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A Fully Coherent Array for Evaporation Duct Height Estimation at Coastal Boundaries

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Abstract

The Coherent Vertical Array (CoVA) system has been designed to be used during the Coastal Land-Air-Sea Interactions (CLASI) mission for evaporation duct height (EDH) estimation by measuring the grazing angle of the incident, ducted signal. High angular resolution and phase coherence is needed in the CoVA system due to the ducted signal having a narrow grazing angle with small variations translating to large variations in EDH estimation. This paper discusses the design of the CoVA system and the methodology used to achieve high phase coherence. The results obtained by CoVA during CLASI will be presented in future work.

1 Introduction

In previous work, the Coupled Air-Sea Processes and EM Ducting Research (CASPER) missions sought to characterize the propagation of signals through the air in a marine environment [1]. More specifically, changes in vertical temperature and humidity can cause the trapping of electromagnetic (EM) waves in atmospheric ducts which significantly affect performance [2]. The evaporation duct height (EDH) can be estimated by measuring the EM field with an array of receivers [3]. Despite these missions, coherent measurement of a ducted wave at a coastal boundary is still needed for a complete description of the meteorological conditions.

In the Coastal Land-Air-Sea Interactions (CLASI) mission, the objective is to measure and estimate the meteorological conditions at coastal (land-air-sea) boundaries. Our approach is to estimate the EDH by transmitting EM waves from buoys in the sea, through the ducting atmosphere receive the signals at the coast using a fully coherent vertical receiver array (CoVA). The mission will take place in Monterey Bay, California, where a pilot study revealed the presence of complex wave fields as well as opportunities for observing onshore and orographic wind sheers combined with variable tidal currents. The CoVA system can measure the incident grazing angle of the ducted waveforms which can be used to estimate EDH. It may also be possible to measure sea surface roughness, but more work is needed to verify this.

In the next section the selection of hardware and design is discussed, followed by a description of the method to assure continuous coherent data collection.

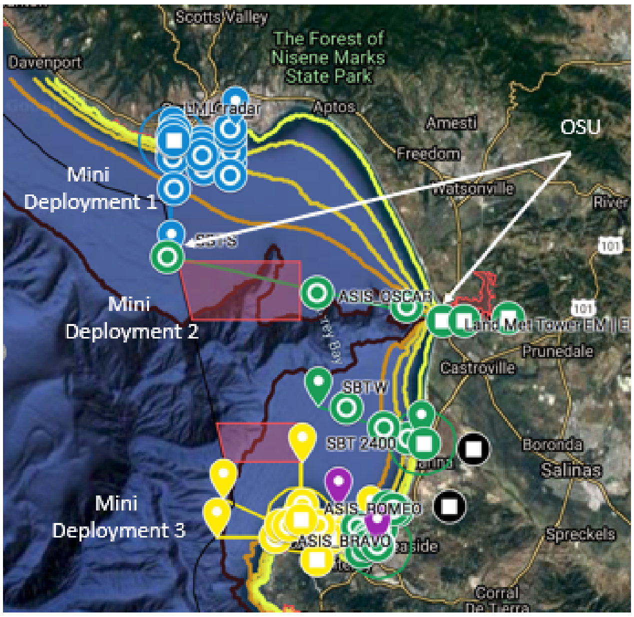

Figure 1. CLASI Equipment Deployment in Monterey Bay. Note the white arrows indicating the location of OSU equipment.

2 Hardware Implementation

The system will be deployed at the Moss Landing Marina Lab Aquaculture Facility from June to October, 2021. It will track 3 Air-Sea Interaction Spar (ASIS) buoys and 1 aircraft transmitter simultaneously using 4 coherent channels with concurrent meteorological and air-sea measurements to supplement the EM data. The buoys and many other pieces of equipment will be deployed in the bay at known distances from the coast as shown in Figure 1. This setup facilitates the EM wave to travel through the duct to the coast where the receiving equipment is stationed, illustrated in Figure 2.

Our antenna setup is a 10m four element linear array. This height is chosen to uniformly sample the signals trapped in the duct, which is anticipated to have an EDH of 10 meters. The grazing angle from signals in a ducted environment generally does not exceed 1 or 2 degrees [4]. This also means that a good EDH estimation will require high precision grazing angle measurements. An ideal array would cover the entire height of the evaporation duct for the highest angular resolution. This corresponds to a verti-

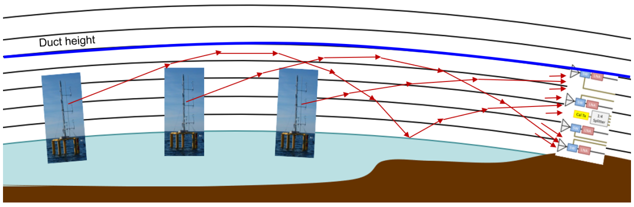

Figure 2. CLASI Evaporation Duct Propagation Environment

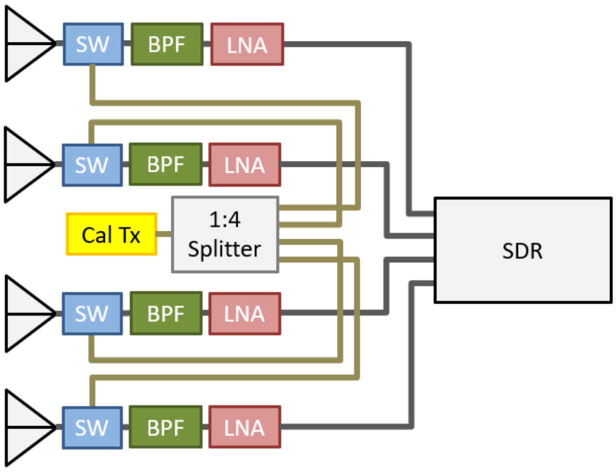

Figure 3. CoVA Receiver System Block Diagram including Calibration Components

cal array size of roughly 10 m. However, such an array will result severe aliasing unless an unrealistically large number of closely spaced receivers are used. Using only 4 elements means this sparse array will have grating lobes showing as close as 3-10 degrees depending on the exact array size, and other design parameters such as the frequency. 4- Because the received signal is ducted and trapped however, the signal arriving at the sea surface at the receiver location will be propagating at grazing angles within 1-2 degrees. This will allow the system to be operational even in the presence of multiple grating lobes at higher angles.

The receiver is the National Instruments USRP-2955 software defined radio (SDR) which is tunable from DC-6 GHz and features four channel fully coherent receiving. This spectrum coverage is important for frequency diverse measurements during auxiliary parts of the CLASI mission. The USRP-2955 contains an RF front end with two intermediate frequency (IF) stages per channel. Four channel full coherence is enabled by local oscillator (LO) sharing for the two IF mixer stages on each channel. Preliminary tests with the device revealed sufficient dynamic range but relatively poor noise floor performance. This will be corrected by adding LNAs in front of each receiver. The input to the LNAs first enters bandpass filters and the output goes through 30 ft phase matched cables to the SDR. Together, these components will be called the RF chain. See Figure 3.

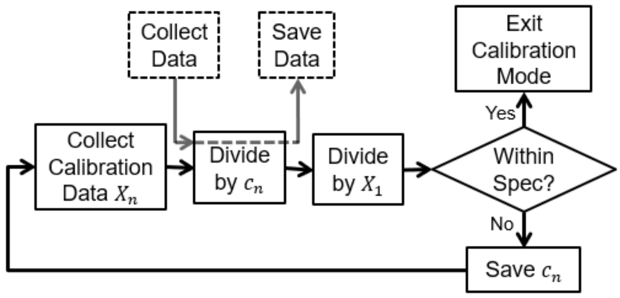

Figure 4. Calibration Routine for Coherent Data Collection

3 Calibration Routine

Grazing angle estimation with angular resolution on the order of tenths of degrees requires minimal phase variance among the receive channels. The USRP-2955 was designed specifically for multi-channel coherent receive operations. When configured for coherence the device maintains phase coherence for a time, but initial calibration and recalibration are still needed. The calibration scheme for the CoVA system provides a tone signal to each channel via a 1-to-4 splitter with each output going to an RF switch connected to the output of the antenna as seen in Figure 3. The phase shift on each channel in the calibration circuit must be characterized to ensure phase aligned signals at the entrance to each channel switch. Under normal operation, the switch passes input from the antenna, through the RF chain and to the SDR. When in calibration mode, the switch instead passes the calibration tone into the RF chain and SDR.

The system will enter calibration mode, activating the calibration transmitter and setting all the RF switches to the calibration input. Figure 4 shows a system diagram of the calibration routine. The calibration tones are received by each channel and are referenced to channel 1 by dividing all channels by the channel 1 signal. The resulting phasors indicate the amplitude and phase offset of each channel from channel 1. Consequently, the phase offset between any channel is revealed. If the phase offset for any channel is not within specifications, this phasor will be saved as the calibration phasor. The SDR will then collect another calibration measurement and divide each channel by its respective component in the calibration phasor. To again check the phase offset from channel 1, all channels are divided by channel 1 and the phase offset will be measured. If within specifications, the program will exit calibration mode and return to collection mode. When collecting data, the valid calibration phasors at matching timestamps will be saved. The calibration phasors characterize the phase shifting behavior of all components past the switch in the RF chain and inside the SDR on each channel. During data processing, the data can be divided by its matching calibration phasor to simulate phase aligned collection. Additional phasors can also be applied to account for fixed phase offsets in the antennas and calibration circuit.

4 Discussion

The CoVA system has been designed for EDH estimation during the CLASI mission. Once the mission is underway, preliminary results may reveal intuitions about the environment. A journal paper on CoVA in CLASI will follow once the mission is complete and meaningful results have been obtained from the data.

5 Acknowledgements

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