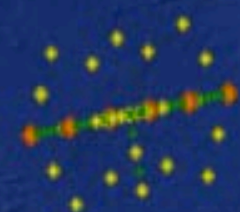
Emerging opportunities for enhanced seafloor observation: seismology, geodesy, and EM



James Gaherty

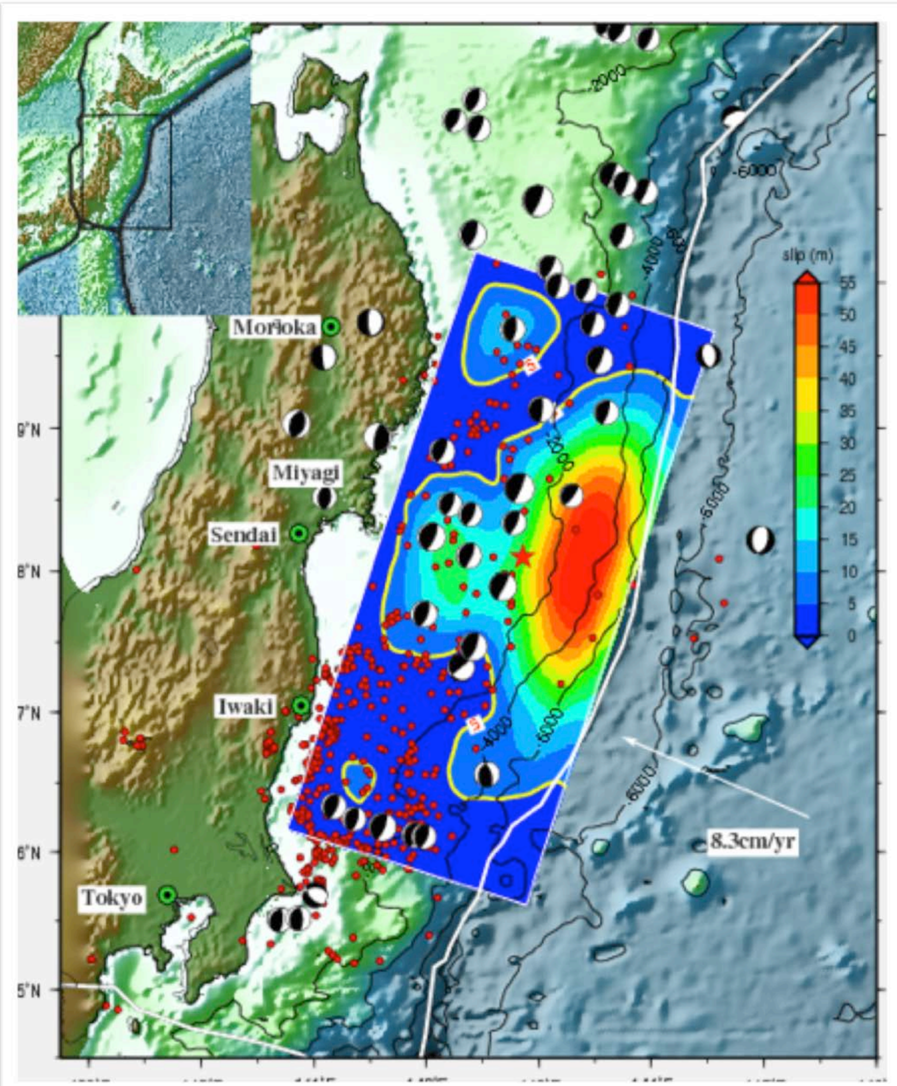
Lamont-Doherty Earth Observatory
of Columbia University

Rob Evans, Kerry Key, Patty Lin, Scott Nooner, Doug Toomey, Spahr Webb, OBSIP

Seafloor Observations: Outline

1. Why do we need observations from the oceans?
2. Current state of observational capabilities
   a) Ocean-bottom seismographs (OBS)
   b) Seafloor Geodesy
   c) Marine Electromagnetics
3. Frontier Needs and Opportunities
   a) Data delivery
   b) Instrument improvement
   c) Long-term observations
4. Obstacles

Why do we need observations from the oceans?



Explicitly called out in

- 7/10 Seismological Grand Challenges
- 3/7 Geodetic Grand Challenges
- 2/8 Ocean Science Board decadal priorities
- (implicit in more)

"Offshore" comprises 71% of surface, most plate boundaries, all subduction zones, great majority of earthquakes and volcanism

The shoreline does not define our science. It should not limit our facilities.

Courtesy Chen Ji

Current OBS Capabilities

160 broadband systems (standard pool plus Cascadia ARRA instruments)

- ~1 year duration at sample rates up to ~100 Hz
- deployment depths: 1000-6000 meters (free-fall, self buoyancy) – 140 systems
  0-1000 m (wireline, pop-up buoy or ROV) – 20 systems
- broadband sensor plus DPG/APG

93 short-period systems (all in standard pool)

- active-source deployments of a few months, sample rates up to 250 hz
- also used as short-period passive deployments for up to ~8 months
- deployment depths 0-5x00 m

Maintained and operated by dedicated technical staff (~10 FTE total)

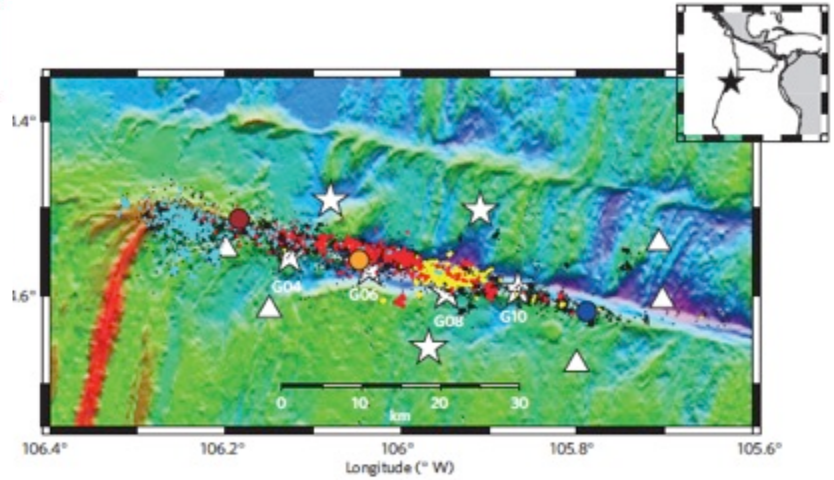
Funded out of OCE-MGG (core) by cooperative agreement with IRIS as lead and LDEO, SIO, and WHOI as subcontractors

OBSIP success

LETTERS
PUBLISHED ONLINE: 22 APRIL 2012 | DOI: 10.1038/NGEO1454
nature geoscience

Variations in earthquake rupture properties along the Gofar transform fault, East Pacific Rise

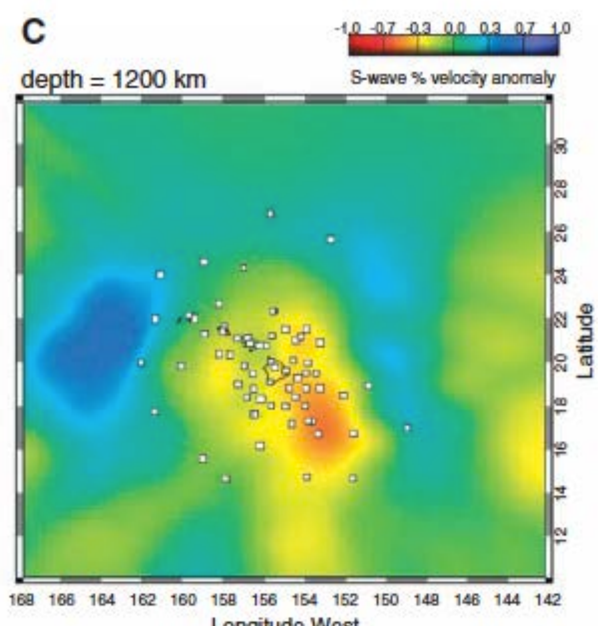
Jeffrey J. McGuire[1]*, John A. Collins[1], Pierre Gouédard[2], Emily Roland[3]†, Dan Lizarralde[1], Margaret S. Boettcher[4], Mark D. Behn[1] and Robert D. van der Hilst[2]



REPORTS

Mantle Shear-Wave Velocity Structure Beneath the Hawaiian Hot Spot

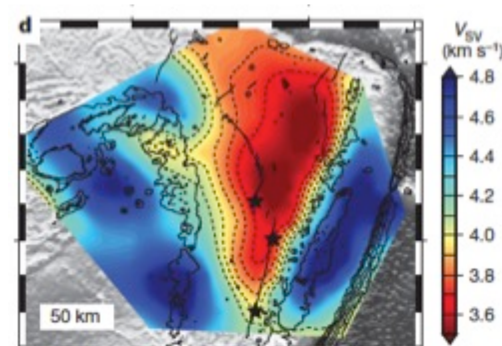
Cecily J. Wolfe,[1]* Sean C. Solomon,[2] Gabi Laske,[3] John A. Collins,[4] Robert S. Detrick,[4] John A. Orcutt,[3] David Bercovici,[5] Erik H. Hauri[2]



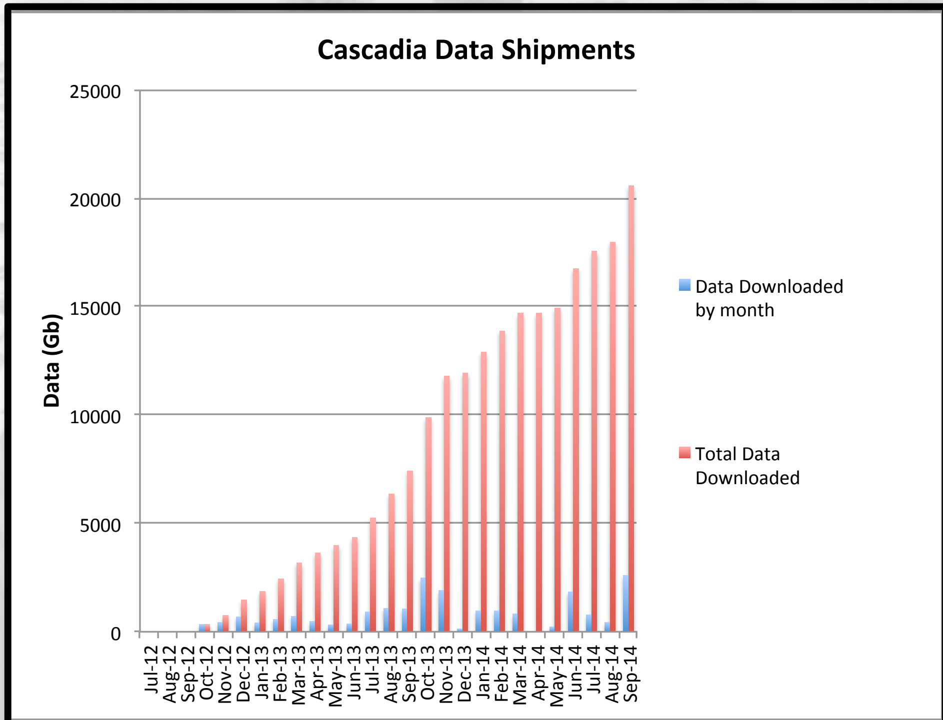
LETTER
doi:10.1038/nature14113

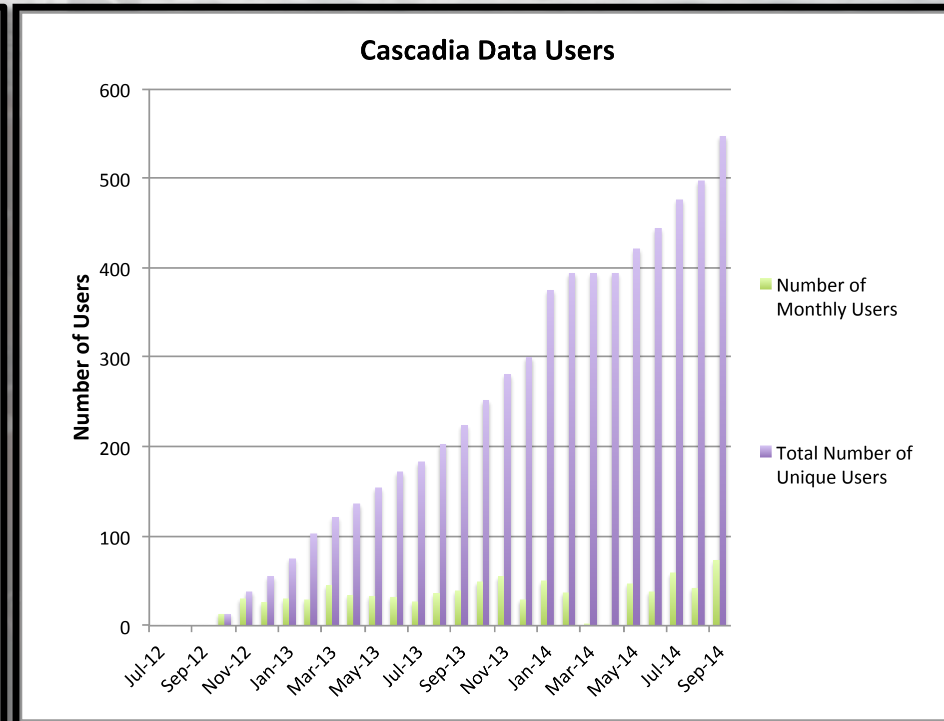
Seismic evidence of effects of water on melt transport in the Lau back-arc mantle

S. Shawn Wei[1], Douglas A. Wiens[1], Yang Zha[2], Terry Plank[2], Spahr C. Webb[2], Donna K. Blackman[3], Robert A. Dunn[4] & James A. Conder[5]



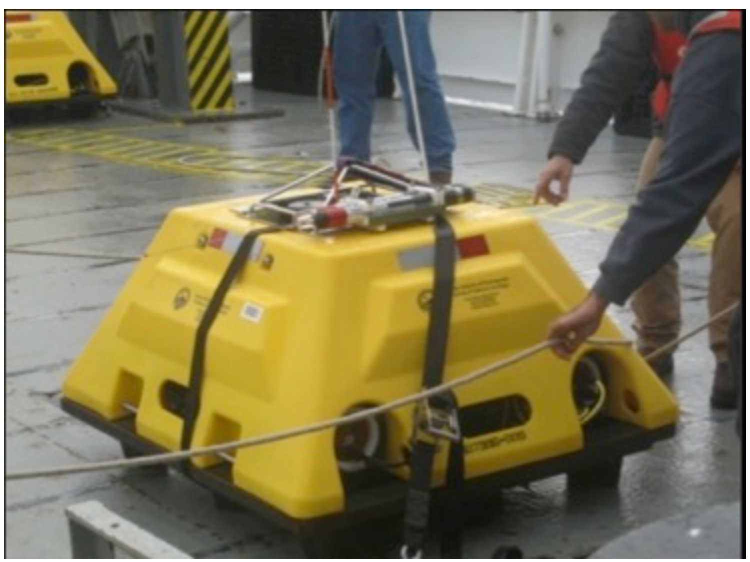
OBSIP success





Courtesy of Doug Toomey. Data compiled by Jessica Lodewyk, OBSIP OMO

Recent and ongoing Enhancements



- Trawler resistance
  - Deploy < 1000 m depth
- Shielding
  - Reduce current-induced tilt on horizontals
- Non-glass flotation
  - Deploy > 5000 m
- Chip-scale atomic clocks
  - Negligible drift

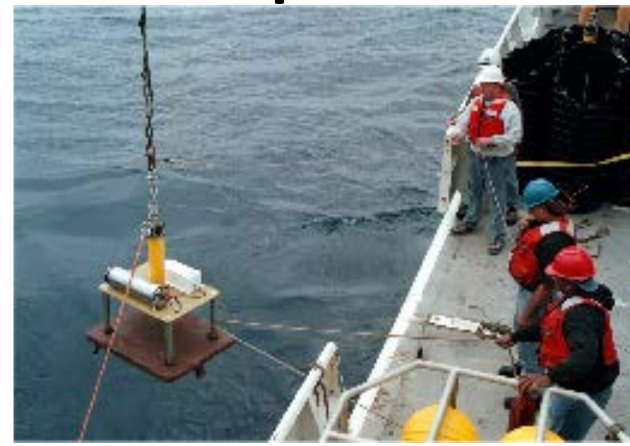
Seafloor Geodetic Techniques

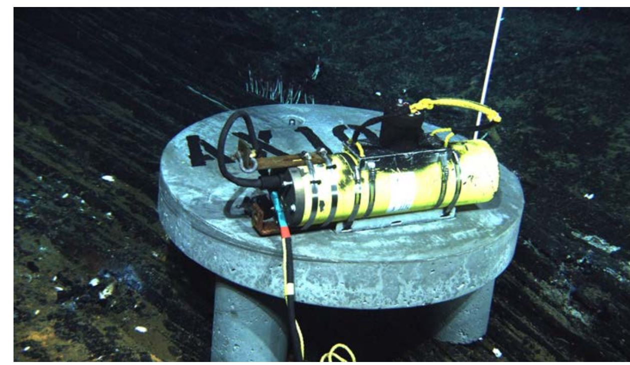
Vertical Deformation

- Bottom Pressure Recorders (BPRs or APGs)
  - Continuous, easy to deploy, but drift
- Mobile Pressure Recorders (MPRs)
  - More precise, but campaign w/ROV
- Tilt sensors
- Self Calibrating Pressure Recorders (SCPRs)
- Repeat high-res AUV Bathymetry
- Borehole Pressure and Tilt

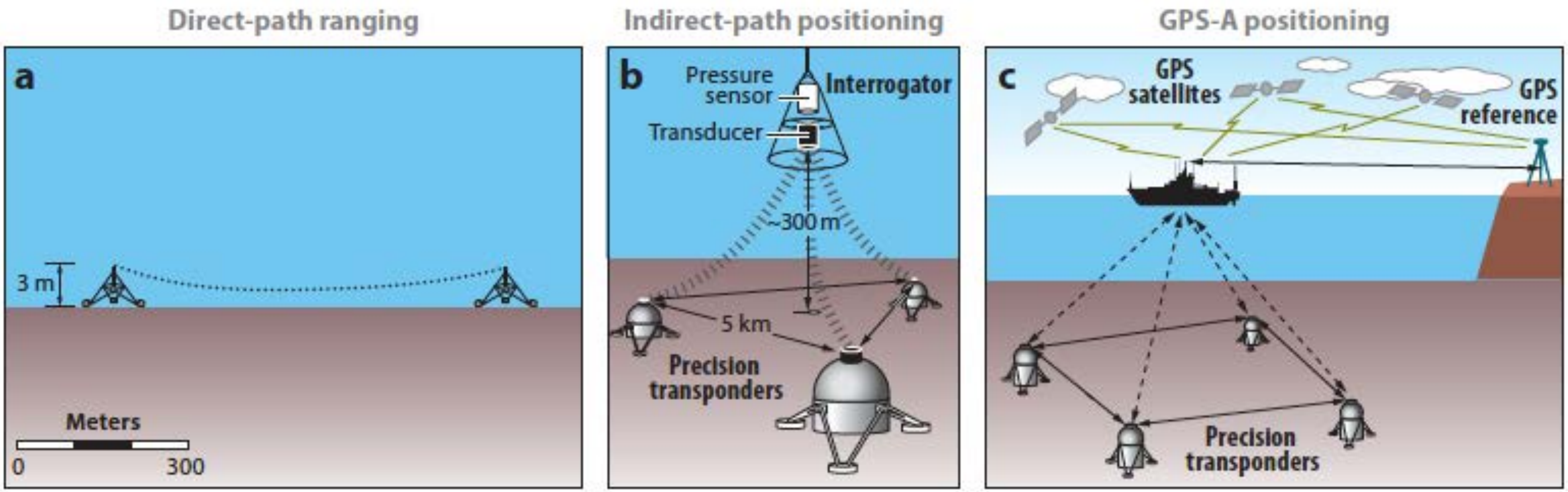
Horizontal Deformation

- Horizontal Acoustic Ranging
- GPS-Acoustic
- Fiber Optic Seafloor Strainmeter (FOSS)

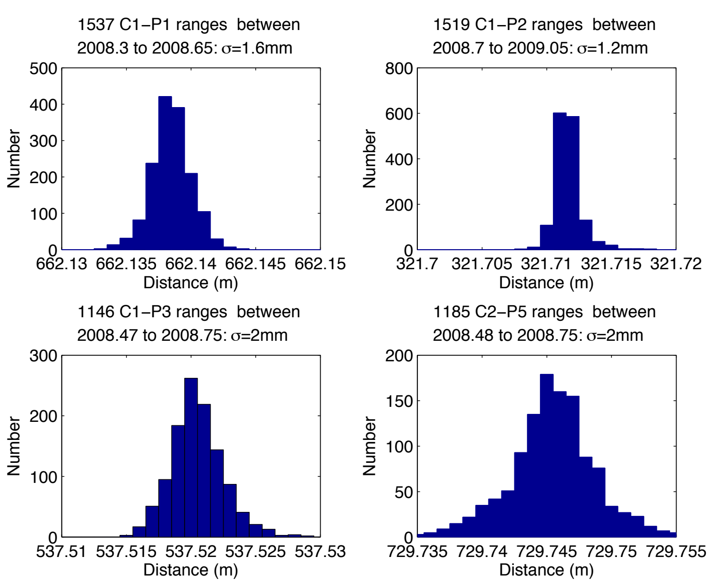




Acoustic Ranging Systems for Seafloor Geodesy



Burgmann and Chadwell, 2014

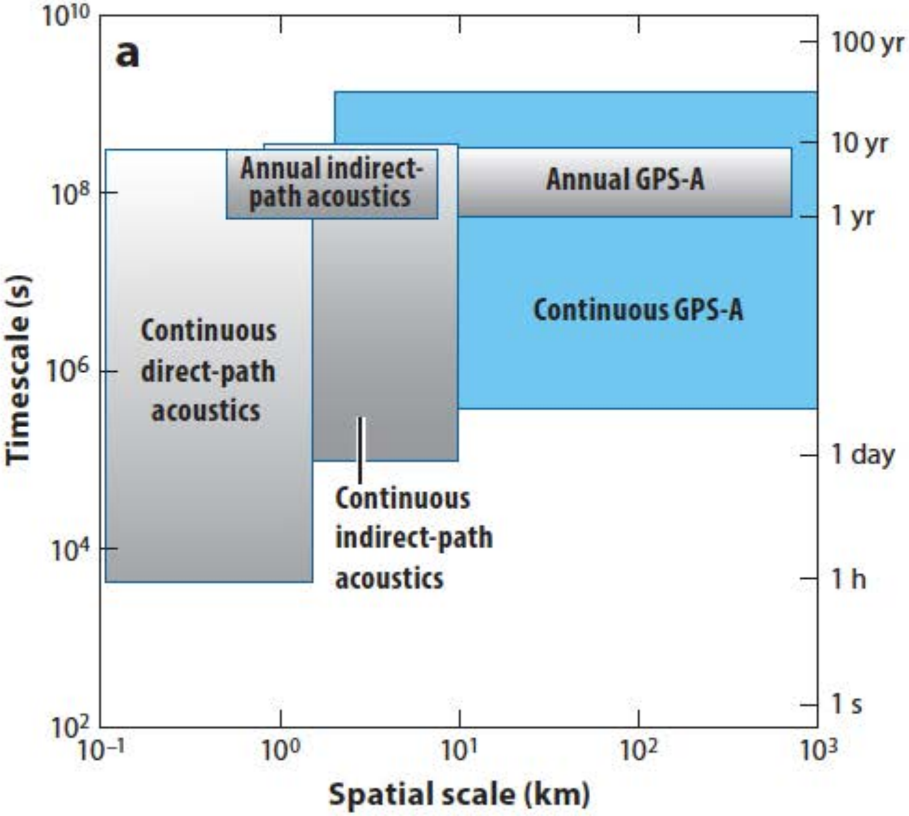


Spiess and Chadwell

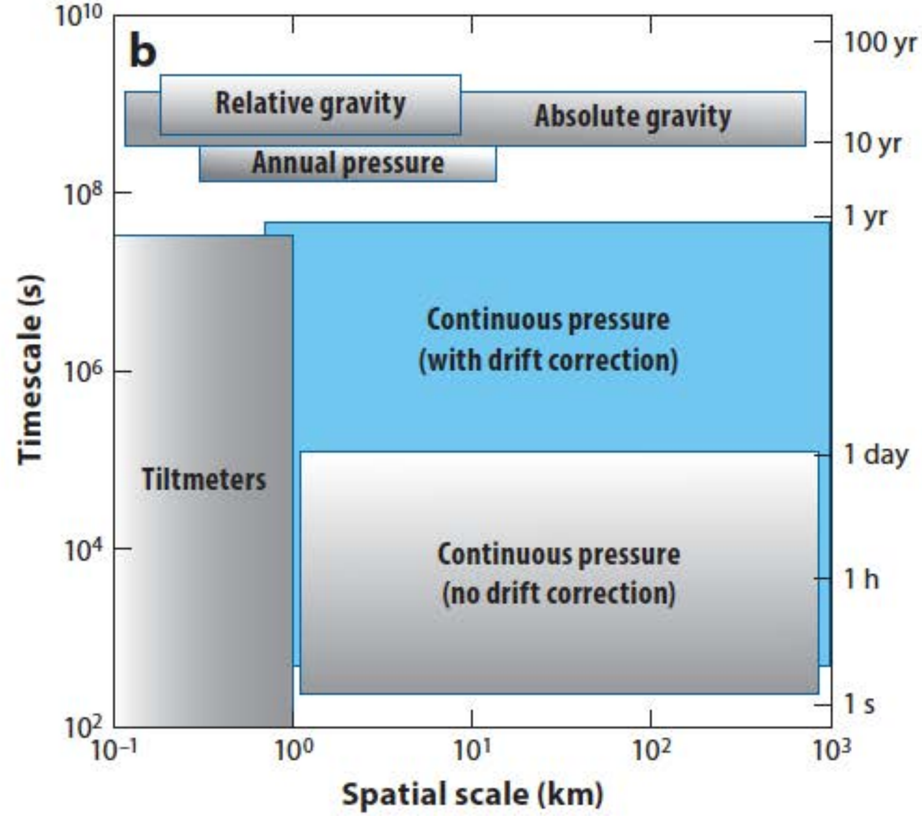
Chadwell, et al, 1999, Chadwick et al, 1999, McGuire and Collins, 2013

Spanning the deformation spectrum

Horizontal

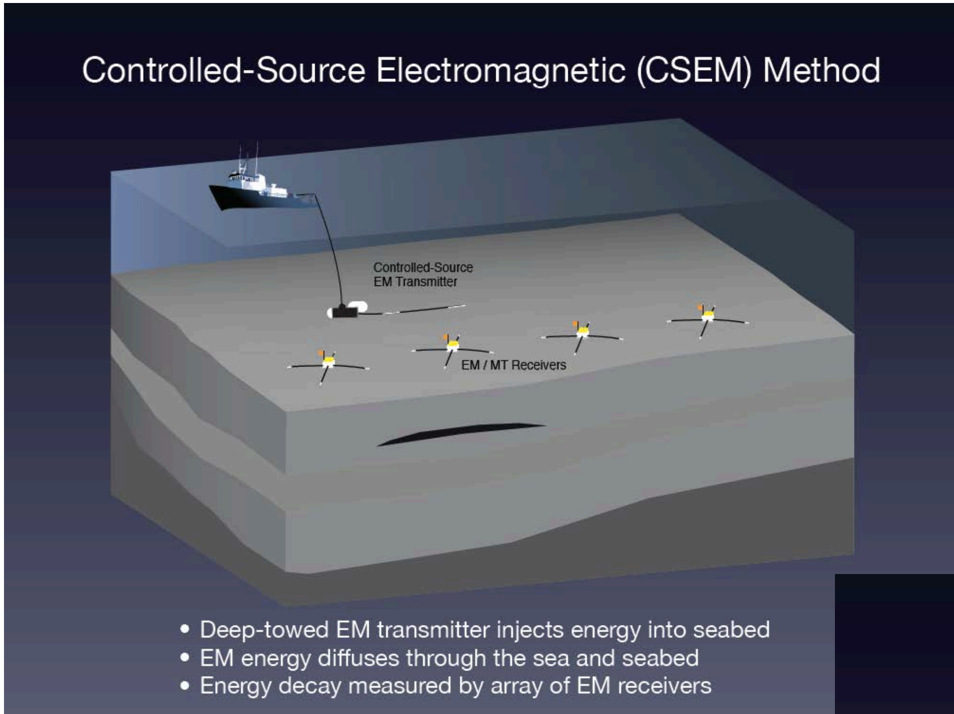


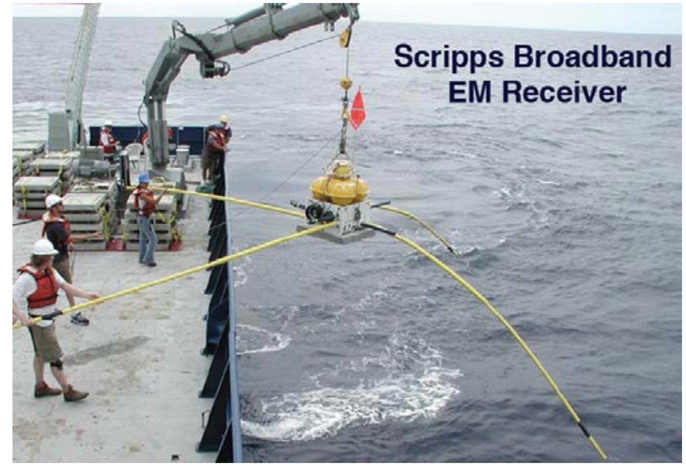
Vertical

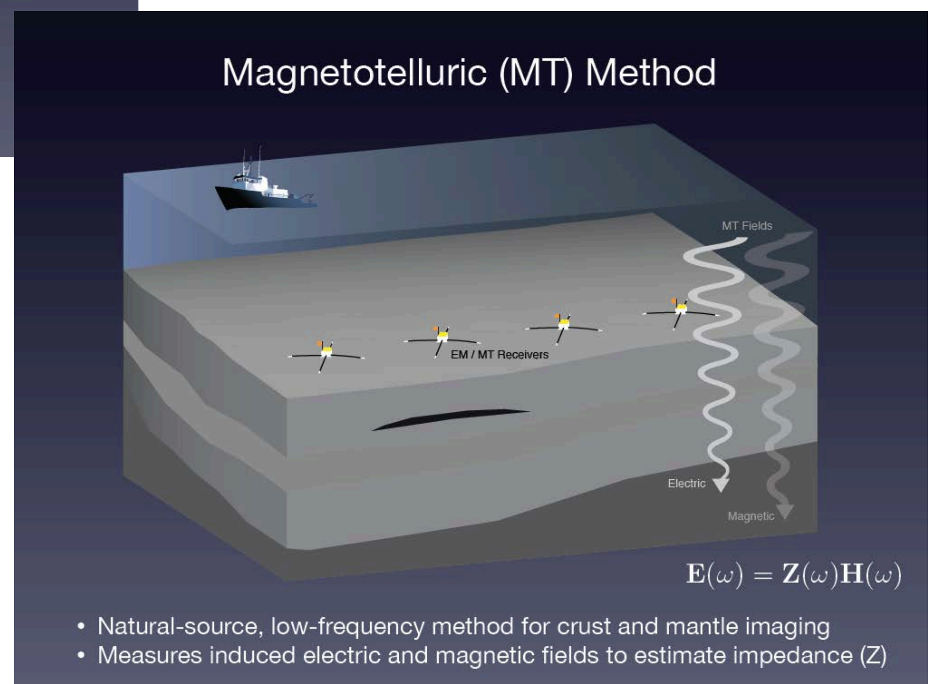


Burgmann and Chadwell, 2014

Marine Electromagnetics

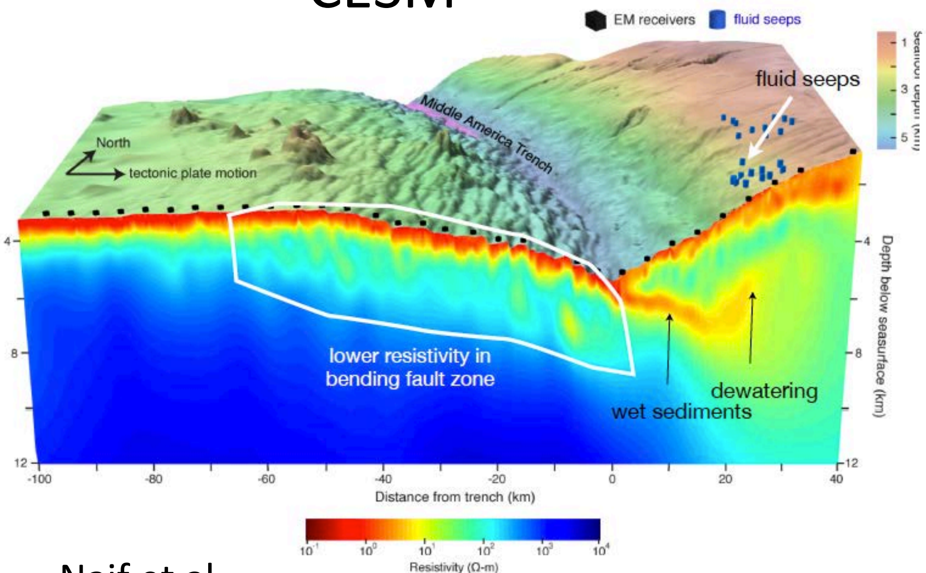






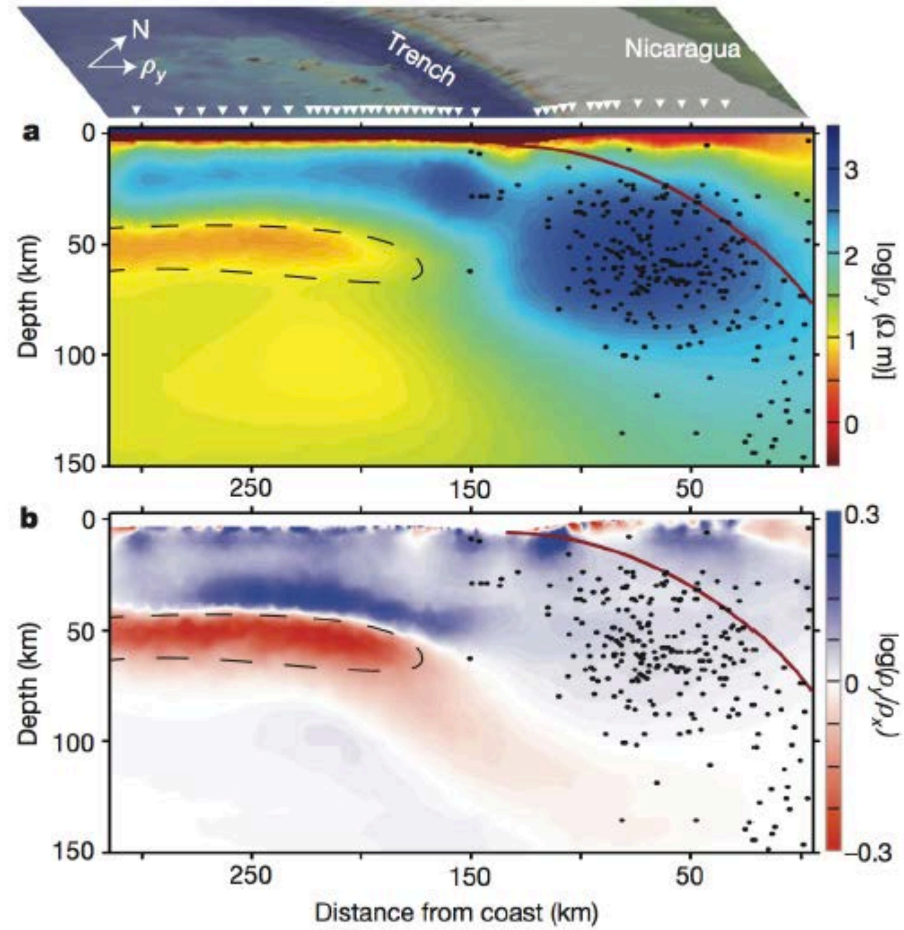
Marine Electromagnetics

CESM



Naif et al.

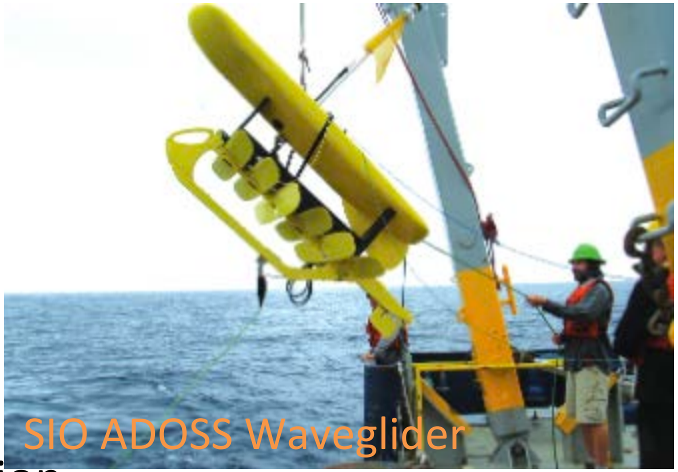
MT



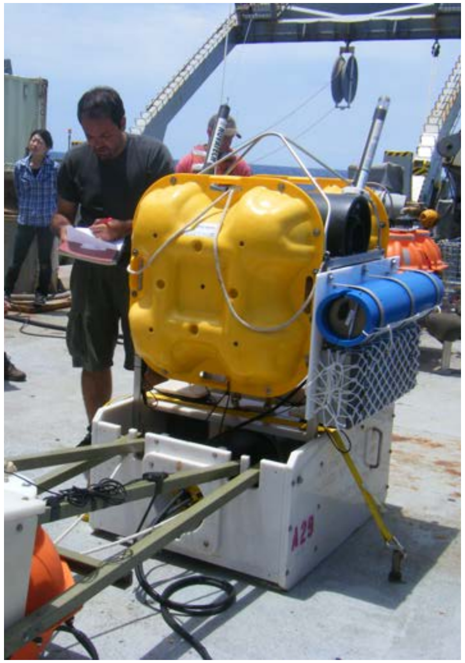
Naif et al, *Nature*, 2013

•Exceptional sensitivity to fluids – hydration, partial melting
•Anisotropic – spatial distribution of heterogeneity, rock fabric
•Resolution analogous to active/passive seismic
•Highly complementary with seismic constraints for resolving tradeoffs

Frontier Challenges and Opportunities



- Remote data delivery
  - Episodic (AUV)
  - Quasi-real-time (cable, buoy, waveglider)
- Improve instrument performance to onshore levels
  - Reduce horizontal noise on seismometers
  - Improve vertical and horizontal geodetic precision
- Multi-sensor mini-observatories
  - Seismic and geodetic-quality pressure
  - Seismic and EM
  - Capitalize on logistics investment
  - Capitalize on data-delivery investment
- Long-term observatories
  - Capitalize on logistics
- International Collaboration
  - Pacific Array, SZO

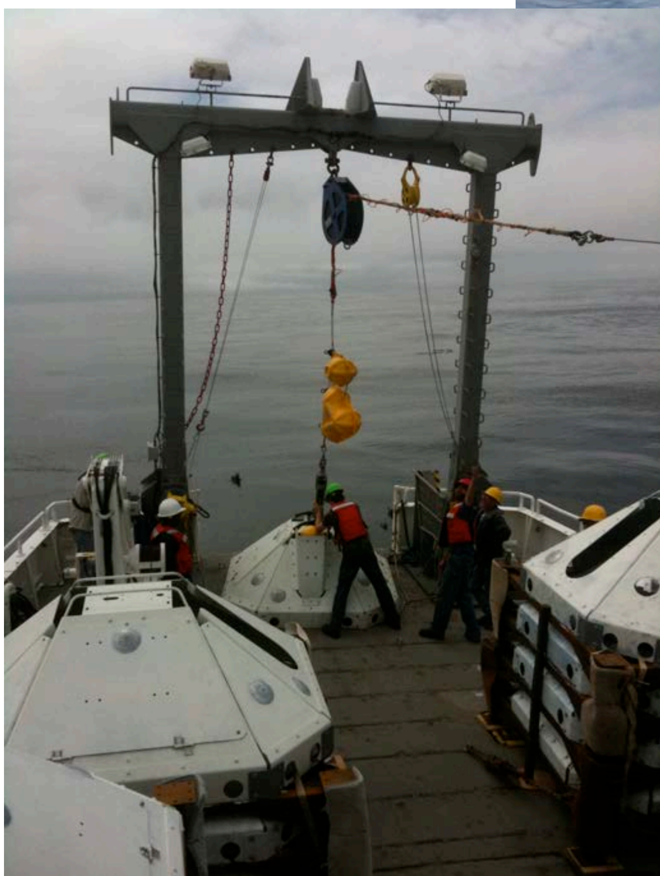


LDEO OBS with Japanese magnetometer

Obstacles

Conclusions of the National Science Board Decadal Survey of Ocean Sciences:

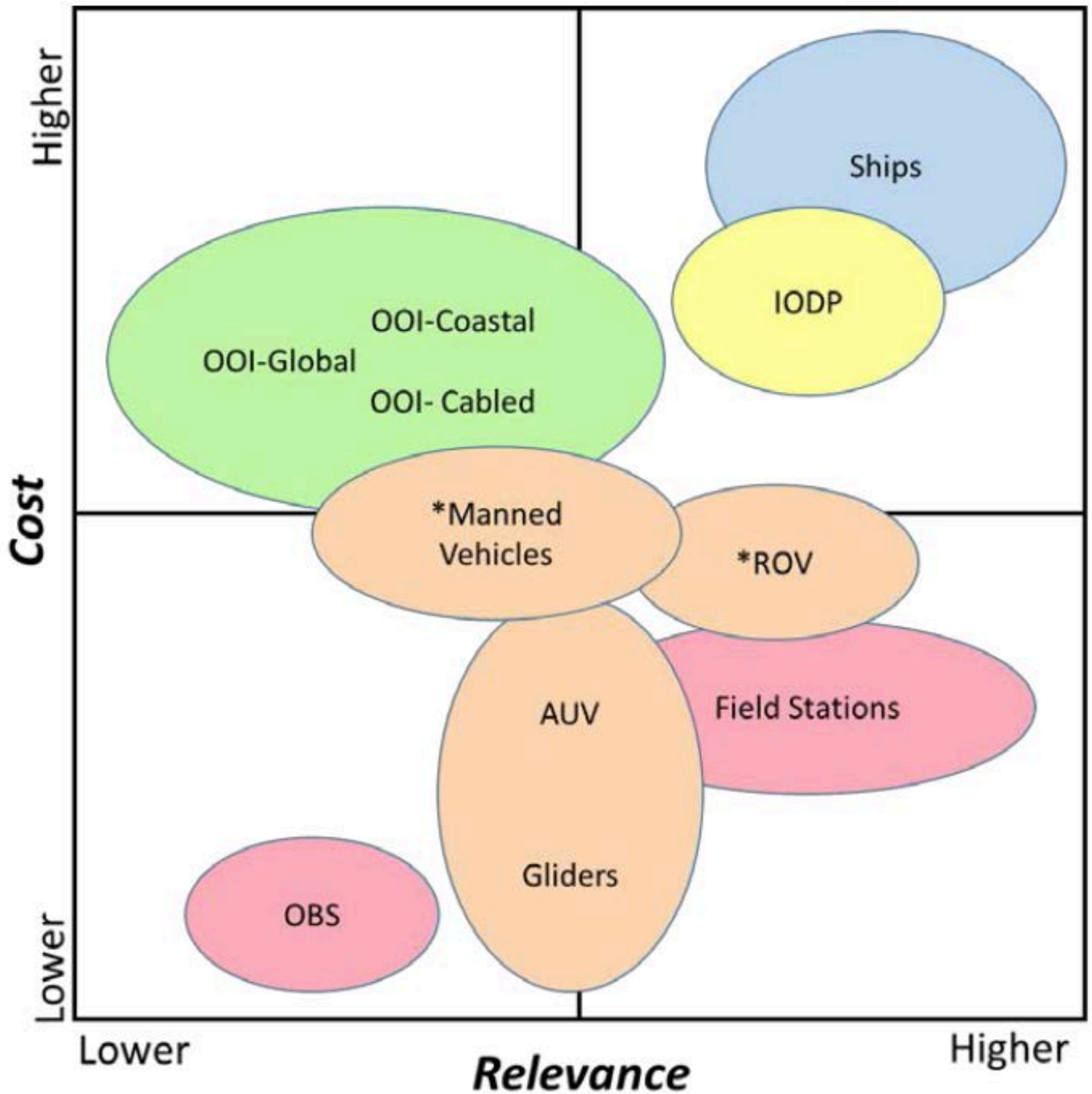
OBS fleet "low relevance" for OCE science



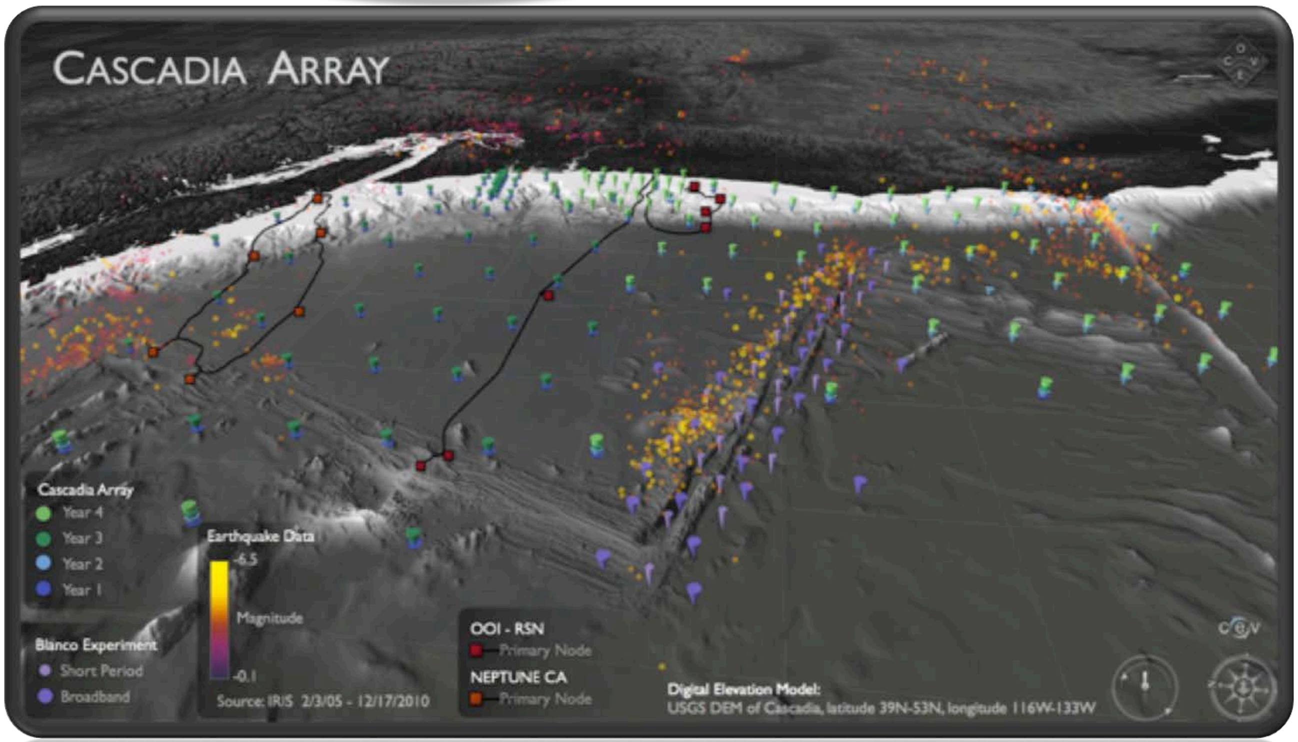
- Working in the oceans is expensive
- Facilities operated by OCE
- Solid Earth Science is a minor fraction of OCE Science Priorities

Obstacles

Conclusions of the National Science Board Decadal Survey of Ocean Sciences:



The Cascadia Initiative: A Sea Change in Seismology

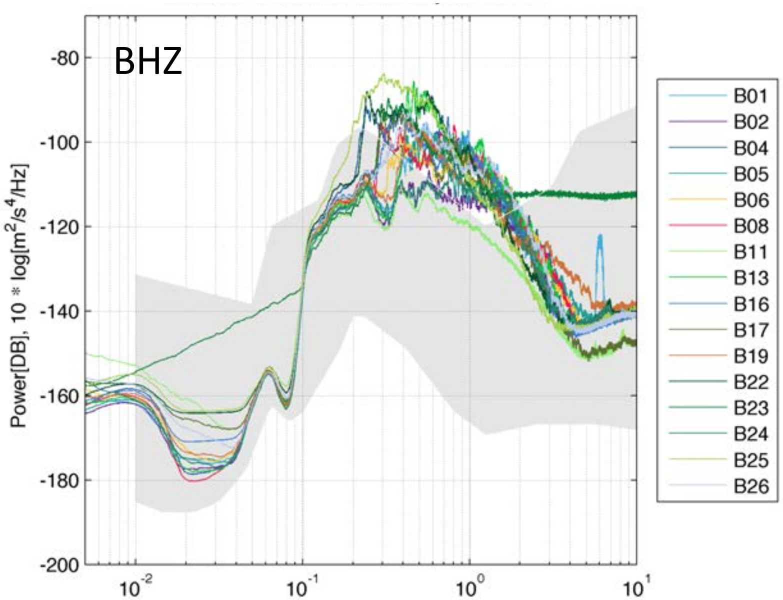


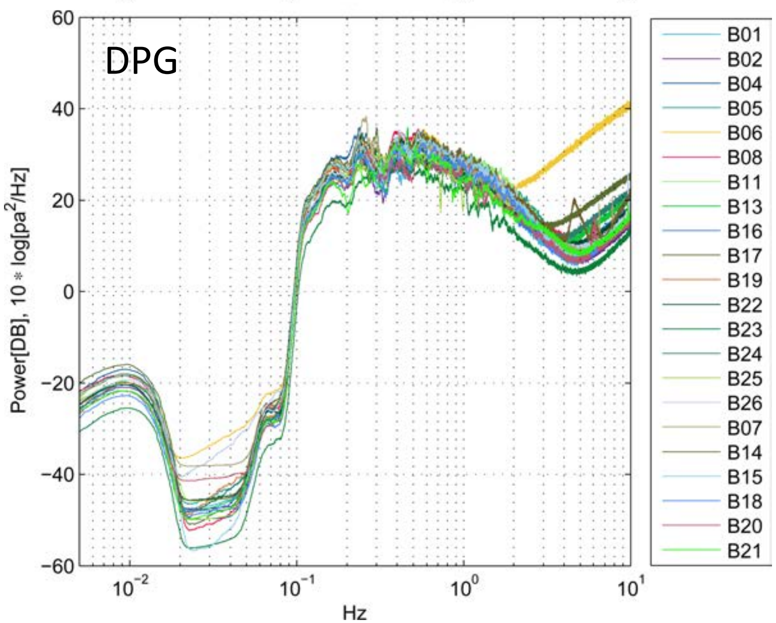
Douglas R. Toomey, Richard M. Allen, John A. Collins, Robert P. Dziak, Emilie E. Hooft, Dean Livelybrooks, Jeffrey J. McGuire, Susan Y. Schwartz, Maya Tolstoy, Anne M. Trehu, William S. Wilcock

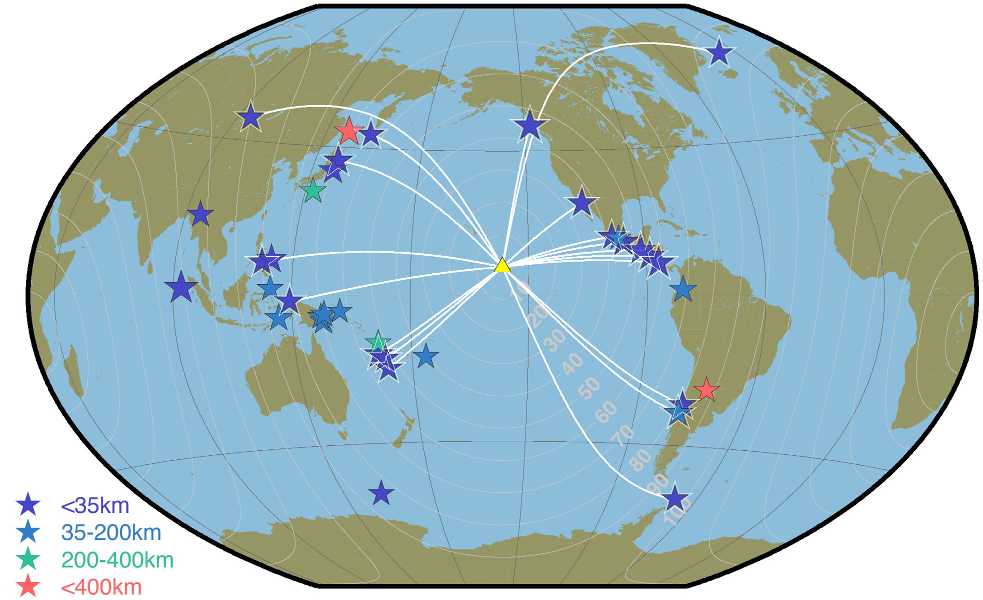
Supported by the National Science Foundation

BBOBS Data Quality

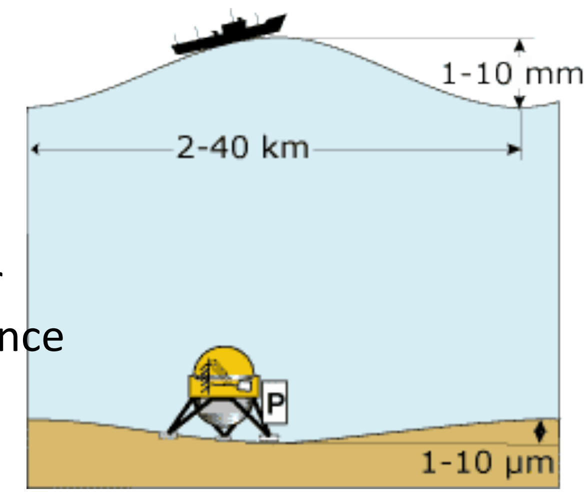
PSD







Seafloor compliance

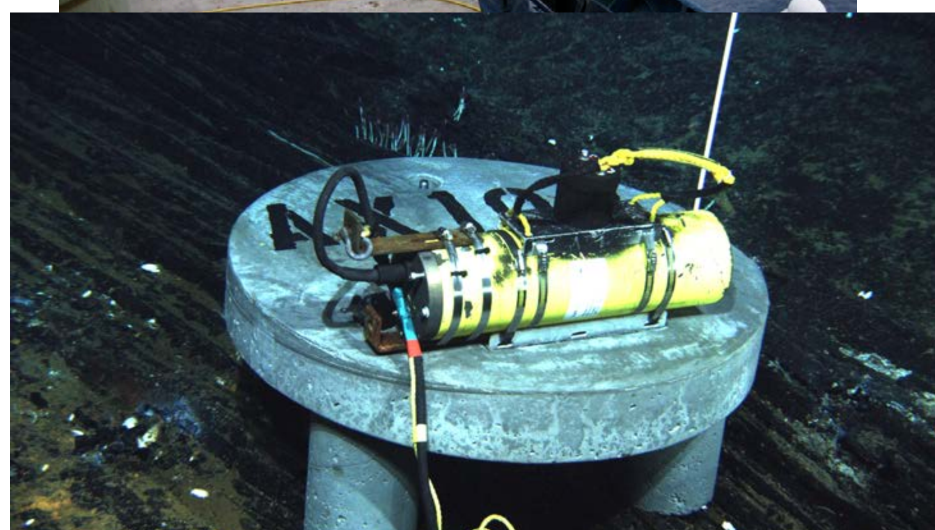


Courtesy of Wayne Crawford

Mobile Pressure Recorders

MPRs

- “Campaign-style” survey using an ROV – analogous to leveling surveys on land.
- Measure water pressure on top of permanent concrete benchmarks.
- Repeat every 1-3 years.

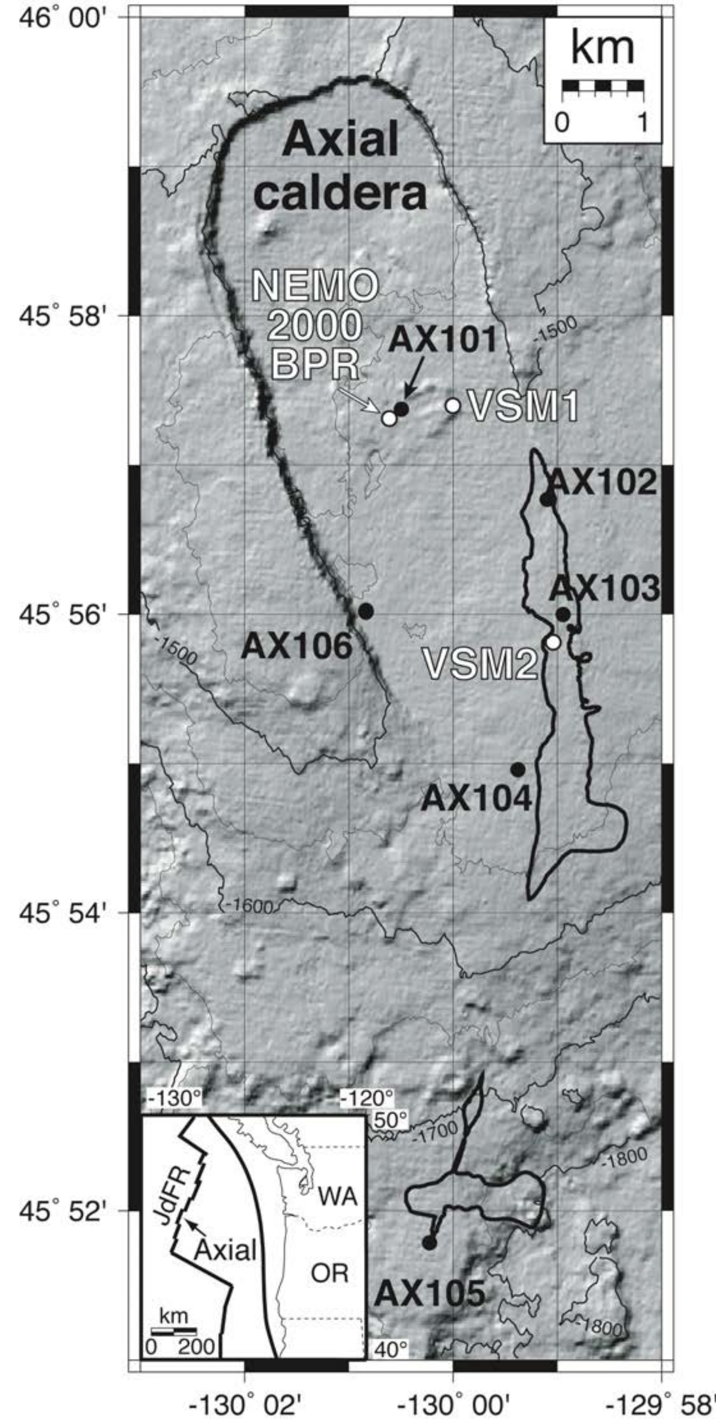


Nooner, Chadwick, Zumberge

Mobile Pressure Recorders

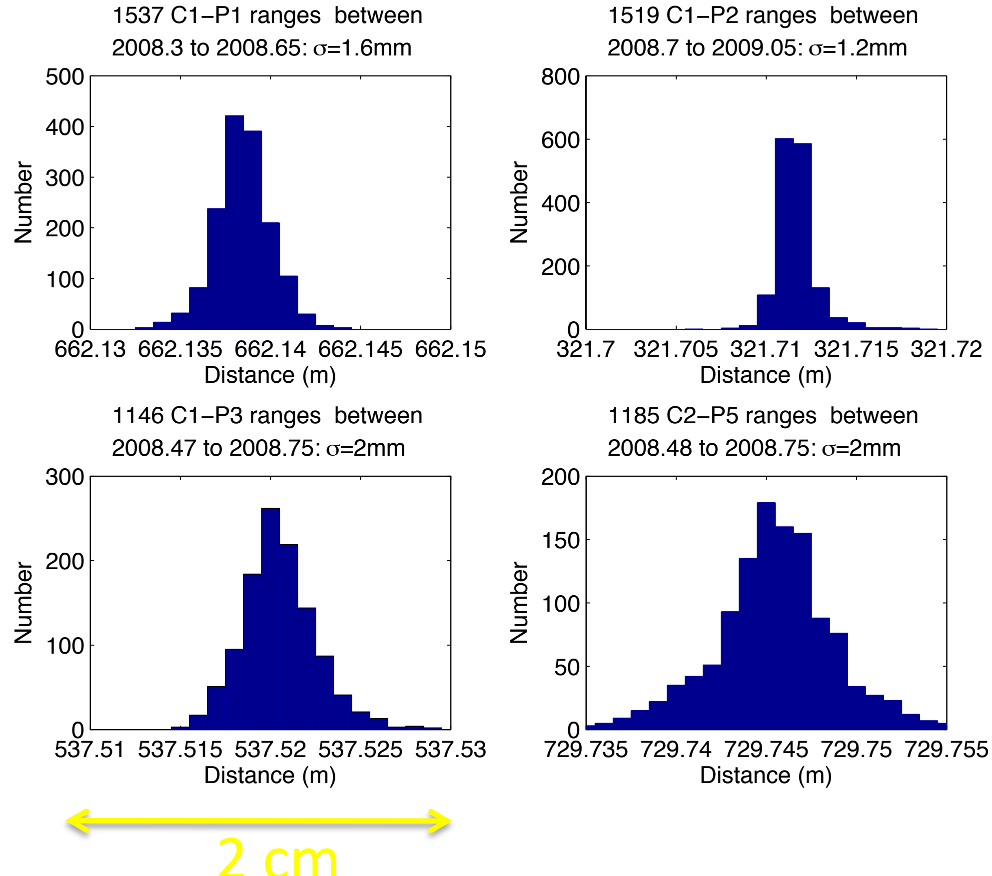
MPRs

- Repeatedly visit benchmarks during a 2-3 day dive (typically).
- Scatter of repeats gives data uncertainty -- typically <1 cm.
- Don’t capture episodic events.



Nooner, Chadwick, Zumberge

Recent Direct Path Acoustic Ranging



~1 mm/yr interseismic strain signals are detectable over 1-5 km baselines.

Discovery Transform Fault, EPR

McGuire and Collins, *G-cubed*, 2013