What Is Geophysics?

Three Motivations · Five Physics Domains · Stakeholder Landscape

ESS 314 — Geophysics | Lecture 1 | March 31, 2026

Marine Denolle · University of Washington

Learning Objectives

By the end of this lecture:

- **[LO-1.1]** State a precise definition of solid Earth geophysics and explain why indirect observation is the defining epistemological constraint
- **[LO-1.2]** Classify any geophysical study into geodynamics, hazards, or resource management — with process and observable named
- **[LO-4.1]** Identify the physics domain governing a given observable and the Earth property it senses
- **[LO-6.1]** Identify four stakeholder communities and their distinct requirements from geophysical knowledge

A Planet We Can Only See the Surface Of

Everything we know about what lies beneath was inferred — not sampled.

> *Seismic waves, gravity, magnetics, heat flow: physics as a telescope pointed inward.*

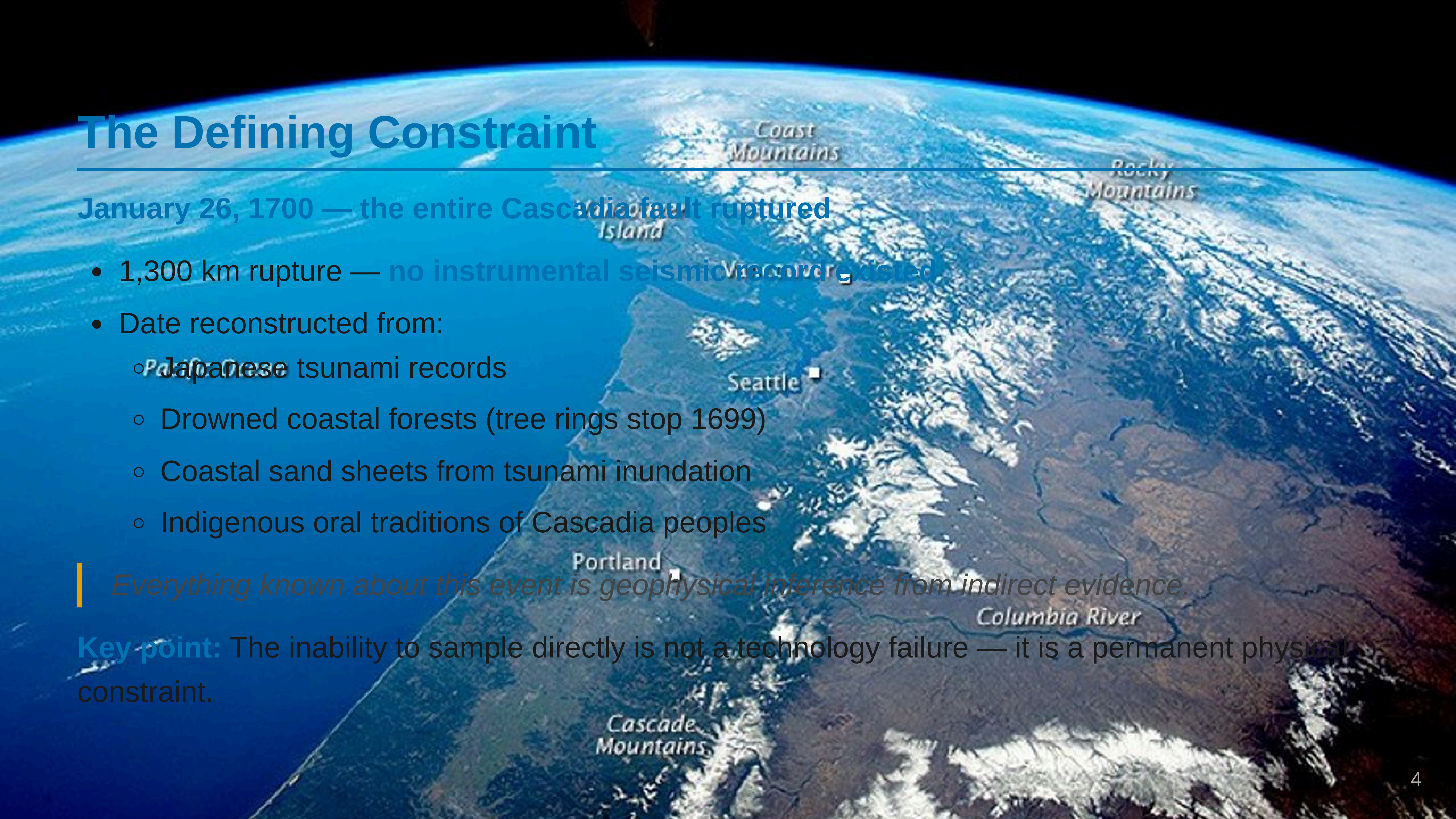
The Defining Constraint

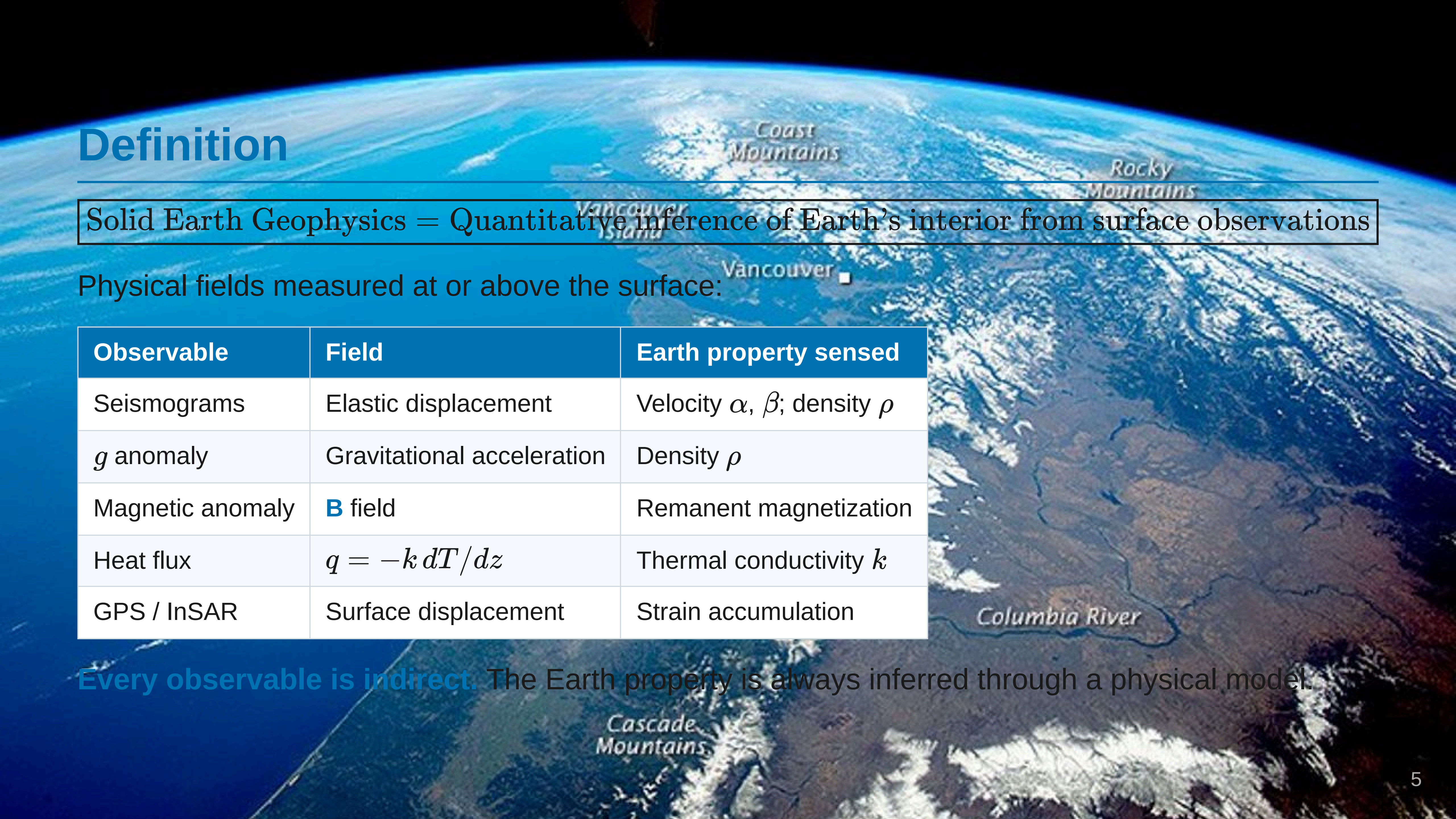
January 26, 1700 — the entire Cascadia fault ruptured

- 1,300 km rupture — **no instrumental seismic record existed**
- Date reconstructed from:
  - Japanese tsunami records
  - Drowned coastal forests (tree rings stop 1699)
  - Coastal sand sheets from tsunami inundation
  - Indigenous oral traditions of Cascadia peoples

> *Everything known about this event is geophysical inference from indirect evidence.*

Key point: The inability to sample directly is not a technology failure — it is a permanent physical constraint.





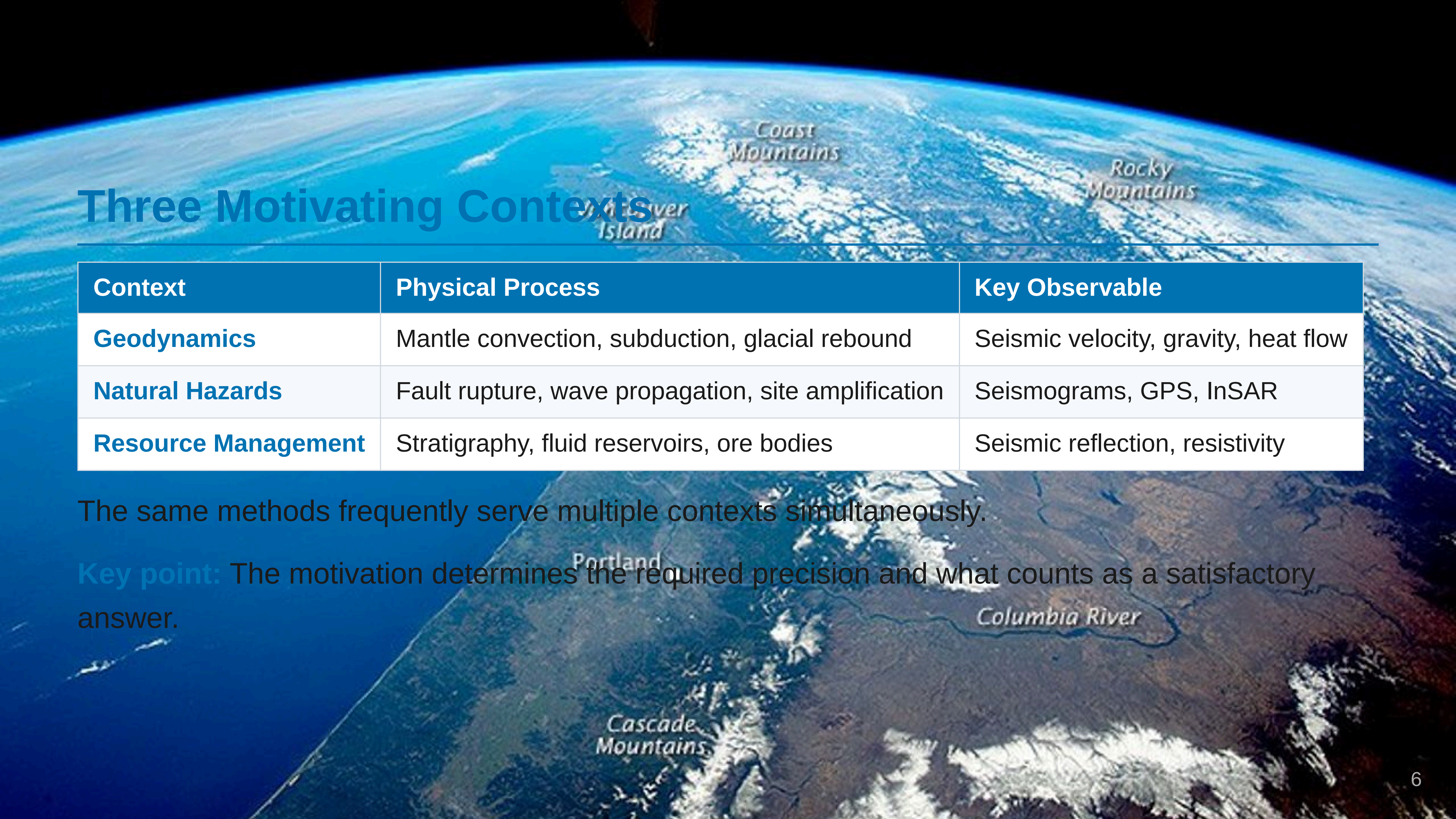
Definition

Solid Earth Geophysics = Quantitative inference of Earth's interior from surface observations

Physical fields measured at or above the surface:

Observable	Field	Earth property sensed
Seismograms	Elastic displacement	Velocity α, β; density ρ
g anomaly	Gravitational acceleration	Density ρ
Magnetic anomaly	**B** field	Remanent magnetization
Heat flux	$q = -k\, dT/dz$	Thermal conductivity k
GPS / InSAR	Surface displacement	Strain accumulation

Every observable is indirect. The Earth property is always inferred through a physical model.



Three Motivating Contexts

Context	Physical Process	Key Observable
Geodynamics	Mantle convection, subduction, glacial rebound	Seismic velocity, gravity, heat flow
Natural Hazards	Fault rupture, wave propagation, site amplification	Seismograms, GPS, InSAR
Resource Management	Stratigraphy, fluid reservoirs, ore bodies	Seismic reflection, resistivity

The same methods frequently serve multiple contexts simultaneously.

Key point: The motivation determines the required precision and what counts as a satisfactory answer.

Geodynamics: How the Planet Works

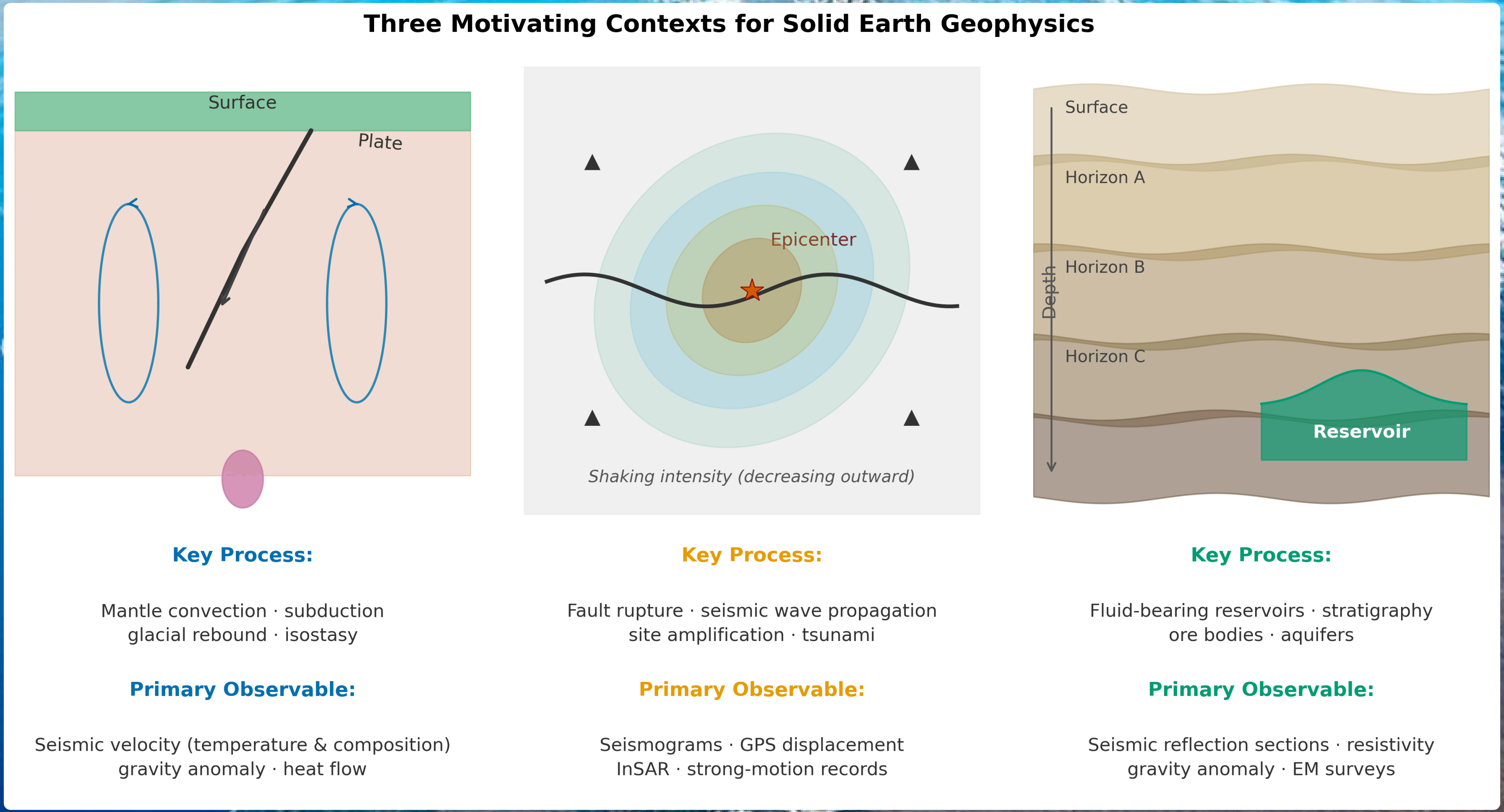


Figure 1.1 — Three motivating contexts. Python-generated: `assets/scripts/fig_three_motivations.py`

- Juan de Fuca Plate subducts at ~3 cm/yr — **measured by GPS, not drilling**

Natural Hazards: Physics for Public Safety

- **ShakeAlert** (Alaska → California): real-time P-wave detection → shaking estimate → warning before S-wave arrives
- Lead time: seconds to tens of seconds
  - Slow high-speed trains · open fire station doors · trigger industrial shutoffs

Uncertainty matters directly:

> *Underestimate shaking → inadequate building design → casualties*
> *Overestimate shaking → wasted resources, public distrust*

Key point: The wave propagation physics in Weeks 2–5 is the direct scientific foundation for this operational system.

Resource Management: Knowing What Is Underground

- Before drilling: **seismic reflection surveys** image stratigraphy kilometers below the seafloor
  - Marine airguns → elastic pulses → reflections off rock interfaces → subsurface image
- Same methods now serve the clean-energy transition:
  - Geothermal resource assessment
  - Critical minerals for batteries
  - CO_2 storage monitoring

Global exploration geophysics: **tens of billions of dollars annually**

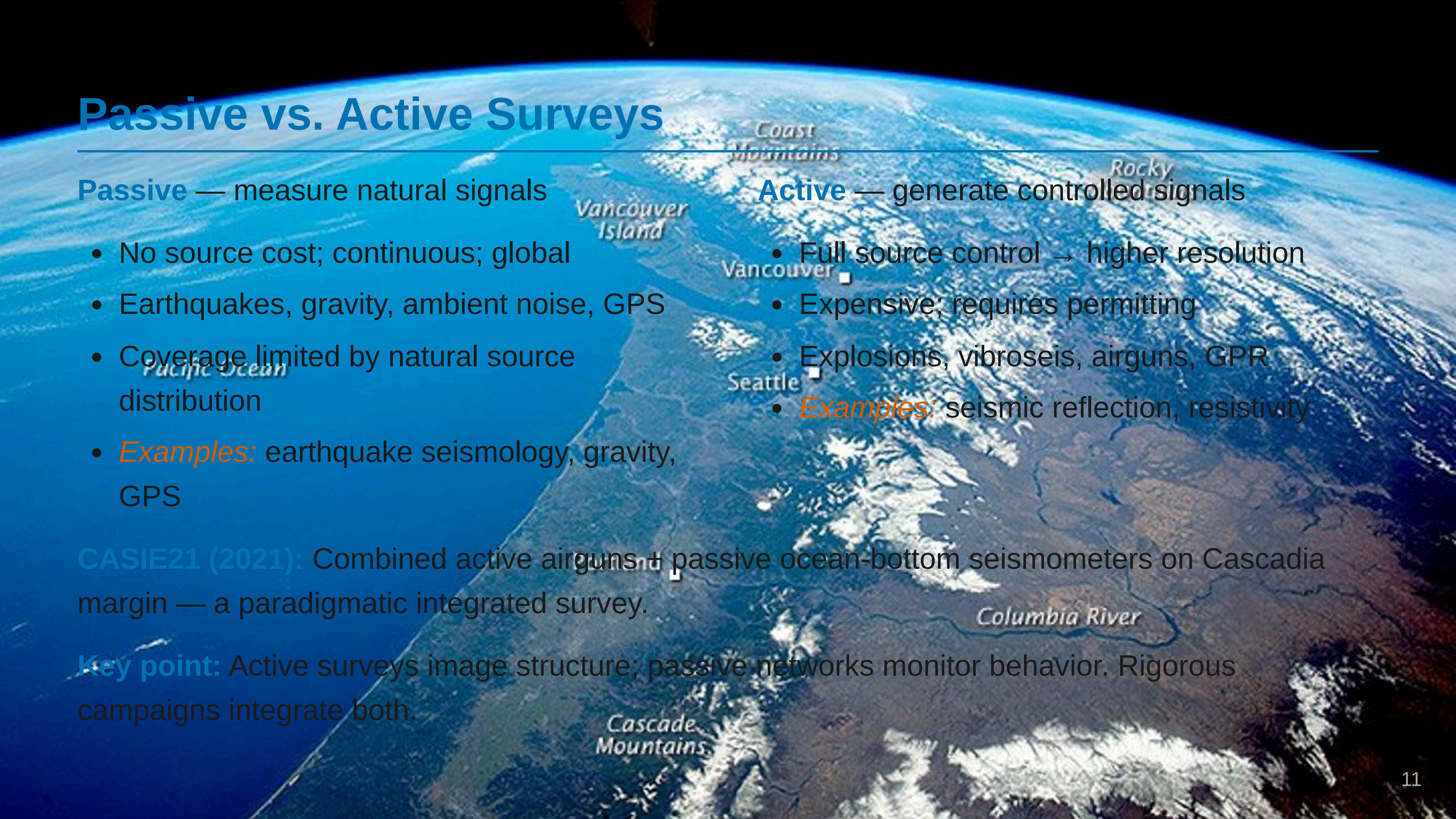
Key point: The motivation changes (petroleum → climate); the physics does not.

Five Physics Domains

Domain	Governing Equation	Earth Property	Observable
Continuum mechanics	$\rho\ddot{\mathbf{u}} = \nabla \cdot \boldsymbol{\sigma}$	λ, μ, ρ	Seismograms
Wave theory	$\nabla^2 u = v^{-2}\partial_{tt} u$	α, β	Travel times
Gravity	$\nabla^2\Phi = 4\pi G\rho$	Density ρ	g anomaly
Electromagnetism	$\nabla \times \mathbf{B} = \mu_0 \mathbf{J}$	σ_e, magnetization	EM anomaly
Thermodynamics	$\rho c_p \partial_t T = \nabla \cdot (k\nabla T)$	T, k	Heat flux q

These equations will be derived in detail during each module.

Key point: Every observable connects to an Earth property through a physical operator. This is the forward problem.



Passive vs. Active Surveys

Passive — measure natural signals

- No source cost; continuous; global
- Earthquakes, gravity, ambient noise, GPS
- Coverage limited by natural source distribution
- *Examples:* earthquake seismology, gravity, GPS

Active — generate controlled signals

- Full source control → higher resolution
- Expensive; requires permitting
- Explosions, vibroseis, airguns, GPR
- *Examples:* seismic reflection, resistivity

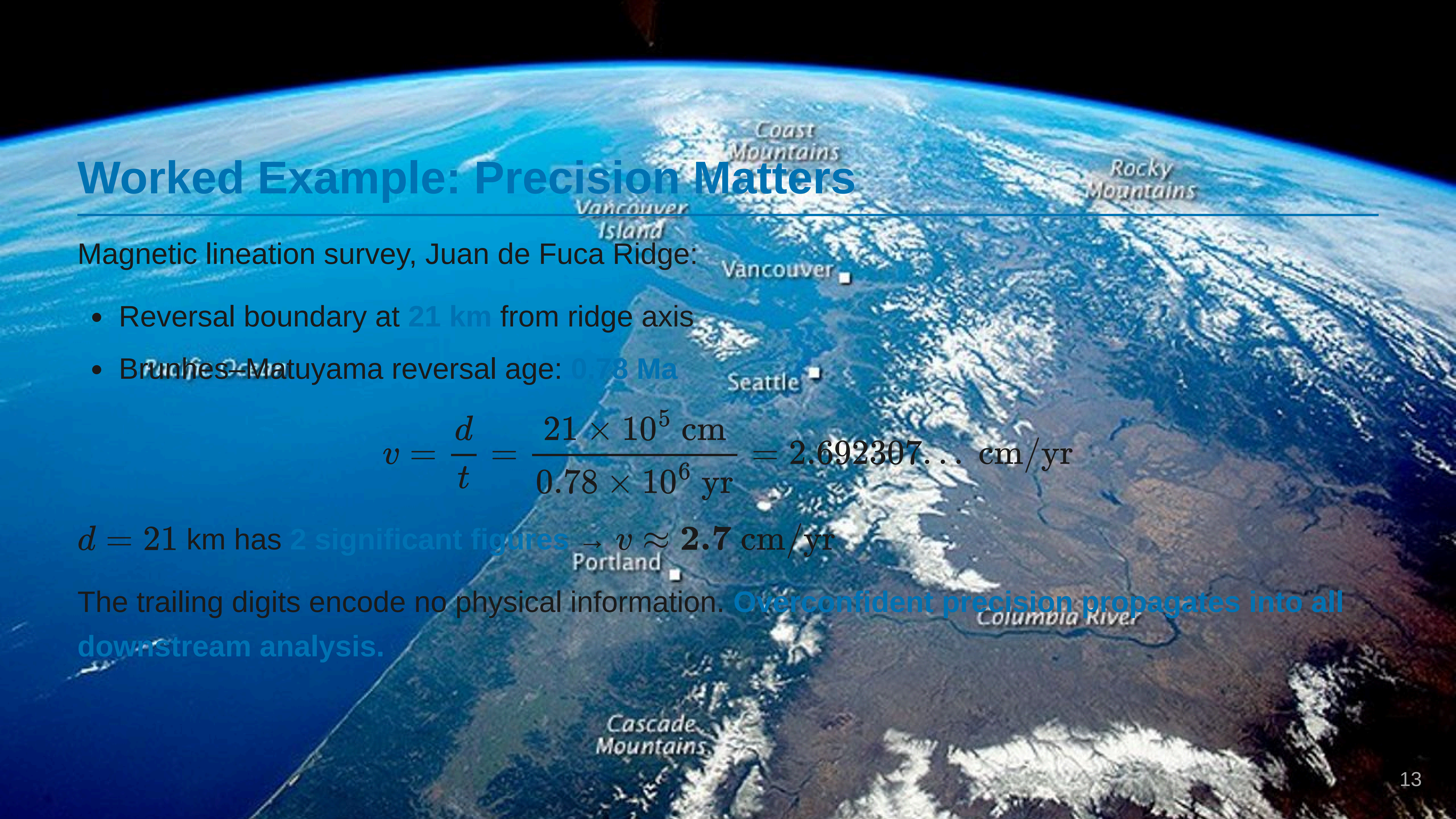
CASIE21 (2021): Combined active airguns + passive ocean-bottom seismometers on Cascadia margin — a paradigmatic integrated survey.

Key point: Active surveys image structure; passive networks monitor behavior. Rigorous campaigns integrate both.

Who Uses Geophysics?

- 🎓 **Research universities** — physical models, open datasets, trained scientists
- 🏛 **Government agencies** — USGS (hazard maps), NOAA (tsunami warning), CTBTO (nuclear monitoring)
- 🏗 **Engineering firms** — site characterization, Vs30, dam safety, tunnel routing
- ⛽ **Energy / mining** — petroleum, geothermal, critical minerals, CO_2 storage
- 🌿 **Environmental agencies** — groundwater, contaminant mapping, GPR
- 🛡 **Defense** — nuclear test monitoring, underground facility characterization

Key point: Geophysics graduates work across all these sectors. Physical reasoning, signal processing, and Python are directly transferable.



Worked Example: Precision Matters

Magnetic lineation survey, Juan de Fuca Ridge:

- Reversal boundary at **21 km** from ridge axis
- Brunhes–Matuyama reversal age: **0.78 Ma**

$$v = \frac{d}{t} = \frac{21 \times 10^5 \text{ cm}}{0.78 \times 10^6 \text{ yr}} = 2.692307\ldots \text{ cm/yr}$$

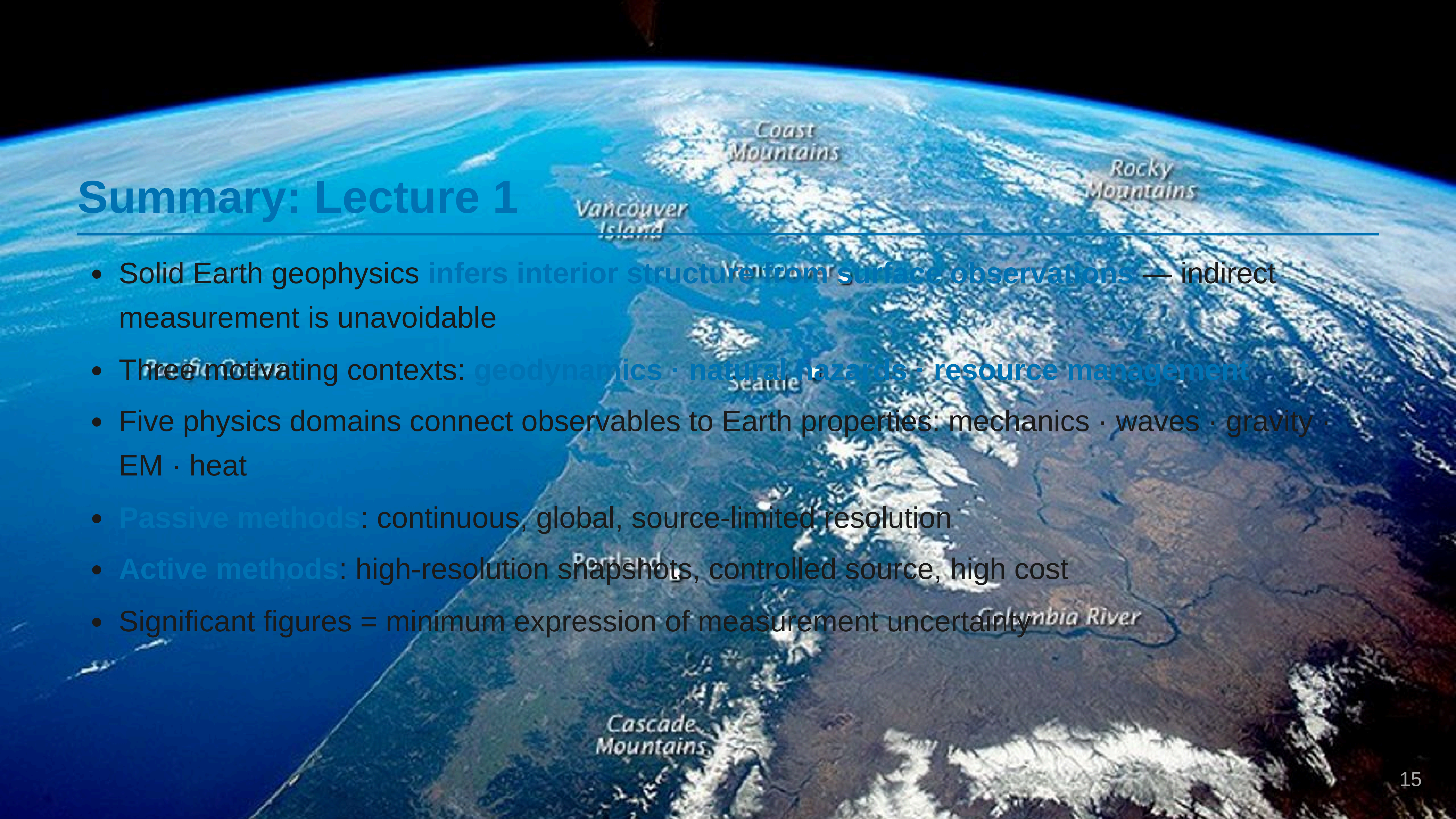
$d = 21$ km has **2 significant figures** → $v \approx \mathbf{2.7}$ cm/yr

The trailing digits encode no physical information. **Overconfident precision propagates into all downstream analysis.**

Concept Check

Discuss in pairs — 3 minutes

1. The magnetic lineation method exploits a naturally occurring signal. What category of survey is it, and what is the natural source it exploits?
2. If greater precision on the spreading rate were needed, which input — distance or age — would be more productive to refine, and on what physical or practical grounds?
3. The calculation assumes the reversal boundary is uniformly 21 km from the ridge axis. What geological processes could violate this assumption?



Summary: Lecture 1

- Solid Earth geophysics **infers interior structure from surface observations** — indirect measurement is unavoidable
- Three motivating contexts: **geodynamics · natural hazards · resource management**
- Five physics domains connect observables to Earth properties: mechanics · waves · gravity · EM · heat
- **Passive methods**: continuous, global, source-limited resolution
- **Active methods**: high-resolution snapshots, controlled source, high cost
- Significant figures = minimum expression of measurement uncertainty

Further Reading & Lab 1

Reading:

- Lowrie & Fichtner (2020) §1.1–1.3 — **free via UW Libraries**
- MIT OCW 12.201: ocw.mit.edu/courses/12-201
- Mousavi & Beroza (2022) Deep-learning seismology, *Science*: doi.org/10.1126/science.abm4470
- PNSN real-time seismicity: pnsn.org

Lab 1 (Friday):

1. Install ObsPy
2. Fetch a PNSN seismogram via IRIS FDSN client
3. Identify P and S arrivals by eye
4. Compute source distance from $t_S - t_P = \Delta(1/\beta - 1/\alpha)$