KAUAI ACOMMS MURI 2011 (KAM11) EXPERIMENT

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1 INTRODUCTION

The Kauai Acomms MURI 2011 (KAM11) Experiment was conducted in shallow water (~80-200 m deep) off the western side of Kauai, Hawaii, over the period 23 June –12 July 2011 [1]. Previous experiments in the area include KauaiEx (2003) [2], Makai (2005) [3], and KAM08 (2008) [4]. The objective of KAM11 was to obtain acoustic and environmental data appropriate for studying the coupling of oceanography, acoustics, and underwater communications. Of specific interest was to collect acoustic and environmental data that will relate the impact of a fluctuating oceanographic environment and source/receiver motion to fluctuations in the impulse response of the acoustic channel between multiple sources and receivers and ultimately to the design and performance characterization of acoustic digital data communication systems in shallow water.

The focus of KAM11 was on fluctuations over scales of a tenth of a second to a few tens of seconds that directly affect the reception of a data packet and packet-to-packet variability. Both fixed and towed source transmissions were carried out to multiple receiving arrays over ranges of 1-8 km along with additional towed source transmissions out to 14 km range. The acoustic transmissions were in three bands covering 3.5 to 35 kHz and included both environmental probing waveforms as well as communication transmissions. The experiment region exhibited substantial daily oceanographic variability. The mixed layer depth changed from as little as 20 m to as much as 60 m or more over the course of 24 hours. Similarly, the wind speed and sea surface conditions exhibited a daily pattern. Environmental data collected included water column sound speed structure (CTDs and thermistor strings), sea surface directional wave field (waverider buoy), and local wind speed and direction.

Examples are provided of the dynamic water column environment, wind speed, and waverider-derived sea surface wave spectra observed during KAM11. In addition, examples of the time-evolving channel impulse response (CIR) under various wind, sea surface, and water column conditions are included.

2 DEPLOYMENT LOCATIONS OF ENVIRONMENTAL SENSORS AND ACOUSTIC ARRAYS

A set of mooring locations were defined and are shown in Fig. 1 adjacent to the 100 m isobath along with the deployment positions of the acoustic sources, receiving arrays, and environmental moorings. A summary description of each identified piece of equipment is given in Table 1.

Identification	Description
UDEL-WB	Waverider buoy
WHOI-TS	Thermistor string
MPL-VLA1	Autonomous vertical receive array – 16 elements – 3.75 m spacing
MPL-VLA2	Autonomous vertical receive array – 16 elements – 3.75 m spacing
MPL-SRA1	Autonomous source-receive vertical array – 8 elements –7.5 m spacing
MPL-SRA2	Ship-deployed source-receive vertical array – 8 element –7.5 m spacing
MPL-SrcT	Source tow – 2 transducers
WHOI-Rx1	Autonomous receive array – 24 elements – 5 cm spacing
WHOI-Rx2	Autonomous receive array – 24 elements – 20 cm spacing
WHOI-Tx1	Autonomous source array – 4 transducers – 0.5 m spacing
WHOI-RxB1	RF buoy-based receive system – 4 elements – 20 cm spacing
WHOI-RxB2	RF buoy-based receive system – 4 elements – 20 cm spacing
WHOI-TxS	Ship-based RF source – 4 transducers – 0.5 m spacing
UDEL-Rx1	Seafloor (tripod) vertical receive array and source – 8 elements – 0.5 m spacing
UDEL-Rx2	Seafloor (tripod) vertical receive array and source – 8 elements – 0.5 m spacing

Table1. Environmental moorings, acoustic sources, and receiving arrays.

Environmental moorings deployed included a thermistor string at Sta04 and a waverider buoy at Sta06. Also, self-recording thermistors were attached to the receive arrays at Sta08 and Sta16.
Two source arrays were deployed. The first was a large-aperture, 8-element source array deployed at Sta02 [5]. The second was a small-aperture, 4-element source array deployed at Sta03. In addition two near-seafloor sources were deployed for shorter periods at Sta05 and Sta07 along with collocated small-aperture, 8-element vertical receive arrays. Two large-aperture, 16-element vertical receive arrays were deployed at Sta08 and Sta16 [6] along with two shorter-aperture, 24-element vertical receive arrays at Sta09 and Sta17. Lastly, a small-aperture, 4-element vertical receive array was deployed from an RF buoy at Sta05 then later at Sta11 for receiving adaptive modulation transmissions from a ship-deployed, small-aperture, 4-element source array. In addition to the fixed-source transmissions, source tows were carried out in the area. These included tows close to and at long range from the receive arrays.

The acoustic transmissions from all sources deployed in KAM11 were in three bands covering 3.5-35 kHz and included both environmental probing waveforms as well as communication transmissions. A majority of the transmissions were from the source arrays deployed at Sta02 and Sta03. These transmissions consisted of a 2 hour sequence of waveforms with the sequence repeated for an extended period of time in order to capture different environmental conditions. At alternating 1 hour intervals, MLS or LFM chirp waveforms were transmitted as channel probes for 9 min. Various communication transmissions filled the remaining 2 hour period. The transmissions from WHOI-Tx1 were in the band 8.5-17.5 kHz and those from MPL-SRA1/SRA2 were in the band 20-32 kHz (10-32 kHz during a 48 hour period when WHOI-Tx1 was off).

3 ENVIRONMENTAL MEASUREMENTS

Examples of the dynamic water column environment observed during KAM11 are shown in Figs. 2-3. The mixed layer depth changes from as little as 20 m to as much as 60 m or more over the course of 24 hours. Similarly, the wind speed and sea surface conditions exhibited a daily pattern. Fig. 4 shows wind speed and direction data along with waverider-derived sea surface wave spectra for the first seven and last six days of the experiment.

4 CHANNEL IMPULSE RESPONSE VARIABILITY

The channel impulse response (CIR) was estimated using various waveforms (e.g. FM chirps and MLS sequences). The channel impulse response between a given source and receiver pair showed considerable variability as a function of wind, surface, and water column conditions. Fig. 5 shows a sequence of impulse response estimates made from matched filtering LFM pulses over a range of wind and surface conditions. The conditions start as windy and rough, get calmer, and then get windy and rough again in the last subfigure. The color axis is in dB and is constant over all of the subfigures. The signals were transmitted by the WHOI-Tx1 source array (Sta03) and received at the WHOI-Rx2 receive array (Sta17) with a source to receiver range of approximately 7 km. The source was at approximately 15 m depth and the receiver was at approximately 50 m depth. The subfigures are labeled with the Julian Date and time (UTC) of the start of the one minute reception that was processed to create the estimates. Notice that the channel impulse response has a higher magnitude and has more stable and well-defined arrivals during calm conditions than it does during windy and rough conditions.

ACKNOWLEDGEMENTS

The KAM11 experiment was sponsored by the Office of Naval Research, Code 322OA, with support from the R/V Kilo Moana and the Pacific Missile Range Facility.

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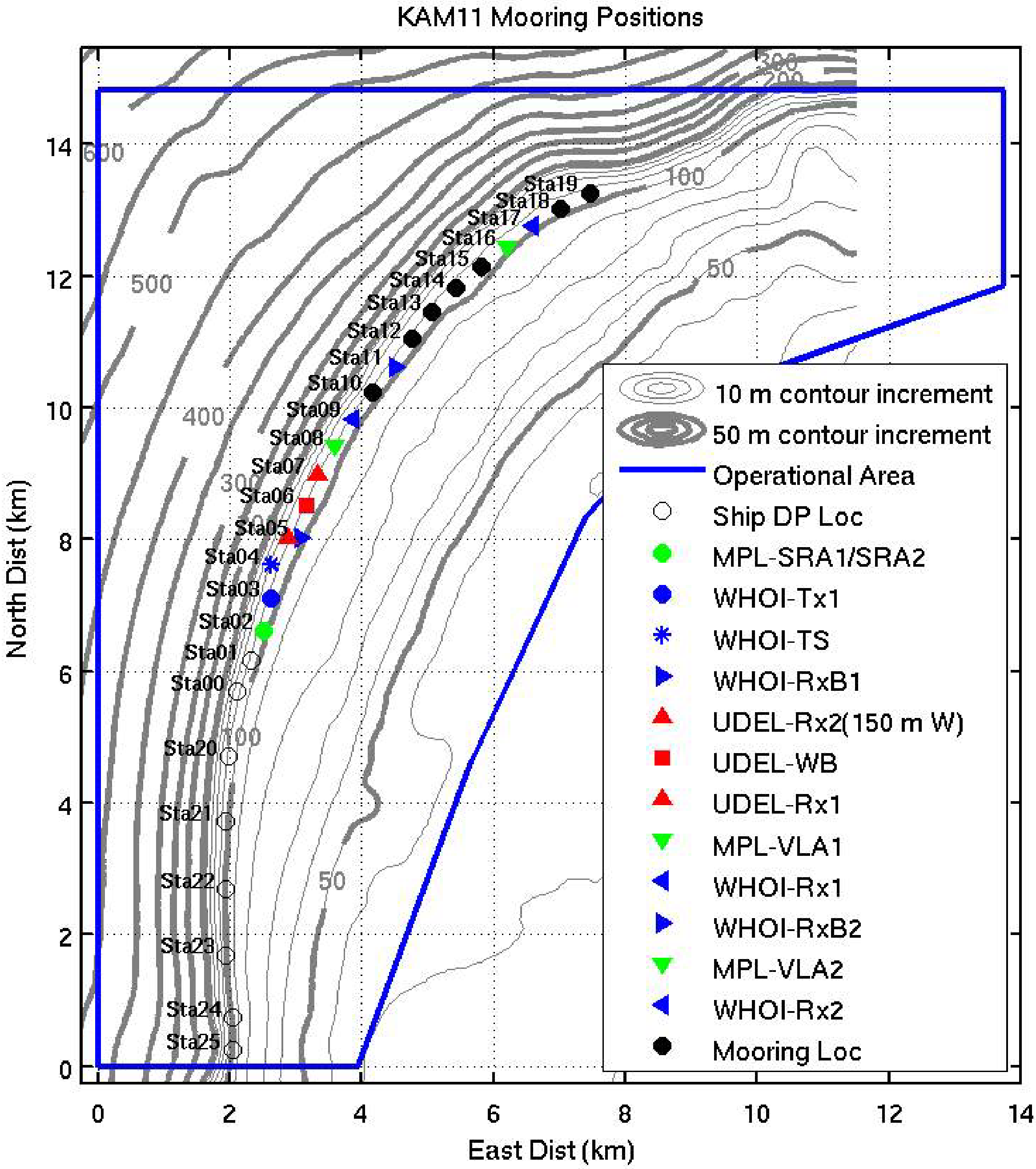
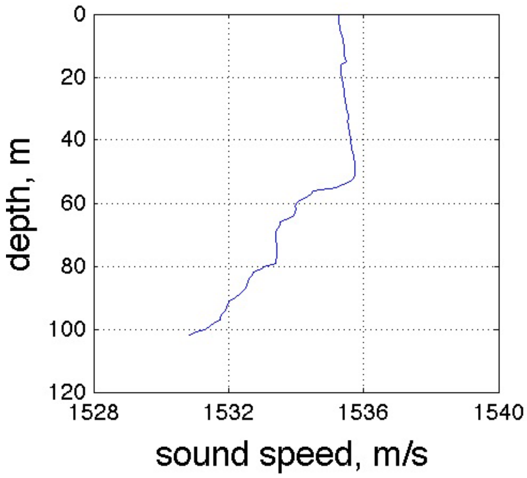
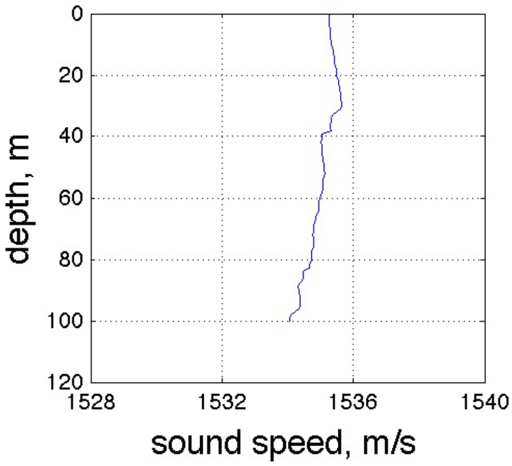


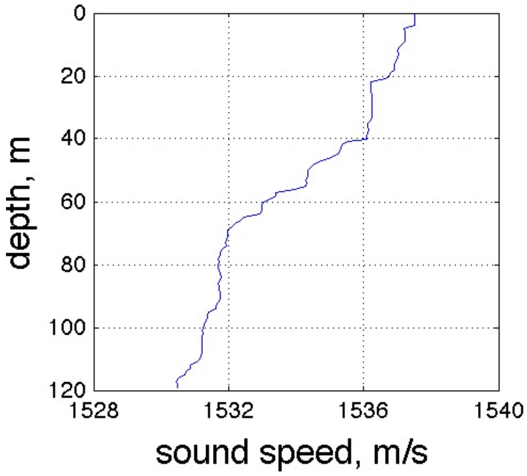
Figure 1. Mooring deployment positions in km with respect to the southwest corner of the KAM11 operational area (22˚04'N, 159˚50'W). Indicated are the deployment locations of both the environmental and acoustic hardware: TS (thermistor string), WB (waverider buoy), SRA (source-receive array), Tx (source array), RxB (receive array buoy), Rx (receive array), and VLA (vertical line array).



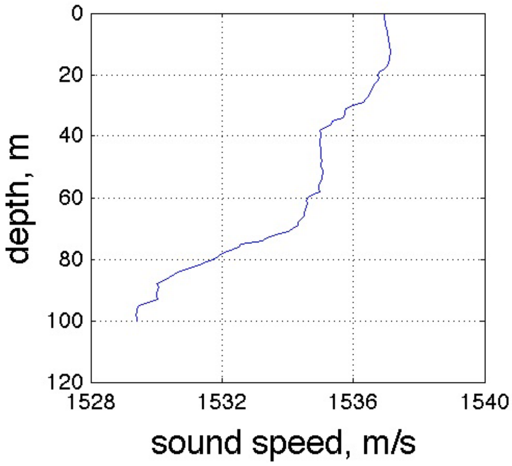
(a) CTD #01, Sta13 (JD175 1945Z).



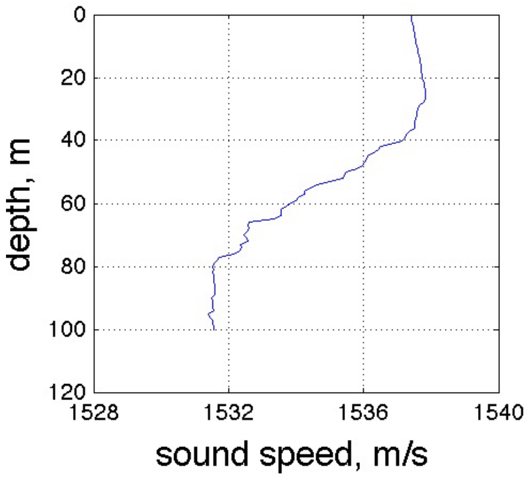
(b) CTD #03, Sta03 (JD176 1915Z).



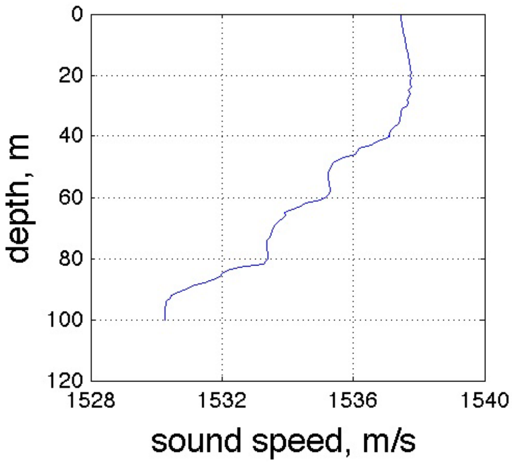
(c) CTD #05, Sta04 (JD184 2037Z).



(d) CTD #08, Sta16 (JD185 0250Z).

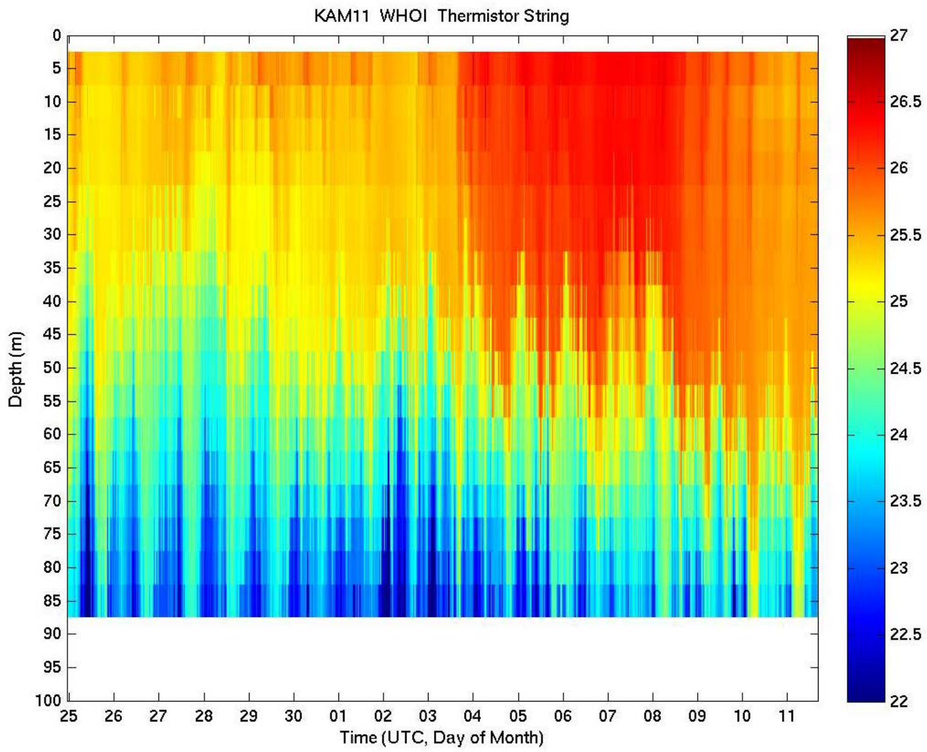


(e) CTD #09, Sta06 (JD187 0540Z).



(f) CTD #10, Sta04 (JD187 0633Z).

Figure 2. Sound speed structure derived from CTD casts at various locations and times.



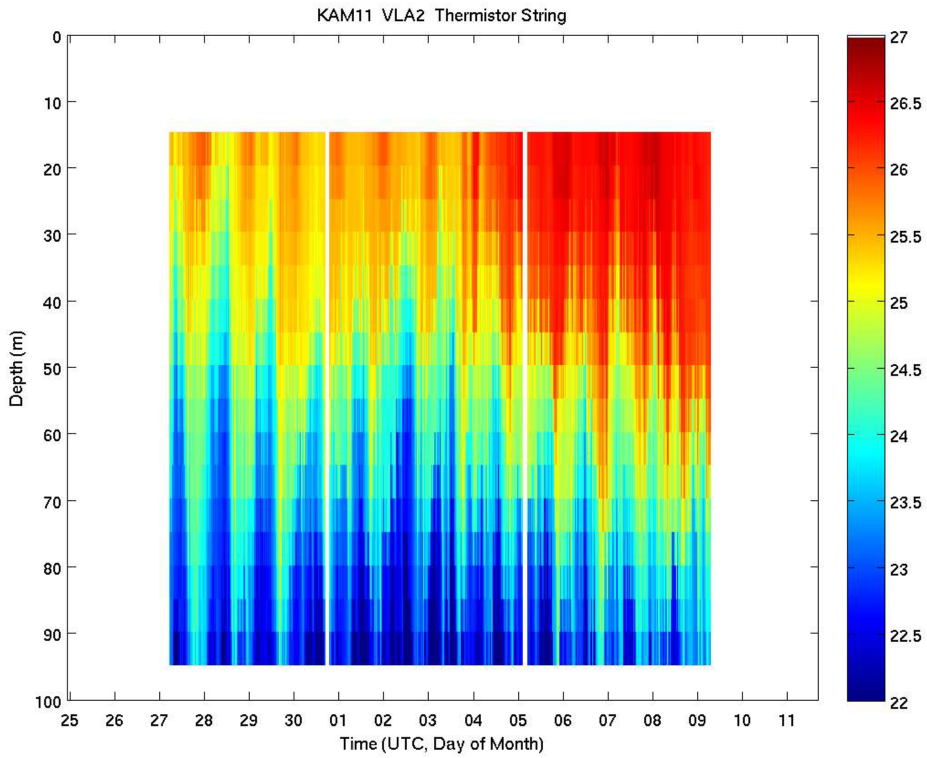


Figure 3. Temperature profiles recorded on the thermistor strings deployed (above) at Sta04 on 24 June 2011 (JD 175) and (below) at Sta16 on 27 June 2011 (JD 178).

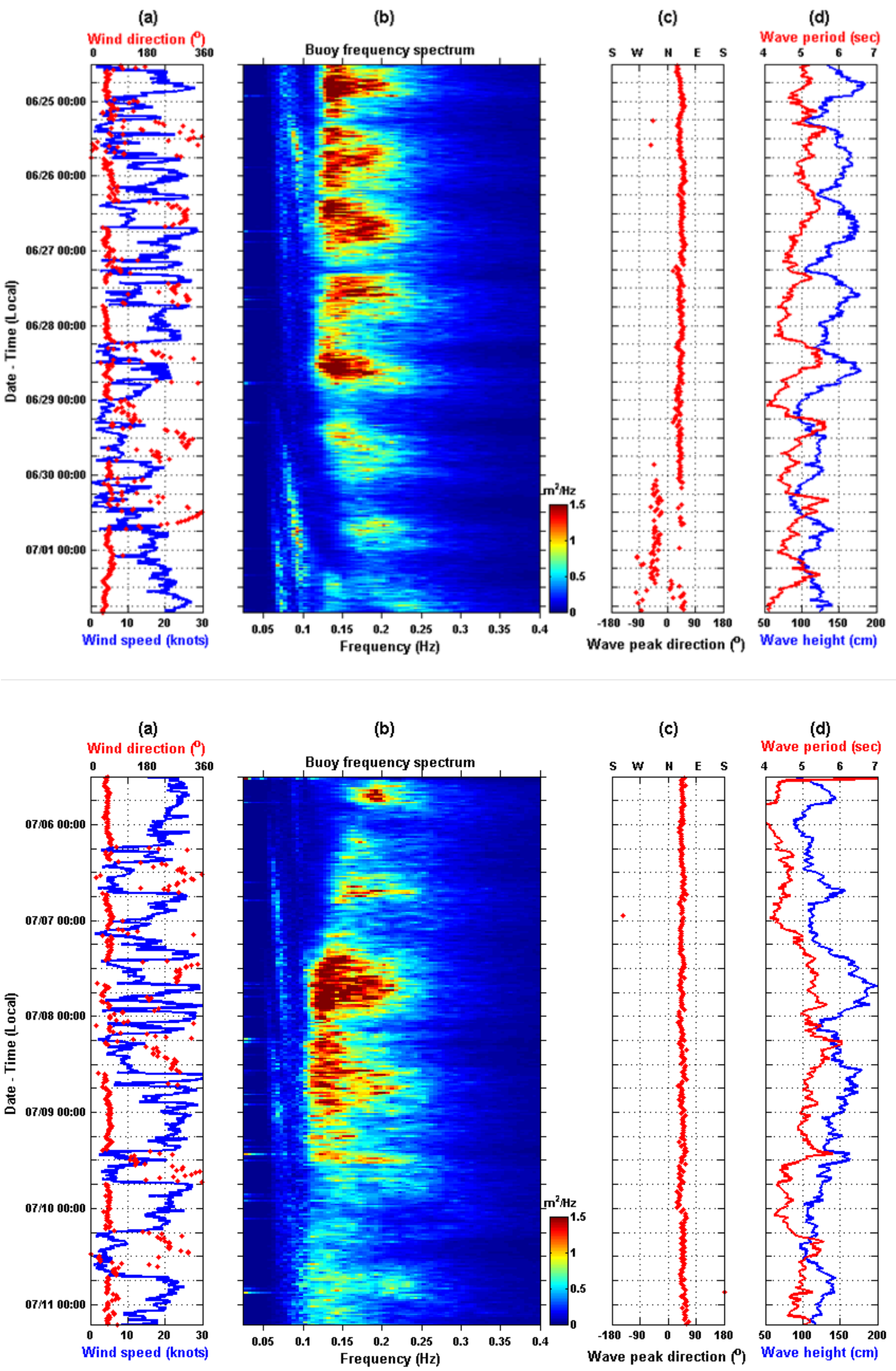


Figure 4. Ship wind speed and direction data along with waverider derived sea surface wave spectra, significant wave height, and wave period during (above) first deployment of the waverider buoy 1200L on 24 June (JD 175) through 2000L on 1 July (JD 182) and (below) second deployment of the waverider buoy 1200L on 5 July (JD 186) through 0500L on 11 July (JD 192). Note that UTC = Local + 10 hrs.

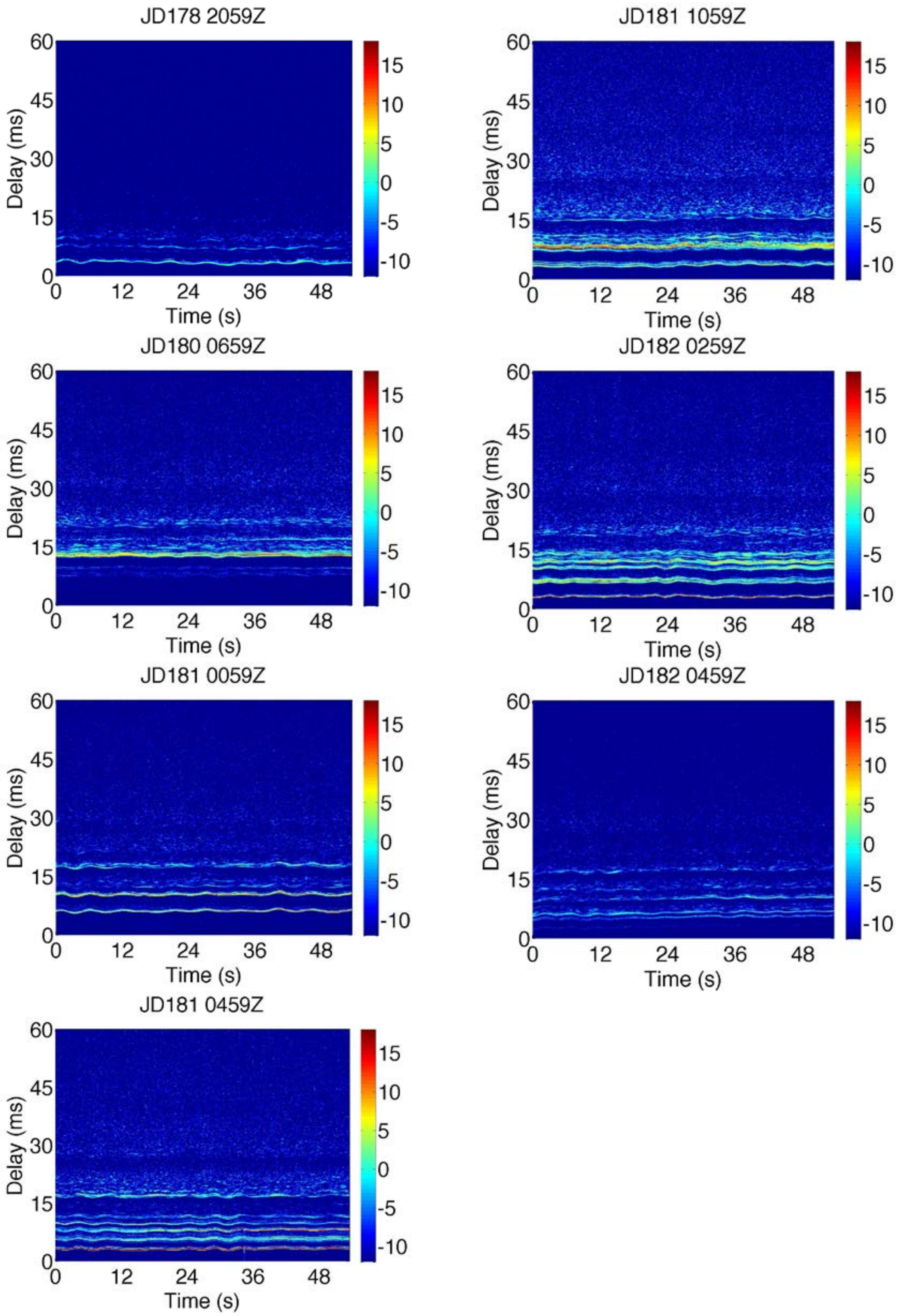


Figure 5. Time-evolving channel impulse response over 1 min intervals from a 15 m deep source (WHOI-Tx1 at Sta03) to a 50 m deep receiver (WHOI-Rx2 at Sta17) at a range of 7 km. Environmental conditions varied from windy and rough, to calm, then windy and rough again.