Observations of surface winds over the world's oceans are a long way from providing complete spatial coverage, basically because they are expensive and difficult to maintain. We propose to use relatively inexpensive acoustic techniques to diagnose surface wind speeds. Turbulent wind adds an inhomogeneous acoustic source to the ocean surface that then propagates underwater. We investigate the feasibility of retrieving the signal observed at some range r from the source and relate it then to the wind speed. The advantages of this technique in addition to its lower cost include the ability to sample surface wind speeds remotely.

We envision a pair of dipole interferometers (Fig. 2). Each interferometer consists of a pair of line arrays A1 and A2 separated by distance 3d and measures the intensity of an acoustic wave from the source but not the bottom. Such profiles are found in an ensemble of hurricane structures. However, the basis can be chosen as appropriate for the study at hand. For example, one might choose the Empirical Orthogonal Functions from an ensemble of hurricane structures.

Theory and Results: How does it work?

The acoustic pressure field at range r, depth z and time due to underwater sources distributed over a plane then the surface of the ocean is approximately:

\[ p(r, z, t) = \sum_{n, \omega} \int \rho u_n(\omega) e^{-j(\omega t - k_n r)} e^{j(\omega t - k_n z)} \, \rho \, \, \, d\omega \]

In (1), \( u_n(\omega) \) is a density of sources and \( \rho \) is the propagation constant given by the boundary problem (2):

\[ \frac{1}{\rho} \frac{\partial}{\partial r} \left( \rho \frac{\partial \phi}{\partial r} \right) + \frac{1}{\rho} \frac{\partial^2 \phi}{\partial z^2} = \delta(\omega) \delta(r-r_0) \delta(z-z_0) \]

For the sound speed profile shown in Fig. 1, the propagation constants \( \rho \) and normal modes \( \phi \) vary with frequency as follows:

\[ \rho(\omega) = \frac{\omega}{c(\omega)} \]

Frequency intervals within which modes intersect with the surface but not the bottom.

We estimate the co-spectrum \( S_{\phi \phi}(r, t) \) of the acoustic field measured at two hydrophones having coordinates \( (r, z) \) and \( (r', z') \) using a least squares method, as shown in the feasibility study. This last condition allows probing of the ocean surface by modes that are not heavily attenuated by the bottom. Such profiles are found in an ensemble of hurricane structures. However, the basis can be chosen as appropriate for the study at hand. For example, one might choose the Empirical Orthogonal Functions from an ensemble of hurricane structures.

When the noise is the signal, what's the noise in the noise?

The uncertainty in \( \phi(\omega) \) is proportional to \( T^{-1/2} F \), where \( T \) is the integration time and \( F \) is the frequency bandwidth. For a nominal wind speed of about 50m/s, a signal-to-noise ratio less than one can be obtained with T about 3 years. For strong winds, the contribution of errors to the finite integration time is relatively small.

Conclusions

• Mapping a surface wind field over areas (20^\circ) or more feasible using acoustic correlation techniques.

• Range information is gathered using a pair of dipole interferometers.

• Each dipole interferometer consists of a pair of receivers separated by ~10km.

• The signal to noise ratio increases as \( T^{-1/2} \), where \( T \) is the integration time. Reasonable results can be obtained with integration times on the order of a few hours.