# Looking into the ocean and Earth’ s interior from their boundary

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**Introduction**

Table 1 summarizes the recent ocean bottom observations in which I have been involved. Although these observations were made solely by seismologists, more than half of the published papers were on the oceanic disturbances, including tsunamis, infragravity (IG) waves, internal tides and frontal bores. Less than half were reports on the solid Earth disturbances including VLF earthquakes and slow seafloor deformation. This fact indicates importance of collaboration of oceanographers and seismologists to analyze and interpret the ocean bottom records. I will pick up several topics from Table 1 to explain what may be required to reach a correct interpretation of the records.

**Example studies**

**No. 2.** Dispersive IG waves incoming to the off-Aogashima pressure gauge array (A-array), south of Japan, were backprojected by the method conventionally used in seismology. The results were combined with oceanographic information about the spatiotemporal variation of significant wave heights of IR waves provided by WAVEWATCH III. This combination made it possible to locate the excitation sources of the observed IR waves.

**No. 3**. Off Miyagi, Japan, 42 tilt events dipping landward in a direction perpendicular to the trench axis were detected by a triaxial accelerometer and a tilt-output from BBOBS through an observational period of 10 months. The possibility of seafloor tilting was precluded by a parallel oceanographic observation using a current-meter operated in a limited period. The current record showed that each tilt event was associated with landward flow of cold water. The thermometer inside the accelerometer confirmed that a tilt event was always associated with temperature drop. Clearly, the recorded tilt events were consequences of the frontal passages of advancing bores (solitary waves characterized by an upsloping surging front followed by cold waters). It would be essential for a single station observation to deploy multiple seismological and oceanographic instruments on the seafloor

**No. 6.** Using the A-array records, we detected the first-mode M2 internal tidal waves propagating with a horizontal phase speed of ~1 m/s in the onshore and offshore directions over the array along the eastern slope of Aogashima Island. The PSD of the internal tide was ~3000 times smaller than that of the M2 external tide. A tide-resolving ocean circulation model (JCOPE-T) was used to simulate the bottom pressure variations at the array. The analysis of the simulated records well reproduced the observed onshore and offshore internal tidal waves. This work represents a good example of collaborations of seismologists and oceanographers.

 

**No. 11.** Slow deformation of the seafloor with a time scale of hours was detected on the records from the far-off Torishima pressure gauge array (B-array) deployed near the Izu-Bonin Trench. Retrieval of signal of this time scale is in general challenging because of the overlaps of tidal disturbances of larger amplitudes and air-pressure disturbances of possibly comparable amplitudes. I developed a method to remove effects of these oceanic and atmospheric disturbances to detect seafloor displacement including its permanent component.

**Discussion**

Based on these limited experiences, I suggest several possible collaborative works between oceanographers and seismologists. Suggestion includes (No.2) monitoring of the IG wavefield in the Pacific Ocean using data from the seafloor networks such as DONET, S-net and NEPTUNE, (No.3) quantification of internal bores generated in the deep ocean by long-term oceanographic observations at the sea bottom, (No.6) update of a tide-resolving ocean circulation model such as JCOPE-T by assimilating data from the seafloor networks, and (No.11) use of the tide-resolving ocean circulation model to remove "noises" of oceanic and atmospheric origins to retrieve "signals" from the Earth's interior.

Keywords: ocean bottom observation, pressure gauge, array observation

**Table 1. Recent results from our ocean bottom observations**

| Phenomenon | No | Observation target | Instrument | Sytem | Authors | Year | Journal | Other tools |
|---|---|---|---|---|---|---|---|---|
| Ocean | 1 | Infragravity waves | OBP | DONET | Tono et al. | 2014 | EPS | |
| | 2 | Infragravity waves | OBP | A-array | Tonegawa et al. | 2016 | JGR-Oceans | HINDCAST/ GLOBAL_IG |
| | 3 | Frontal bores | OBA+OBT | Off-Miyagi | Fukao et al. | 2016 | JGR-Oceans | Currentmeter+ Thermometers |
| | 4 | Tsunamis | OBP | A- array | Fukao et al. | 2018 | Sci. Adv. | JAGURS code |
| | 5 | Tsunamis | OBP | A- array | Sandanbata et al. | 2018 | PAGEOPH | |
| | 6 | Internal tide | OBP | A-array | Fukao et al. | 2019 | JGR-Oceans under review | JCOPE-T |
| Ocean/ Solid Earth | 7 | Island deformation by tsunamis | OBP | A-array | Nishida et al. | 2019 | JGR | BBS on Aogashima Is. |
| Solid Earth | 8 | VLF earthquakes | BBOBS | Off-Kii array | Sugioka et al. | 2014 | Nature Geo. | |
| | 9 | VLF earthquakes | BBOBS | DONET | To et al. | 2015 | PEPI | |
| | 10 | Ambient HF seafloor noise | OBS | Off Shikoku array | Tonegawa et al. | 2015 | Nature Com. | |
| | 11 | Slow seafloor uplift | OBP+ BBOBS | B-array | Fukao et al. | 2019 | in progress | |

OBP: Ocean Bottom Pressure Gauge
BBS: BroadBand Seismometer on land (3-components)
OBS: Short-period Ocean Bottom Seismometer (3-components)
BBOBS: BroadBand Ocean Bottom Seismometer (3-components)
OBT: Tilt-outputs from BBOBS (2-components)
A-array: Off Aogashima array of OBPs with BBOBS at one site
B-array: Far-off Torishima array of OBPs with BBOBS at one site