High resolution measurements of nonlinear internal waves and mixing on the Washington continental shelf

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LONG-TERM GOALS

We are interested in the general problems of internal waves and ocean mixing. Knowledge of these is important for advancing the performance of operational and climate models, as well as for understanding local problems such as pollutant dispersal and biological productivity. Most of the ocean's physical and acoustic environments are significantly modified by internal waves. In the specific case of nonlinear internal waves (NLIWs), the currents and displacements of the waves are strong enough to impact surface and under-sea operations and communication. The pilot research described here will begin to improve our knowledge and predictive ability of NLIWs and their impacts on the Washington shelf. Additionally, it will form the foundation for better understanding of NLIW generation, their propagation in strongly sheared coastal currents, and their associated mixing on continental shelves worldwide.

OBJECTIVES

- Measure the time-evolution of wave structure by tracking as many waves as possible from generation to eventual dissipation.
- Quantify dissipation and mixing associated with the waves and identify the processes leading to wave dissipation using our Modular Microstructure Profiler (MMP).
- Identify wave generation sites and evolution using a combination of SAR satellite imagery, Shallow Water Integrated Mapping System (SWIMS) and shipboard acoustics (Biosonics).

APPROACH

Observations from a real-time mooring that we maintain on the Washington continental shelf indicate an extremely energetic field of NLIWs propagating onshore. As a fraction of the water depth, their amplitude is among the largest in the world (Alford et al, 2012). The waves propagate through a strongly time-variable sheared coastal jet current, and appear to be generated as remote internal tides shoal onto the shelf break. In this project we used our Shallow Water Integrated Mapping System (SWIMS) and Modular Microstructure Profiler (MMP) instruments to directly measure their spatial structure and mixing, in order to 1) better understand the propagation and dissipation of strongly nonlinear internal waves in sheared currents and 2) characterize their effects on the acoustic, physical and biological environment of the region.

WORK COMPLETED

In May 2014 we tested MMP from APL's local work boat, the R/V Jack Robertson.

In August 2014 we conducted a highly successful 8-day cruise on R/V Oceanus. We used our towed and dropped profilers, the Shallow Water Integrated Mapping System (SWIMS) and the Modular Microstructure Profiler (MMP), as well as moorings, shipboard radar and an echosounder to track the waves as they shoaled. Chris Jackson assisted in obtaining 9 SAR images concurrent with our August 2014 cruise.

Madeleine Hamann, a Scripps graduate student, went on the cruise and has been analyzing the data under the supervision of Matthew Alford.

RESULTS

Observations in 2014 included:

1. Direct turbulence measurements following several waves with MMP
2. Extremely high-resolution wave-tracking exercises using ship's radar, echo sounder, and SWIMS showing detailed evolution and indirect turbulence measurements of 6 waves as they shoaled
3. Detailed, real-time moored measurements at the Cha Ba mooring
4. Additional moored measurements with a bottom-mounted ADCP at the shelf break and five locations inshore of our measurements
5. 36-hour tidally-resolving transects showing the generation conditions leading to wave formation
6. Nine synthetic aperture images collected during our cruise with assistance from Chris Jackson and Hans Graber.

In the past fiscal year:

1. Routines were developed in order to infer dissipation of turbulent kinetic energy directly from temperature fluctuations measured by a SeaBird FP07 on the SWIMS package. This capability allows higher spatial and temporal resolution of the distribution of turbulence along each wave crest due to the higher sampling rate possible with the SWIMS package. Preliminary results suggest the dissipation rates are enhanced at the interface between upper and lower layers where shear is enhanced. Dissipation is also enhanced in a layer that originates near the bottom around the 60-m isobath and extends offshore (see Figure 2).
2. Data from three shipboard ADCPs were reprocessed to obtain higher temporal resolution during the passage of the high-frequency waves and to prevent the usual processing parameters from voiding anomalous, high velocities that are induced by the passage of NLIWs in the near surface layers. The velocity measurements were greatly improved and allowed for the computation of shear for waves sampled with the MMP.
3. Wave trains sampled with MMP were examined to assess to the spatial distribution of dissipation along the wave crests. The largest waves tracked exhibited enhanced dissipation and high shear leading to subcritical 4-m Richardson number along the interface, suggesting shear instability between opposing layers as a mechanism for enhanced dissipation (see Figure 3, right). However, smaller amplitude waves did not exhibit the same dissipation patterns, with turbulence at the trailing edge and core of the waves as observed by Moum et al (2003).
4. NLIW trains arrive regularly at ChaBa every 12.4 hours with variable characteristics as observed by Zhang et al. (2015). Analysis of the exact propagation direction of each wave following the methods of Chang et al (2011) using shipboard measurements has proven difficult, and further work is required. Based on the velocity data from NEMO-SS (deployed ~300m SE of ChaBa, see Figure 1), it appears that most waves propagate to the NNE near the shelf break, and after passing ChaBa turn further to the East. There are some anomalies. Some “rogue” soliton trains appear irregularly, out of phase with the “regular” packets. For at least one “rogue” wave, its signature in velocity is apparent at NEMO-SS before its signature in isopycnal displacement is apparent at ChaBa (see Figure 4), indicating that the wave may have come from a generation site different than that of waves regularly observed at ChaBa.

IMPACT/APPLICATIONS

The Washington waves are extremely strong, but completely uncharacterized prior to this work. An assessment of them will allow determination of 1) their possible impact on navigation; 2) their possible effect in mixing and setting local watermass properties; and 3) the effect of their turbulence and transport on the local ecosystem. Additionally, a general understanding of waves in sheared currents will benefit a variety of problems.

RELATED PROJECTS

This project would not have been possible without funds from a related award to transition SWIMS and MMP to Alford’s group from Mike Gregg’s.

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PUBLICATIONS

None.

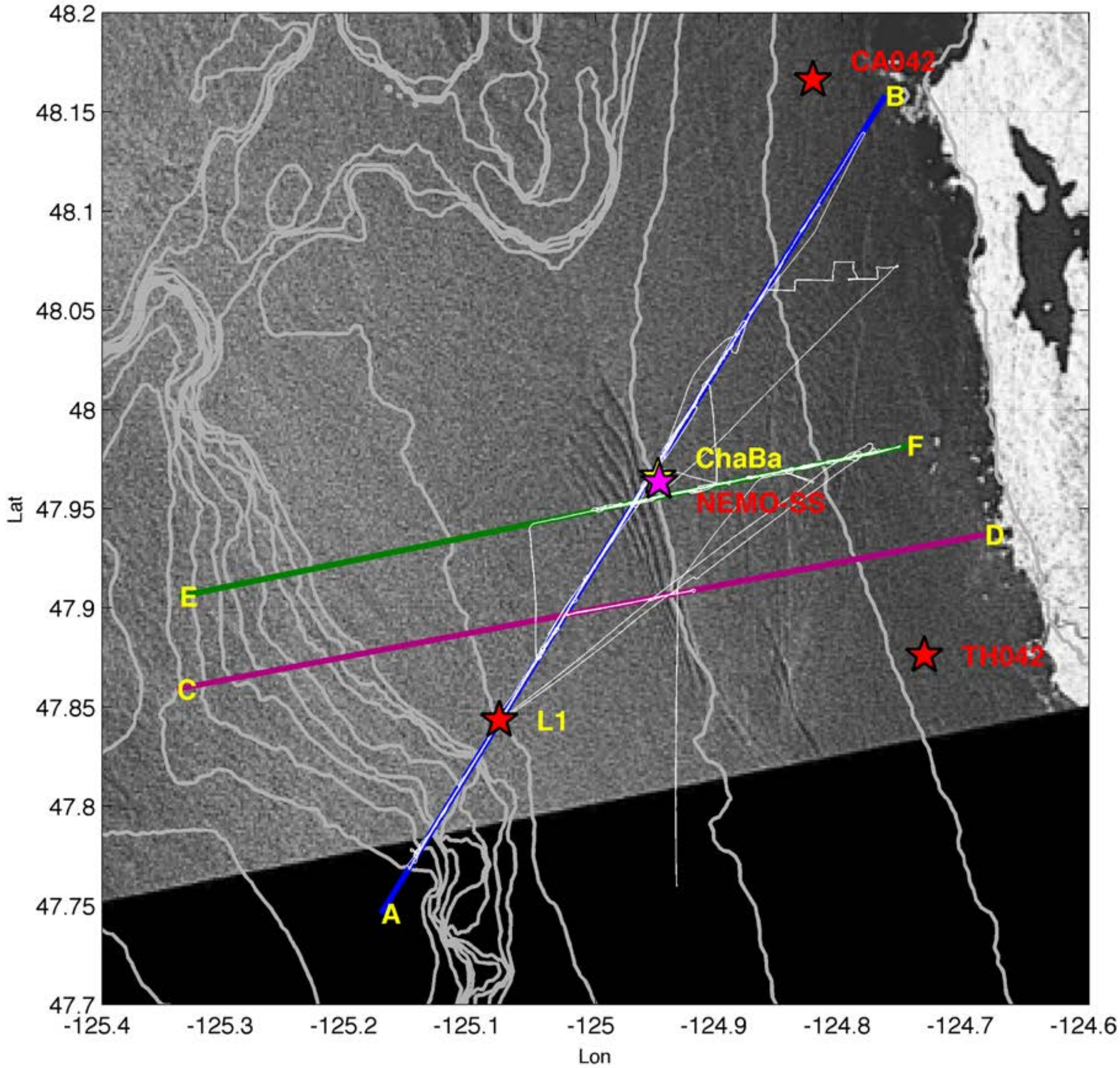

Figure 1: High Resolution bathymetry contours of the study region, mooring locations and survey lines. Synthetic aperture radar (SAR) imagery showing the wave crests traveling onshore is over plotted. Contours are every 50 m until 500 m, and then every 200 m after that.

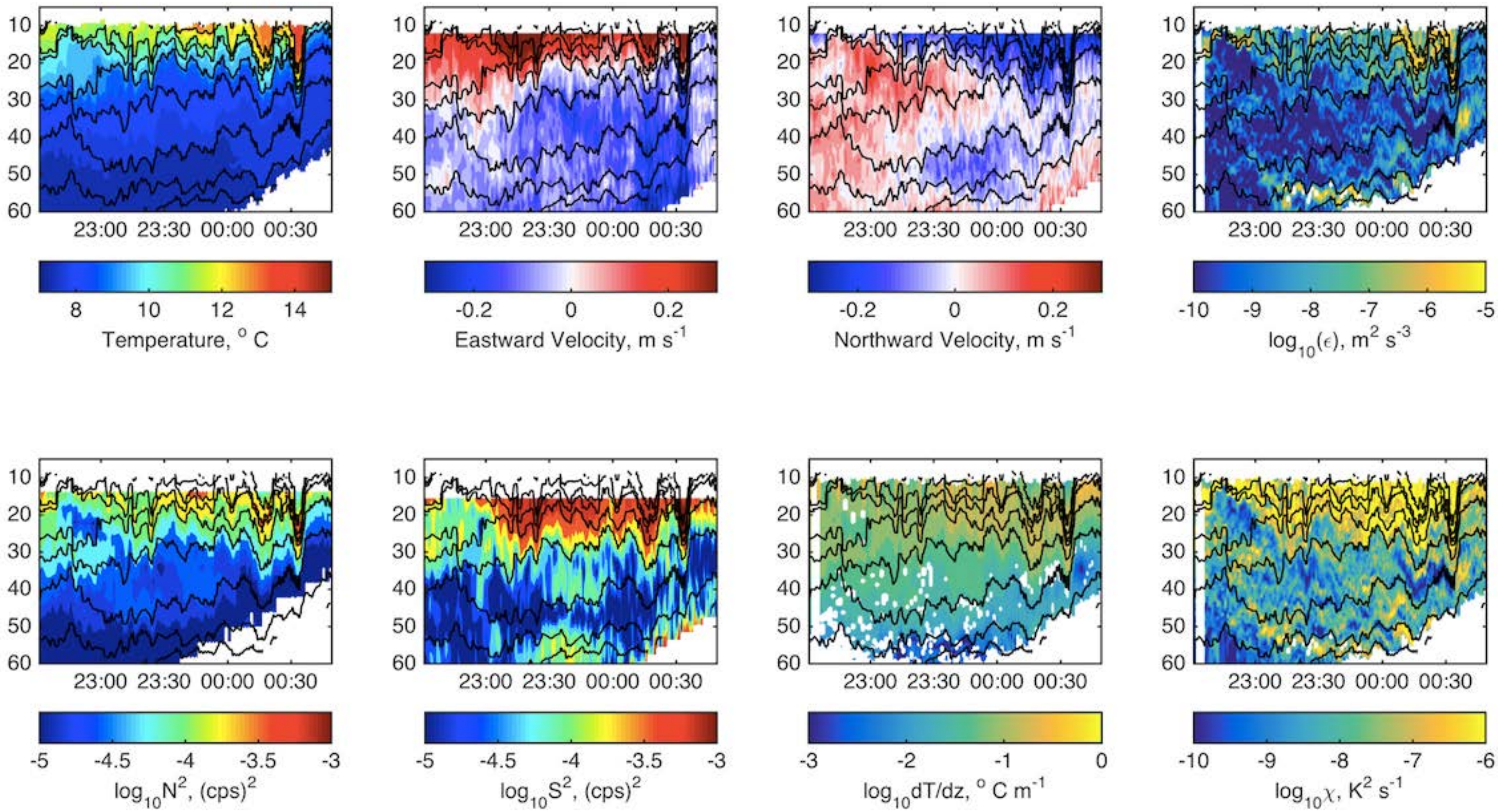

Figure 2: Sections of (from left to right, top to bottom) temperature, East- and North-ward velocity, dissipation of turbulent kinetic energy (ε) buoyancy frequency (N^2), shear (S^2), temperature gradient, and dissipation rate of thermal variance (χ) measured from the SWIMS package along a section through a NLIW train moving onshore from the 100 m isobath.

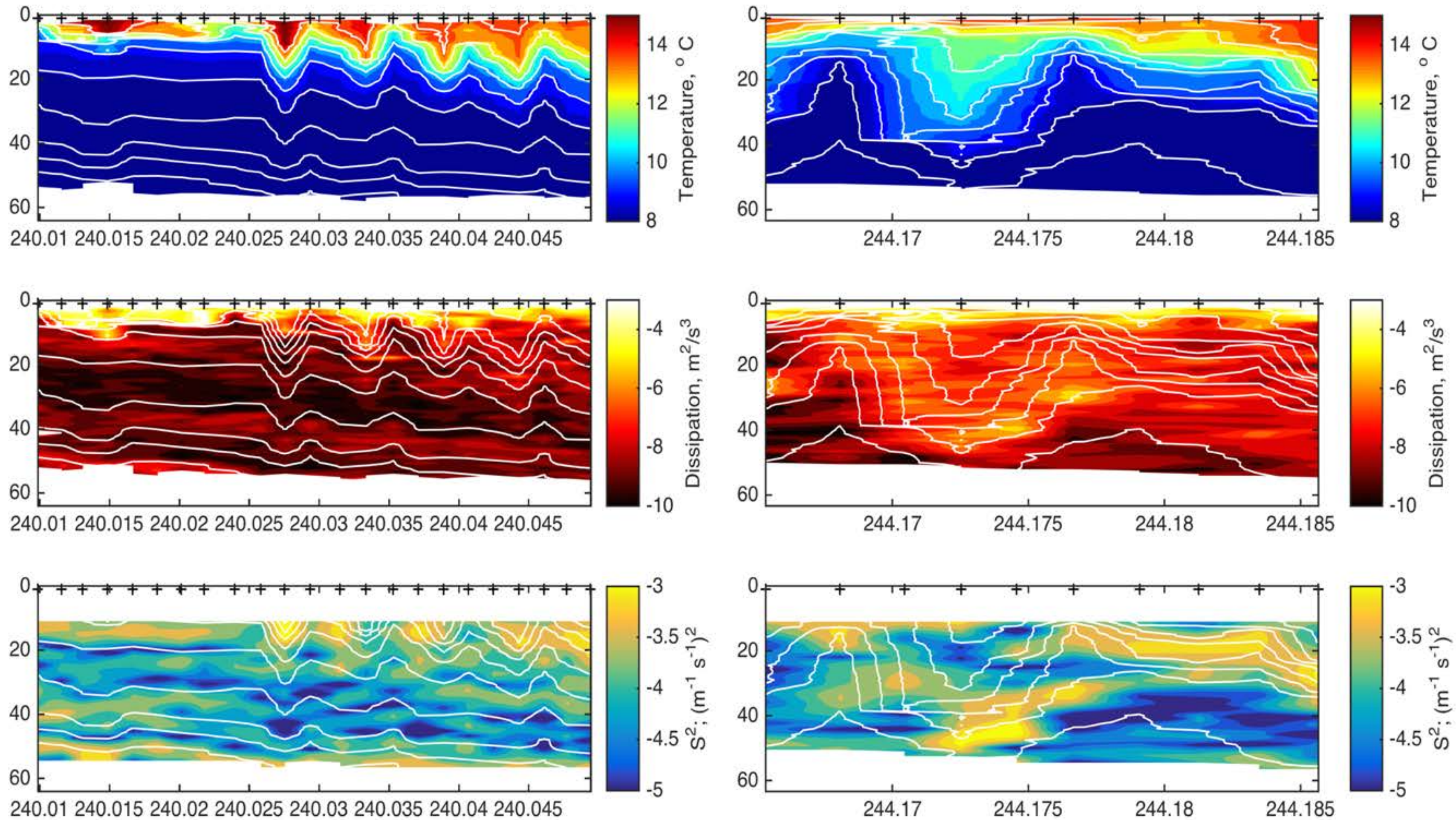

Figure 3: Temperature and dissipation of turbulent kinetic energy from measurements made by the MMP (top and middle), and shear computed from measurements from the shipboard ADCP (bottom). Sections have not been altered to account for movement of the ship, which was ~1 knot against the direction of each waves' propagation. The lefthand panels highlight a wave train with a smaller amplitude observed on August 29; the righthand panels show the first past through the largest amplitude wave, which we observed on 9/2.

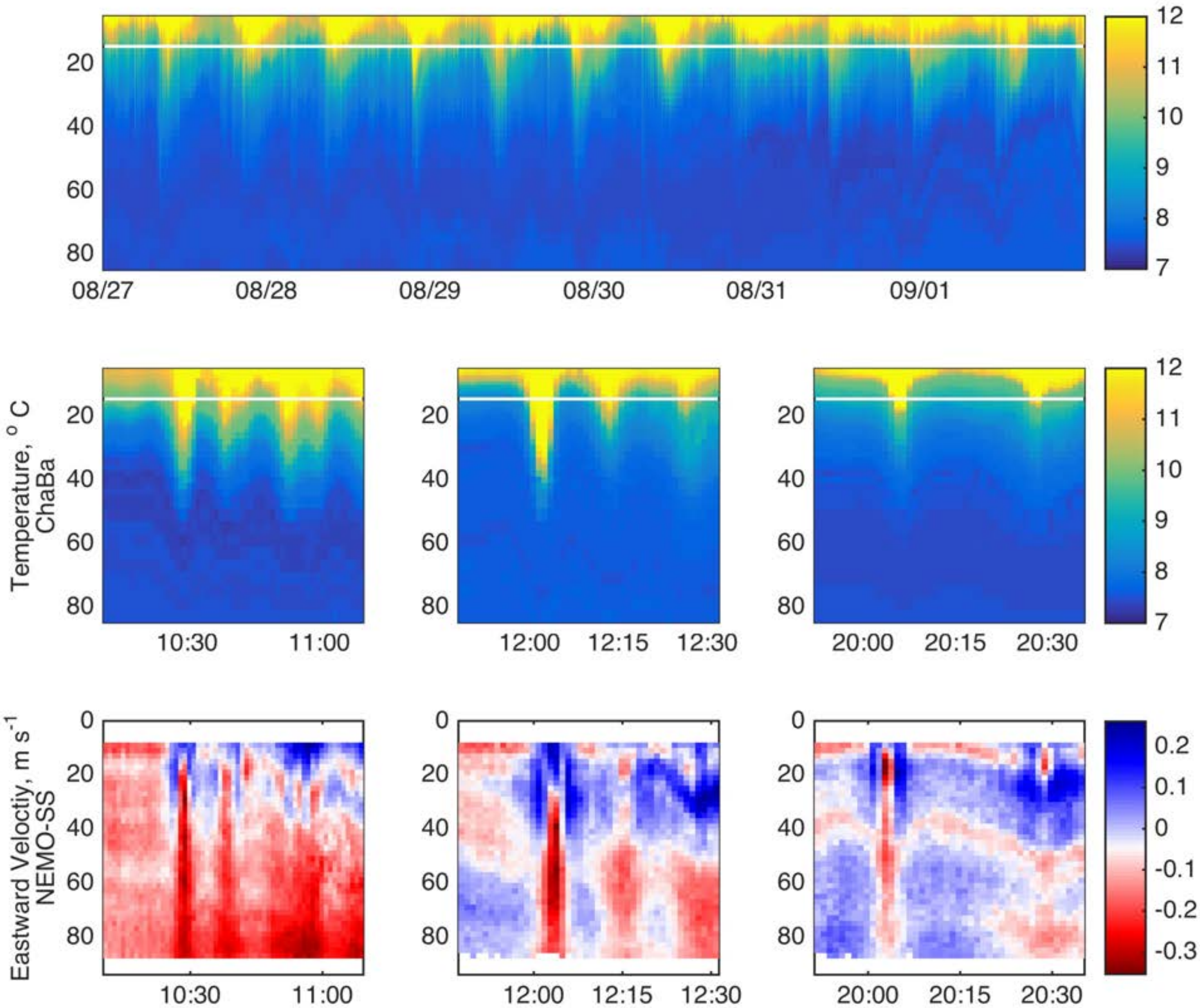

Figure 4: Time-series of temperature from Cha-Ba (top and middle) and eastward velocity from NEMO-SS (bottom). The top panel shows the full time series over six days during the experiment; the lower two rows show zoomed sections from three wave events identified in the record. The leftmost section shows a typical solitary wave train that appear regularly with M2 frequency at ChaBa. The middle section shows an atypical train that appeared on the same day 1.5 hours later. The right-most panel shows another atypical pair of solitons that did not occur with regular phasing, and whose signature is seen at NEMO-SS slightly before it is seen at ChaBa.