Data Analysis and Synthesis for the ONR Undersea Sand Dunes in the South China Sea Field Experiments

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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

- Quantify the seafloor characteristics in a field of recently-discovered undersea sand dunes spanning roughly 250 m to 400 m depth over the upper continental slope NE of Dongsha Island
- Study how enhanced bottom roughness in the dune field affects energy dissipation in the nonlinear internal waves and tides as they shoal
- Work with the acoustics team to determine how the large bedforms and wave-induced sound speed fluctuations impact sound propagation and loss in the vicinity of the dune field
- Attempt to ascertain the mechanism of dune formation and determine why they are unique to this particular location

APPROACH

A three-pronged approach was used to study the bottom characteristics, physical oceanography, and impact of the bottom configuration and physical oceanography on acoustic propagation.

- The space and time scales of the dune field were determined via repeated multibeam bottom surveys in 2012, 2013, and 2014. Bottom grabs and cores were obtained to determine sediment type and size distributions.
- Moorings and shipboard observations were deployed to study the physical oceanography, most notably the shoaling internal tides and large, highly nonlinear high-frequency internal waves (NLIWs).

- Acoustic travel times were observed both along and across the dune crests, both with and without the presence of large-amplitude nonlinear internal waves along the propagation path.

WORK COMPLETED

The 2014 Intensive Operations Period (IOP) was a three-ship operation including the R/V OCEAN RESEARCHER 1 (OR1) from May 31 – June 6, 2014; the OR5 from June 10 – 21; and the OR3 from June 6 – 10. The moorings were deployed from OR1 and recovered from OR5, thus spanning one entire spring/neap cycle (the full moon was on June 13, 2014). The OR3 was dedicated to towed acoustic operations (Linus Chiu, NSYSU, Chief Scientist) and policing the moorings from local vessel traffic when the bigger ships were in port. Lowered source work and "wave-chasing" operations were done from the OR1 and OR5 in addition to the mooring work. An important emphasis of the 2014 field program was to obtain much better near-bottom observations of the currents and water properties beneath passing large amplitude nonlinear internal waves (NLIWs) and tides than have been obtained in any of the previous SCS internal wave experiments. More specifically:

- A ten-element moored array was deployed supporting both acoustic (sound sources and hydrophones) and environmental (u, v, T, S, p) sensors to observe and understand sound transmissions in both the along- and across-dune crest directions. Moorings were deployed offshore of, central to, and just beyond (inshore of) the dune field (Figure 1).
- A sound source was towed in a circle around the central mooring to observe sound transmission along additional oblique transmission paths.
- At discrete locations, a sound source was lowered from the OR5 to study propagation along radials stemming from the moored VLA.
- The ship was positioned with the CTD/LADCP as close to the bottom as possible to observe the bottom currents and sediment resuspension processes as the NLIWs passed. The instrument frame also supported a transmissometer, fluorometer, optical backscatterometer, two MAVS acoustic current meters, and bottom imaging systems. Once the waves passed the ship, the ship was quickly repositioned ahead of the wave to do it again. This was done as many times as possible as the waves moved up-slope.
- Grab samples of the bottom were obtained on dune crests and in the troughs to characterize the sediment types and grain size distributions in the dunes.
- When foul weather prohibited any other work, additional multi-beam echo sounder (MBES) surveys were conducted to examine the temporal changes to the dune field.
- The first data analysis workshop was held during March 2015 in Taipei.

RESULTS

A complete analysis of the MBES and sediment data was performed by Profs. Song and Lou of National Taiwan University. The MBES survey revealed two different regions with a very clear line of demarcation along the change in bottom slope (Figure 1). On the steeper slope, the typical dune height was 4 m with a wavelength of order 100 m. Over the shallower slope, the typical maximum heights were 10-15 m with 260 m wavelength. Farther downslope in slightly deeper water, the dunes were "parted" which is to say non-sinusoidal with troughs much wider than the narrow crests. To the accuracy of the analysis, the dunes did not move between 2013 and 2014 implying very long time scales for dune migration. This admits the possibility of more optimal bottom-mounted instruments in future experiments. Also, the shallower slope was critical to the diurnal tide while the steeper slope was critical to the semidiurnal tide. This allows the waves to move parallel to the mean bottom slope and remain in contact with the bottom for extended periods of time. The material (quartz) and grain shape (rounded) of the sediments also indicates very old material. The dunes have been there for a very long time.

As in all previous data sets from the region, two "families" of waves dubbed the a-waves and the b-waves were observed. The wave amplitudes tracked the fortnightly envelope in the generation region, taken to be barotropic tide in the Luzon Straits. Based on a lag time of 48.5 hours from the straits to mooring RPO, the a-waves were coming off the larger ebb beat and the b-waves off the previous flood beat. Most of the a-waves were already formed by the time they reached the most offshore mooring, but many of the b-waves were locally formed as the internal tide shoaled, most especially between 342 m and 266 m. Regardless of wave type, the number of waves per packet tended to increase as the waves shoaled. Based on theoretical considerations, this was due to the formation of a dispersive tail rather than wave breaking [Vlasenko and Hutter, 2002; Aghsaee et al., 2010; Lamb and Warn-Varnas, 2015]. The waves likely don't start breaking until they reach the 100 m to 150 m depth range which is well beyond the dune field.

An interesting new result is the observed double a-waves which arrived about two hours apart near spring tide (Figure 2). The origin of these previously overlooked waves is unknown and deserves further study.

If and how the shoaling NLIWs influence the dune formation process remains a subject of further investigation. The length scale of the dunes is much smaller than the wavelength, but may be a match for the global instability in the separated downslope flow behind the wave [Bogucki et al., 2005; Diamessis and Redekopp, 2006; Stastna and Lamb, 2008]. Once resuspended, the sediment may be transported farther by the internal tides and background currents.

IMPACT/APPLICATION

Bottom acoustic scattering conditions are expected to be quite different from previously observed regions outside the dune field. The intensive near-bottom observations beneath the NLIWs should provide new information on if/how these waves resuspend and redistribute bottom sediment over the continental slope. The new observations should also expand understanding of how much energy is dissipated on the continental slope over varying bottom strata.

TRANSITIONS

The field work was just completed during June 2014. Transitions are expected as the analysis continues.

RELATED PROJECTS

The acoustics side of the project is funded by ONR 321OA. See related annual reports by C.-S. Chiu and D. B. Reeder, Naval Postgraduate School. The project is jointly funded by the National Science Council of Taiwan under grants to National Taiwan University (NTU) and National Sun Yat-sen

University (NSYSU). The principal invesigators of the Taiwan side are Profs. Y. J. Yang and C. Chen (NTU) and Prof. L. Chiu (NSYSU).

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PUBLICATIONS

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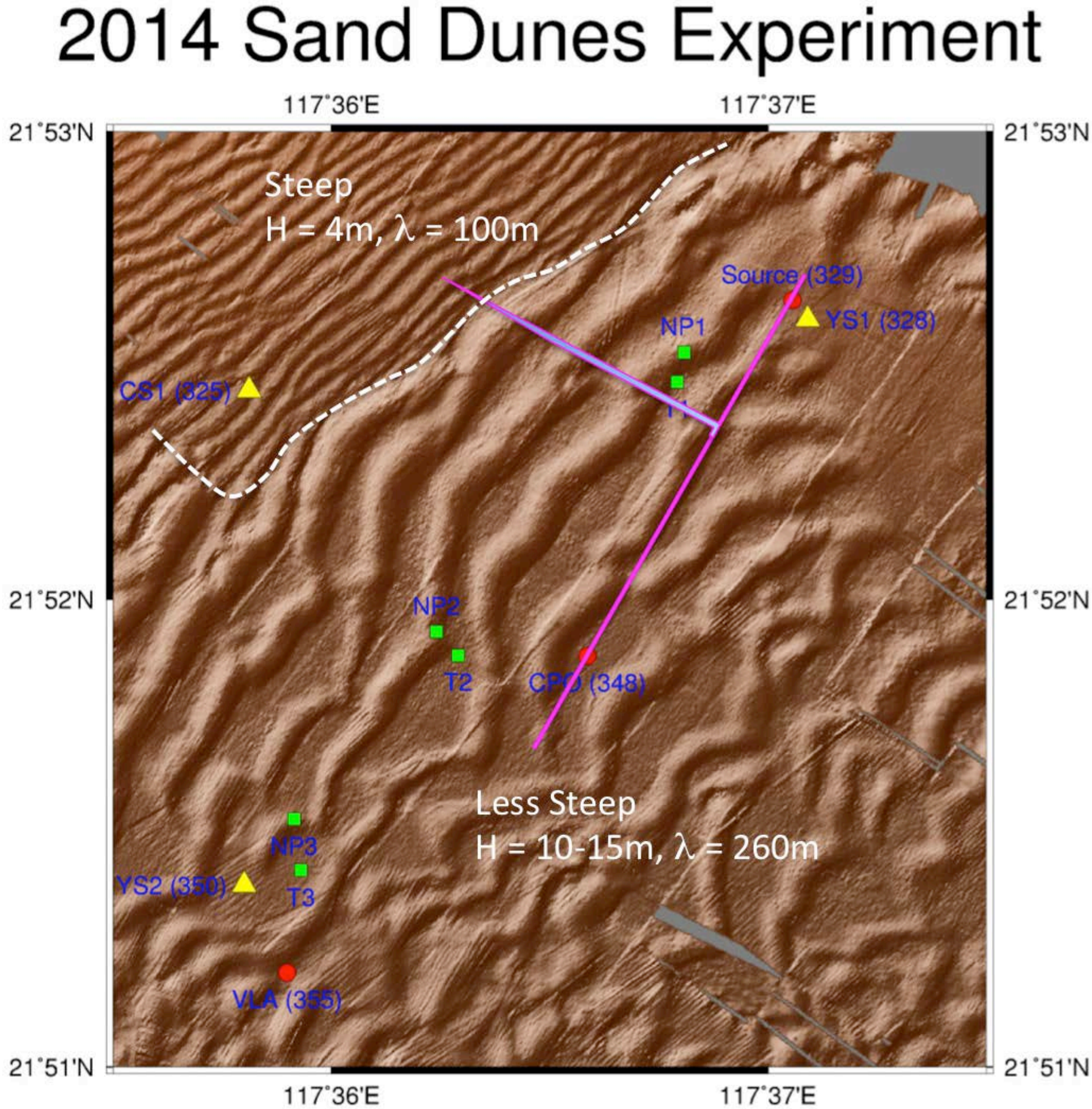

Figure 1. A view of the sea floor in the study region based on the 2014 multibeam echo sounder (MBES) survey. The white dotted line marks an abrupt change of mean bottom slope, steeper to the left. A few of the sediment grab locations are indicated by the green squares. The internal wave propagation direction is indicated by the magenta arrow, based on the arrival times at moorings "source" and "CPO."

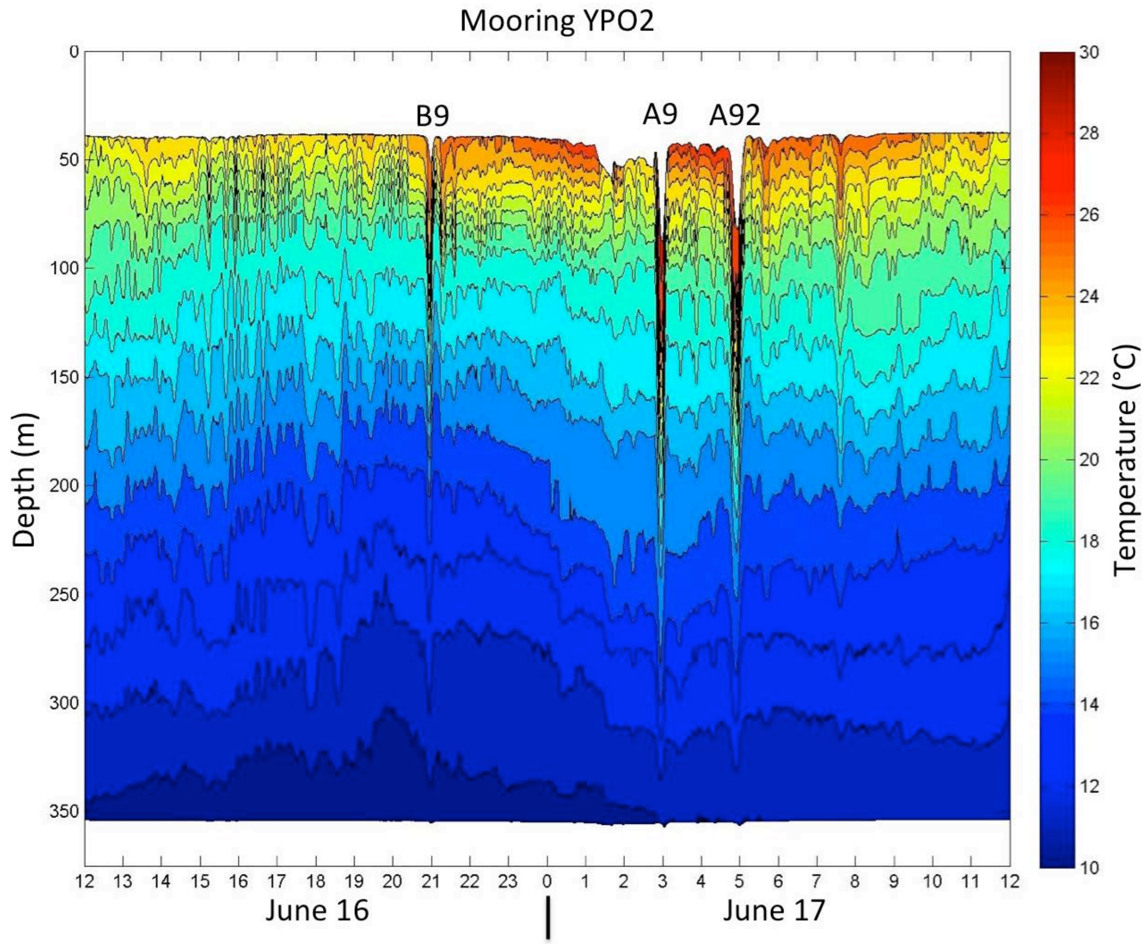

Figure 2. Time series of temperature at mooring YPO2 on the 386 m isobath, towards the offshore edge of the dune field. Wave B9 shows a typical packet structure, locally formed, while waves A9 and A92 are two distinct waves two hours apart.