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Profiling Ocean Currents From a Moving Ship

The speed and direction of ocean currents can change in several dimensions: with depth, with position, and with time. At the core of many modern instruments that measure this ever-changing picture is a common idea: using sound in the sea. Several facets of sound make it attractive for measuring the ocean: sound can be used to measure remotely, even at great distances, using sound does not require any moving parts, and the characteristics of sound are altered predictably by ocean conditions.

The instrumentation used on board this ship for measuring ocean currents takes advantage of all three of these properties--in particular, the third. Sound transmitted into the ocean can have its pitch changed in the echoes heard back—this is called the Doppler effect. It provides a means to measure both how fast ocean currents are moving and in what direction.

The acoustic echoes can be analyzed to determine this same information for many depths, all at the same time. The resulting data is called an ocean current profile. When they are continuously measured from a moving vessel, these profiles paint a picture of how the ocean currents are varying with depth and along the path of the ship. In addition, by repeatedly traveling over the same path, scientists collect a picture of how these sections of ocean currents change with time.

Acoustic Method for Measuring Currents

The instrumentation used on board this ship for measuring ocean currents is called an Acoustic Doppler Current Profiler (ADCP) and it is a sonar-based device. It uses a similar measurement method to hand-held radars used in police “speed traps” on highways or at sports events to measure how fast objects are moving.

For the measurements made on board this ship, water speed information in several directions (east, north, vertical) is desired so the signal or “ping” is emitted along four beams simultaneously (see Figure 1). The beams are slanted downward from the ADCP to be able to measure at many depths. Viewed from above, they appear to be pointing north, south, east, and west. At many depths, plankton carried by the water currents scatter the sound back to the ADCP, which listens for the echoes. Those returning later come from deeper in the water. Using the known speed of sound to convert elapsed time to depth, the ADCP assigns different depths to corresponding parts of the echo record.

Echoes reflected by particles moving relative to the ADCP return with a change in frequency. The ADCP measures this change, the Doppler shift, as a function of depth to obtain water velocity at 128 depths. Duplicating this capability would require lowering a string of 128 mechanical current meters (see Figure 1). For the 75kHz operating frequency used on Norrona, the ADCP can profile water currents to depths of 800m, even 1000m in cold waters with high amounts of plankton. Every 2 seconds, a new profile is recorded. These data are averaged together for some minutes before a new output is displayed.

The ADCP has other useful capabilities: measuring its own motion over the seabed (to depths of 1000m), which can provide a speedometer for the ship, measuring range to the seabed like an echo sounder, and profiling the distribution of suspended materials.

Measuring from Moving Ships

Particularly challenging is making accurate measurements of ocean currents from a moving ship. The reason for this is that the ship is typically moving at many times the speed of the water. Two different types of measurements must be combined: one is the velocity of the ship while the other is the apparent velocity of the water as seen by instruments or people on board the moving ship.

To depths of 1000m, the ADCP can make both types of measurements. It then combines the data internally to compute the true water velocities. In deeper waters, the GPS satellite navigation system is used to determine the velocity of the ship quite accurately. By inputting this information to the ADCP it can compute profiles of actual water velocity in any location.

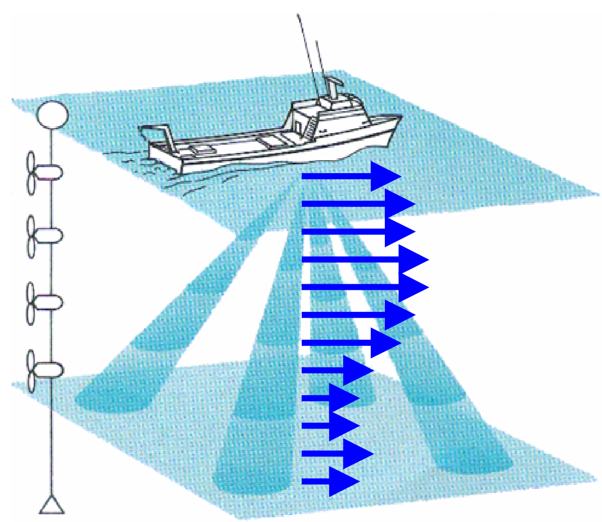

Figure 1. Velocity profile compared to current meter string.

Technology

The ADCP operating on board Norrona uses a modern transducer configuration called a *phased array*. Its operation switches between an underwater loudspeaker and microphone. The transducer emits/receives the acoustic signals from its flat face, which is composed of an *array* of about 1000 ceramic elements, covered in urethane. (See Fig. 2.) The elements are arranged in a fixed pattern and are each wired to transmit a specific signal, identified by its *phase.* When the acoustic signals from all of these elements are emitted simultaneously, they interfere with each other in an organized manner to form beams in the four specific directions, slanted at 30 degrees from vertical.

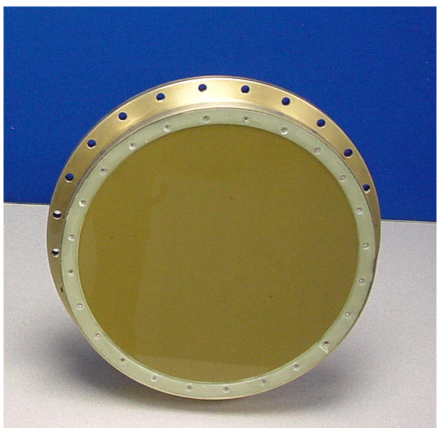

Figure 2. 75 kHz Phased Array ADCP

Immediately after emitting the "ping", the system switches to its listening mode to receive the echoes scattered back by the plankton. In this mode, the system listens preferentially in the directions of the acoustic beams. It can therefore discern from where the echoes arrive.

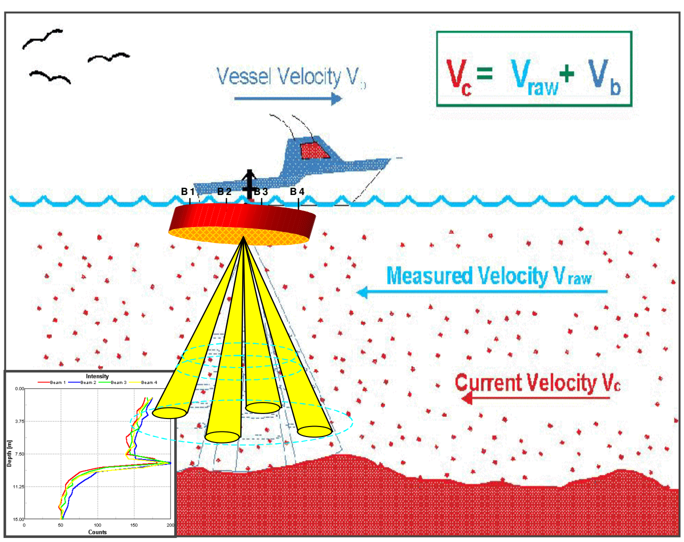

Figure 3. Schematic of ADCP operation

Data Processing

We mentioned earlier how the ADCP assigns depth layers to the echo record. By knowing the directions and depths from which the echoes returned, the processing in the on-board computer can compute a velocity profile of water currents. These velocity data are relative to the ship's motion and orientation. To include this latter information in the calculations, the computer interrogates other sensors on board the ship.

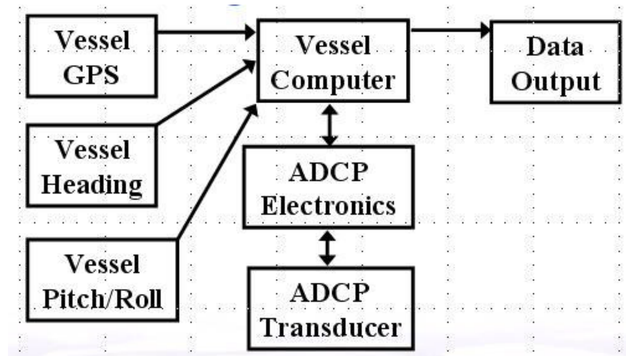

Figure 4. Information flow for ADCP computations

The end result is that the motion of the ocean currents relative to the earth is obtained at many depths. These measurements, which are made continuously while the ship is moving, are displayed in 2-dimensions to reveal how the strength and direction of oceans currents change with depth along the ship's path.

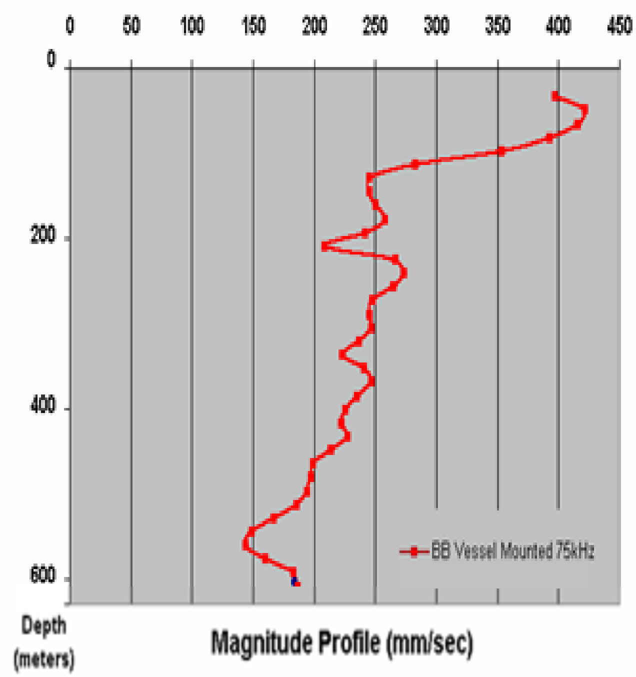

Figure 5. Velocity profile from 75kHz Phased Array ADCP

Observations

An example of the powerful advantage of this technology is displayed in Fig. 6. The data here were collected with a 38 kHz Phased Array ADCP aboard the Japanese ship, R.V. Kaiyo, off Mindanao, Philippines. Current profiles to depths in excess of 1000 m reveal an intricate spatial pattern. On this occasion, the path of the ship cut across a strong subsurface eddy. The currents at great depth are very strong and are circulating in a closed loop. This explains their reversal in direction indicated by the contrasting colors. Notice that the flow pattern in the depths does not reach the surface. In fact, at the right hand side of the figure, surface currents are moving in the opposite direction to the deeper currents. Seeing this impressive variation to great depths and along the ship's path is uniquely possible with the Acoustic Doppler Current Profiler.

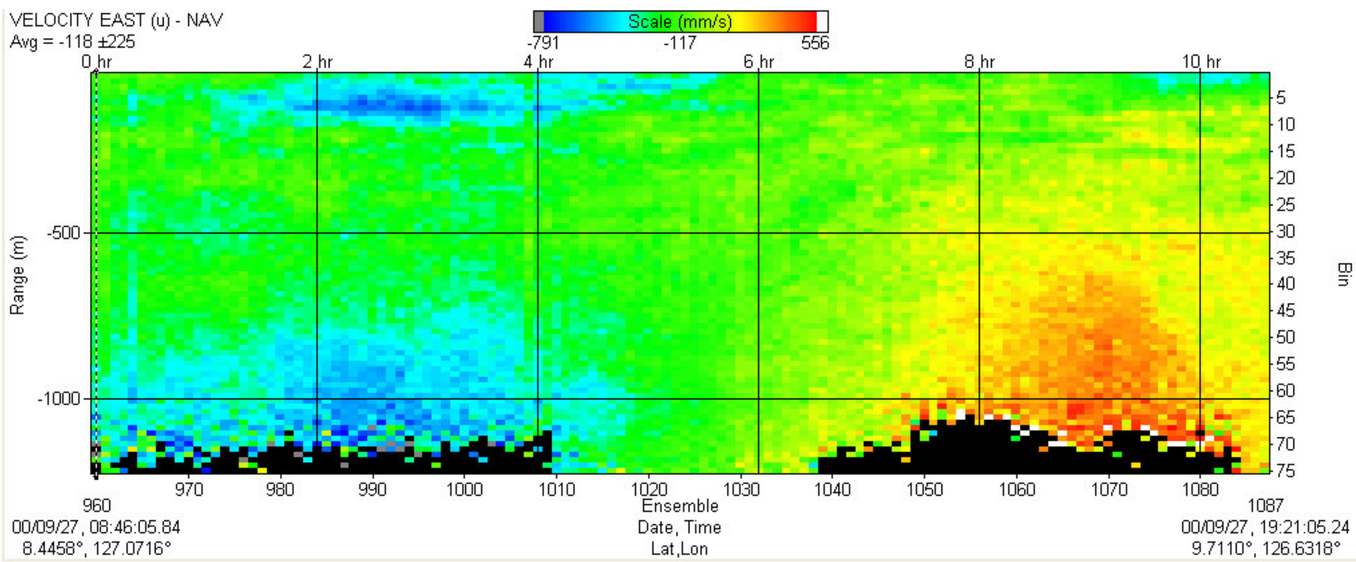

Figure 6. Two-dimensional display of ocean currents in the tropical Western Pacific. Colors represent water speed to the East.

Doppler Effect

Credit: http://www.physics.purdue.edu/astr263l/inlabs/doppler.html

Almost everyone has noticed that when a fire truck siren passes by, the sound of the siren changes. When the siren is approaching, the sound has a high pitch. At the moment the siren passes, the sound changes to a lower pitch. This is called **Doppler Effect**. The fire truck siren is emitting sound waves of a certain frequency, or wavelength. Note that the frequency of a wave is inversely proportional to its wavelength. When the siren is moving relative to the observer, the frequency or wavelength is shifted. If the siren and observer are getting closer to each other, the frequency is shifted higher (or the wavelength is shifted shorter). If the siren and observer are moving away from each other, the frequency is shifted lower (or the wavelength is shifter longer). Measuring the frequency shift permits the speed of the truck to be calculated.