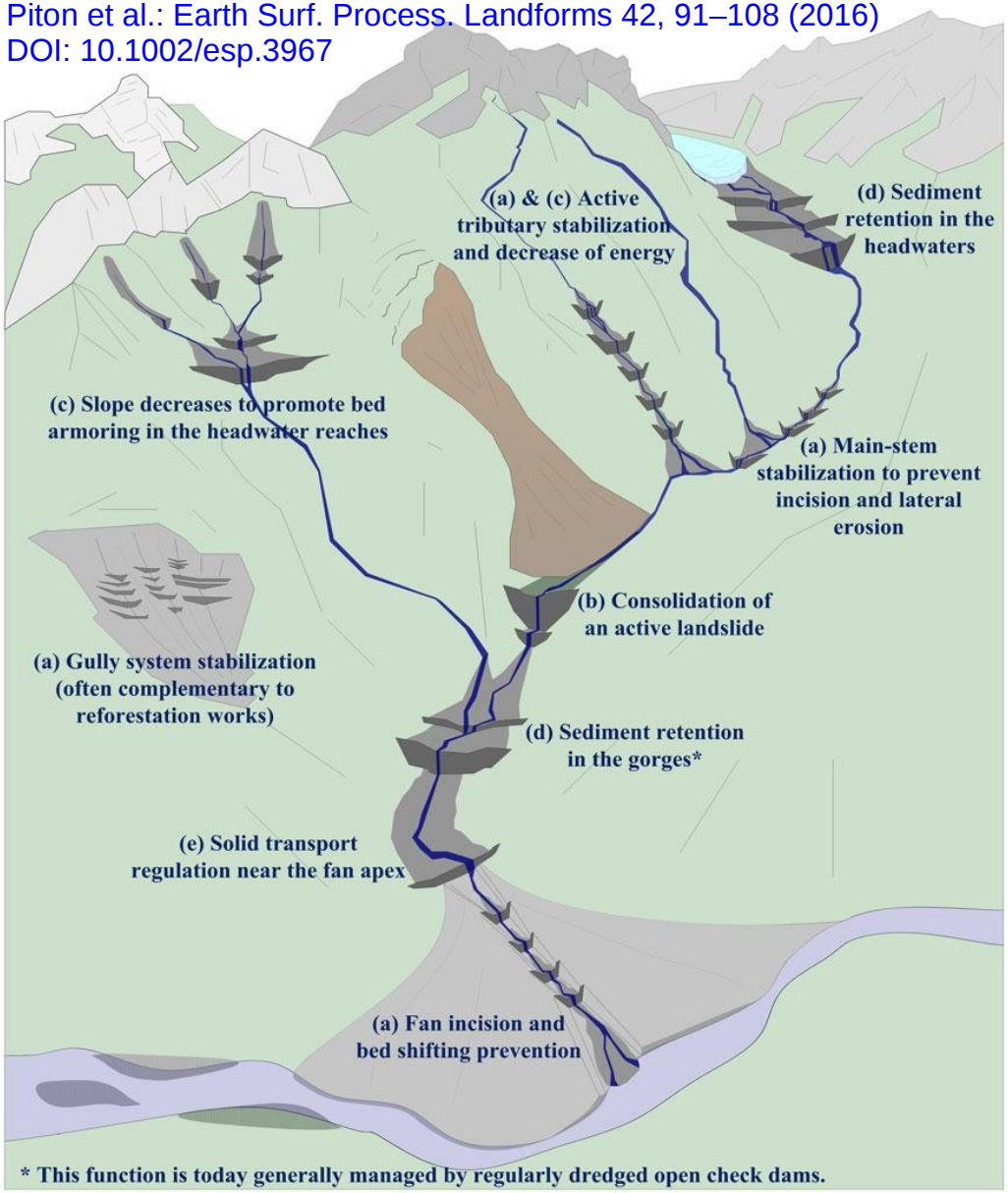
I. Introduction: Sediment Disasters and Role of Dams

- **Debris flows** are fastly moving, dens mixture of material phenomena that endanger mountanious area and can reach even a few tens of kilometres (e.g., rain triggered debris flows damaged Vargas, Venezuela in 1999).
- **Passive measures** reduce the impact of flows (evacuation system, hazard mapping, monitoring system)
- **Active measures** control the spatio-temporal evolution of flows (dam, channel)
- **Role of dams: stabilization, sediment retention, transport regulation**

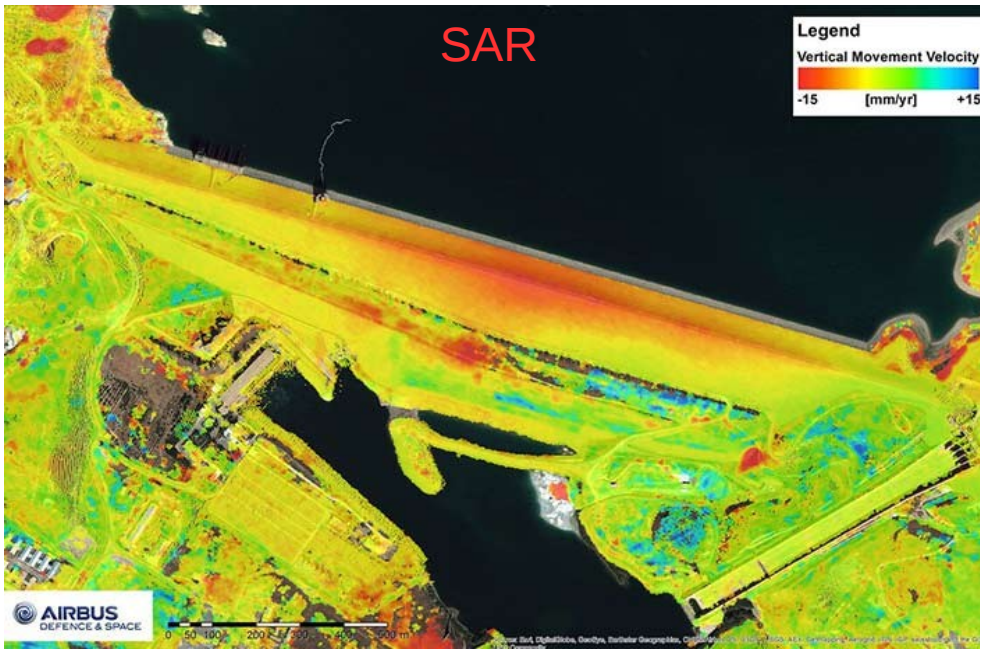
USGS, https://pubs.usgs.gov/of/2001/ofr-01-0144/

Piton et al.: Earth Surf. Process. Landforms 42, 91–108 (2016)
DOI: 10.1002/esp.3967

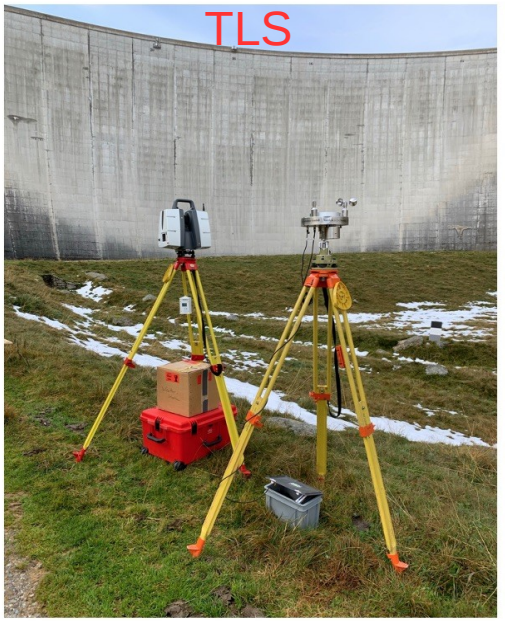


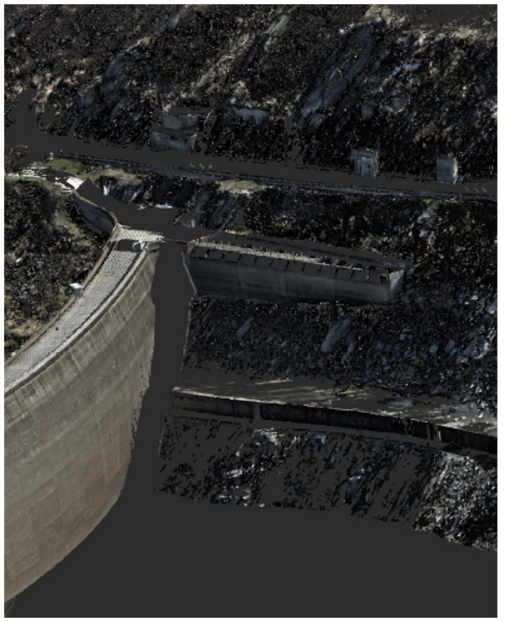
Sctructural Health Monitoring (SHM) of Dams

- SHM is applied for identifying anomalous behaviours and allowing **construction control, design verification, performance evaluation and safety.**
- **Extensometers** are applied to measure the relative displacements between the base rocks and dam foundations.
- **Fiber optics** are applied for measuring the surface deformations on dams
- **Terrestrial Laser scanners (TLS)**, **global positioning systems (GPS) and synthetic aperture radars (SAR)** are utilized precise (at the order of a few millimetres) measurement of surface displacements.
- **Thermometers** are applied for continuous monitoring of air temperature that is an input for time-series analysis of stress and deformation data.
- **High-resolution seismography and electrical resistivity tomography (ERT)** are applied for assessing the internal structure of dams by means of detecting anomalies caused by structural failures (such as fractures or long-term degradation).
- **What can muography add to these techniques?**
  Remote, passive, density sensitive and high resolutional imaging.



https://www.intelligence-airbusds.com/newsroom/case-studies/ogme/dam-monitoring-with-terrasar-x/#gallery-4

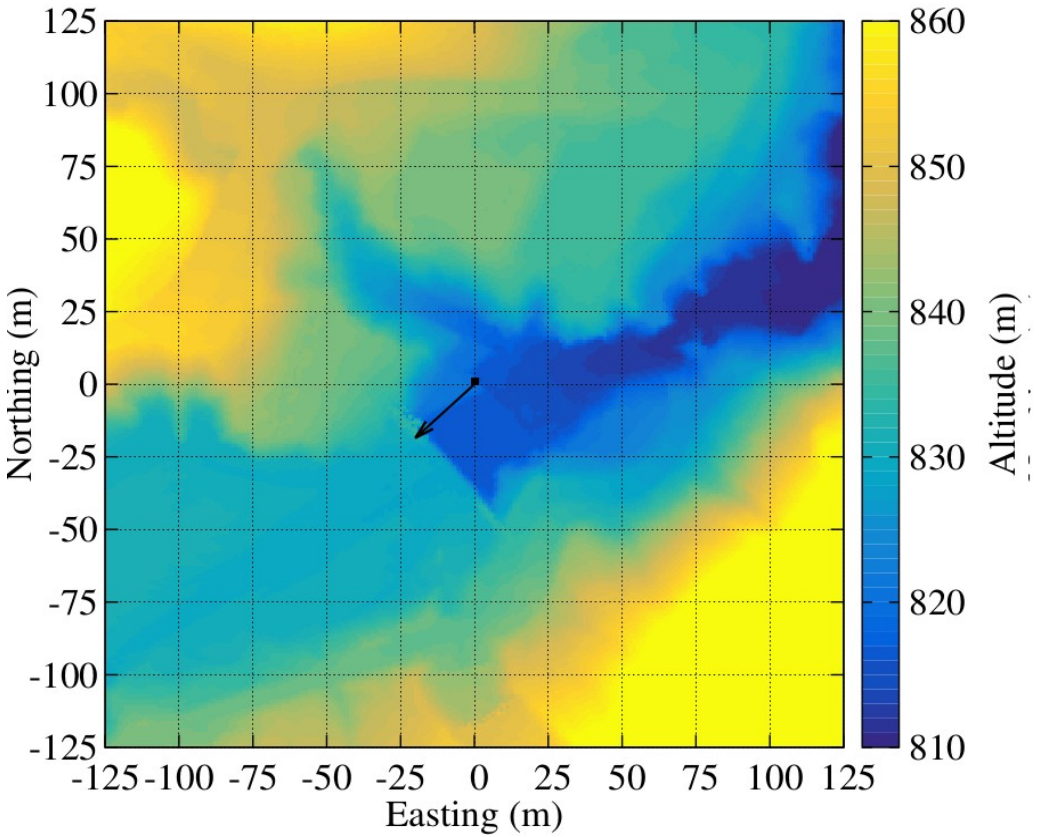




https://gseg.igp.ethz.ch/research0/applications/spatially-continuous-dam-monitoring0.html

II. Experimental Methods and Instrumentation

- **Motivation of Sabo FF: inspecting dam structures for deciding about renovation or reconstruction**
- A Sabo Check dam was selected in the Karasu river, Gunma Prefecture, Japan
- This dam is applied for sediment redemption since 1951. It has a width of 67 m and height of 18 m.
- Topography data was recorded with spatial resolution of 1 m by 1 m (Tone River Basin Sabo Office).



Measurement setting

- Multi-wire Proportional Chamber(MWPC)-based tracking system was applied with six tracking layers with the size of 40 cm by 40 cm each (see more about detector technology in the talk by D. Varga)
- Detector location: latitude of 36.437 N◦ , longitude of 138.684 E◦ and altitude above sea level of 819.6 m at a distance of 26.1 m from the dam
- Data collection: 24th December 2020 – 2nd February 2021, mainenance after 3 weeks for replacement of batteries and gas bottle

D. Varga, L. Oláh, G. Hamar, H. K. M. Tanaka, T. Kusagaya: Muographic Observation Instrument, WO2017187308A1
https://patents.google.com/patent/WO2017187308A1/en
http://www.eu-jp-tthelpdesk.eu/technologies/muographic-observation-instrument/

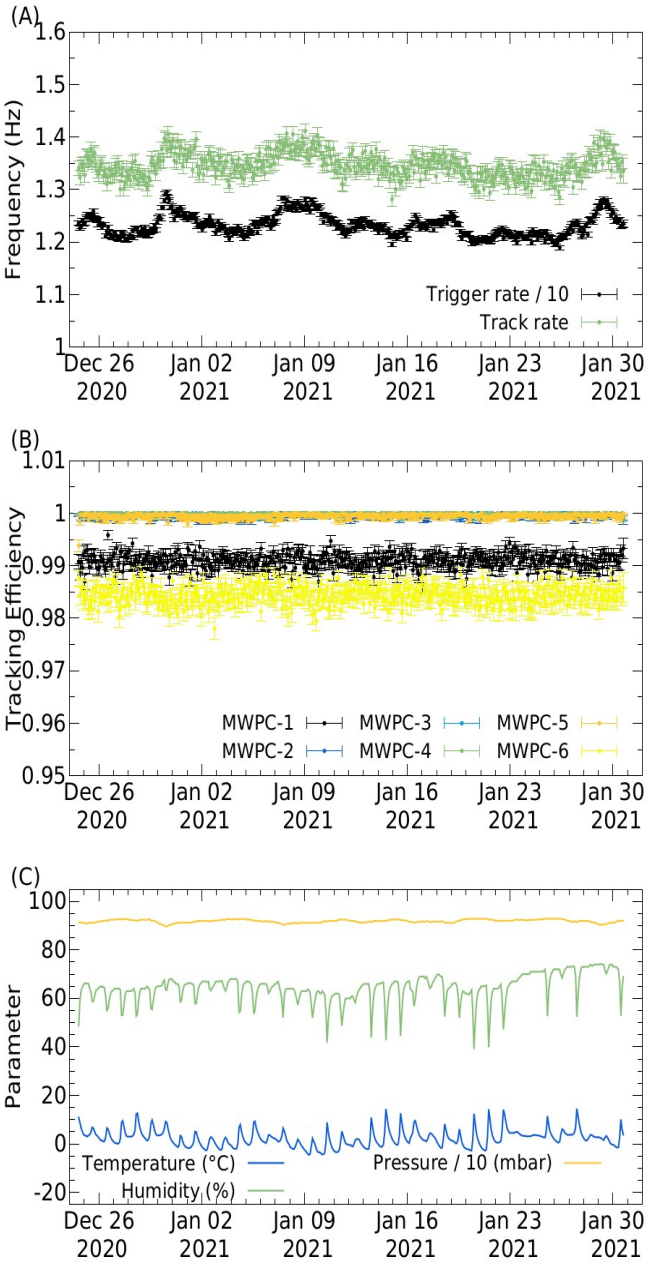
III. Data Analysis and Simulation Methods

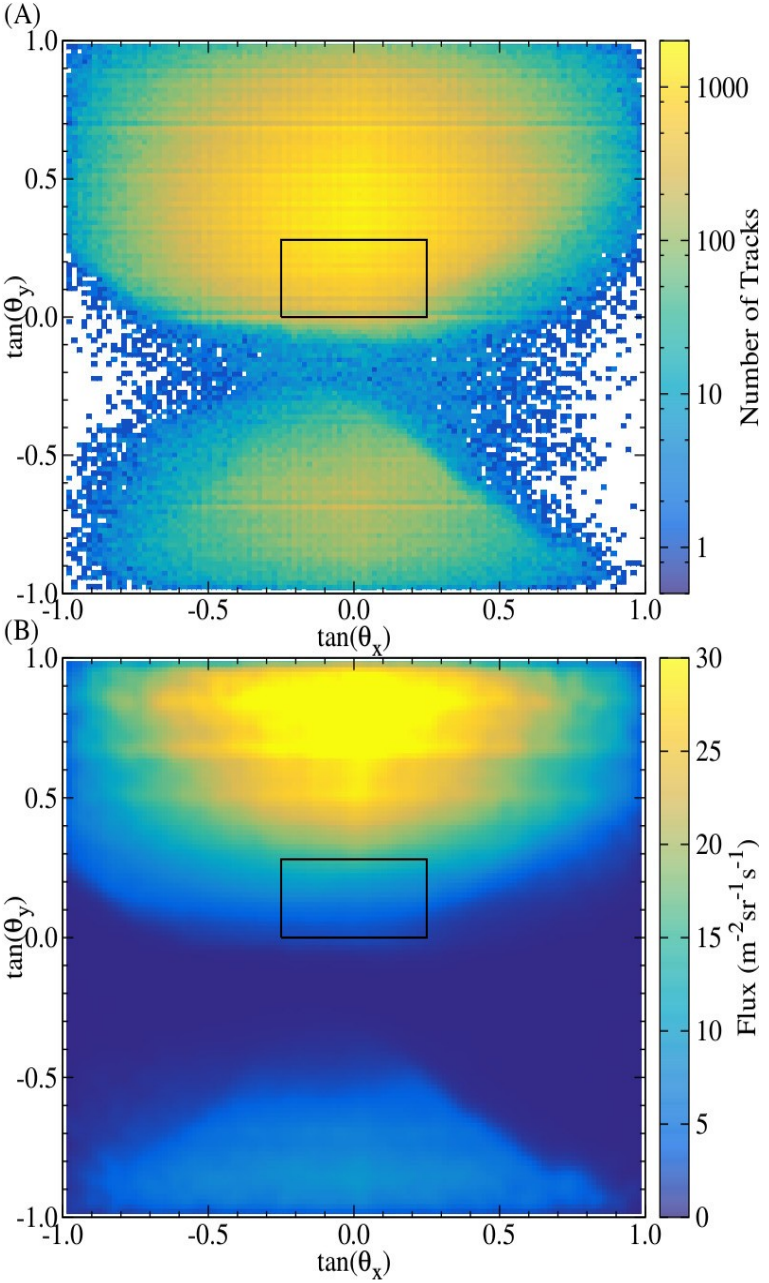
HEP analysis methods:
- cluster reconstruction

- combinatorial tracking (**Trigger rate: 12.5 Hz** & **Track rate: 1.35 Hz**)

- combinatorial efficiency calculation (**> 98 %**)

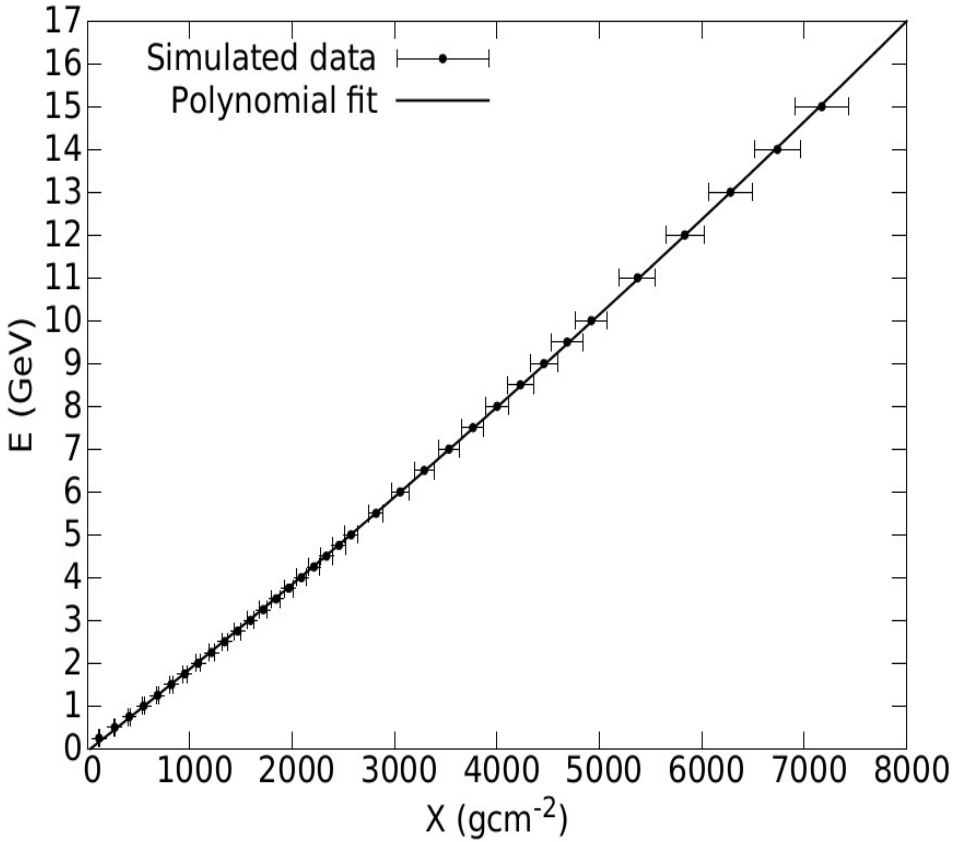
- flux calculation as a function track slopes (**20 mrad by 20 mrad** pixels → **0.5 m by 0.5 m** spatial resolution)

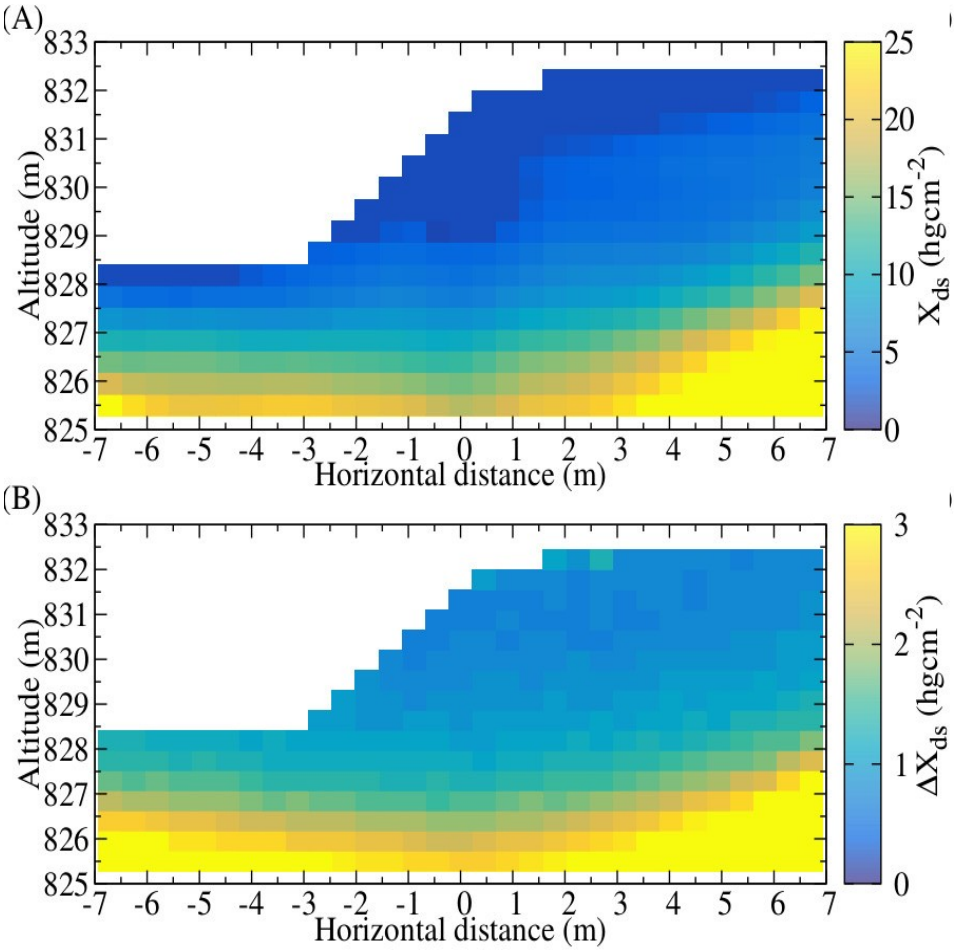




Simulation methods

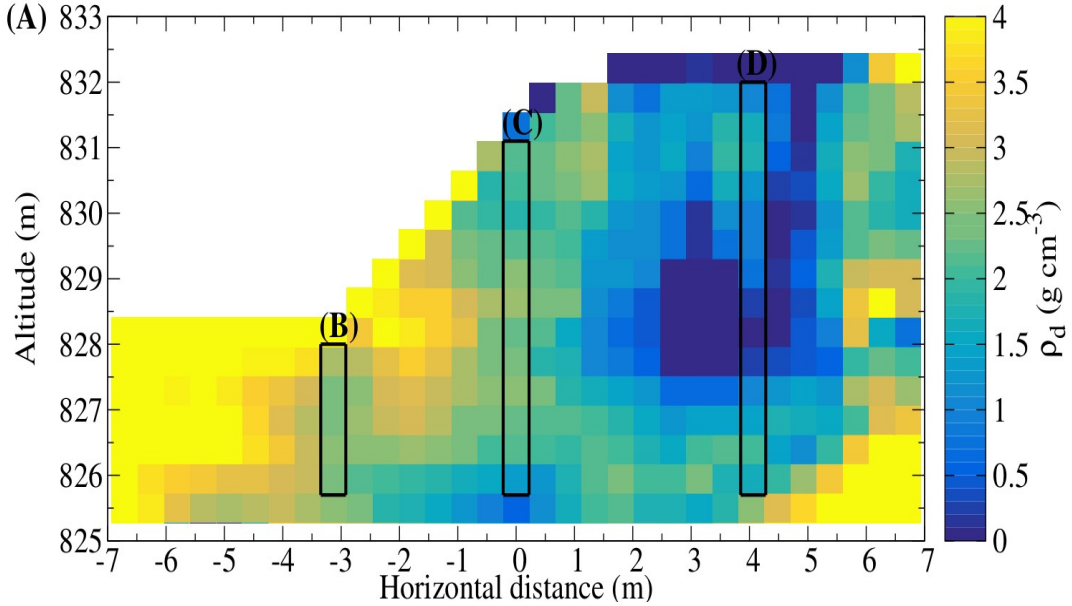
- Muon absorption was simulated in concrete using GEANT4 to extract the energy thresholds across the dam body
- Muon spectra (parametization based on ADAMO data, Bonechi et al. ICRC 2005, Vol 9. p283) were integrated to deduce expected fluxes → density-lengths
- Dam density= (Total density-length - sediment path-length x sediment density) / dam path-length
- Density of sediment : 1.8 g/cm3 via sampling of materials

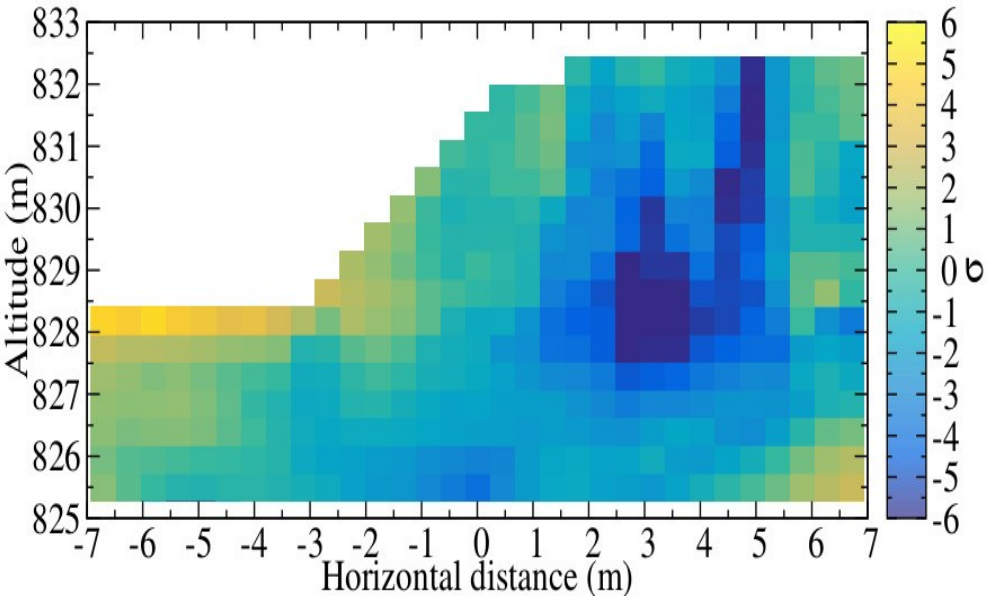


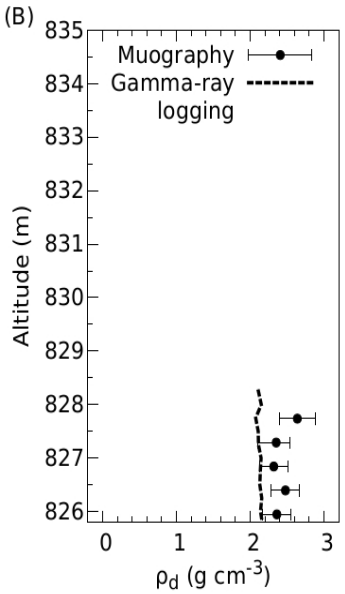


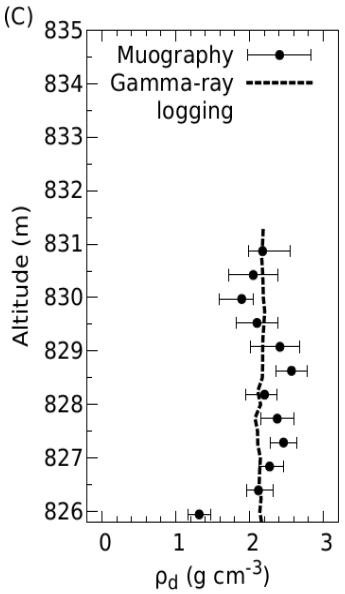
IV. Results

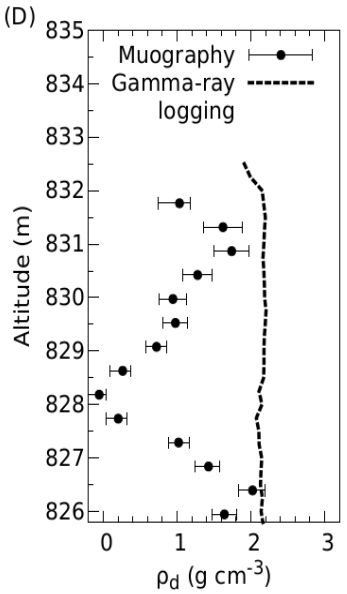
- Significant density reduction was observed across the dam body where cement released out
- Density values were not quantified precisely at the crown of the dam and at the edges











Muographic and gamma-gamma logging density data (acquired by Sabo FF) were compared:

(1) Data were found consistent in the regions without density inhomogeneities

(2) Muography can extend the range of gamma-gamma logging to observe density inhomogeneities

V. Discussion

- (Multi-directional) muography can be challenging due to topographic constraints → drones?
- Muography is passive, remote for other techniques with either range or resolution limitations
- Debris dams are good targets to test and optitmize muography for intermediate (< few 10 m) sizes

- **TODO:**
  - Precise terrain model has to be created if density information is required
  - Muon spectra models have to be improved in 100 MeV – 10 GeV energy regime for high-precision muography
    → see NEWCUT http://journals.andromedapublisher.com/index.php/JAIS/article/view/264/125

- Detailed description can be found in the manuscript entitled "**Structural Health Monitoring of Sabo Check Dams with Cosmic-Ray Muography**" that was submitted to iScience:
  https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4453784

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Thank you for your attention!