Submarine Sand Dunes on the Continental Slope in the South China Sea and Their Impact on Internal Wave Transformation and Acoustic Propagation

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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

- Determine how nonlinear internal waves (NLIW) and tides interact with the sea floor to form and maintain the large (>16 m) sand dunes over the Chinese continental slope NE of Dongsha Island
- Study how enhanced bottom roughness in the dune field affects wave transformation and energy dissipation in the 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.

APPROACH

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

- Characterize the space and time scales of the dune field via repeated multibeam bottom surveys. The dunes are nominally 10-20 m tall with 350 m between crests, in water roughly 250 m – 600 m deep [Reeder et al., 2011]. Their migration rate and formation mechanism is unknown. Bottom grabs and cores will be used to determine sediment type and size distributions.
- Moorings and shipboard observations will be used to study the physical oceanography most notably the shoaling internal tides and large, highly nonlinear high-frequency internal waves.

These waves are known to impact the area from previous studies e.g. [Ramp et al., 2004]. The working hypothesis is that the very high-speed NLIW do the initial work of resuspending the bottom sediments which are subsequently transported around by the tides and other lower-frequency currents.

- Acoustic travel times will be 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

Results from the 2013 pilot study were reported in last year's annual report. The interested reader is referred there for more details. The remainder of this report will focus on the activities surrounding the 2014 Intensive Operations Period (IOP). A three-ship operation was employed to conduct the IOP 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.
- 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 since May 2013.

RESULTS

Preliminary analysis of the temperature and salinity data suggest a data set rich in nonlinear internal waves, unlike the 2013 pilot study when there were none. This will prove useful for comparing the acoustic propagation with/without NLIWs. As in all previous data sets from the region, both type a- and type b-waves were observed (Figure 2). The propagation time from the Luzon Strait to mooring RPO was about 48.5 hours, estimated via a small adjustment to the well-known propagation time from the Luzon Strait to ASIAEX mooring S7. Mooring YPO2 was 2 hours and 2 minutes closer, about 46.5 hours. These times were used to lag back the wave arrivals for comparison to the tidal beat in the Luzon Strait. The pattern match was remarkable with the a-waves coming off the larger ebb beat and the b-waves off the previous flood beat. The overall wave amplitudes matched the fortnightly forcing pattern, as observed in previous experiments.

A more local view of the waves was obtained by lagging the time series according to the propagation times between moorings and off-setting them by 2 °C for clarity. An example is shown for waves generated near spring tide in the Luzon Strait (Figure 3). The b-waves were clearly observed at all four moorings, and arrived about 50 min later each day. The really large a-waves near spring tide (A8 and A9) had clearly split even before reaching the most offshore mooring YPO2. The number of waves per packet increased across the shelf as the waves shoaled. The sharpness of the fronts was quite remarkable and often exceeded 1° C per minute, not only in the NLIW but also in the tidal fronts. The ADCP data (not shown) show that these fronts were formed by the collision of the b-wave with the opposing off-shelf local tide.

The moored ADCPs all worked well and returned high-resolution data (4-m bins every 20 s) throughout the water column, however these data have not been fully processed at the time of this writing. The lowest ADCP on each mooring reached the bottom and thus new information on the bottom currents under passing NLIW and strong tidal currents was obtained.

IMPACT/APPLICATION

Bottom scattering conditions are expected to be quite different from previously observed regions outside the dune field. Intensive near-bottom observations beneath the NLIWs is new and should provide new information on if/how these wave 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. Linus Chiu (NSYSU).

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PUBLICATIONS

None at this time.

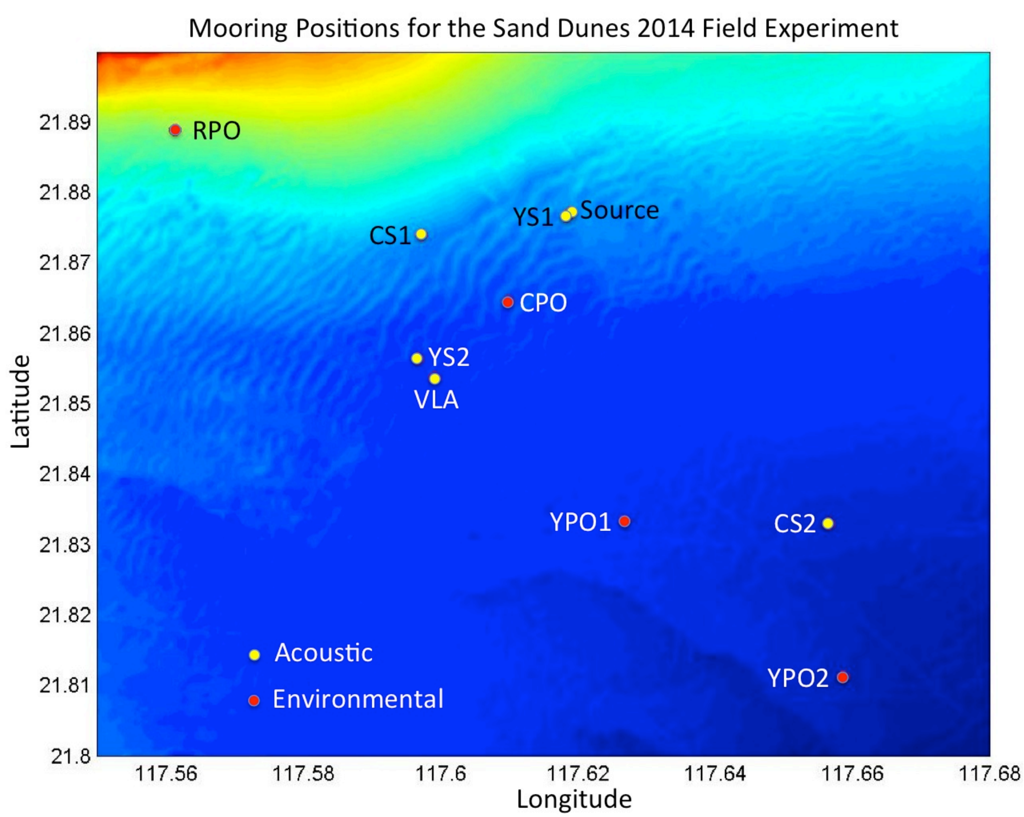

Figure 1. Mooring positions on bottom topography for the ONR Sand Dunes June 2014 moored array in the northeastern South China Sea. Maximum relief in the region of the highest dunes was 16 m near CPO. YPO2 lies ahead of the dune field as the wave travels, YPO1 and CPO are in the dune field, and CPO is just past the dune field.

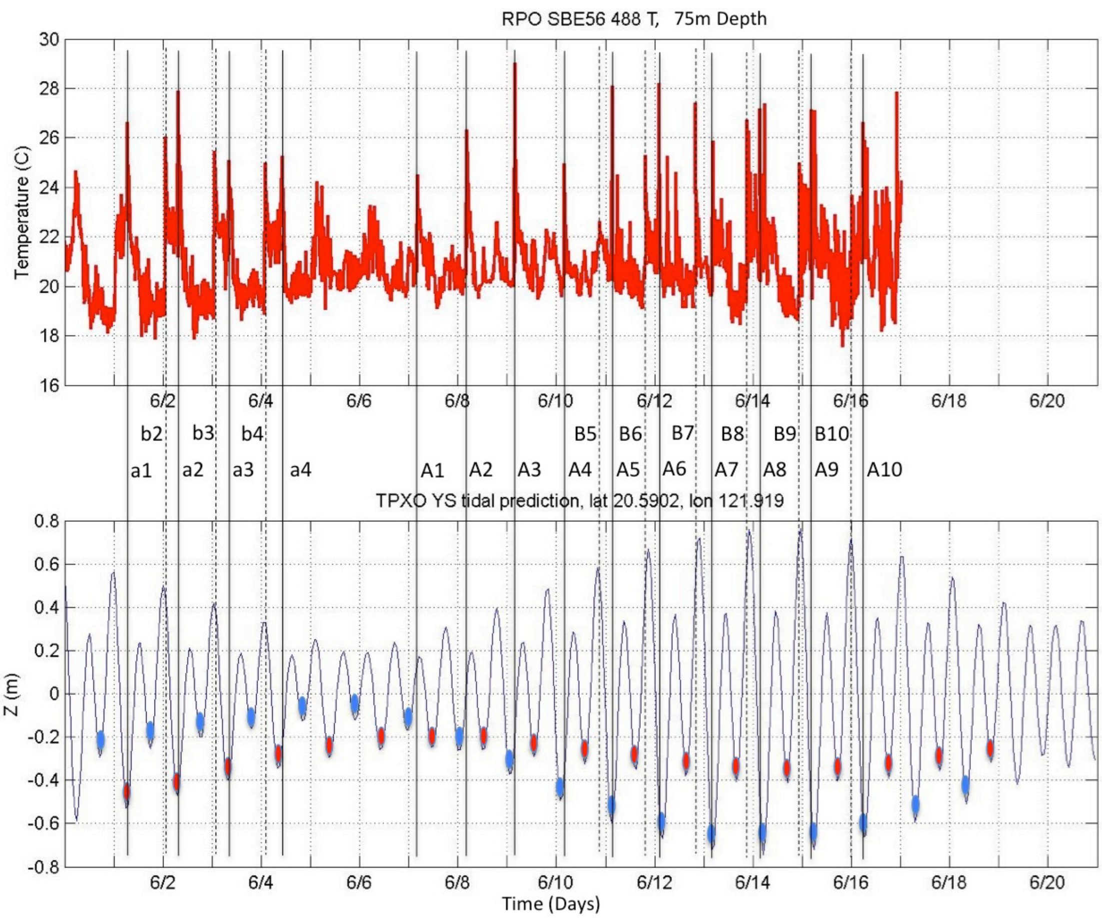

Figure 2. Temperature from 75 m depth on mooring RPO (water depth 266 m) plotted over the tidal heights in the Luzon Strait as generated from the TPXO global tidal model. The temperature time series has been lagged back 48.5 hours to allow for the propagation time from the strait to the mooring. The blue and red dots illustrate how the stronger beat during the first fortnight became the weaker beat during the second fortnight. Vertical solid lined indicate a-waves, and dotted lines indicate b-waves. For details see text.

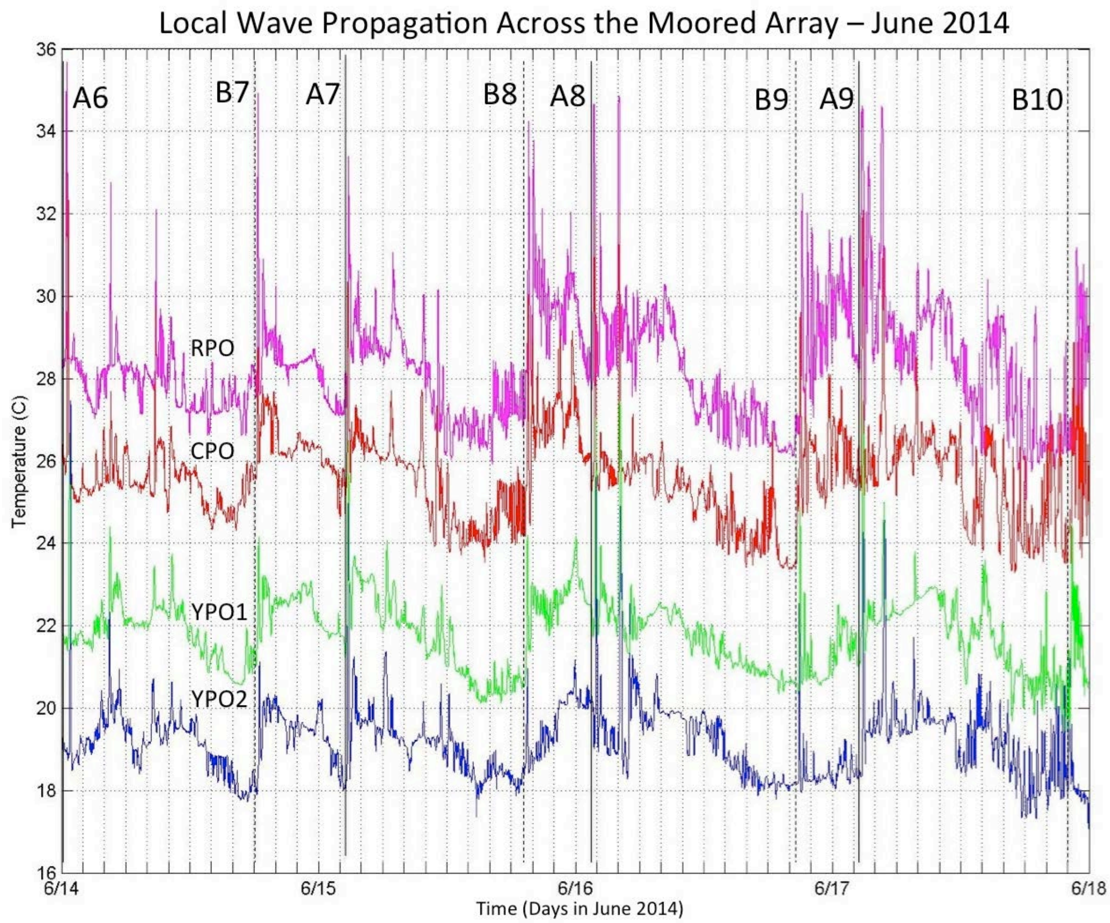

Figure 3. Temperature time series near 75 m depth from each of the four moorings spanning the June 2014 moored array. Each time series has been lagged to allow for the propagation time between moorings, and offset by 2°C for clarity. The (a, b) waves are indicated by a (solid, dashed) vertical line. This figure represents a time of strong generating tides in the spring/neap cycle.