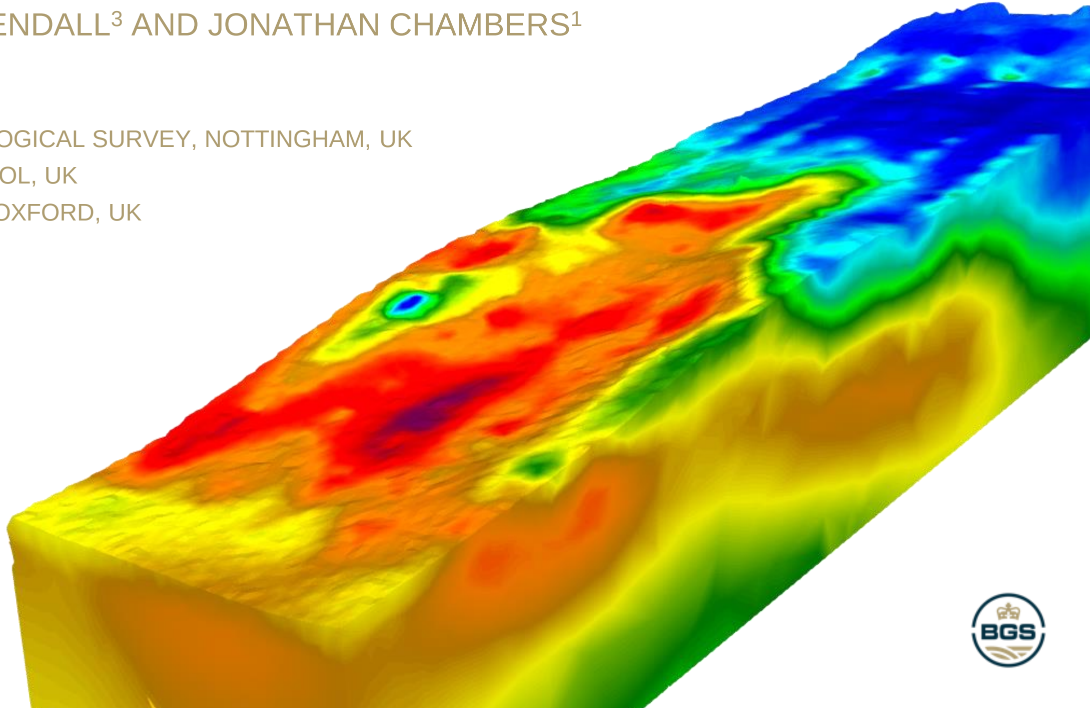
Geophysical imaging for local landslide early warning systems

JIM WHITELEY[1,2], ARNAUD WATLET[1], MICHAEL KENDALL[3] AND JONATHAN CHAMBERS[1]

[1] SHALLOW HAZARDS AND EARTH OBSERVATION, BRITISH GEOLOGICAL SURVEY, NOTTINGHAM, UK
[2] SCHOOL OF EARTH SCIENCES, UNIVERSITY OF BRISTOL, BRISTOL, UK
[3] DEPARTMENT OF EARTH SCIENCES, UNIVERSITY OF OXFORD, OXFORD, UK



Extended version

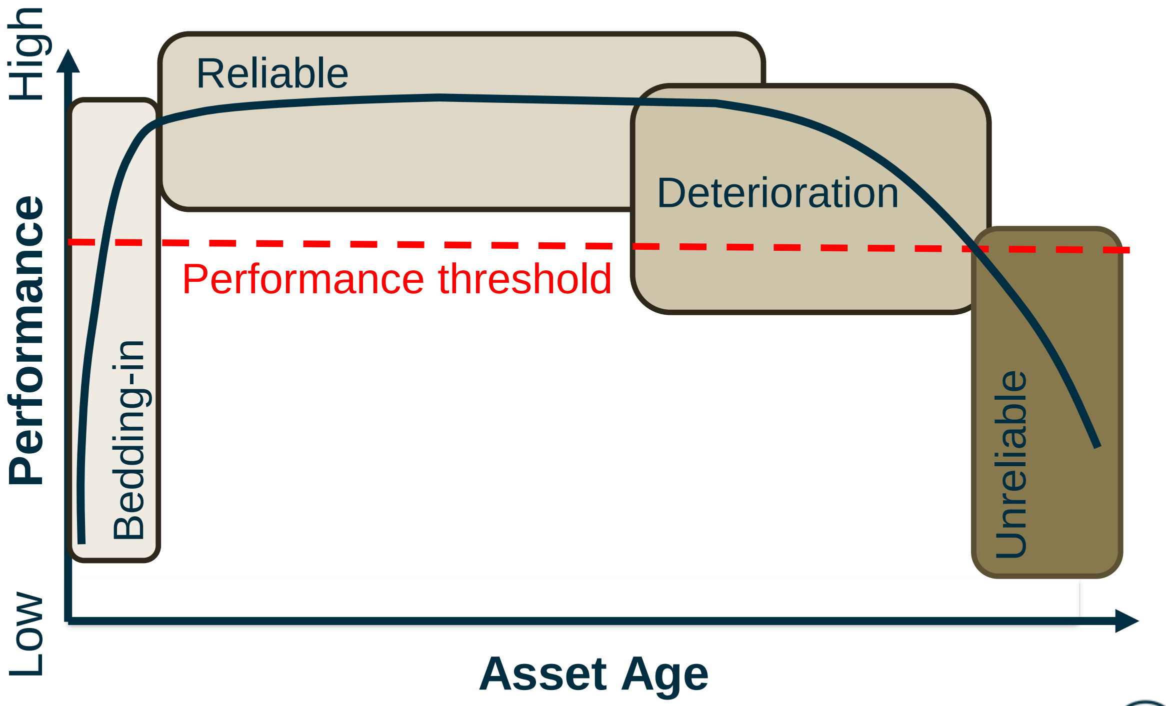
Contents (extended version)

- Introduction
  - Slope condition and early warning
  - Geophysics as part of the toolbox
  - Which kind of geophysics?
  - Developments in geophysical monitoring

- Geophysical imaging for LoLEWS
  - A framework for including geophysical imaging in LoLEWS
    - Design
    - Monitoring
    - Forecasting
    - Decision support
  - Geophysical uncertainty
  - The BGS PRIME ERT monitoring system

Slope condition and early warning

- **Condition monitoring** – a concept borrowed from civil engineering

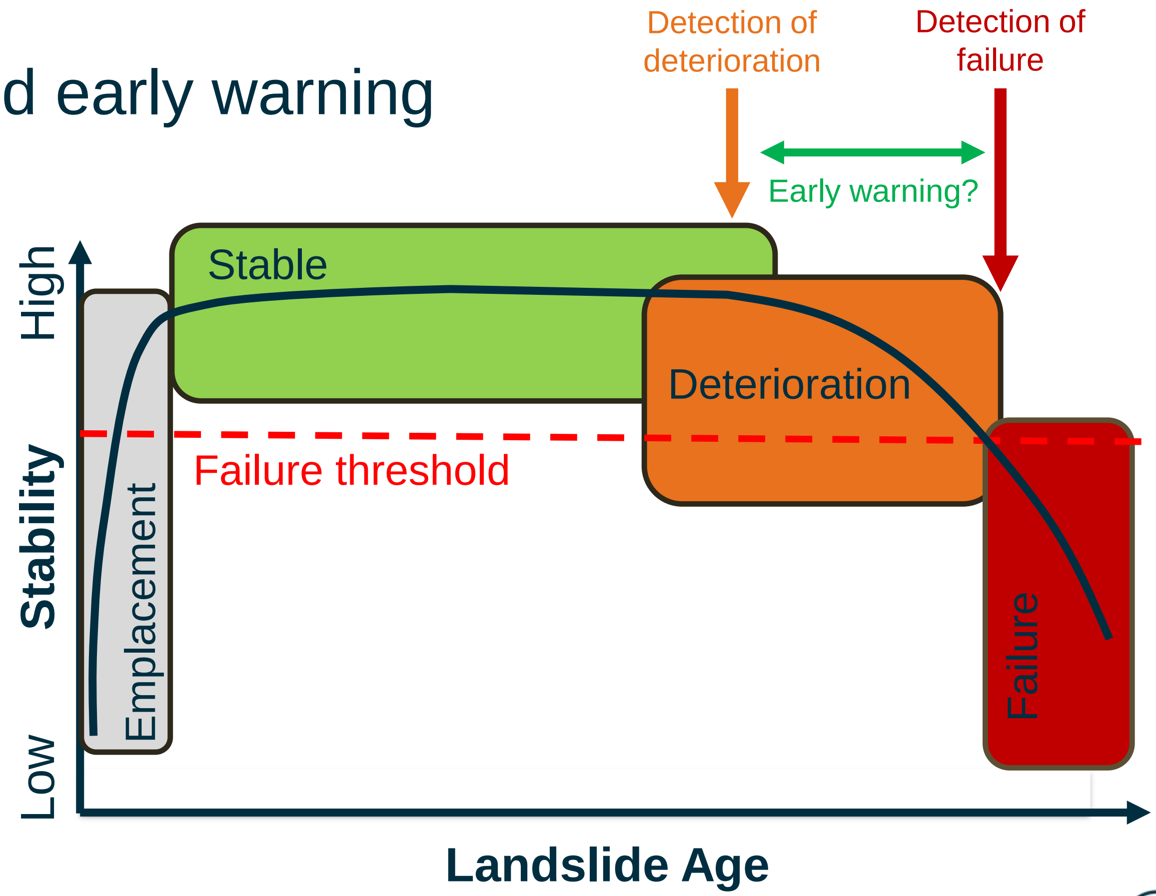


After Briggs et al., 2019.

International Conference on Smart Infrastructure and Construction (ICSIC)

Slope condition and early warning

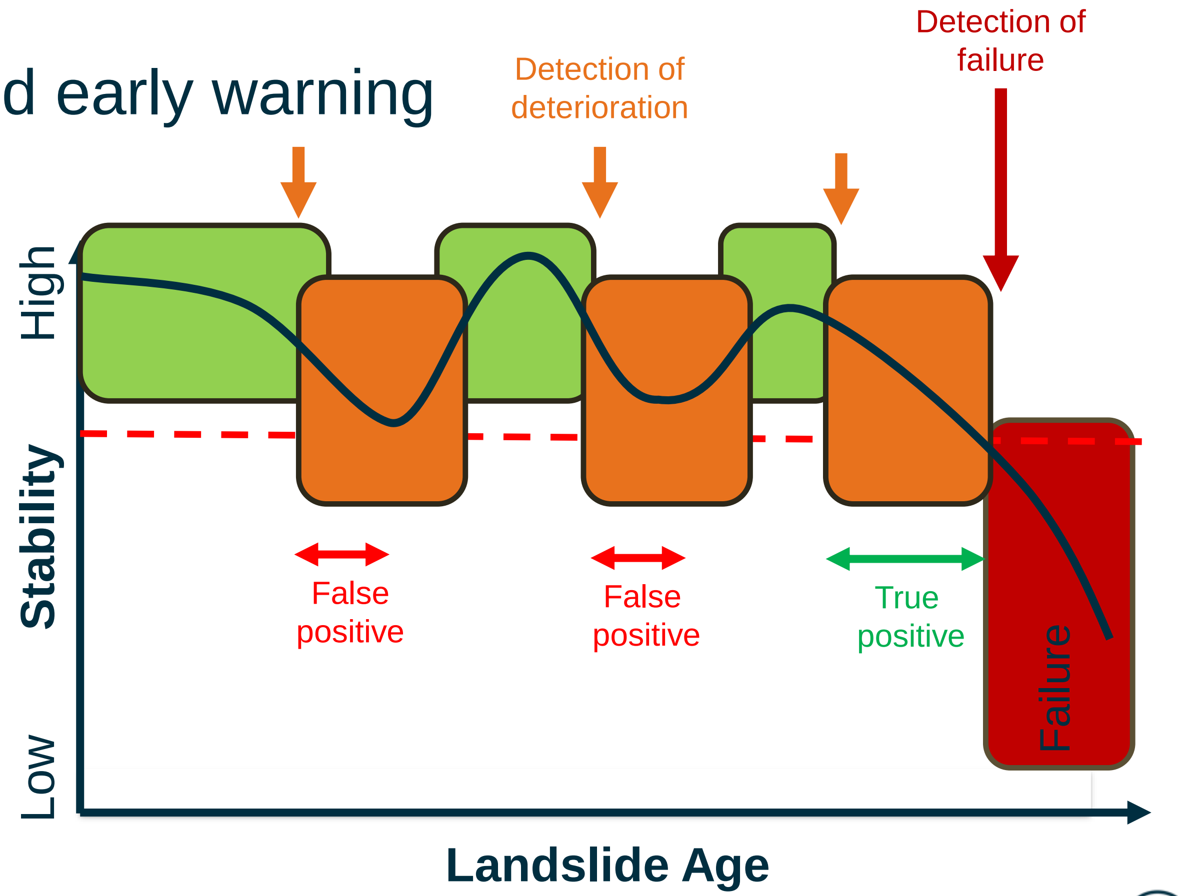
- **Condition monitoring** – a concept borrowed from civil engineering
- Maximise the time from detection of deterioration onset to point of failure



After Briggs et al., 2019.
International Conference on Smart Infrastructure and Construction (ICSIC)

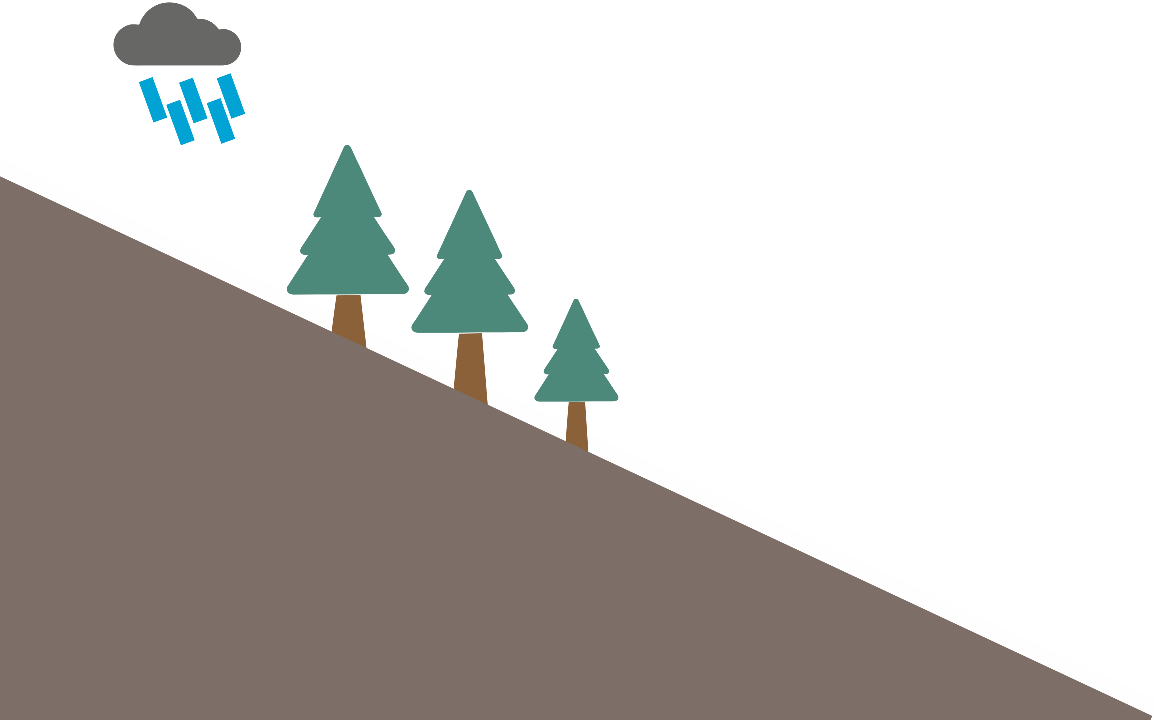
Slope condition and early warning

- **Condition monitoring** – a concept borrowed from civil engineering
- Maximise the time from detection of deterioration onset to point of failure
- Pathway of stability curve may be complex

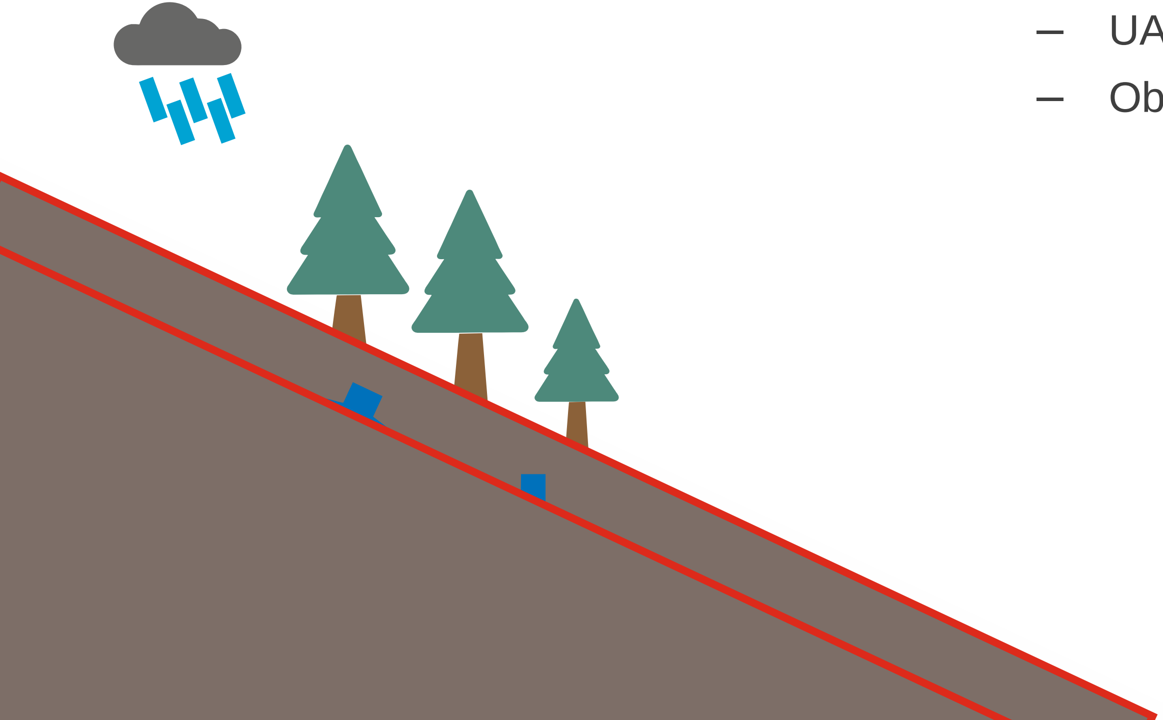


After Briggs et al., 2019.

Landslide investigation tools – getting a clear picture

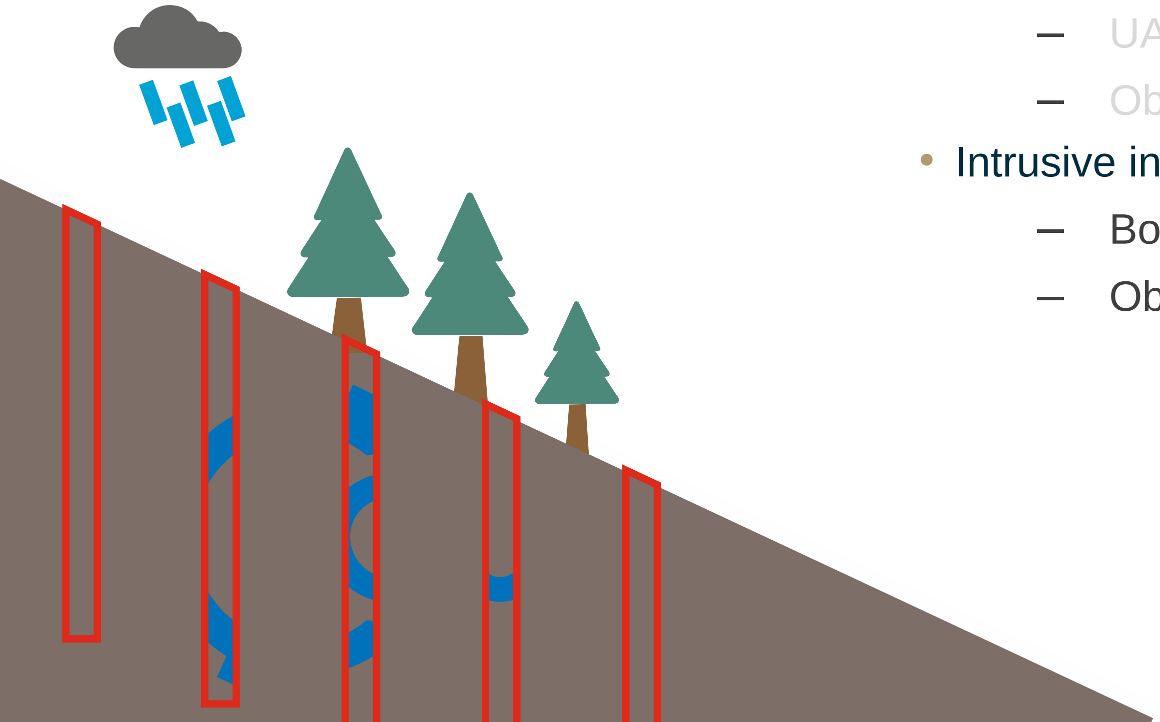


Landslide investigation tools – getting a clear picture



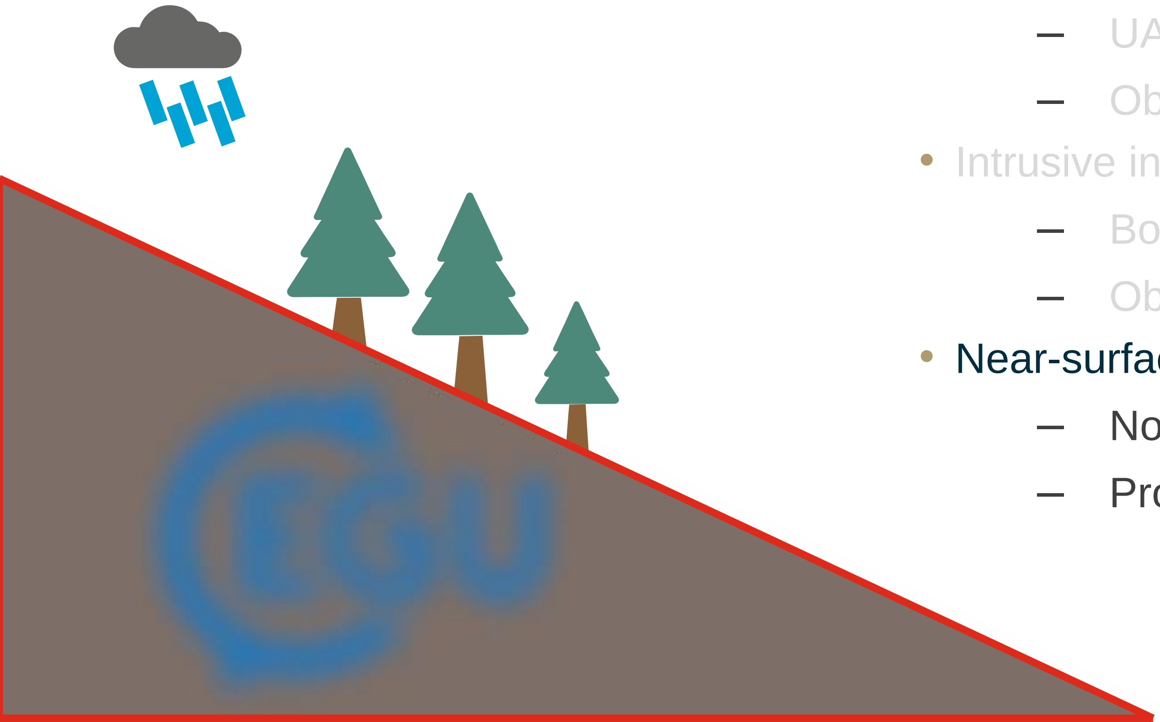
- Remote sensing
  - UAV / InSAR
  - Observations / measurements

Landslide investigation tools – getting a clear picture



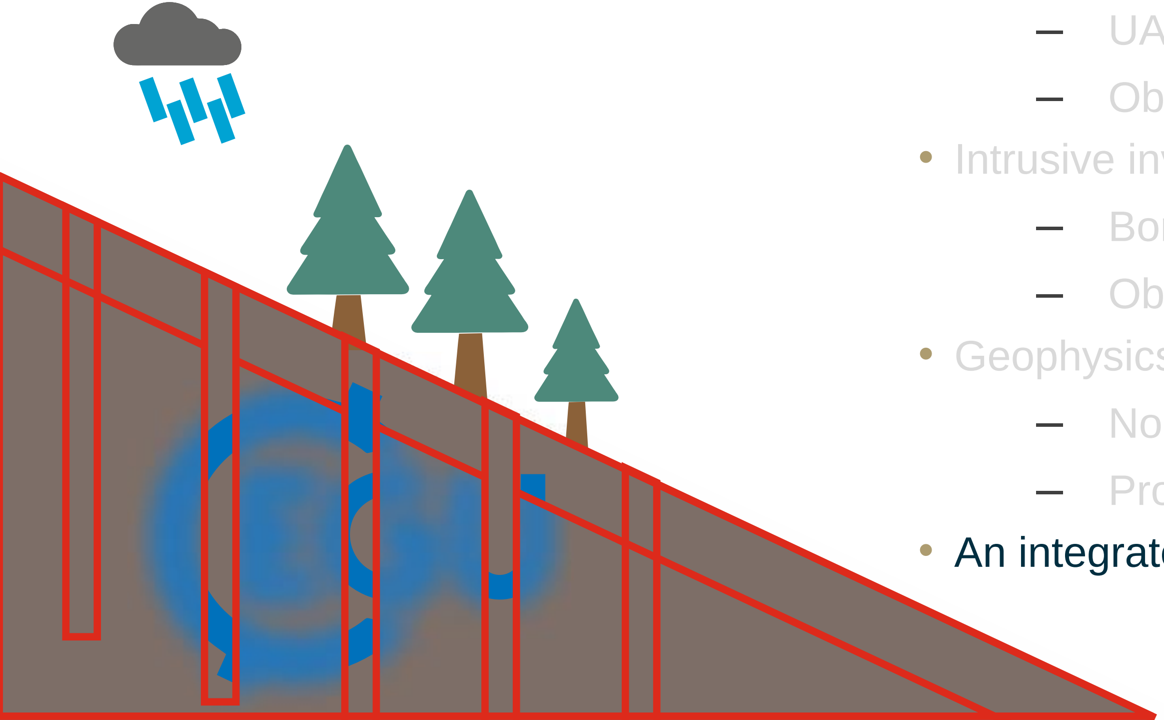
- Remote sensing
  - UAV / InSAR
  - Observations / measurements
- Intrusive investigations / observations
  - Boreholes / trial pits / sensors
  - Observations / field and lab tests

Landslide investigation tools – getting a clear picture



- Remote sensing
  - UAV / InSAR
  - Observations / measurements
- Intrusive investigations / observations
  - Boreholes / trial pits / sensors
  - Observations / field and lab tests
- Near-surface geophysics
  - Non-invasive surface measurements
  - Proxies of ground condition

Landslide investigation tools – getting a clear picture

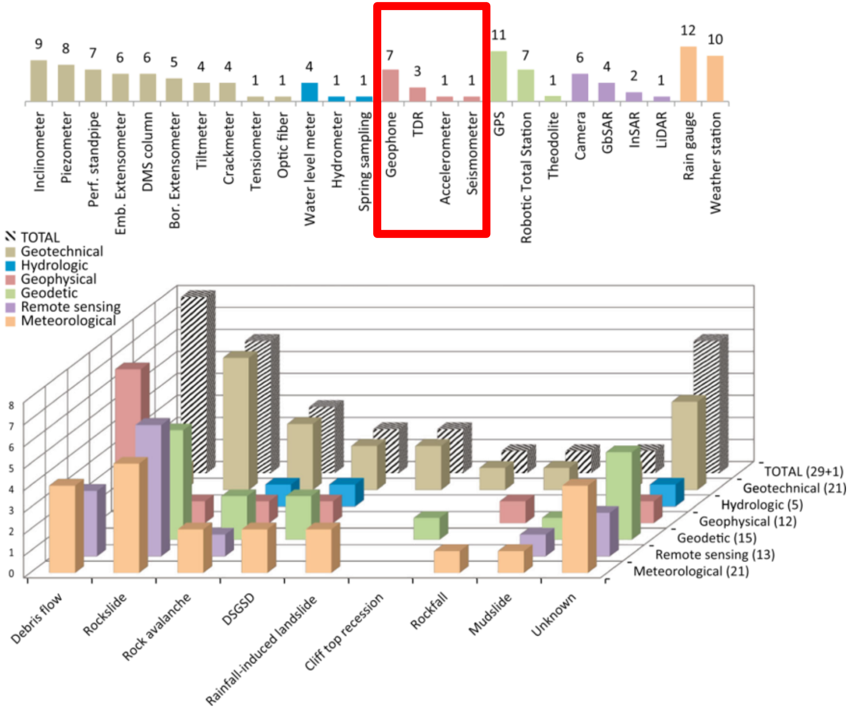


- Remote sensing
  - UAV / InSAR
  - Observations / measurements
- Intrusive investigations / observations
  - Boreholes / trial pits / sensors
  - Observations / field and lab tests
- Geophysics
  - Non-invasive surface measurements
  - Proxies of ground condition
- An integrated approach!

‘Geophysics’ for LoLEWS

- *“…monitoring changes in the landslide mass by observing physical parameters of soil or rock masses (e.g., density, acoustic/elastic parameters, resistivity)”*

(Pecoraro et al., 2019)



Pecoraro et al., 2019. *Landslides.*

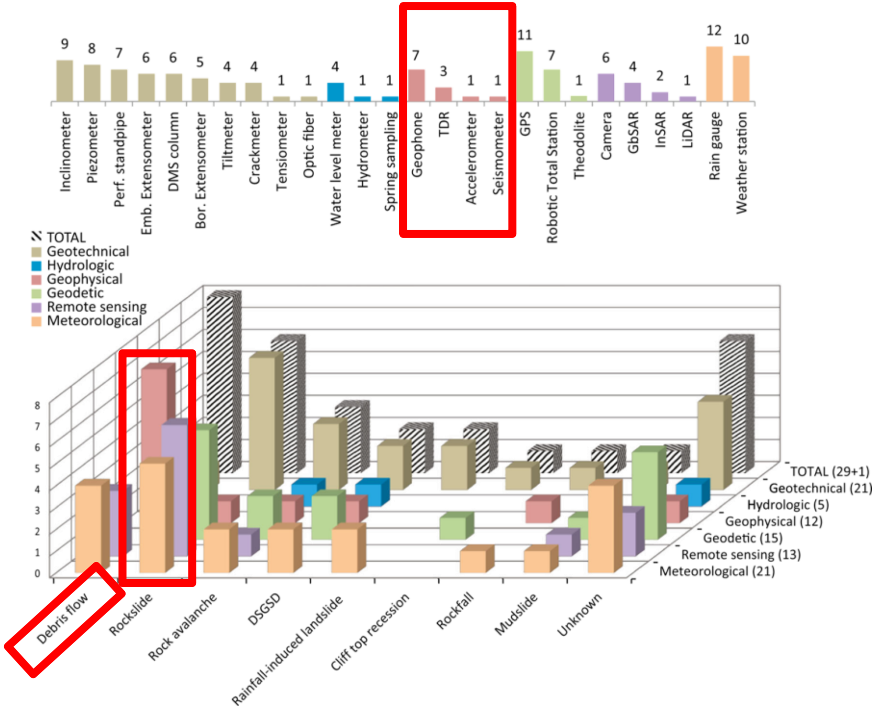
‘Geophysics’ for LoLEWS

- *“…monitoring changes in the landslide mass by observing physical parameters of soil or rock masses (e.g., density, acoustic/elastic parameters, resistivity)”*

(Pecoraro et al., 2019)

- *“Measurements … to produce cross-sections or volumetric models of the subsurface”*

(Whiteley et al., 2021)



Pecoraro et al., 2019. *Landslides.*

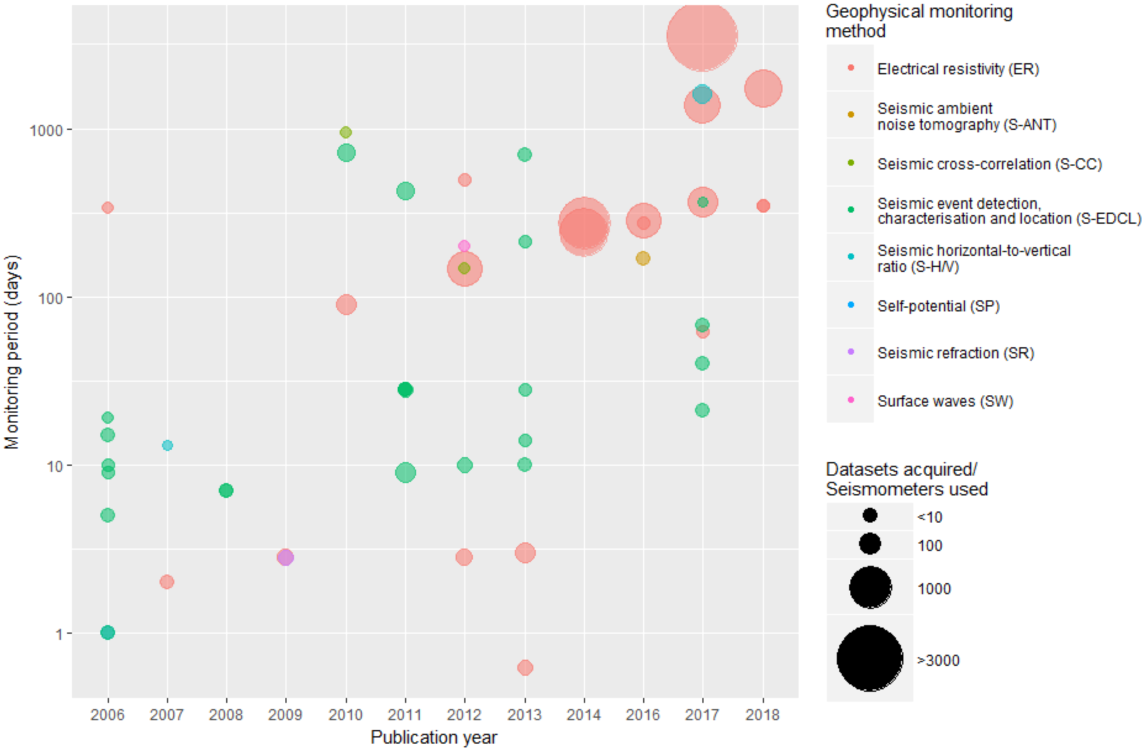
- No imaging capability in the ‘geophysical’ methods identified by Pecoraro et al. (2019) – mostly applied to fast-moving slides (e.g., debris flows)

- **Geophysical imaging** – longer lead times to failure by considering whole-slope

Developments in geophysical monitoring

- Increasing capability of time-lapse geophysical imaging systems
- Systems reaching maturity, but not (currently) integrated in to operational LoLEWS
- Distributed Acoustic Sensing (DAS) systems a very recent development being applied to landslide monitoring

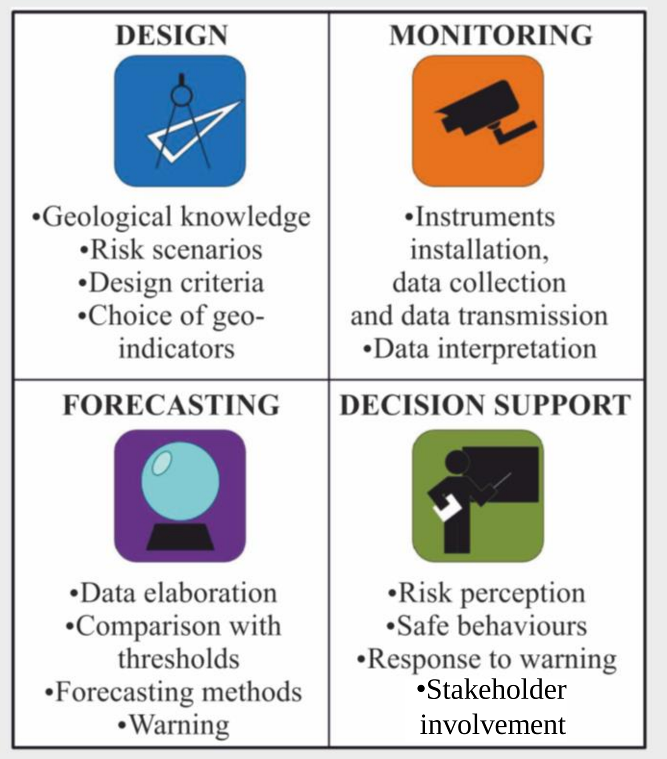
(e.g., Clarkson et al., 2021)



Whiteley et al., 2019. *Rev. Geophys.*

Local landslide early warning systems (LoLEWS)

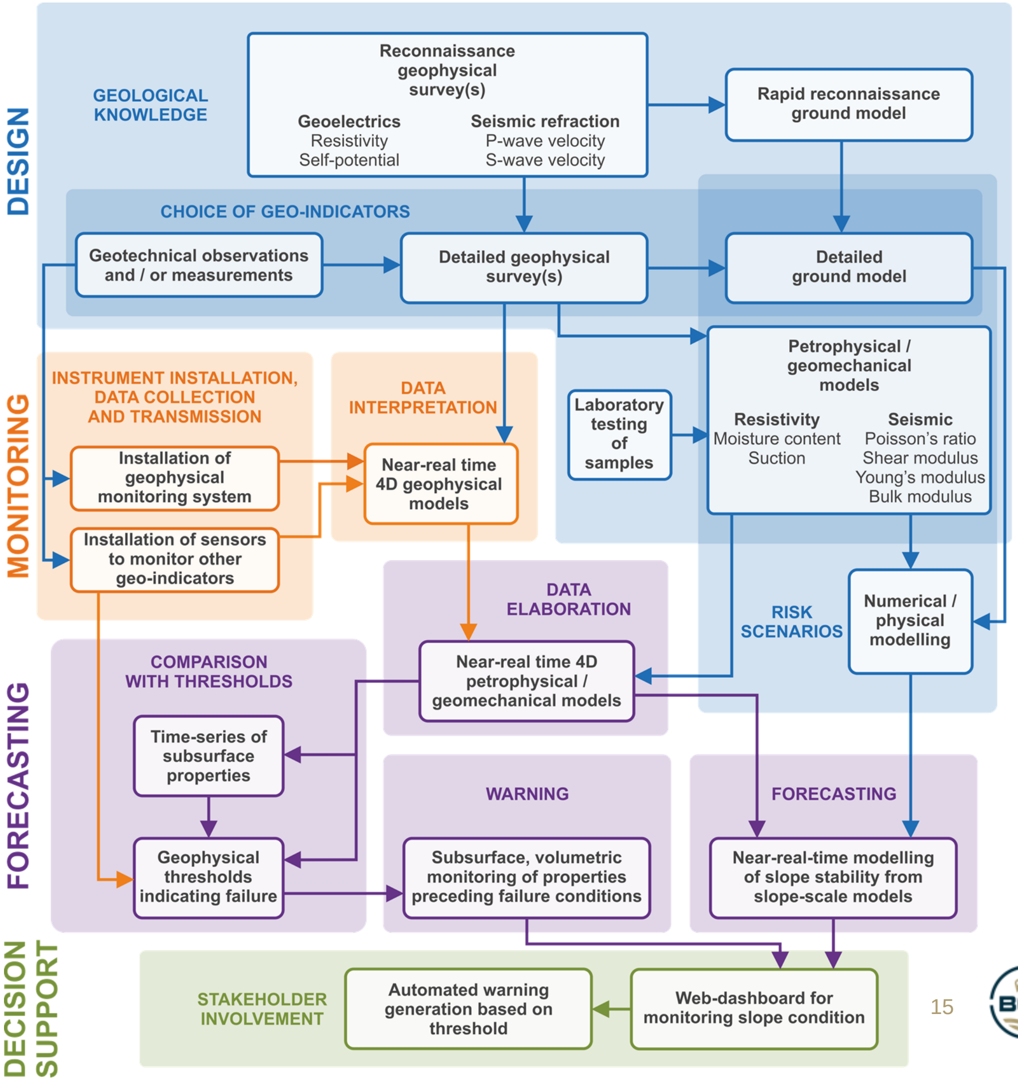
- Adapting the framework by Intrieri et al. (2013):
  - "**Education**" -> "**Decision support**"
  - "**Population involvement**" -> "**Stakeholder involvement**"
  - "**Instrument installation / data collection / transmission**" -> single activity
  - "**Data interpretation**" -> part of **monitoring**
  - "**Data elaboration**" -> part of **forecasting**



After Intrieri et al., 2013. *Nat, Hazards Earth Syst. Sci.*

The “case” for geophysical imaging in LoLEWS

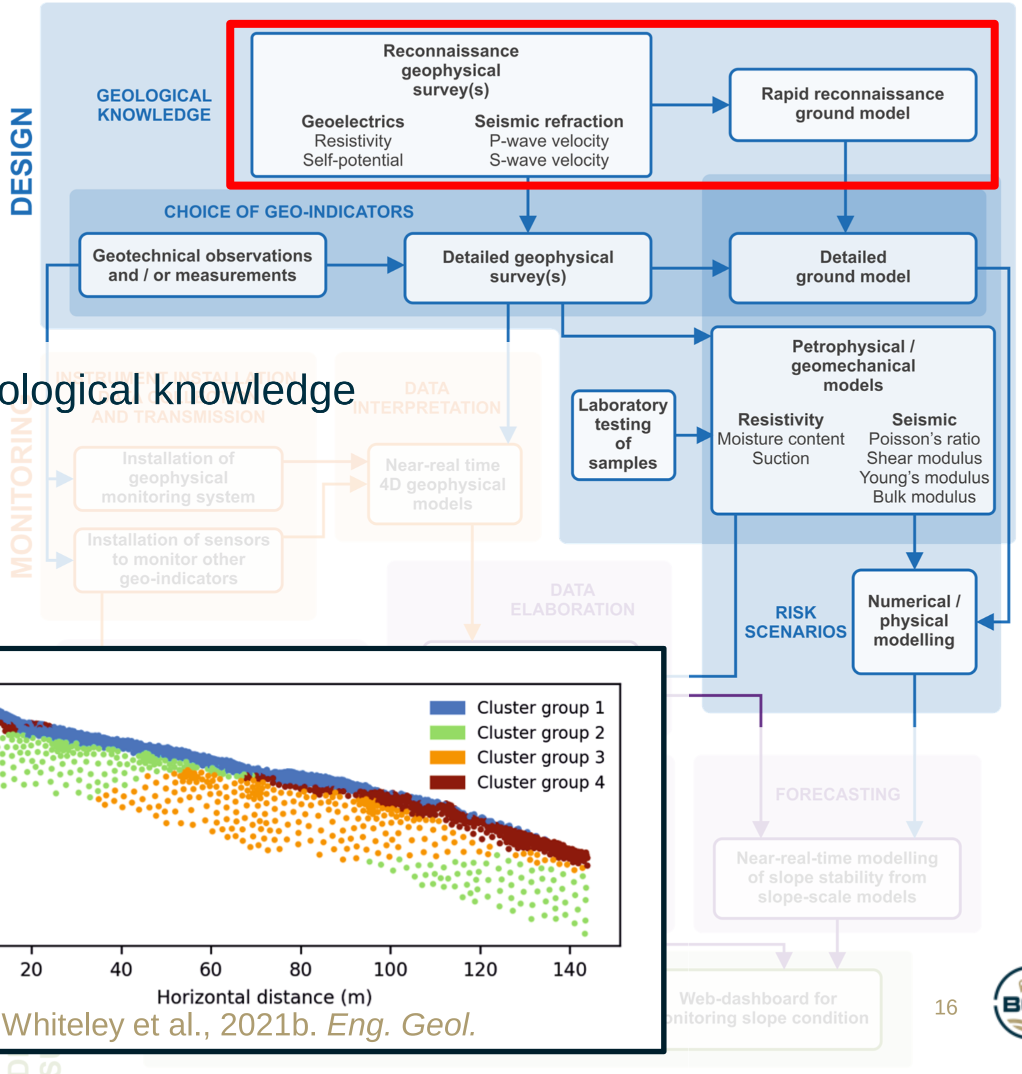
- Not a replacement for established approaches -> identify areas where geophysical information (and related activities) can supplement and / or enhance existing data

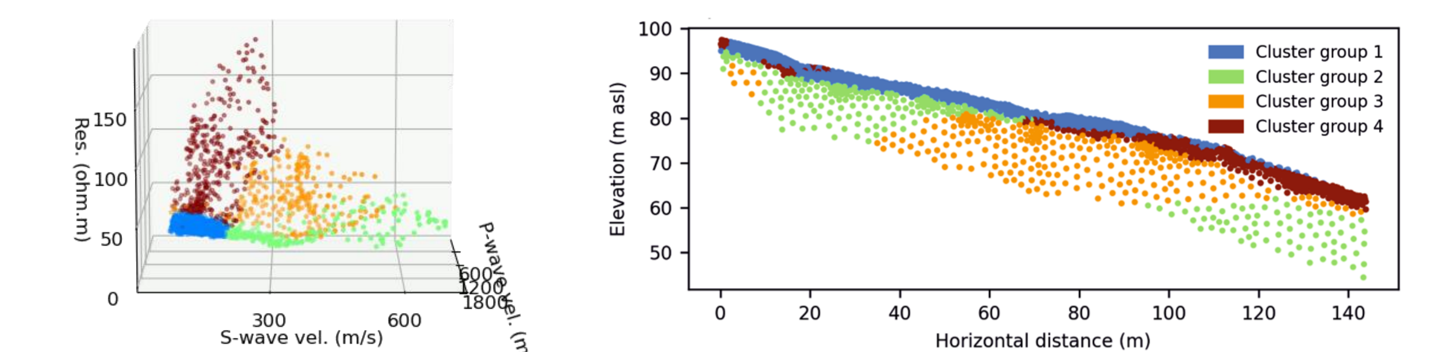


Whiteley et al., 2021a. *Nat, Hazards Earth Syst. Sci.*
After Intrieri et al., 2013. *Nat, Hazards Earth Syst. Sci.*

LoLEWS design

- Reconnaissance surveys -> rapid geological knowledge

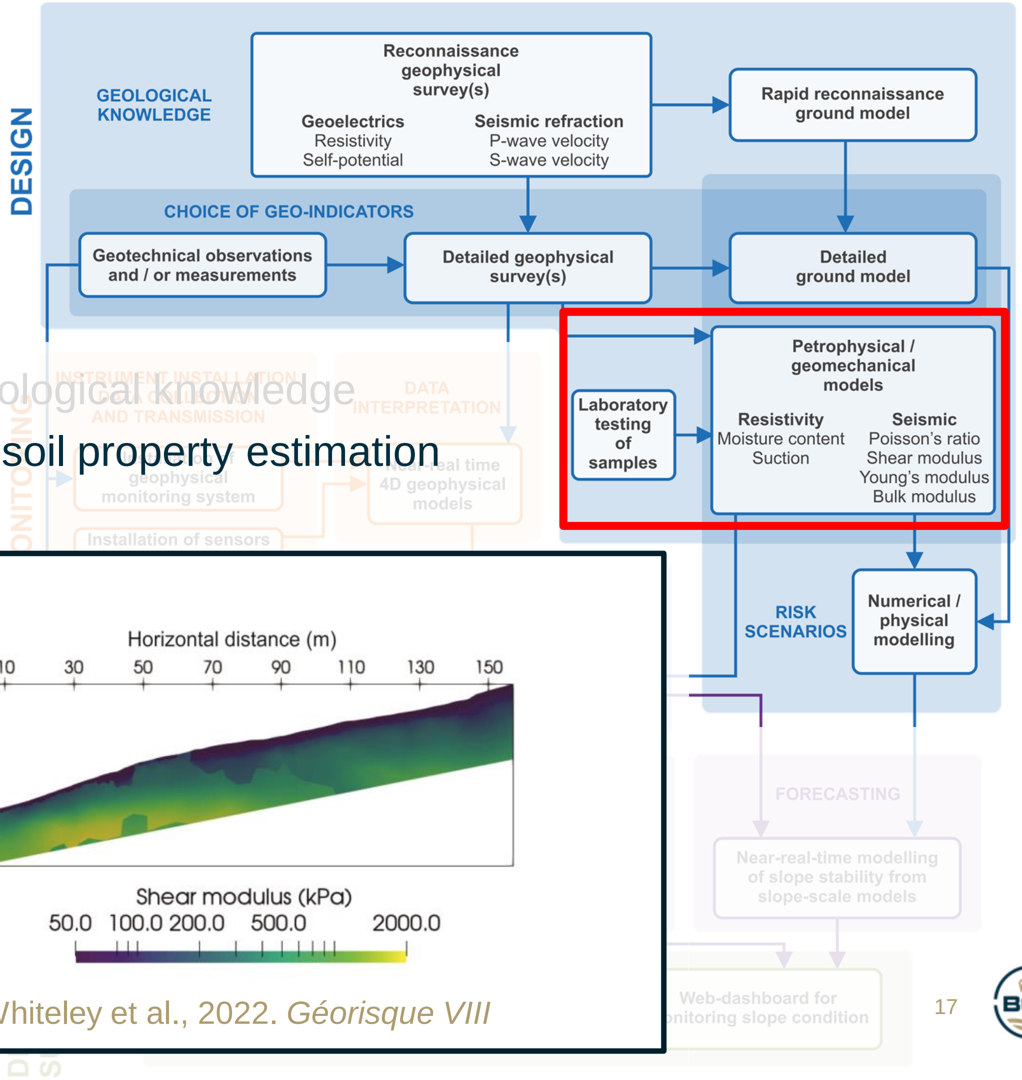


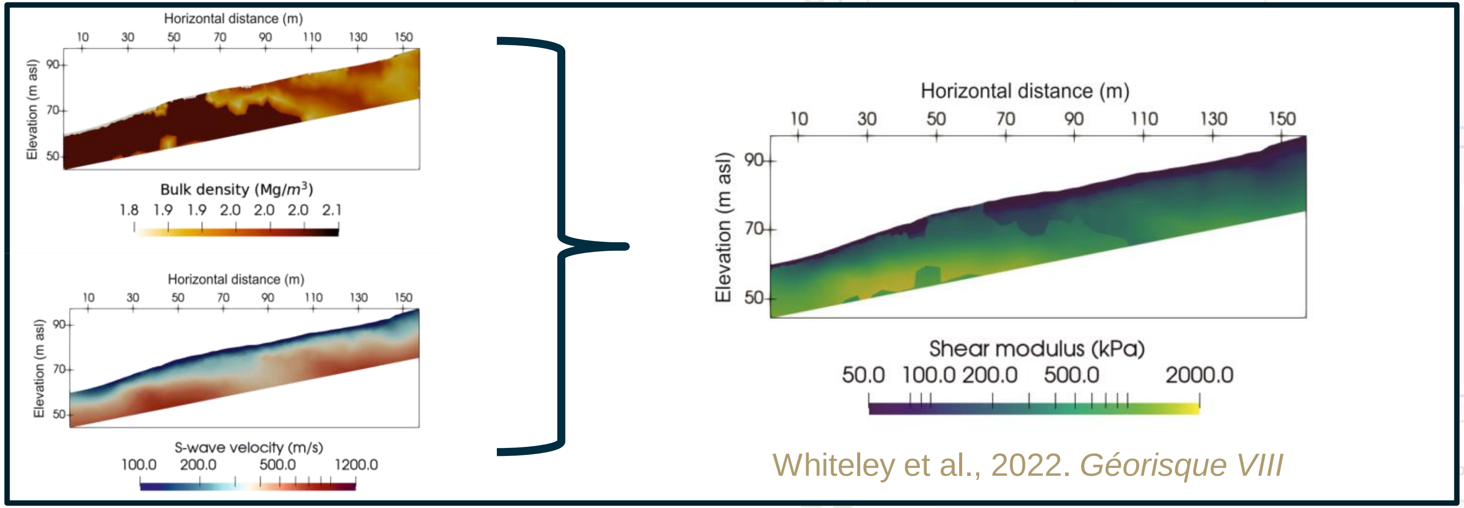


Whiteley et al., 2021b. *Eng. Geol.*

LoLEWS design

- Reconnaissance surveys -> rapid geological knowledge
- Petrophysical models -> slope-scale soil property estimation

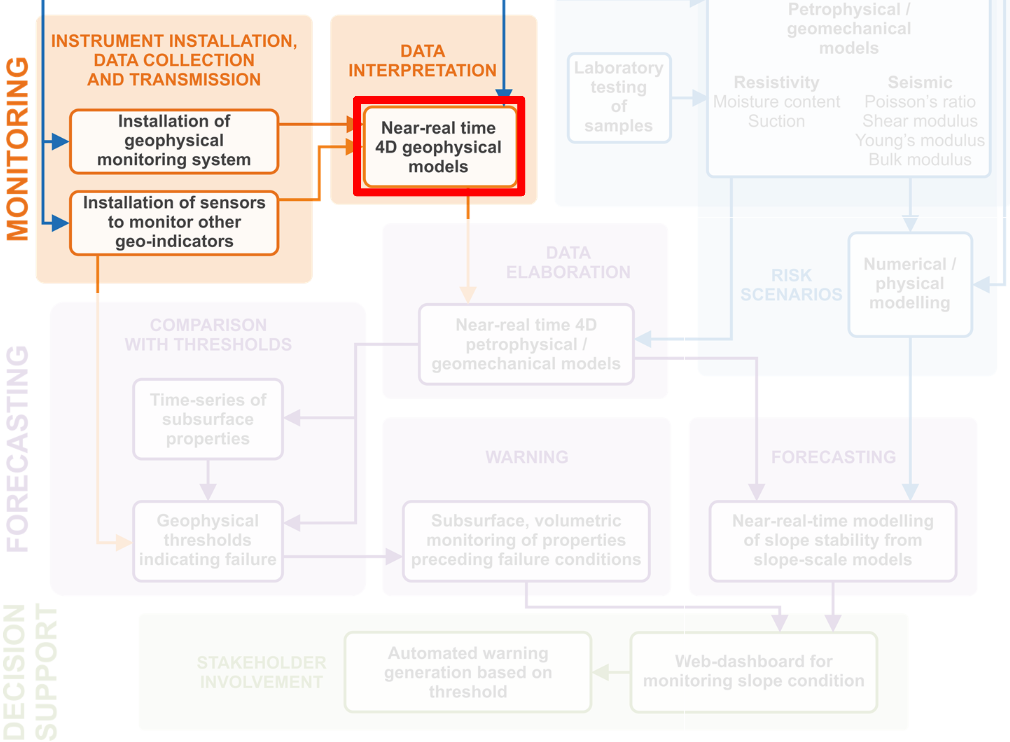


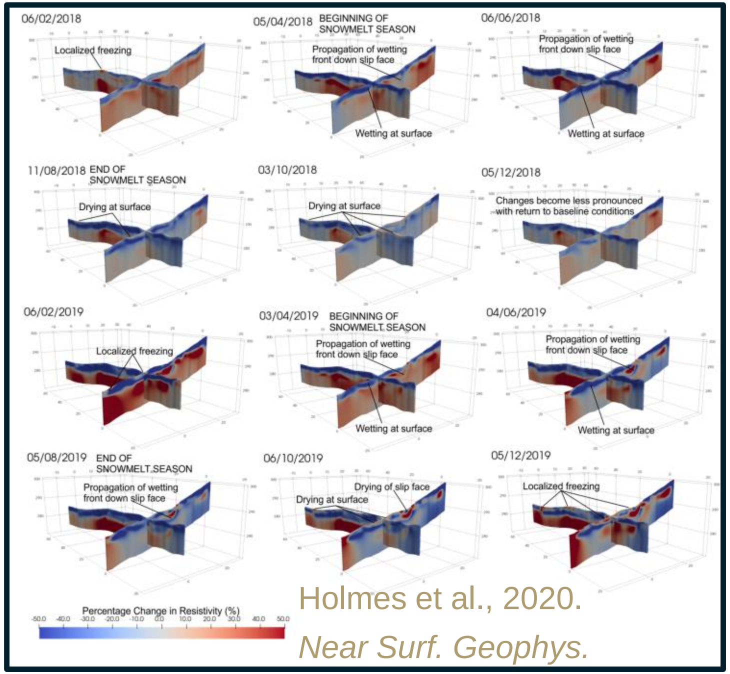


Whiteley et al., 2022. *Géorisque VIII*

LoLEWS monitoring

- 4D geophysical models



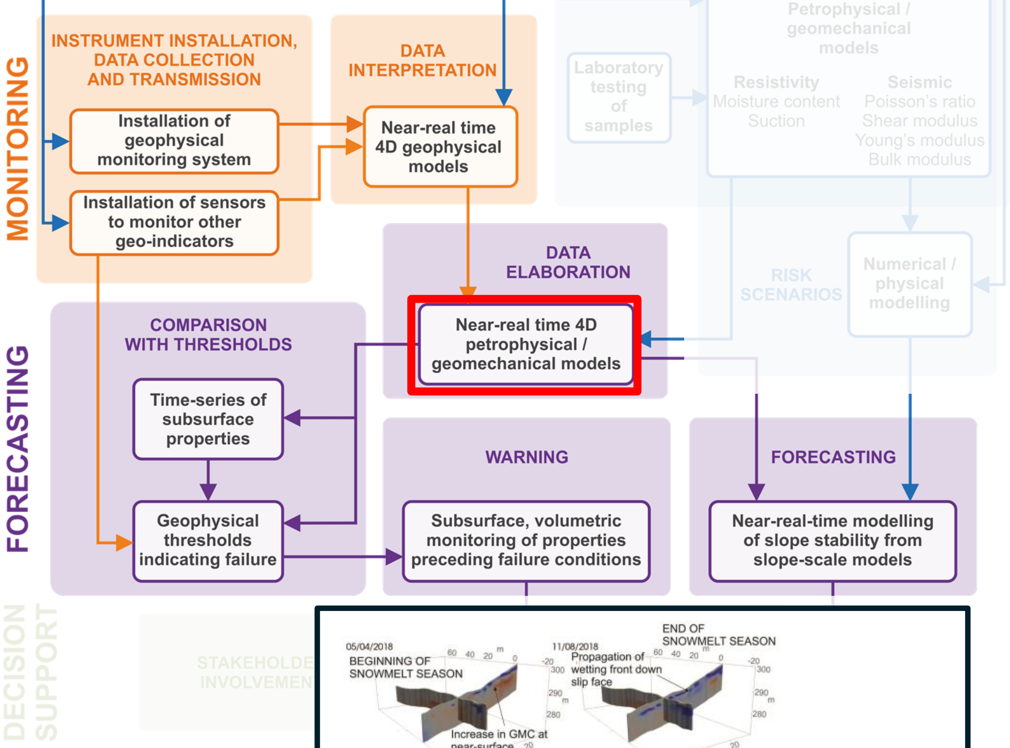


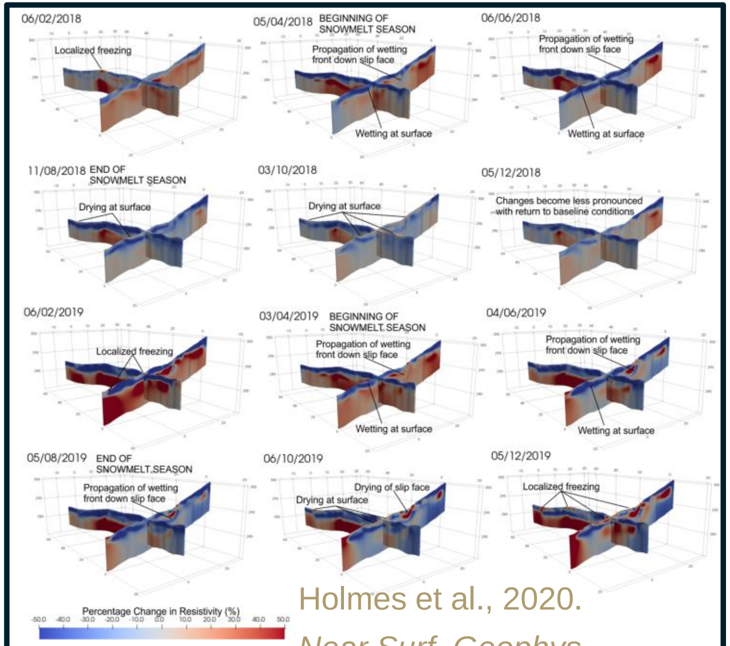
Holmes et al., 2020.
Near Surf. Geophys.

4D resistivity

LoLEWS monitoring and forecasting

- 4D geophysical models
- 4D petrophysical models

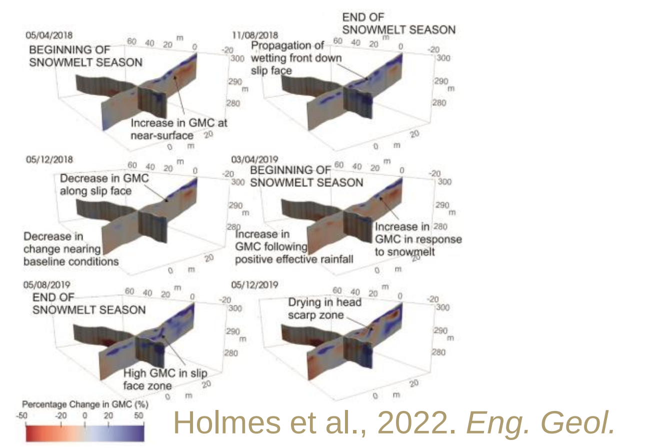




Holmes et al., 2020. *Near Surf. Geophys.*

← 4D resistivity

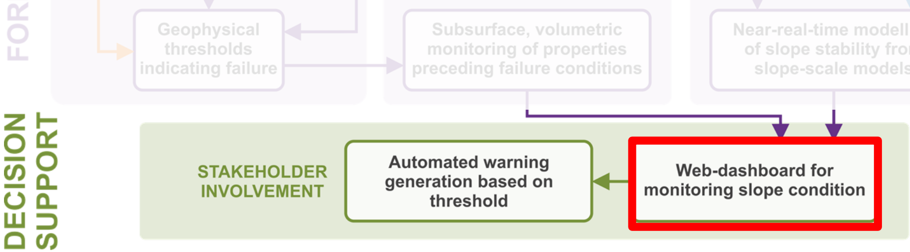
4D moisture →



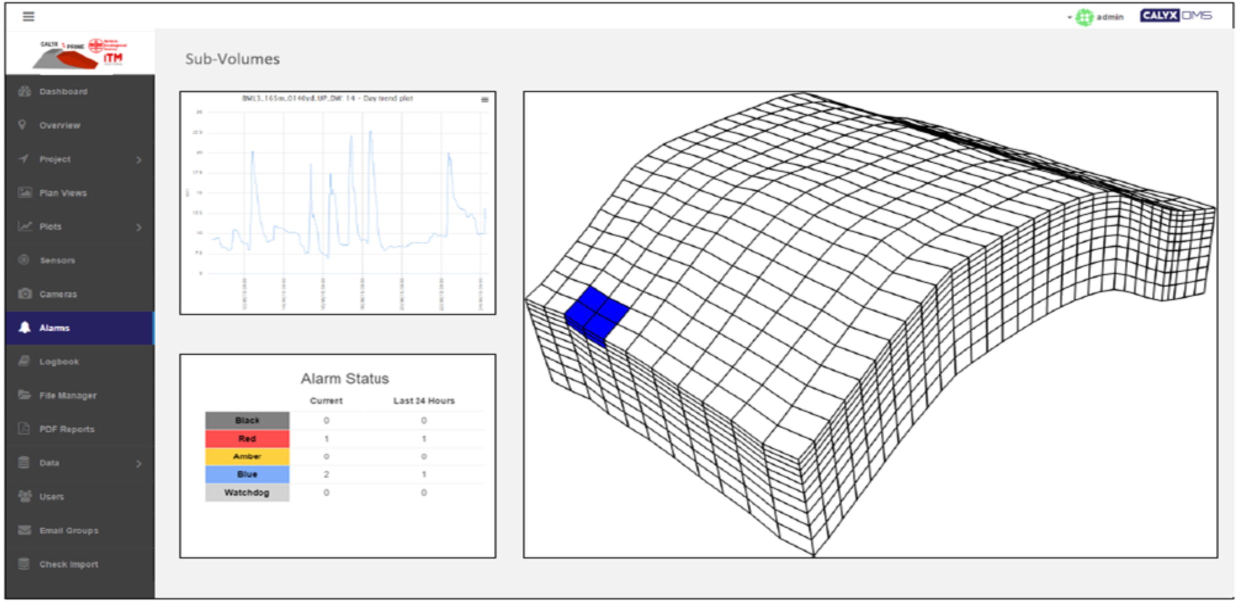
Holmes et al., 2022. *Eng. Geol.*

LoLEWS decision support

- Information and alarm delivery



BGS & ITM Monitoring
Calyx Prime – Conceptual Screenshots

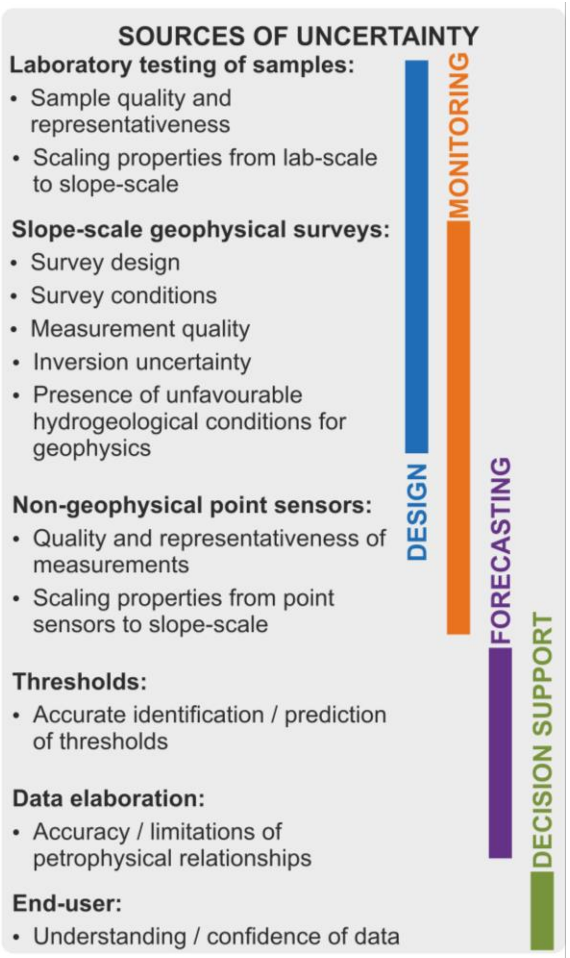


Ability to define sub-volumes – intention is to make this user definable and sub-volumes can then be treated as individual sensors. This means resistivity and GMC data can be plotted and used to trigger alarms etc.

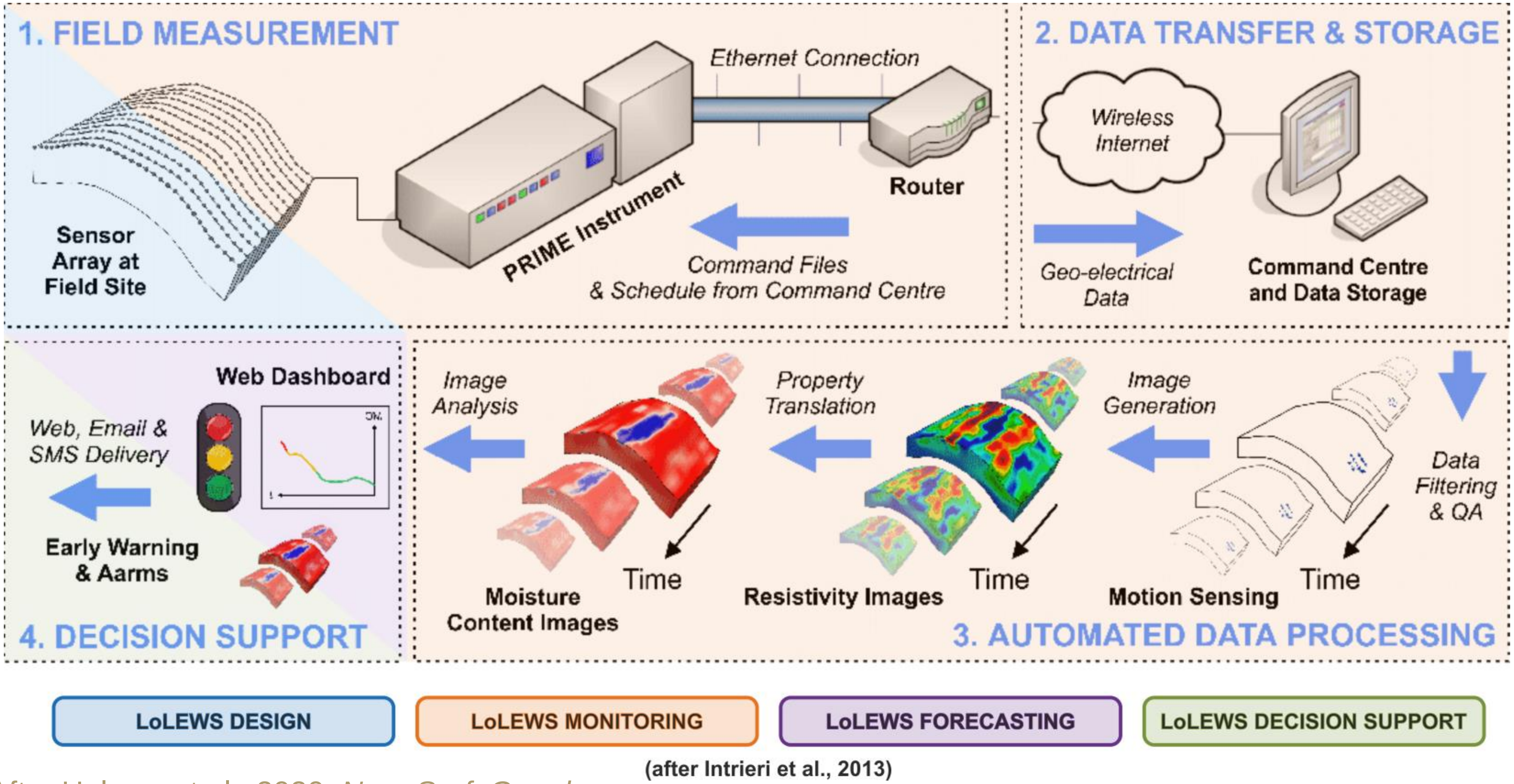
24 August 2015

Uncertainties in geophysical imaging

- Geophysical images produced from a process of data inversion – fitting a model to real-world data
- Different methods have different (and overlapping) sensitivities to different soil properties
- Many geophysical surveys still rely on expert opinion to process and interpret data
- Petrophysical transforms rely on extrapolation of small-scale properties to slope-scale



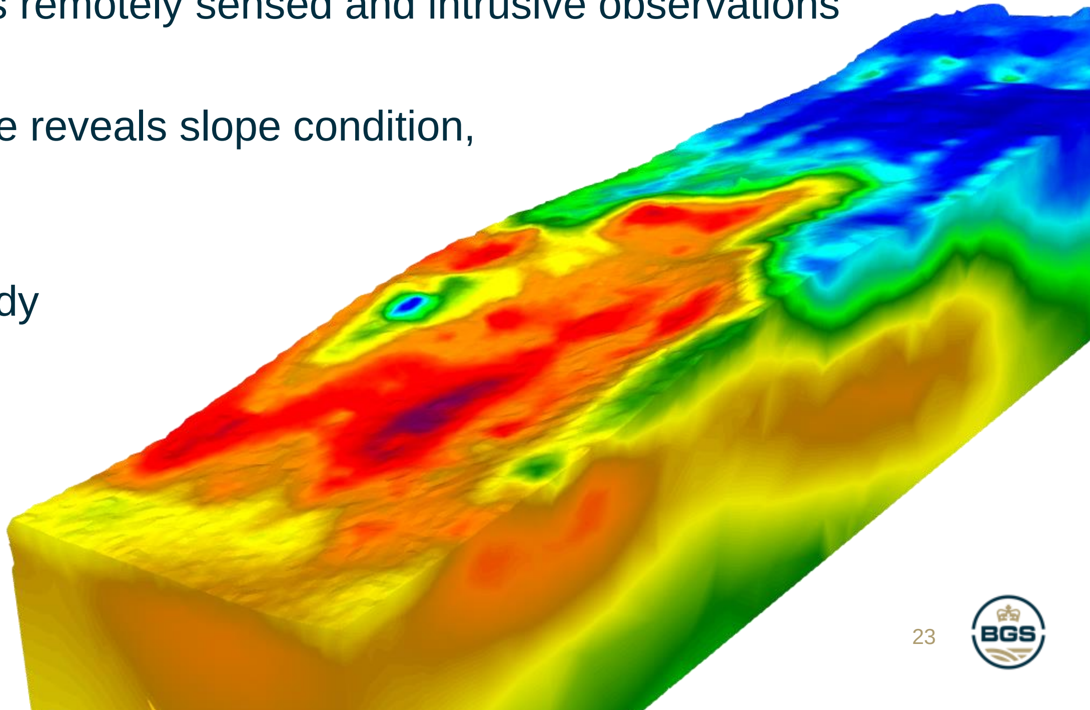
BGS PRIME ERT monitoring



After Holmes et al., 2020. *Near Surf. Geophys.*

Conclusions

- Geophysical imaging provides unique insights in to slope-scale processes at the whole-slope scale, which supplements remotely sensed and intrusive observations
- Holistic assessment of the whole-slope reveals slope condition, identifying periods of vulnerability
- Geophysical imaging systems are ready for inclusion in LoLEWS, and can supplement existing strategies



Thank you for reading

Questions?
jwhi@bgs.ac.uk

This talk is based on:
https://doi.org/10.5194/nhess-21-3863-2021

Nat. Hazards Earth Syst. Sci., 21, 3863–3871, 2021
https://doi.org/10.5194/nhess-21-3863-2021

Natural Hazards and Earth System Sciences
EGU

Brief communication: The role of geophysical imaging in local landslide early warning systems

Jim S. Whiteley[1,2], Arnaud Watlet[1], J. Michael Kendall[3], and Jonathan E. Chambers[1]

[1]Shallow Geohazards and Earth Observation, British Geological Survey, Environmental Science Centre, Nicker Hill, Nottingham, NG12 5GG, United Kingdom
[2]School of Earth Sciences, University of Bristol, Wills Memorial Building, Queens Road, Bristol, BS8 1RJ, United Kingdom
[3]Department of Earth Sciences, University of Oxford, South Parks Road, Oxford, OX1 3AN, United Kingdom

Correspondence: Jim S. Whiteley (jwhi@bgs.ac.uk)

Received: 24 July 2021 – Discussion started: 29 July 2021
Revised: 4 November 2021 – Accepted: 17 November 2021 – Published: 23 December 2021

Abstract. We summarise the contribution of geophysical imaging to local landslide early warning systems (LoLEWS), highlighting how the design and monitoring components of LoLEWS benefit from the enhanced spatial and temporal resolutions of time-lapse geophysical imaging. In addition, we discuss how with appropriate laboratory-based petrophysical transforms, geophysical data can be crucial for future

due to developments in supporting technology and databases and because of their low cost of implementation and low impact on the environment. LEWS are commonly divided into two groups: territorial landslide early warning systems (TeLEWS; also known as geographical landslide early warning systems), covering large areas at the catchment or multi-catchment scale and encompassing many vulnerable slopes

References

Briggs, K. M., Dijkstra, T. A. & Glendinning, S. 2019. Evaluating the Deterioration of Geotechnical Infrastructure Assets Using Performance Curves. *International Conference on Smart Infrastructure and Construction 2019 (ICSIC).*

Clarkson, P., Minto, C., Crickmore, R., Godfrey, A., Purnell, B., Chambers, J., Dashwood, B., Gunn, D., Jones, L., Meldrum, P., Watlet, A. & Whiteley, J. Distributed Rayleigh Sensing for Slope Stability Monitoring. 55th U.S. Rock Mechanics/Geomechanics Symposium, 2021. ARMA-2021-1229.

Holmes, J., Chambers, J., Meldrum, P., Wilkinson, P., Boyd, J., Williamson, P., Huntley, D., Sattler, K., Elwood, D., Sivakumar, V., Reeves, H. & Donohue, S. 2020. Four-dimensional electrical resistivity tomography for continuous, near-real-time monitoring of a landslide affecting transport infrastructure in British Columbia, Canada. *Near Surface Geophysics,* 18**,** 337-351.

Holmes, J., Chambers, J., Wilkinson, P., Meldrum, P., Cimpoiaşu, M., Boyd, J., Huntley, D., Williamson, P., Gunn, D., Dashwood, B., Whiteley, J., Watlet, A., Kirkham, M., Sattler, K., Elwood, D., Sivakumar, V. & Donohue, S. 2022. Application of petrophysical relationships to electrical resistivity models for assessing the stability of a landslide in British Columbia, Canada. *Engineering Geology***,** 106613.

Intrieri, E., Gigli, G., Casagli, N. & Nadim, F. 2013. Brief communication "Landslide Early Warning System: toolbox and general concepts". *Nat. Hazards Earth Syst. Sci.,* 13**,** 85-90.

Pecoraro, G., Calvello, M. & Piciullo, L. 2019. Monitoring strategies for local landslide early warning systems. *Landslides,* 16**,** 213-231.

Whiteley, J. S., Chambers, J. E., Uhlemann, S., Wilkinson, P. B. & Kendall, J. M. 2019. Geophysical Monitoring of Moisture-Induced Landslides: A Review. *Reviews of Geophysics,* 57**,** 106-145.

Whiteley, J. S., Watlet, A., Kendall, J. M. & Chambers, J. E. 2021a. Brief communication: The role of geophysical imaging in local landslide early warning systems. *Nat. Hazards Earth Syst. Sci.,* 21**,** 3863-3871.

Whiteley, J. S., Watlet, A., Uhlemann, S., Wilkinson, P., Boyd, J. P., Jordan, C., Kendall, J. M. & Chambers, J. E. 2021b. Rapid characterisation of landslide heterogeneity using unsupervised classification of electrical resistivity and seismic refraction surveys. *Engineering Geology***,** 106189.

BGS