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

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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 0-500 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

Variations in earthquake rupture properties along the Gofar transform fault, East Pacific Rise
Jeffrey J. McGuire*, John A. Collins¹, Pierre Gouédard², Emily Roland³*, Dan Lizarralde¹, Margaret S. Boettcher⁴, Mark D. Behn⁵ and Robert D. van der Hilst⁶

Mantle Shear-Wave Velocity Structure Beneath the Hawaiian Hot Spot
Cecily J. Wolfe,²∗ Sean C. Solomon,² Gabi Laske,³ John A. Collins,⁴ Robert S. Detrick,⁴ John A. Orcutt,³ David Bercovici,⁵ Erik H. Hauri⁶

LETTER
Seismic evidence of effects of water on melt transport in the Lau back-arc mantle
S. Shawn Wei¹, Douglas A. Wiens¹, Yang Zha², Terry Plank³, Spahr C. Webb², Donna K. Blackman³, Robert A. Dunn⁴ & James A. Conder⁵
OBSIP success

Cascadia Data Shipments

- Data Downloaded by month
- Total Data Downloaded

Cascadia Data Users

- Number of Monthly Users
- Total Number of Unique Users

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
Spanning the deformation spectrum

Burgmann and Chadwell, 2014
Marine Electromagnetics

Controlled-Source Electromagnetic (CSEM) Method

- Deep-towed EM transmitter injects energy into seabed
- EM energy diffuses through the sea and seabed
- Energy decay measured by array of EM receivers

Magnetotelluric (MT) Method

- Natural-source, low-frequency method for crust and mantle imaging
- Measures induced electric and magnetic fields to estimate impedance (Z)

\[ E(\omega) = Z(\omega)H(\omega) \]
• 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
Obstacles

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

OBS fleet “low relevance” for OCE science

The R/V Marcus G. Langseth
Recommended that NSF consider taking out of service

- 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


Supported by the National Science Foundation
BBOBS Data Quality

PSD

BHZ

Power[DB], 10 \times 10^2 m^2/s^2/Hz

10^{-3} 10^{-1} 10^0 10^1

<35km
35-200km
200-400km
<400km

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

1537 C1–P1 ranges between 2008.3 to 2008.65: $\sigma=1.6\text{mm}$

1519 C1–P2 ranges between 2008.7 to 2009.05: $\sigma=1.2\text{mm}$

1146 C1–P3 ranges between 2008.47 to 2008.75: $\sigma=2\text{mm}$

1185 C2–P5 ranges between 2008.48 to 2008.75: $\sigma=2\text{mm}$

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

Discovery Transform Fault, EPR