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Transitioning Results From Recent ONR WESTPAC Field Programs to Operational Use (IWISE Analysis Expansion)

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LONG-TERM GOAL

The long-term goal is to enhance our understanding of coastal oceanography by means of applying simple dynamical theories to high-quality observations obtained in the field. My primary area of expertise is physical oceanography, but I also enjoy collaborating with biological, chemical, acoustical, and optical oceanographers to work on interdisciplinary problems. I collaborate frequently with numerical modelers to improve predictive skill for Navy-relevant parameters in the littoral zone.

OBJECTIVES

The objective of this grant is to improve understanding of how the large-amplitude internal waves and tides in the northeastern South China Sea are generated via interaction of the barotropic tide with the ridges and islands in the Luzon Strait. In addition to the problem's inherent scientific interest, understanding the generation problem is essential for developing a forecast model to predict the wave characteristics in the deep basin and on the Chinese continental slope and shelf.

APPROACH

The approach is to particpate in a major ONR-sponsored field program in the Luzon Strait and northeastern South China Sea during 2010-2011. Called the Internal Waves in Straits Experiment (IWISE), the program is a logical follow-on to the Nonlinear Internal Waves Initiative (NLIWI) but will focus more closely on the generation problem, rather than on free propagation and wave dissipation during the earlier experiments. A large team of investigators from the U.S. and Taiwan is participating. Our primary collaborator in Taiwan is Prof. Y. J. Yang of the Marine Sciences Department, Naval Academy. He and Dr. Ramp were the co-leaders of cruises on Taiwanese vessels during the pilot study (June 2010) and the intensive observations program (IOP, August 2011). We have two key thrusts: Moored and shipboard observations south of Taiwan on the northern Heng-Chun ridge; and two far-field deep-water moorings near 18° 30'E to monitor wave arrivals. The Heng-Chun site has not been previously explored, even though numerical studies suggest it is an important generation site. The far-field moorings will be combined with the PIES observations obtained by D. Farmer (UVic) and the source moorings of M. Alford (APL/UW) and J. Nash (OSU) to trace the progression of individual waves from the ridges to the deep basin. The program has an exciting

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numerical modeling component: We work especially closely with Oliver Fringer (Stanford) and Maarten Buijsman (NRLSSC).

WORK COMPLETED

Following the successful pilot study on the OCEAN RESEARCHER II during June/July 2010, the later calendar year 2010 months were spent processing and analyzing the data. The preliminary results were presented at the ONR hot wash meeting during January 2011 in Taipei, and somewhat more refined results at a seminar at the National Taiwan University in July 2011. The IOP cruises were conducted during July – September 2011 from the OCEAN RESEARCHER III. These included a basin mooring deployment cruise during July (Figure 1), two cruises to the northern Heng-Chun Ridge during August, and a mooring recovery cruise during September. All the moorings were successfully recovered and the instruments returned full records of temperature (T), salinity (S), and current velocity (u, v). The preliminary results were presented at a workshop in Kaohsiung, Taiwan, during March 29-31, 2012. The data analysis continues and manuscripts for publication are in preparation.

RESULTS

The essential result of the pilot study was the discovery of a mode-2 nonlinear internal wave near the source, generated by supercritical flow off the top of the Heng-Chun Ridge during the ebb (towards the Pacific) tide [Ramp et al., 2012]. The wave was released on the flood tide and propagated westward, although its fate could not be determined by this limited data set. During the short pilot study cruise only one such wave was realized and no moored observations were obtained. One goal for the IOP was therefore to spend a week at the site to determine the robustness of the initial results and the importance of the waves downstream with respect to contributions from other generation sites.

During August 2011, a combination of a mooring, three anchor stations, and underway CTDs were used to study wave generation and propagation (Figure 1). Many more mode-2 waves were observed, most commonly just after the ebb tide turned. The mooring frequently observed packets containing 4-5 waves each (Figure 2) in contrast to the pilot study wave which was believed to be solitary. The waves were characterized by a westward core velocity of order 50 cm s^{-1} and eastward return flow exceeding this amount above and weaker below (Figure 2). The isotherms were displaced upward by order 50 m in the top half of the waves and downward by a similar amount in the lower half. The wave packets were also clearly visible in the EK500 backscatter data and were associated with spectacular surface signatures (Figure 3). At times, several rows of alternating slicks and breaking waves were visible on the sea surface (Figure 3). The packets mostly propagated westward but other waves were occasionally observed propagating SSW, indicating at least two active sources nearby. The analysis continues with the energetics and dissipation calculations and comparison to numerical models.

Not to be overlooked are the results from the two basin moorings. These moorings were unique in providing the first observations of the meridional variability, in contrast to earlier mooring deployments which were along an east/west transect. Both the a-waves and the b-waves were observed at both moorings, although many more b-waves were observed at mooring N than S (Figure 4). The a-waves arrived about 4 hours earlier at S than N vs. only 2.5 hours for the b-waves. This was due primarily to the shape and propagation direction of the wave fronts. Combining the data with the PIES data and source moorings is still a work in progress. Preliminary results however suggest that the a-waves were generated on the ebb tide in the Luzon Strait and the b-waves on flood, in agreement with earlier work [Ramp et al., 2010; Zhang et al., 2011].

IMPACT/APPLICATION

The large amplitude NLIW propagating westward across the northeastern SCS have a significant impact on naval operations. They have a large impact on acoustic propagation loss as demonstrated in previous publications [Duda et al., 2004: Chiu et al., 2004]. They also induce large, sharp buoyancy fluctuations and water displacements in the thermocline both in the deep basin and after shoaling onto the Chinese continental shelf. The work described here is intended to facilitate real-time prediction of these phenomena for operational use.

TRANSITIONS

Some progress has been made by the team towards practical tactical decision aids for the Navy, regarding the occurrence and prediction of the large-amplitude, nonlinear interanal waves [Jackson, 2009; Ko et al., 2009]. Some of our data sets were used in developing these tools. The PI retains a courtesy appointment at the Naval Postgraduate School and has regular contact with the U.S. Navy via officer-students and faculty there.

RELATED PROJECTS

The ONR PhilSea10 project [Worcester et al., submitted; Colosi et al., submitted] may be useful in determining the internal wave propagation to the east of the Luzon Strait ridges. Please see associated annual reports for more details.

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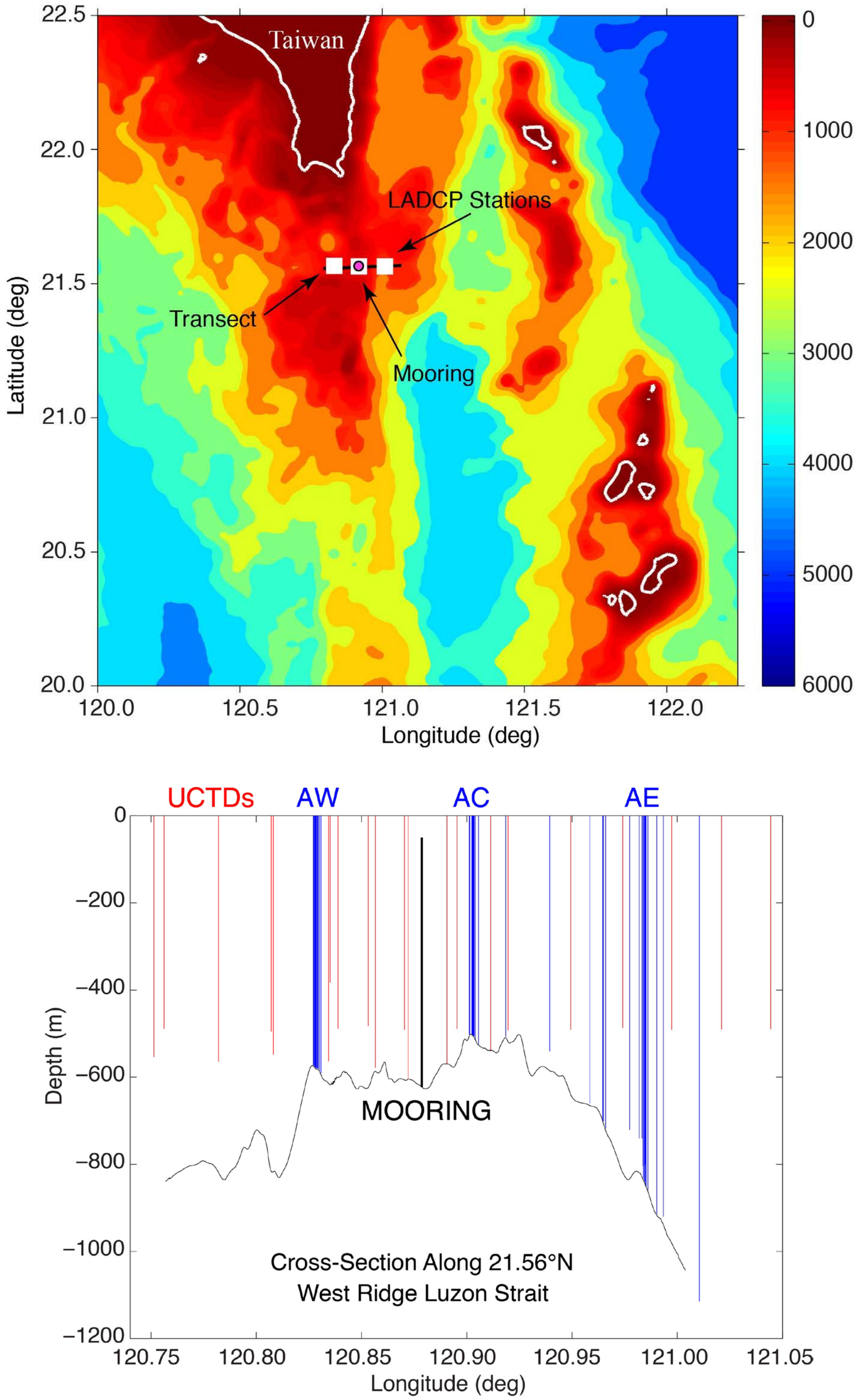

Figure 1. Locator map showing the August 2011 experiment site south of Taiwan (top) and a cross-sectional view of the transect shown by the black line (bottom). Underway CTD stations are in red and CTD/LADCP stations in blue.

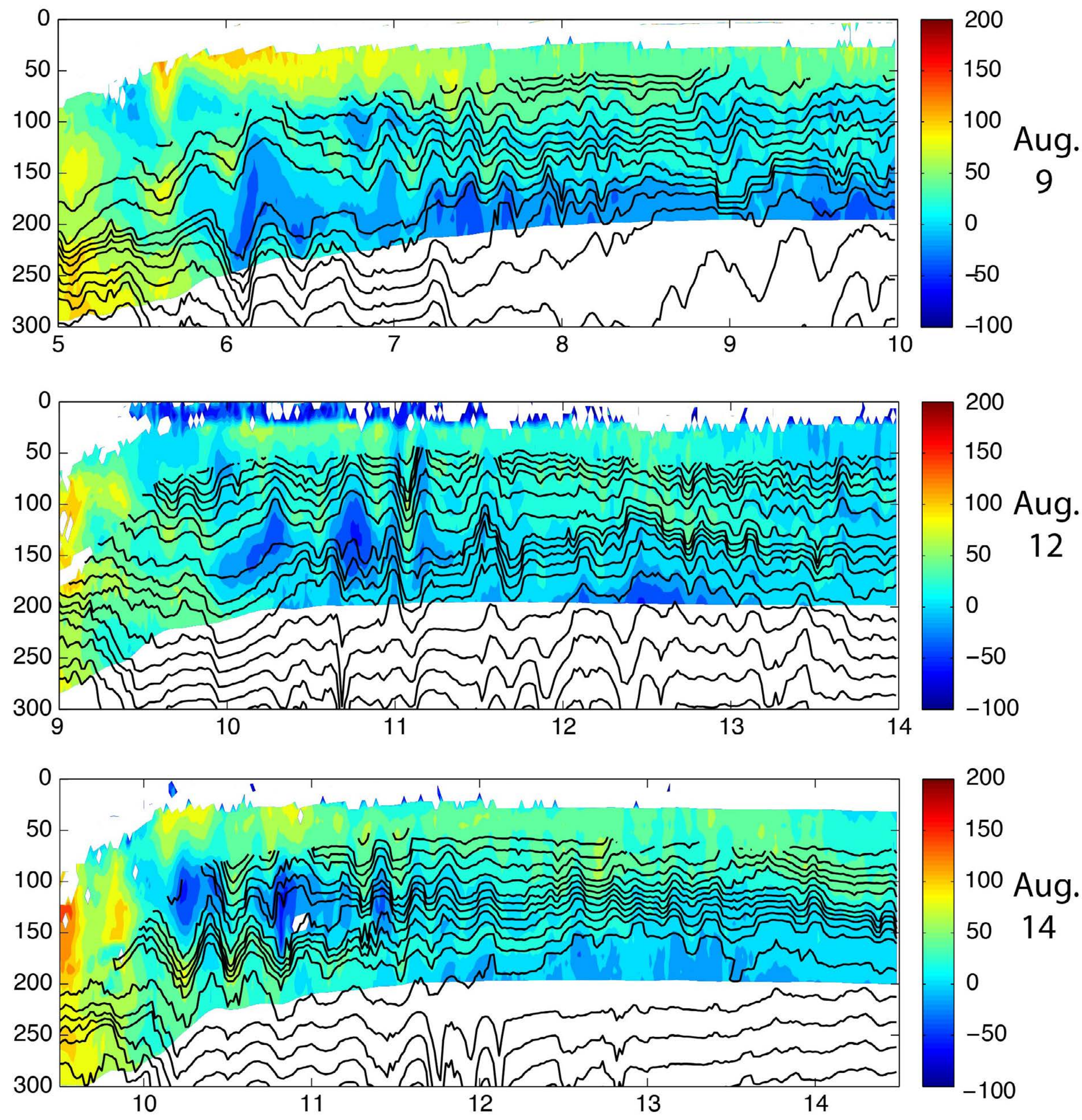

Figure 2. Moored time series of isotherm displacements (black lines) over zonal velocity (color) on expanded scales for five hours just past the ebb tide for August 9 (top), August 12 (middle), and August 14, 2011 (bottom). The mooring position is shown in Figure 1.

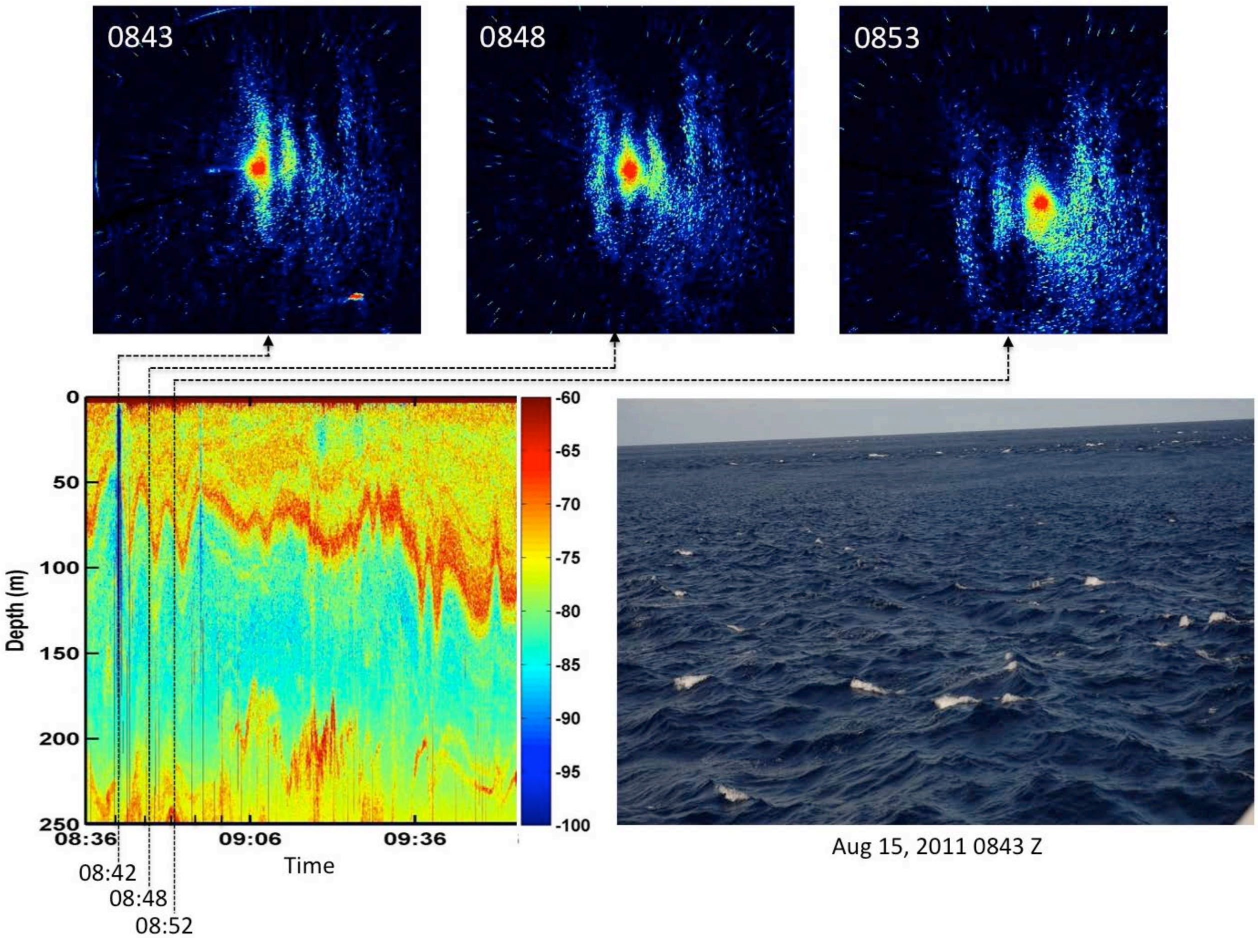

Figure 3. A train of convex mode-2 internal waves passing the R/V OCEAN RESEARCHER 3 on August 15, 2011, captured in three different data sets. The top panels are from the ship's digitally recording radar, the lower left panel is from the EK500 120 kHz backscatter, and the lower right panel is a photograph taken from the ship looking eastward while the ship was located in the first row of breaking waves. All three sensors show at least four waves in this packet.

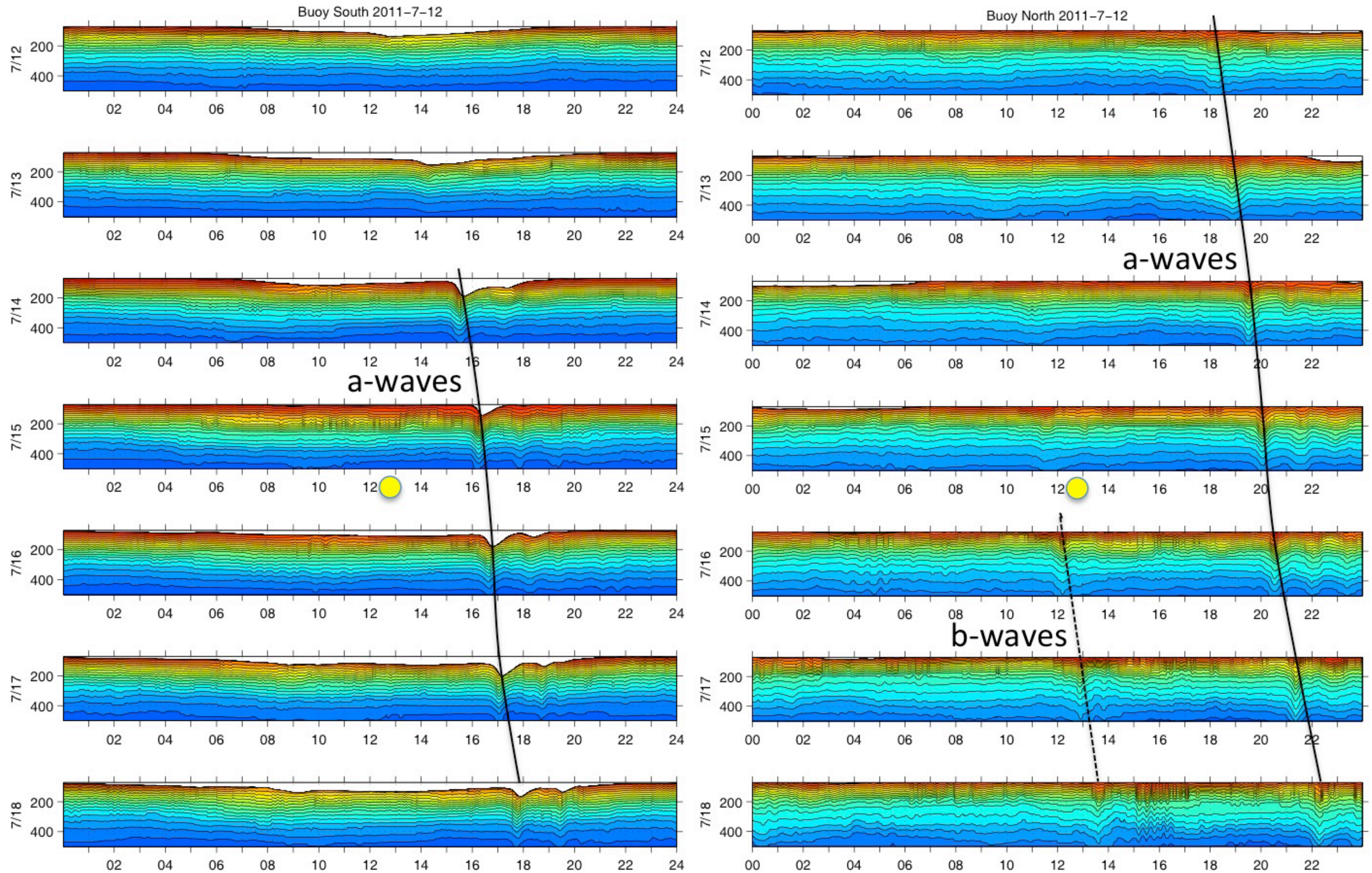

Figure 4. Temperature time series from buoy S (left) and buoy N (right) during July 12-18, 2011. The a-waves arrived at buoy S four hours earlier than buoy N on average. There were more b-waves observed at buoy N than at buoy S.