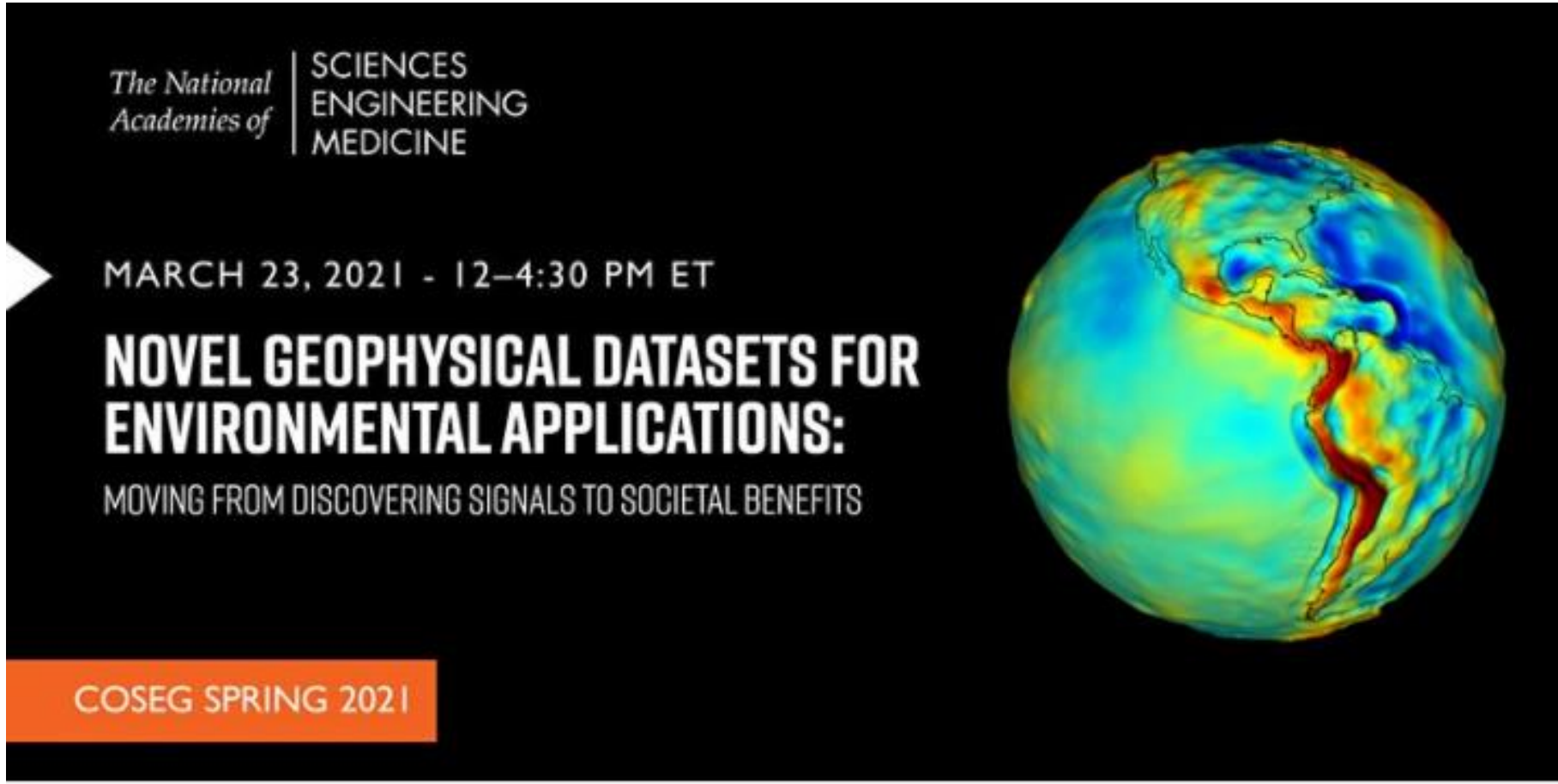
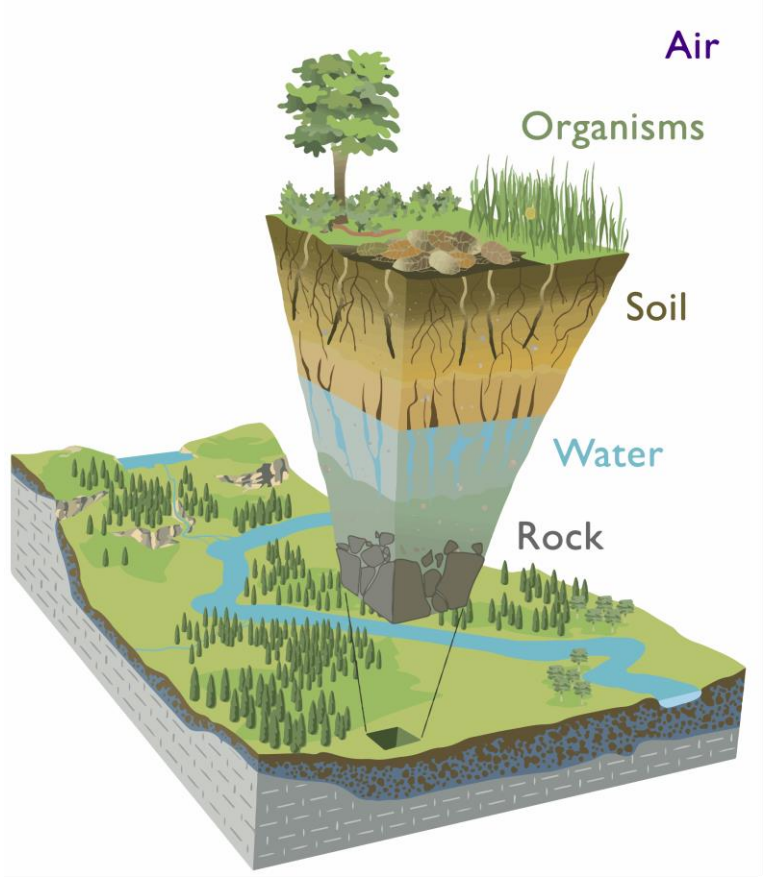
Advances and Applications in Near-Surface Geophysical Imaging

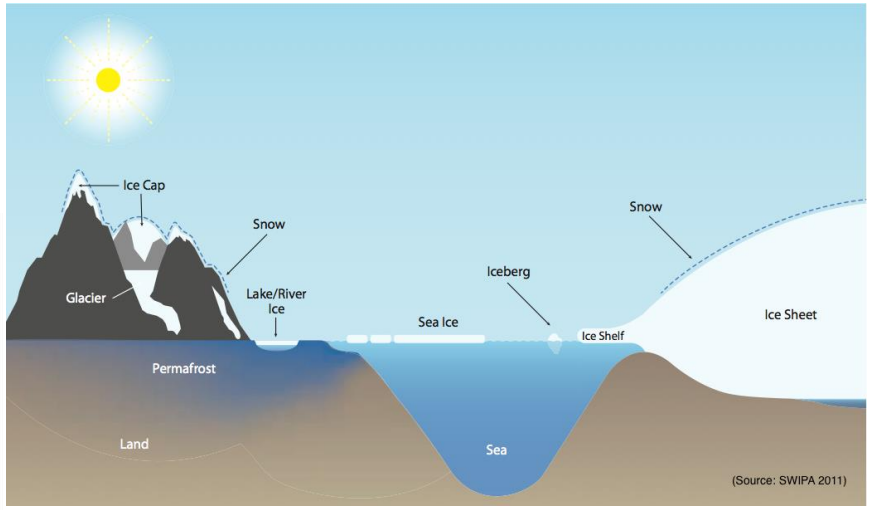
Sarah Kruse
University of South Florida



Near-Surface Geophysical Imaging – top few 100 meters

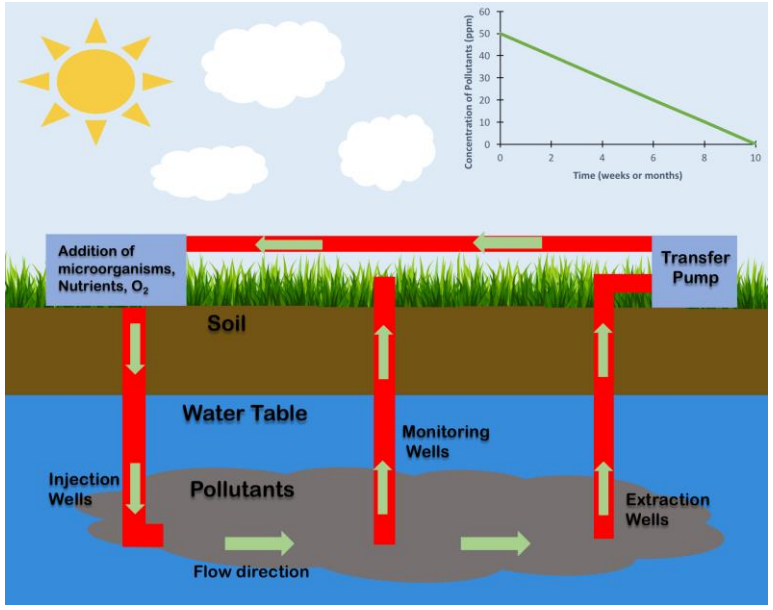


The Critical Zone



The Cryosphere

Natural Hazards
(Iceland this week)



Bioremediation

Near-Surface Geophysical Imaging

Examples of science being done now

- Cryosphere
- Groundwater Hydrology
- Volcanic Hazards
- Filling gaps in measurement scales
  - coverage area - depth
  - coverage area - time
- DEI, social justice

Near-Surface Geophysical Imaging

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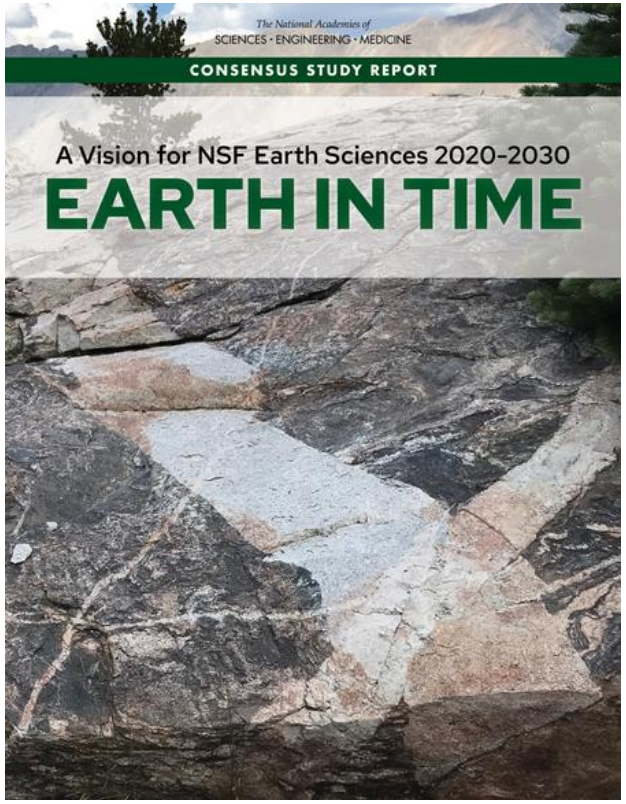
What we could do with a national near-surface geophysics center

Near-Surface Geophysical Imaging

What we could do with a national near-surface geophysics center



Recommendation: [NSF] EAR should fund a Near-Surface Geophysics Center

Near-Surface Geophysical Imaging

Examples of science being done now

What we could do with a national near-surface geophysics center

National Facilities

IRIS (SAGE)
UNAVCO (GAGE)
CTEMPS

Cyberinfrastructure:
CUAHSI
OpenTopo

Near-Surface Geophysical Imaging

4. What is an earthquake?

5. What drives volcanism?

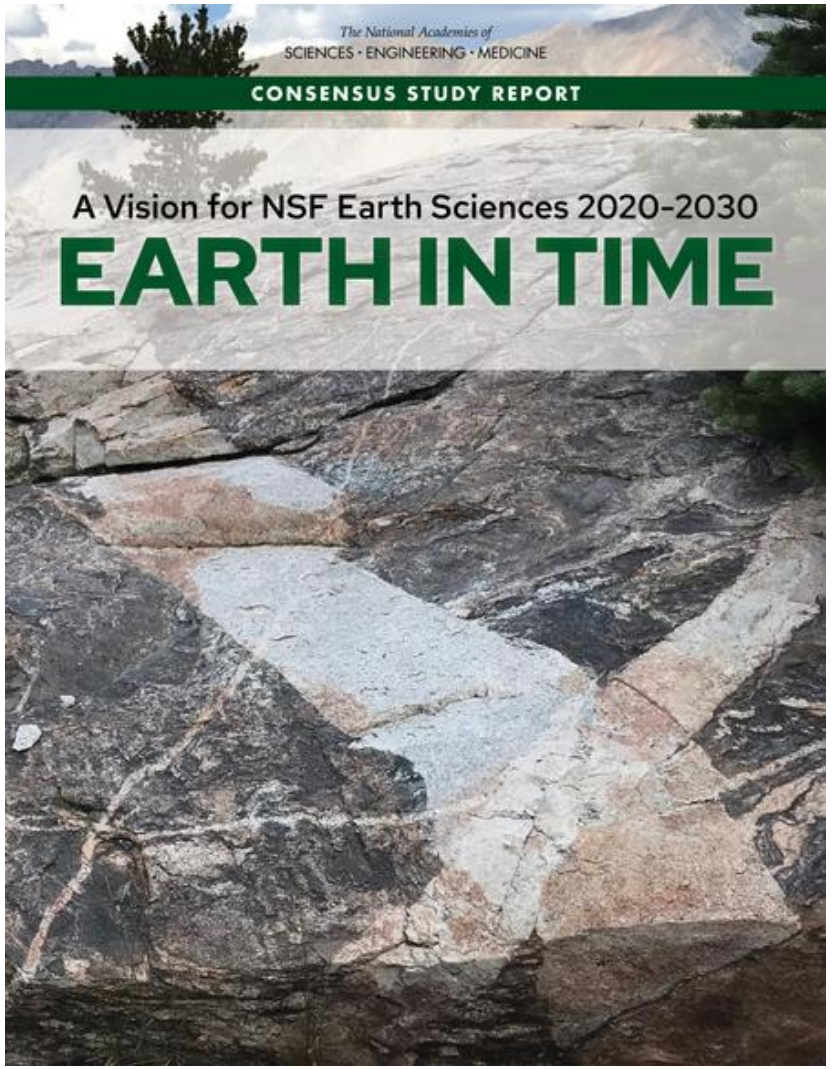
6. What are the causes and consequences of topographic change?

7. How does the critical zone influence climate?

8. What does Earth's past reveal about the dynamics of the climate system?

9. How is Earth's water cycle changing?

12. How can Earth science research reduce the risk and toll of geohazards?



Earthquakes

Volcanoes

Topography

Critical Zone

Climate

Water Cycle

Geohazards

Earthquakes

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Geohazards

GPR ground penetrating radar

ERT electrical **resistivity** tomography

EM electromagnetic methods (induced currents)

NMR nuclear magnetic resonance

IP induced polarization

SP self-potential or spontaneous potential

Seismics

Gravity

Magnetics

Earthquakes

Volcanoes

Topography

Critical Zone

Climate

Water Cycle

Geohazards

Solid Earth Geophysics

~MT

GPR ground penetrating radar

ERT electrical **resistivity** tomography

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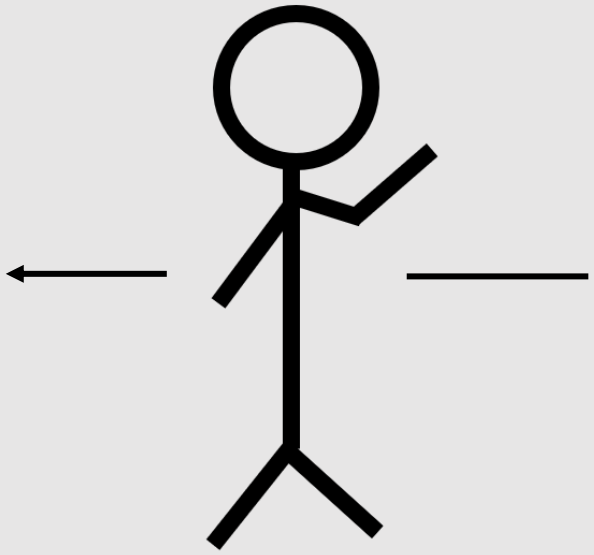
- **Earthquakes**
- **Volcanoes**
- **Topography**
- **Critical Zone**
- **Climate**
- **Water Cycle**
- **Geohazards**



- **GPR** — ground penetrating radar
- **ERT** — electrical **resistivity** tomography
- **EM** — electromagnetic methods (induced currents)
- **NMR** — nuclear magnetic resonance
- **IP** — induced polarization
- **SP** — self-potential or spontaneous potential
- **Seismics**
- **Gravity**
- **Magnetics**

Near-Surface Geophysical Imaging

Examples of science being done now

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What we could do with a national near-surface geophysics center

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Geohazards

The Cryosphere

road damage, permafrost melt, Alaska

The Cryosphere

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Geohazards

- How does liquid water affect snow, glacier, and permafrost dynamics?
- What controls snowpack distribution and water content?
- What controls water movement in the active layer above permafrost?
- What is the distribution and thickness of ice-rich permafrost deposits?
- How are sensitive features like Antarctic lakes and ice shelves evolving?

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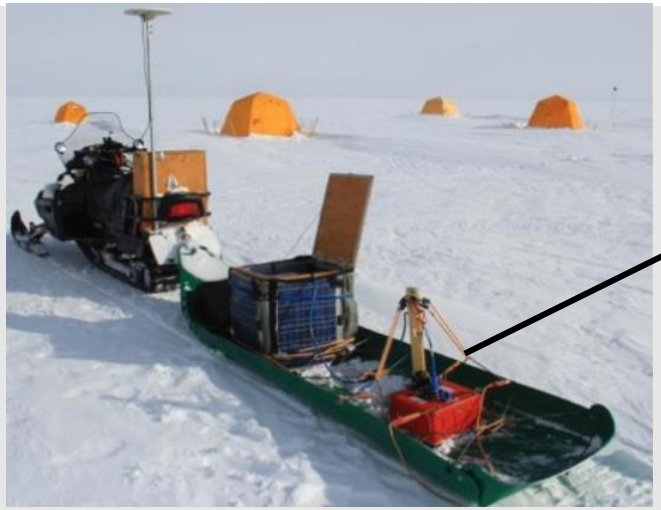

Photos from A. Parsekian, U Wyo

GPR

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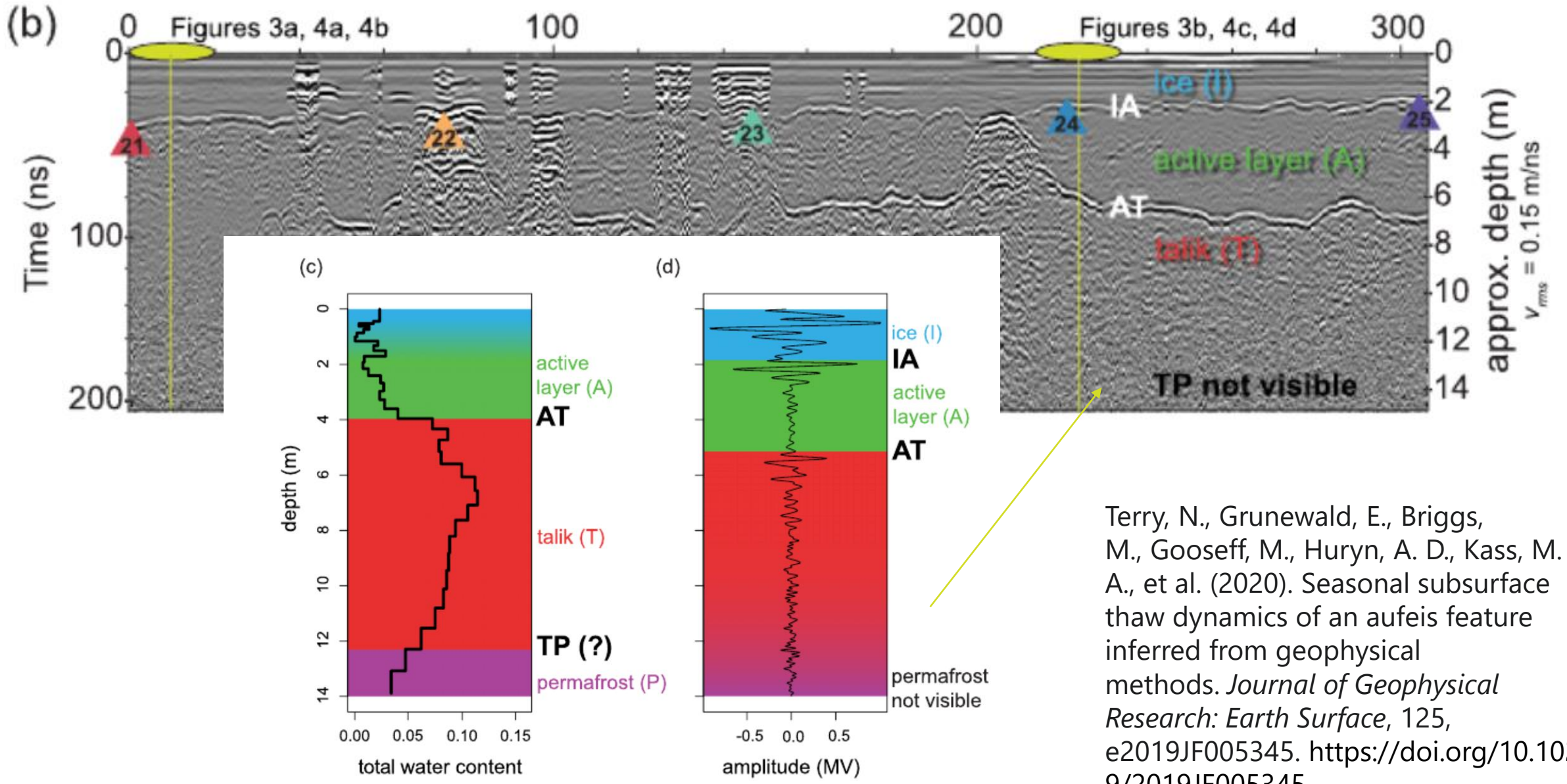
Integrating GPR and NMR to interpret permafrost thaw



Terry, N., Grunewald, E., Briggs, M., Gooseff, M., Huryn, A. D., Kass, M. A., et al. (2020). Seasonal subsurface thaw dynamics of an aufeis feature inferred from geophysical methods. *Journal of Geophysical Research: Earth Surface*, 125, e2019JF005345. https://doi.org/10.1029/2019JF005345

The Cryosphere

Earthquakes

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Research limited by: access

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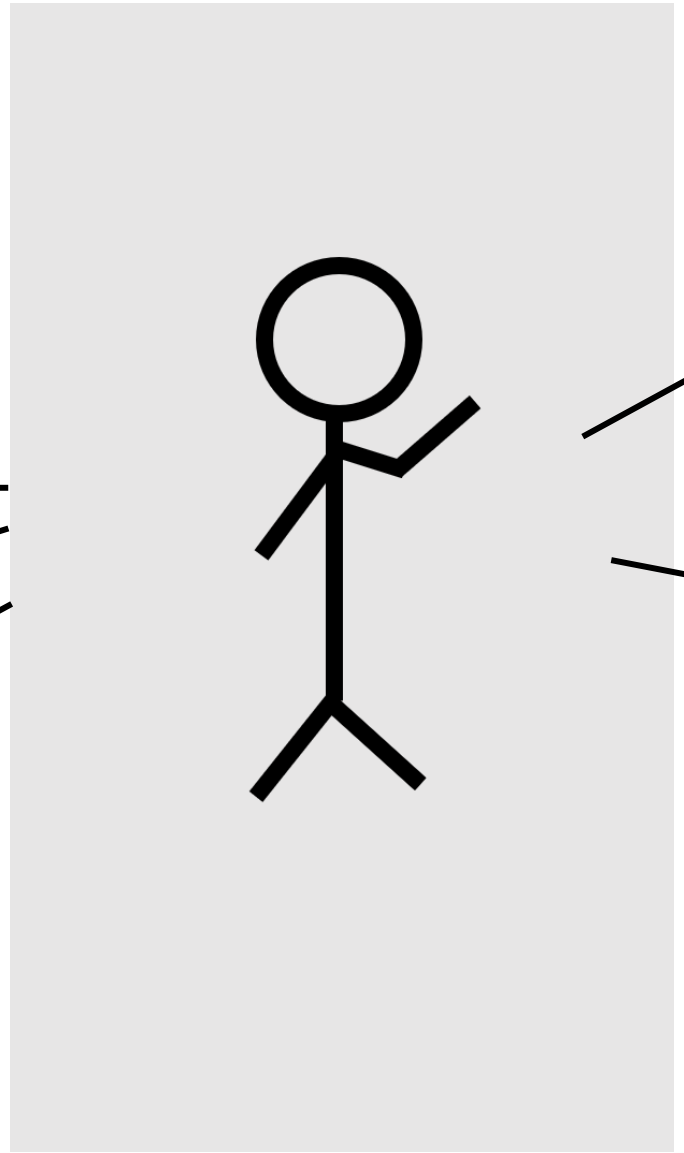

GPR

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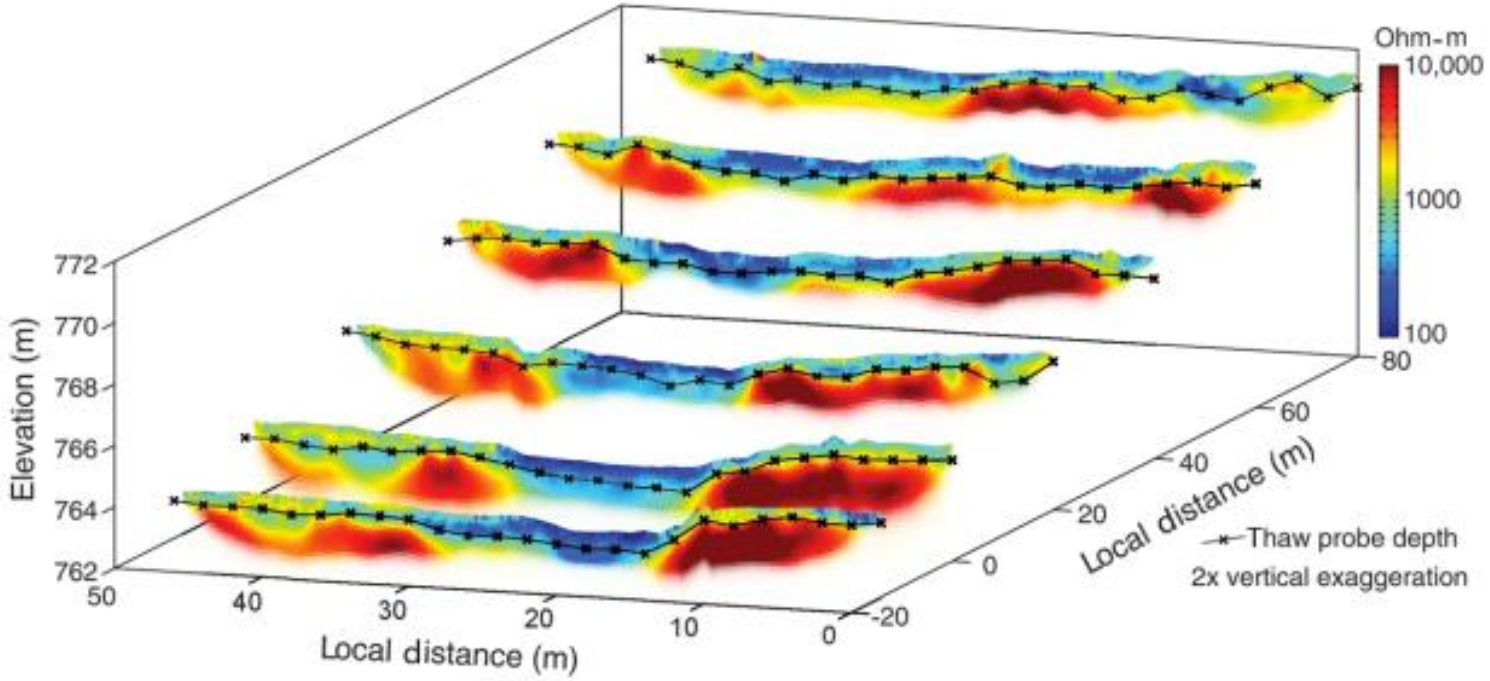
Identifying hydrologic flowpaths on arctic hillslopes



Emily B. Voytek, Caitlin R. Rushlow, Sarah E. Godsey, Kamini Singha; Identifying hydrologic flowpaths on arctic hillslopes using electrical resistivity and self potential. Geophysics 2016;; 81 (1): WA225–WA232. doi: https://doi.org/10.1190/geo2015-0172.1

The Cryosphere

Earthquakes

Volcanoes

Topography

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Community needs example:

- Access
- electrode development

GPR

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Near-Surface Geophysical Imaging

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What we could do with a national near-surface geophysics center

Groundwater Hydrology

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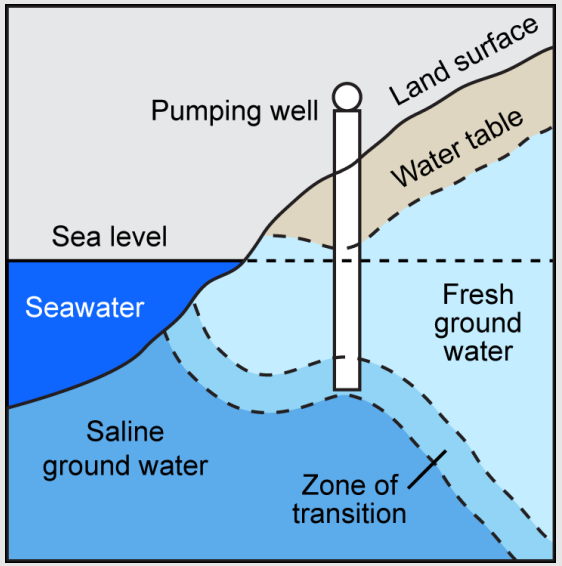
Saltwater intrusion in coastal aquifers



epa.gov

Subsidence from groundwater withdrawal; food security

usgs.gov

Groundwater Hydrology

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Geohazards

Rosemary Knight's
Environmental Geophysics Group,
Stanford

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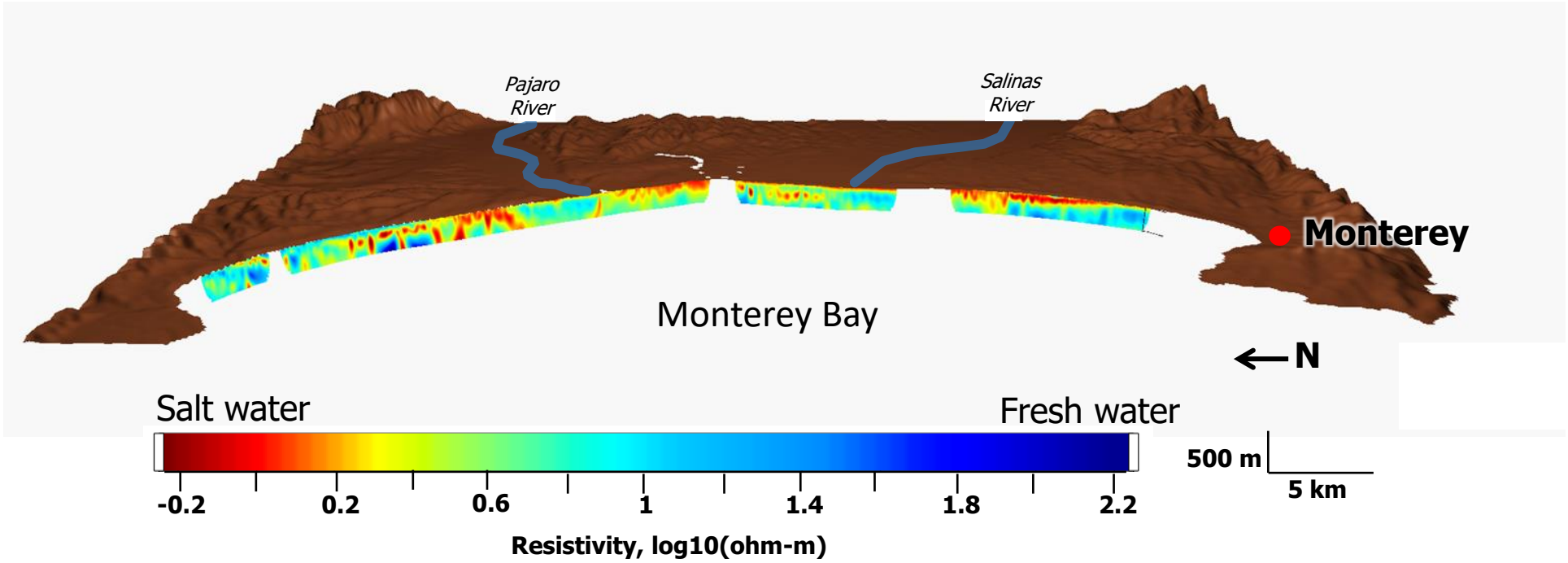
Watershed scale - Saltwater intrusion

Resistivity to a depth of ~ 300 m, over ~40 km



Goebel, M., Knight, R., Pidlisecky, A., Resistivity imaging reveals complex pattern of saltwater intrusion along Monterey Coast, *J. of Hydrology*, 2017.

Rosemary Knight's
Environmental Geophysics Group,
Stanford

Central Valley of CA

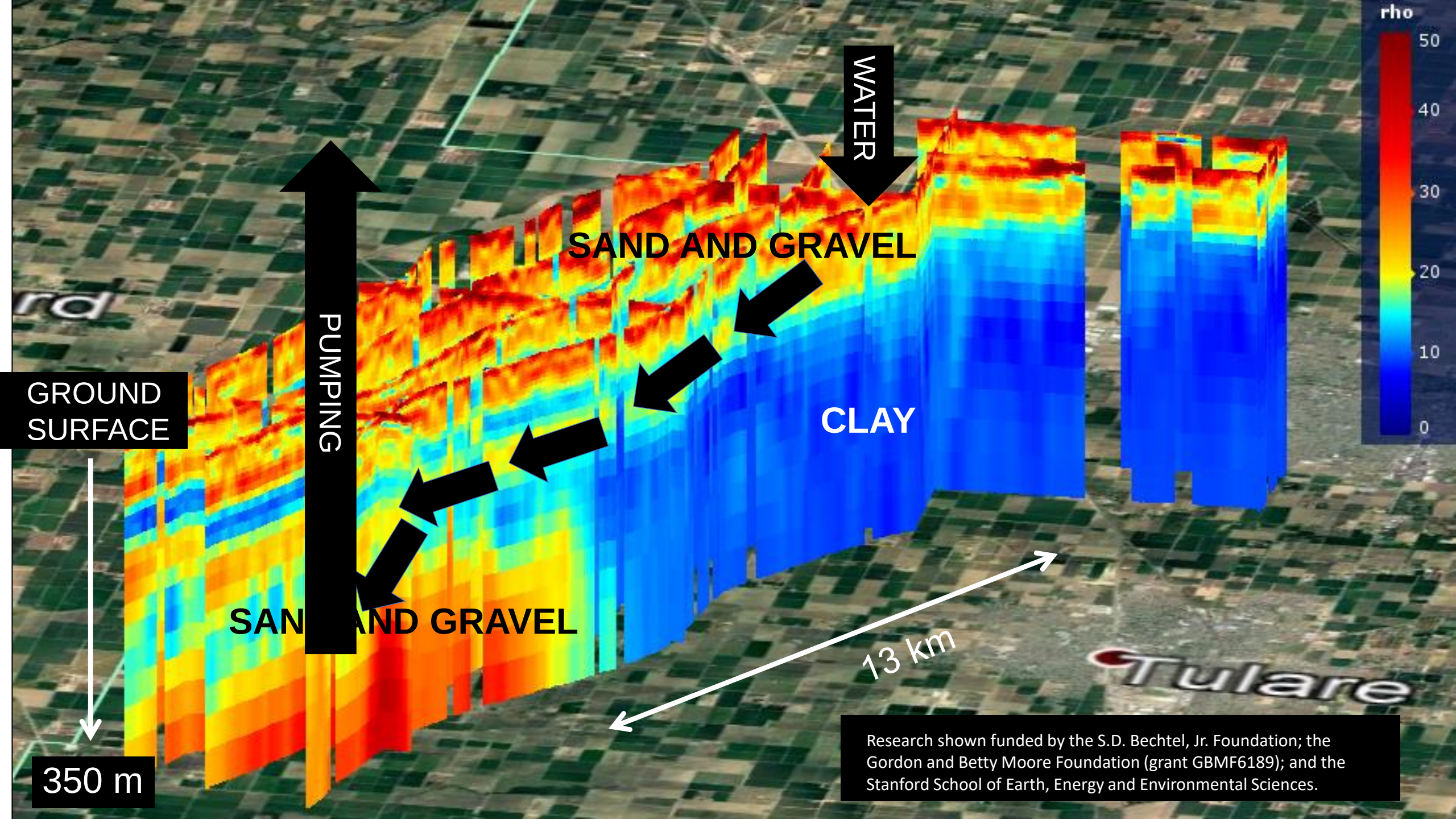
InSAR Data
Jan 2015 – Sept 2019:
Total subsidence up to 1.3 m / 4.3 ft

Over-pumping – water levels declining

Impact on infrastructure – including the aqueducts moving the surface water

Rosemary Knight's
Environmental Geophysics Group,
Stanford

Watershed scale



Research shown funded by the S.D. Bechtel, Jr. Foundation; the Gordon and Betty Moore Foundation (grant GBMF6189); and the Stanford School of Earth, Energy and Environmental Sciences.

Groundwater Hydrology

Earthquakes

Volcanoes

Topography

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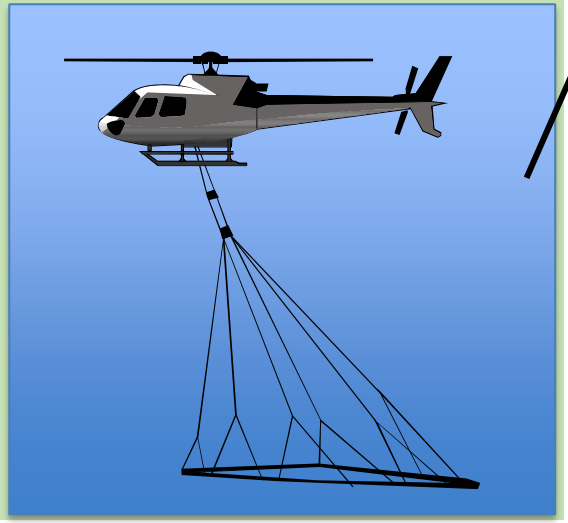
Geohazards

Research limited by:

- Data quality metrics
- Open-source software for experiment design
- Data repository



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Near-Surface Geophysical Imaging

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What we could do with a national near-surface geophysics center

Volcanic Hazards

Earthquakes

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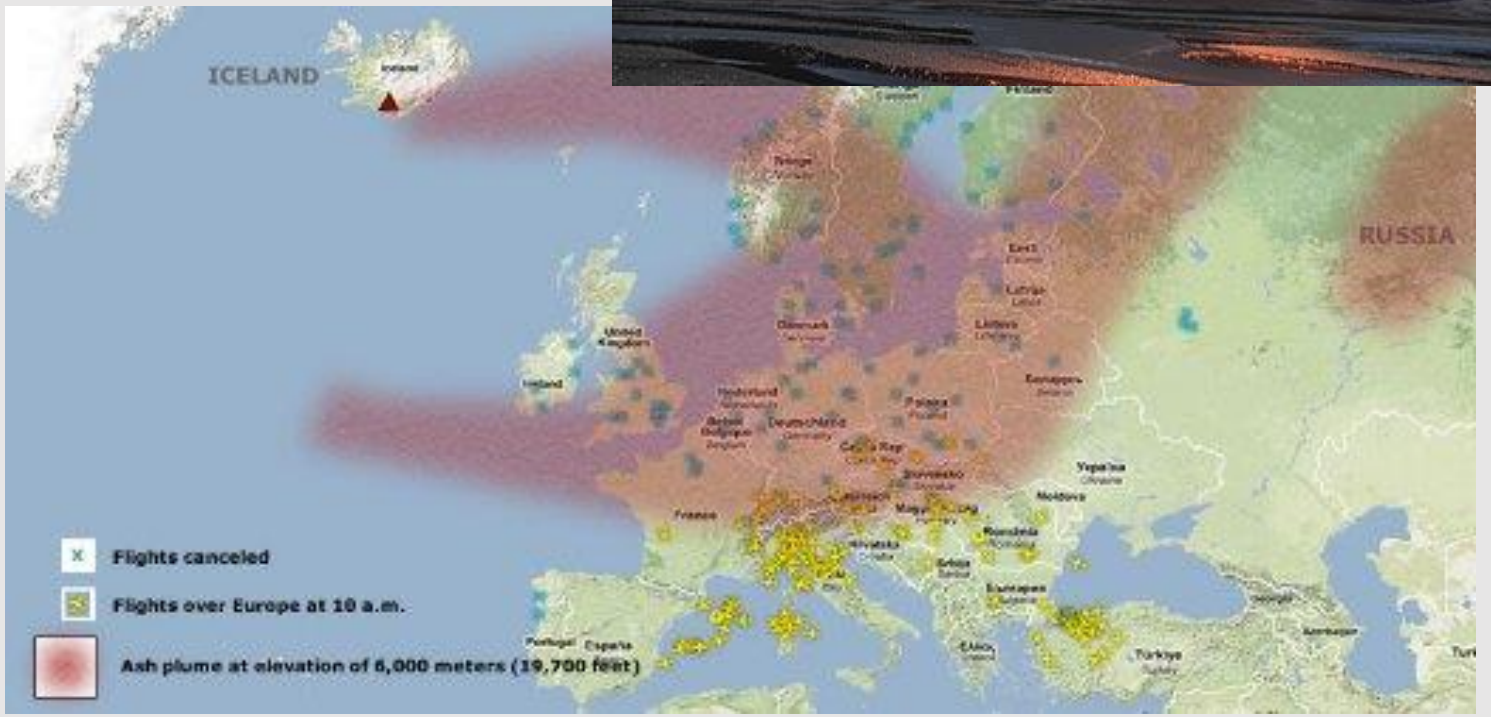
Hazard Assessments-

- eruption explosivity
- ash plumes



Earthquakes

Volcanoes

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Geohazards

Volcanic Hazards

- Do eruption and transport models explain the distribution of ash deposits from violent eruptions?
- How does volcano stratigraphy affect erosion?
- Can we recover the explosivity of past eruptions from shallow stratigraphy?
- Can expansion of the monitoring toolkit improve eruption forecasting?

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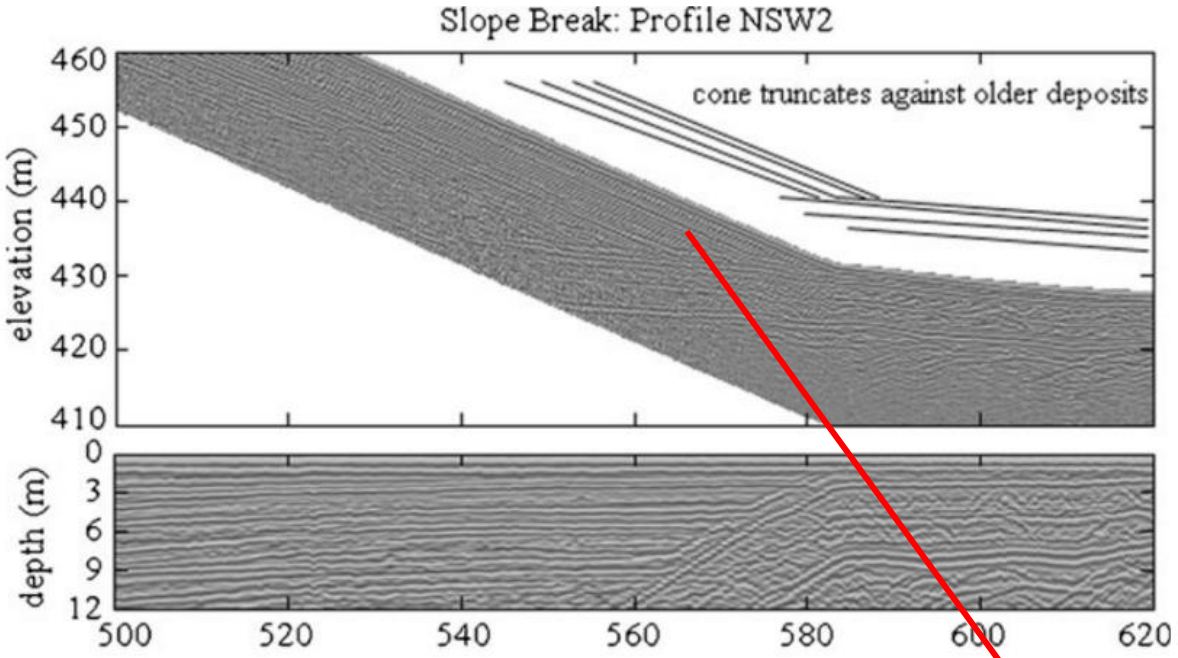
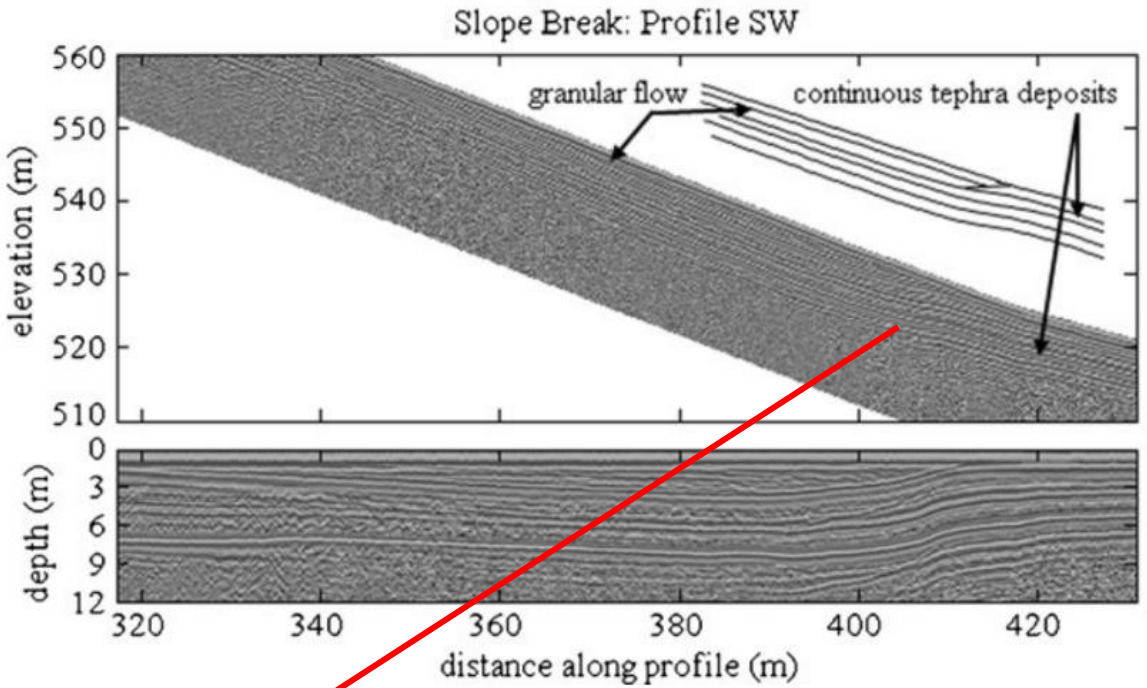
Volcanic Hazards

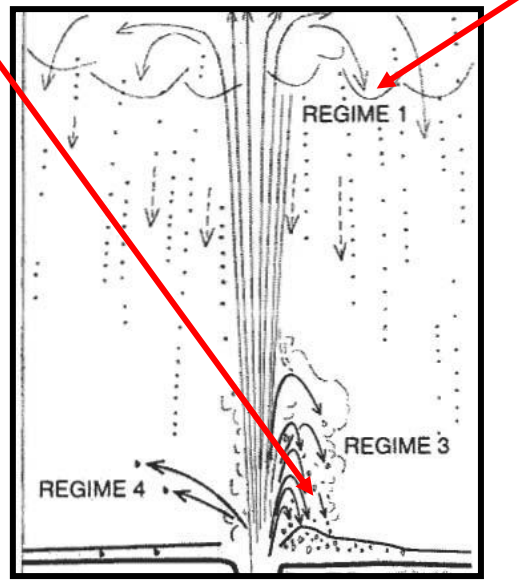
23 eruptions since 1850

Cerro Negro, Nicaragua

Volcanic Hazards







L. Courtland, S. Kruse, C. Connor, Violent Strombolian or not? Using ground-penetrating radar to distinguish deposits of low- and high-energy scoria eruptions, Bull. Volc, 75:760 (2013)

Houghton et al. (2004)

Volcanic Hazards

Earthquakes

Volcanoes

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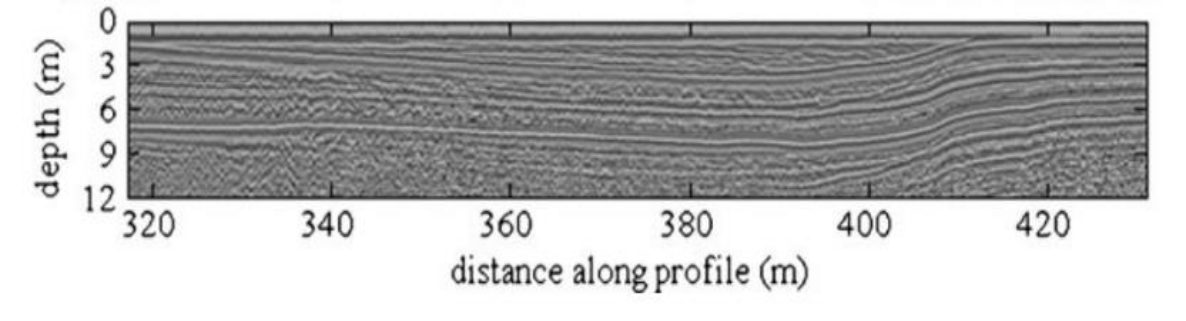
Geohazards

Community needs example:

GPR gives: layer thickness



Hazard assessor wants: kg/m^2 ash landed

Need porosity

- -correct for water content
- -need NMR or seismics
- -better with multi-offset GPR

→ **broader access to equipment**

GPR

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Near-Surface Geophysical Imaging

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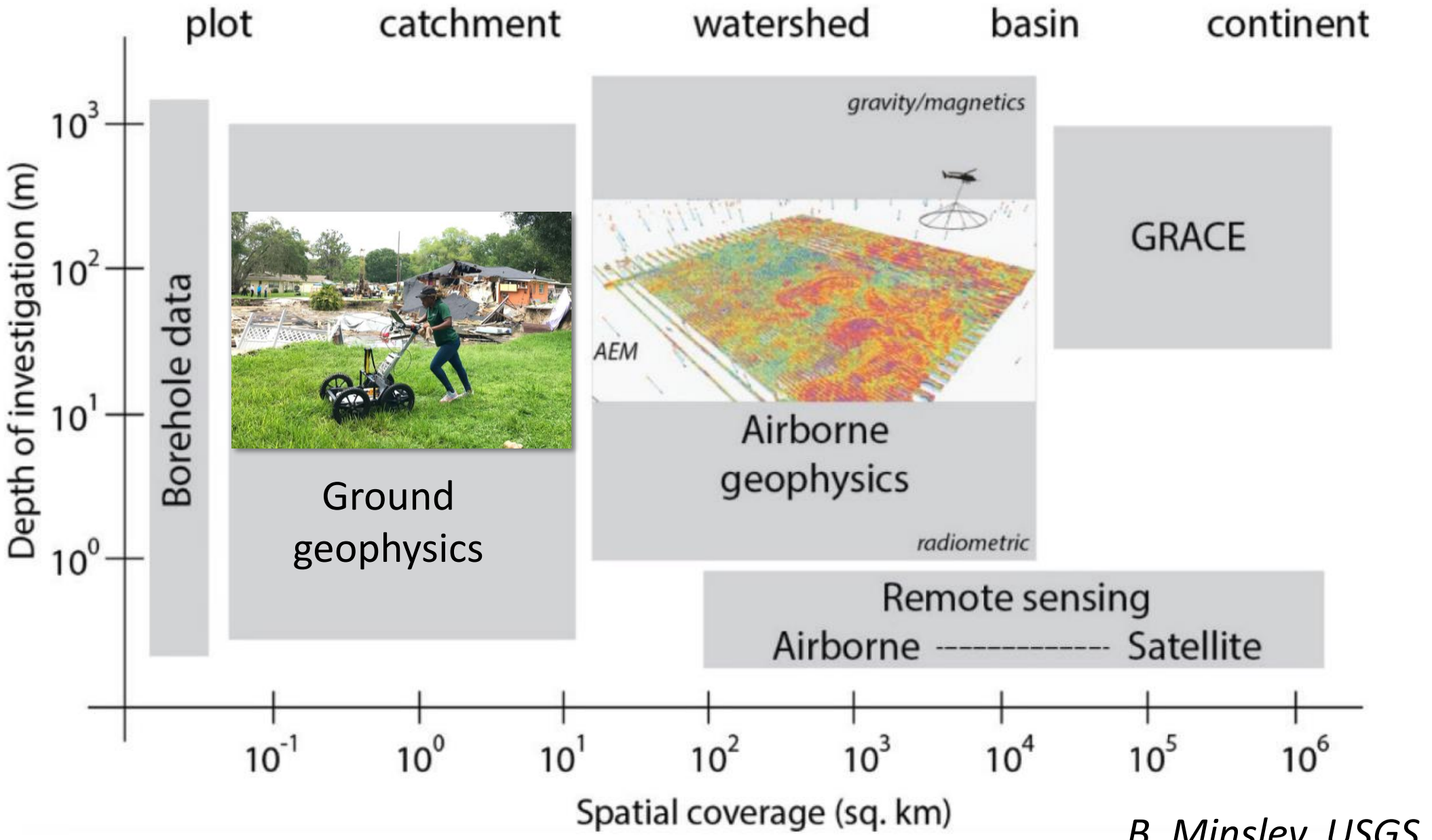
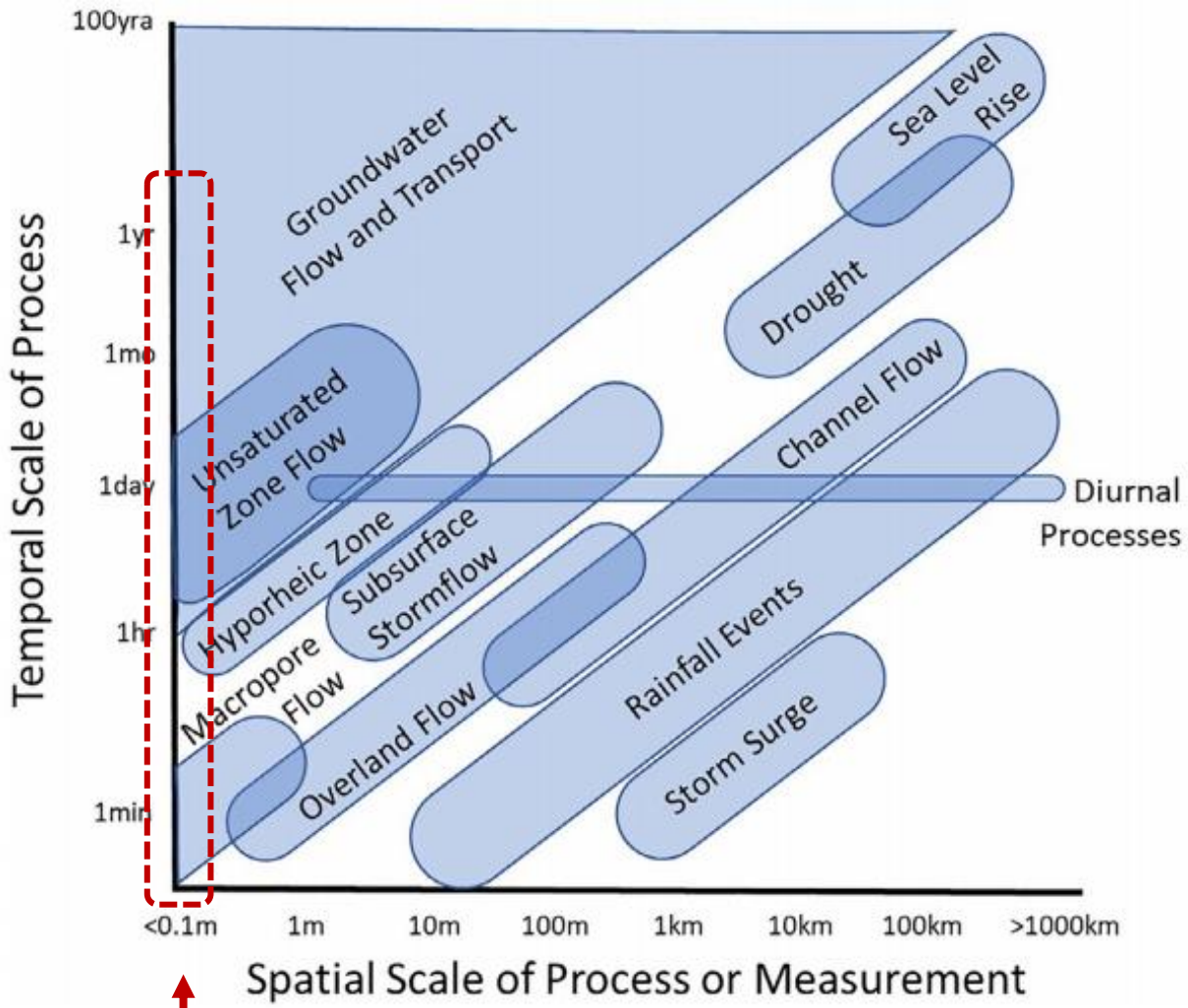


B. Minsley, USGS

Validating Remote Sensing Observations of Permafrost Active Layer Thickness

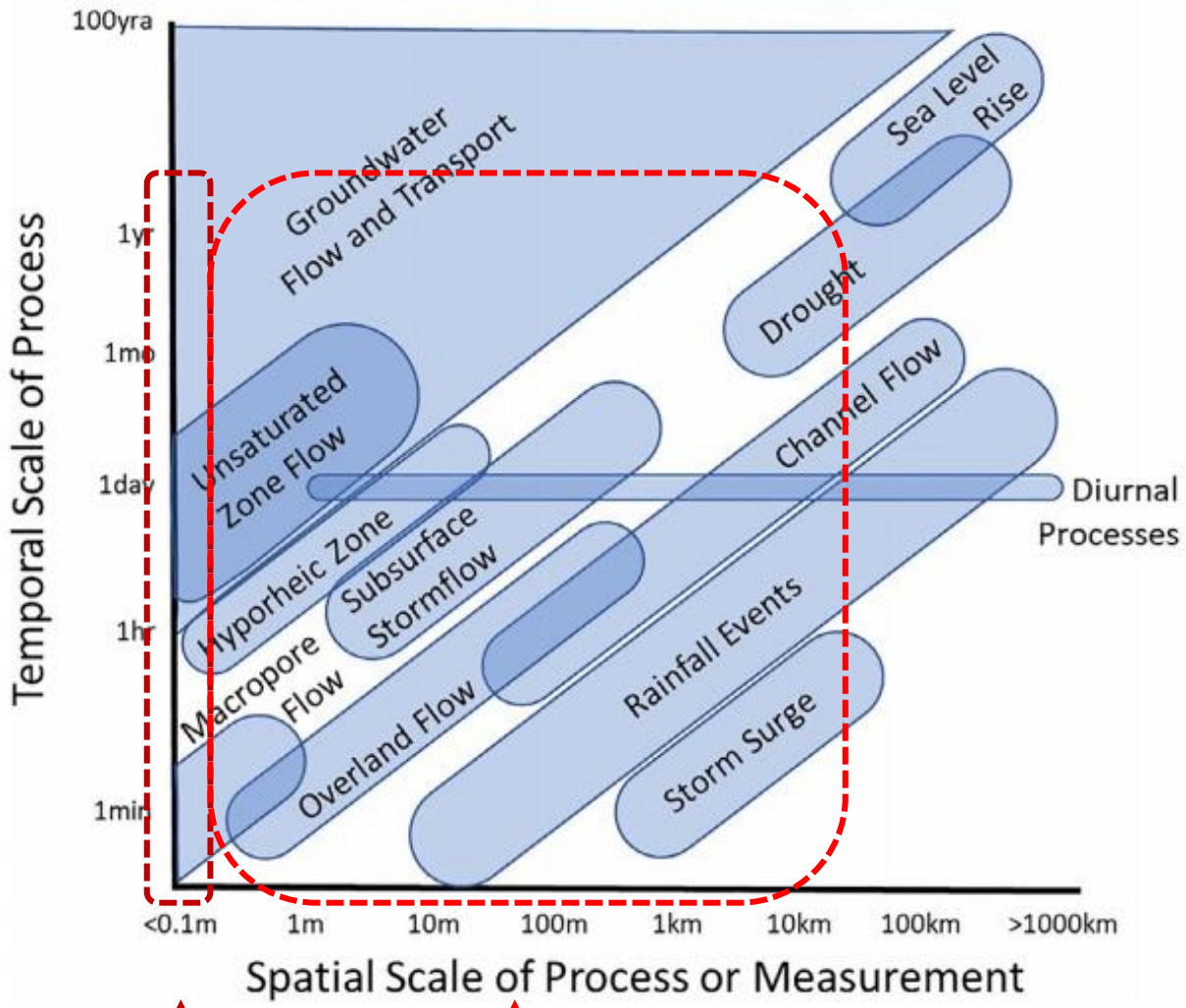
Schaefer, K., Liu, L., Parsekian, A., Jafarov, E., Chen, A., Zhang, T., ... & Schaefer, T. (2015). Remotely sensed active layer thickness (ReSALT) at Barrow, Alaska using interferometric synthetic aperture radar. *Remote Sensing*, *7*(4), 3735-3759.

From A. Parsekian



logging sensor

From S. Moysey, 2021, Encyclopedia of Geology, Hydrogeophysics, p. 477-494, Elsevier.



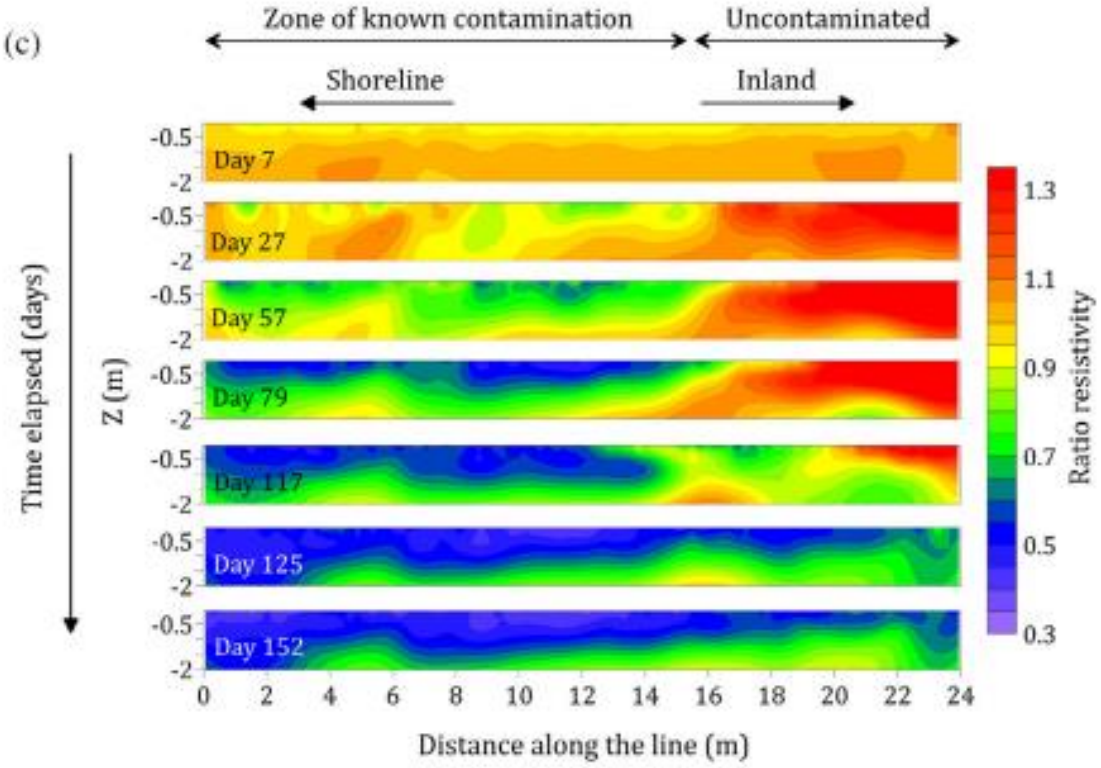
logging sensor

networks of sensors or geophysical monitoring

From S. Moysey, 2021, Encyclopedia of Geology, Hydrogeophysics, p. 477-494, Elsevier.

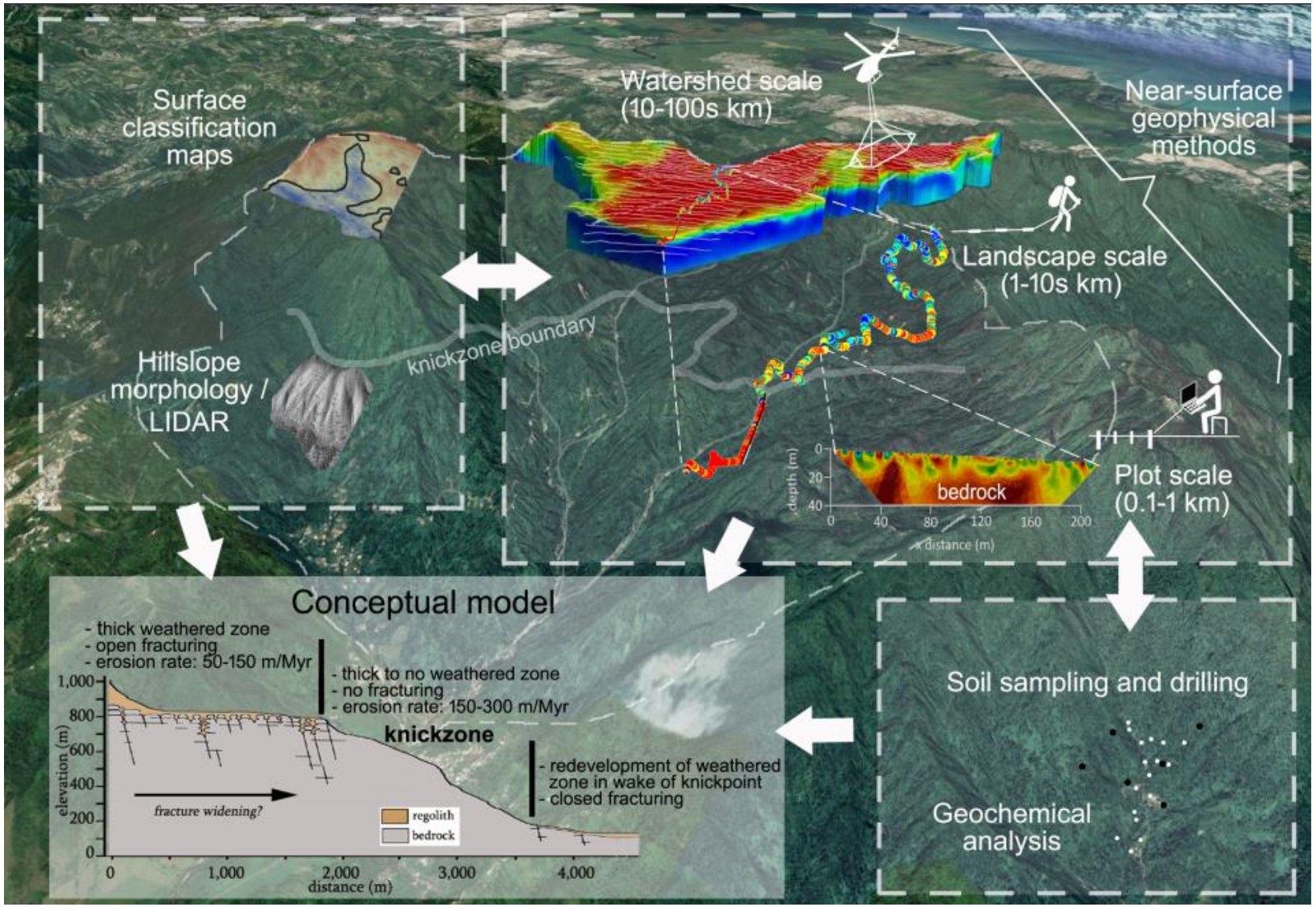
2D time-lapse resistivity monitoring

Natural attenuation of oil in sediments after the BP oil spill, Louisiana



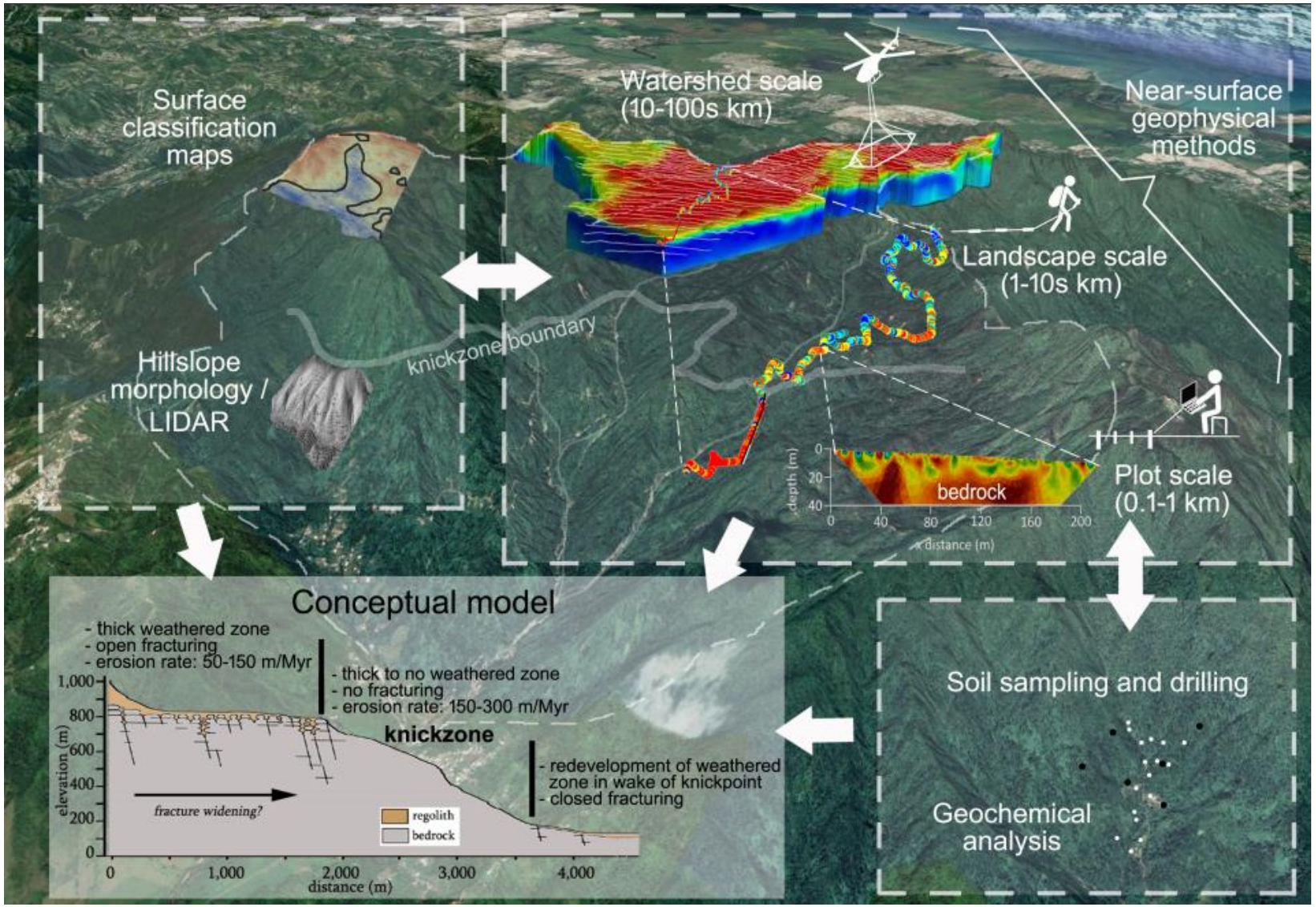
Heenan et al. (2014) modified in Slater and Binley (2020), Advancing hydrological process understanding from long-term resistivity monitoring systems, WIREs Water, doi.org/10.1002/wat2.1513

3D coverage in complex terrain



From Xavier Comas, FAU

3D coverage in complex terrain



- Airborne EM expensive
- Resistivity systems require cabling

From Xavier Comas, FAU

3D spatial + temporal coverage of resistivity in complex terrain

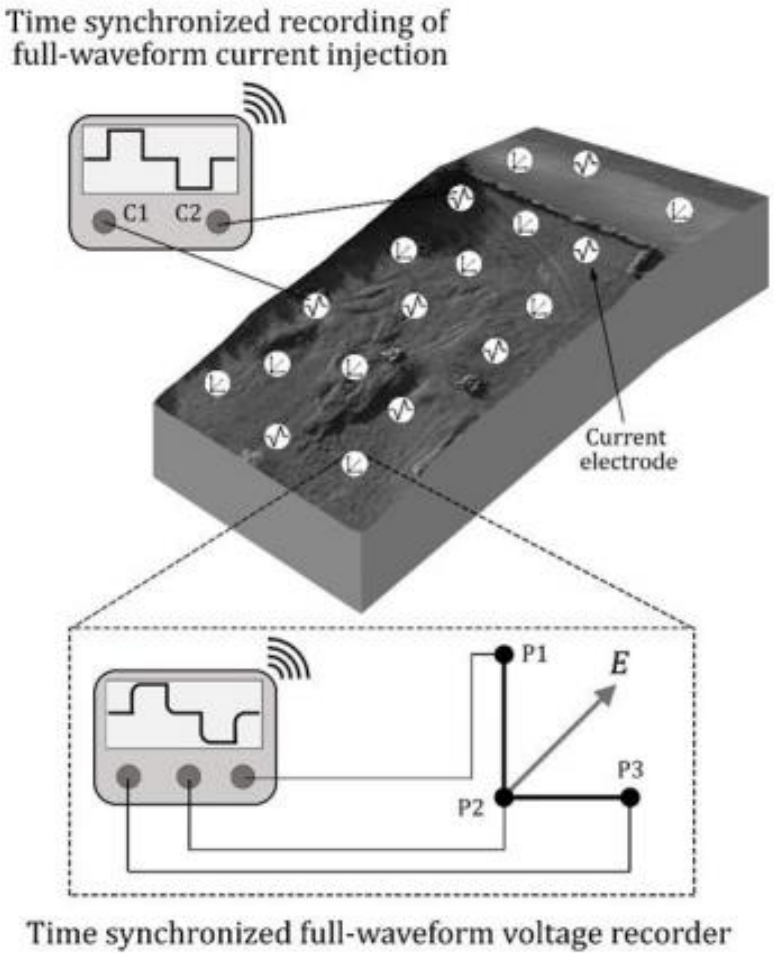


Fig. 1. Concept of 3D resistivity and IP imaging using a fully distributed system.

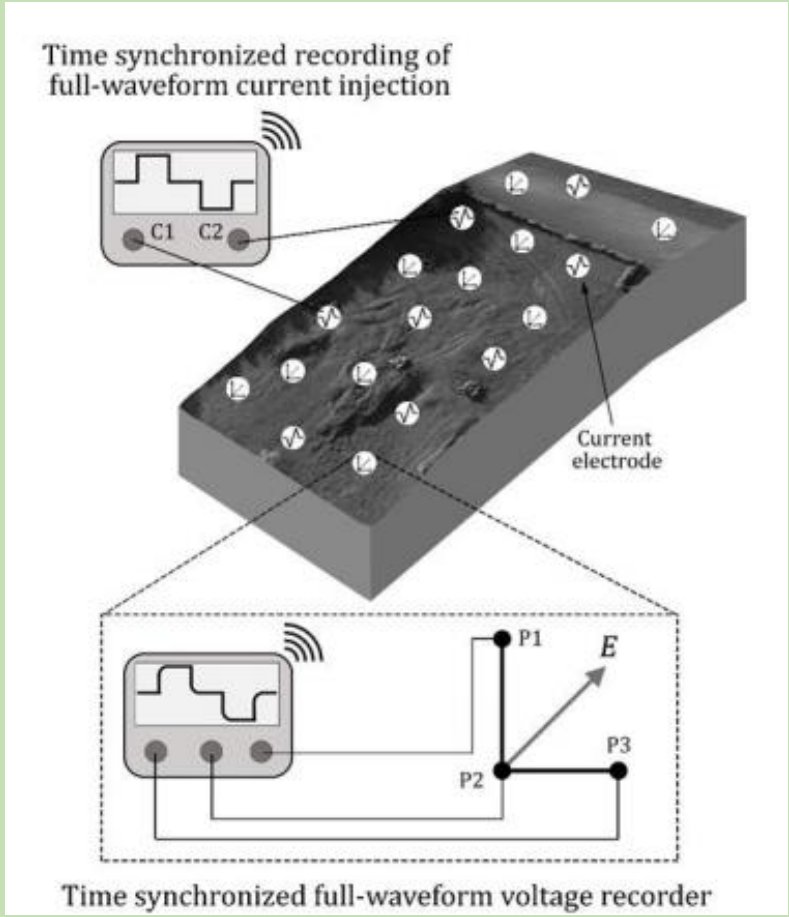
From L. Slater and C. Zhang, Next generation electrical imaging instrumentation for characterization and monitoring of the near surface Earth, white paper to NSF, 2020, following Truffert et al. (2019) https://doi.org/10.1190/GEM2019-032.1

Filling gaps in measurement scales

- Earthquakes
- Volcanoes
- Topography
- Critical Zone
- Climate
- Water Cycle
- Geohazards

Community needs example:

- Community input on instrument development



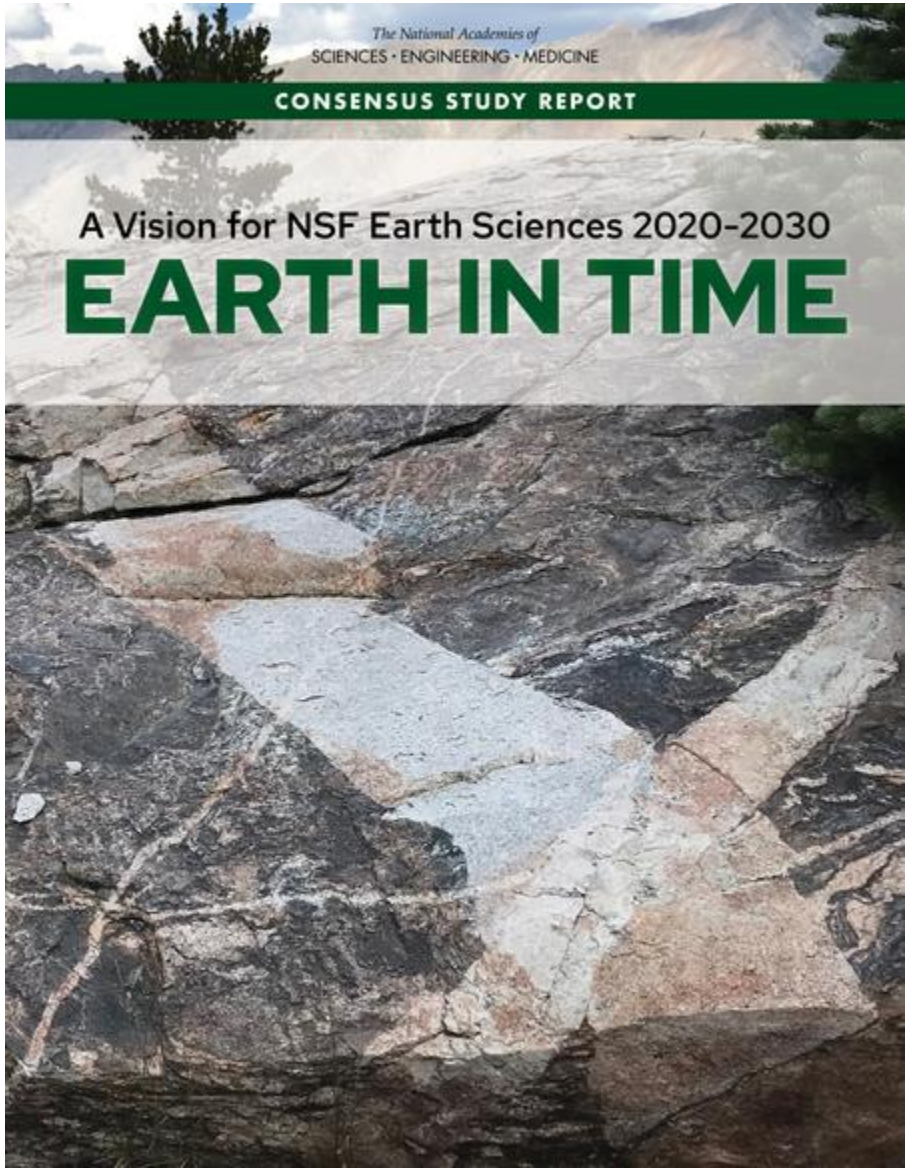
- GPR
- ERT
- EM
- NMR
- IP
- SP
- Seismics
- Gravity
- Magnetics

Near-Surface Geophysical Imaging

Examples of science being done now

- Cryosphere
- Groundwater Hydrology
- Volcanic Hazards
- Filling gaps in measurement scales
  - coverage area - depth
  - coverage area - time
- **DEI, social justice**

What we could do with a national near-surface geophysics center



Recommendation: EAR should enhance … investment … to improve diversity, equity, and inclusion within the Earth science community.

Photo from Jorden Hayes, Dickinson College

uaries Sports Opinion Entertainment Lifestyles E-edition Buy & Sell

LIVE NFL live: Follow the latest scores and update

Photos: Dickinson College students survey Mount Holly Springs cemeteries

Mar 29, 2018

Dickinson College students use ground penetrating radar Wednesday to pinpoint the locations of bodies buried in two in Mount Holly Springs.

Mount Holly Springs Cemetery Survey

DEI, Social Justice

Community needs:

- Broader access to basic instrumentation
  - HBCUs, many institutions without endowments can't afford commercial rental rates
- Training
- Teaching materials

Photo from K. Keating

GPR

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Conclusions

Examples of science being done now

- **Cryosphere**
- **Groundwater Hydrology**
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  - **coverage area - depth**
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Earthquakes

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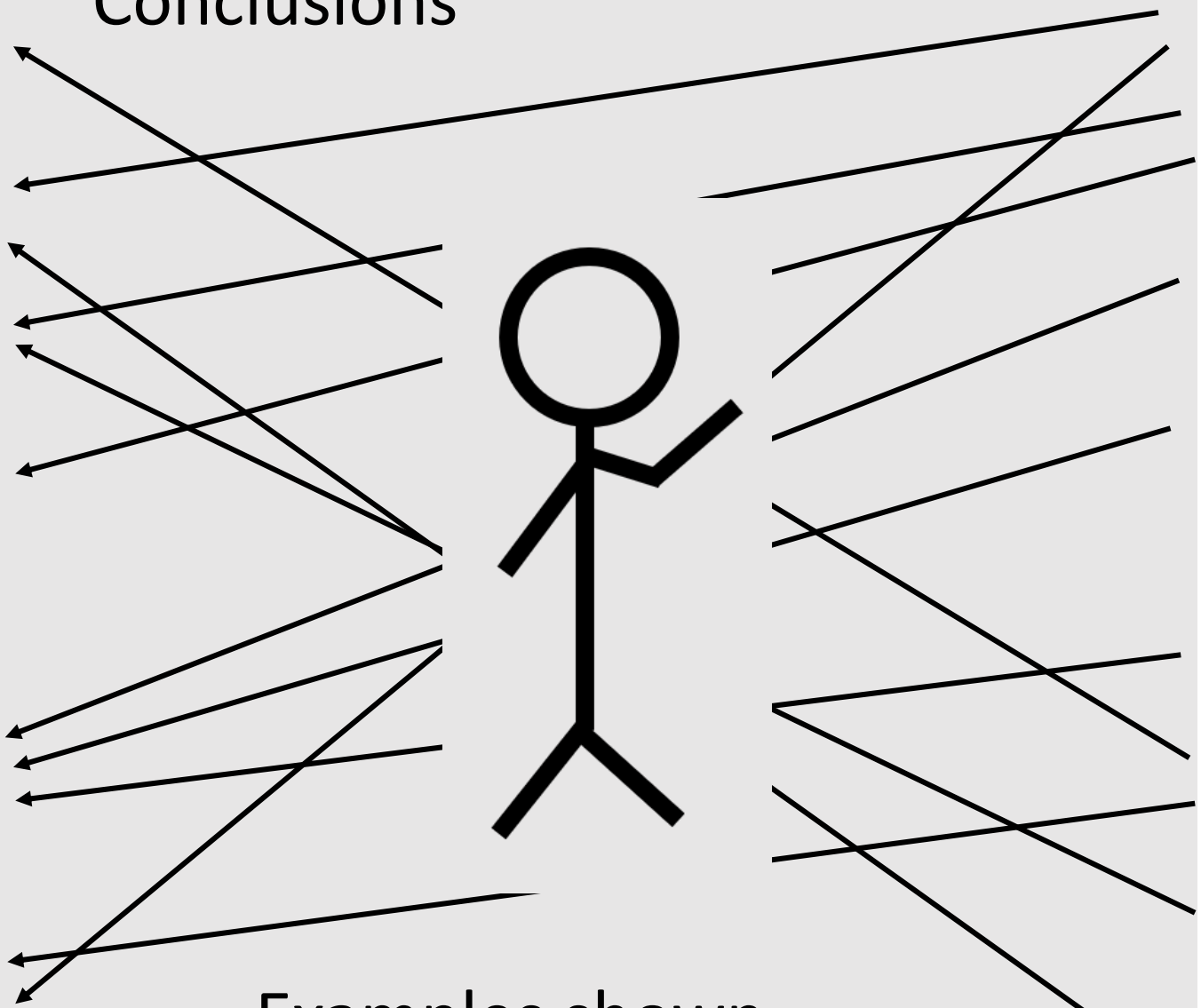

Examples shown –
a small subset of NS science

GPR

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- **Groundwater Hydrology**
- **Volcanic Hazards**
- **Filling gaps in measurement scales**
  - **coverage area - depth**
  - **coverage area - time**
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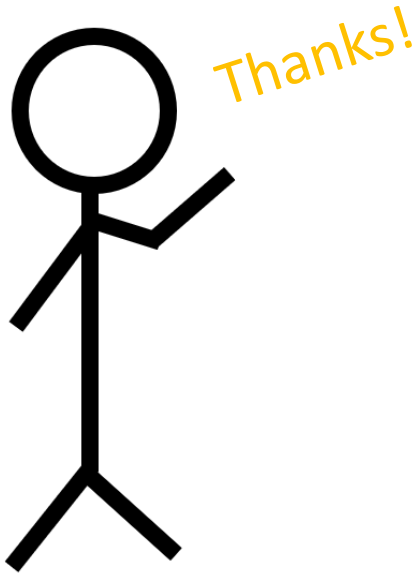
Near-surface science would be accelerated by investments in-

- Broader access to both basic and high-end equipment and training
  -> *transformative research will involve*
  integrated methods
  multi-scale data
- Methods and equipment development
  -> machine learning, inversion
- Open-source software
- Data quality metrics, data repositories



Contributors to this presentation:

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Rosemary Knight, *Stanford*
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Andy Parsekian, *University of Wyoming*
Kamini Singha, *Colorado School of Mines*
Lee Slater, *Rutgers-Newark*