Laboratory and Field Measurements of Turbulence under Breaking Waves.

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1- INTRODUCTION

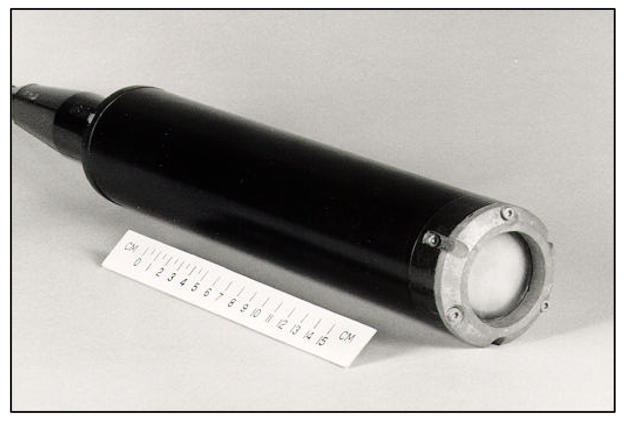
• The surface-wave zone has received considerable attention in recent years. This is partly a result of the realization that wave breaking and Langmuir circulations may lead to enhanced dissipation in the surface boundary layer.

• Historically, dissipation rates have been determined by time series measurements and the use of Taylor's hypothesis.

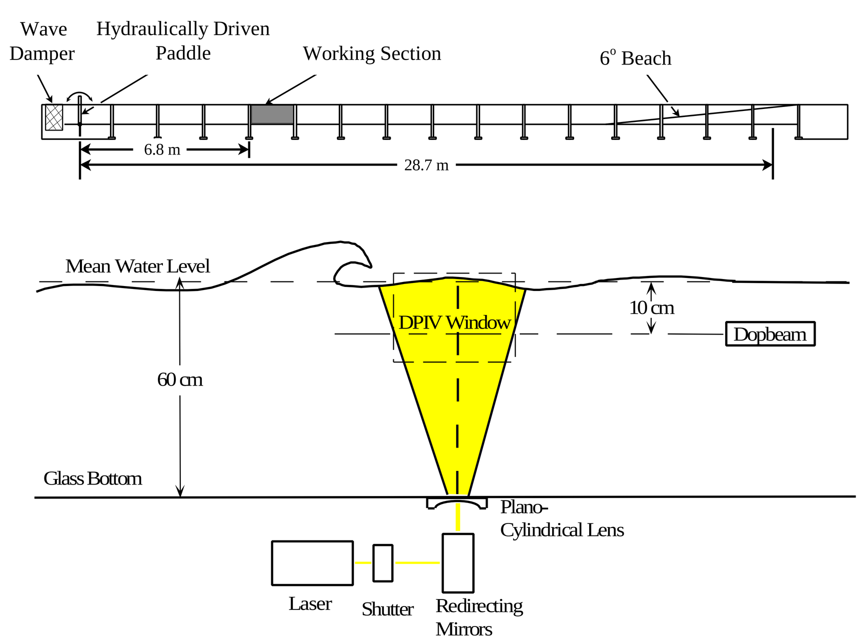
• However, in the shallow surface layer, the use of Taylor's hypothesis is made difficult by the orbital motion under surface waves and the relatively small thickness of the layer.

➡ Direct spatial measurements are then required.

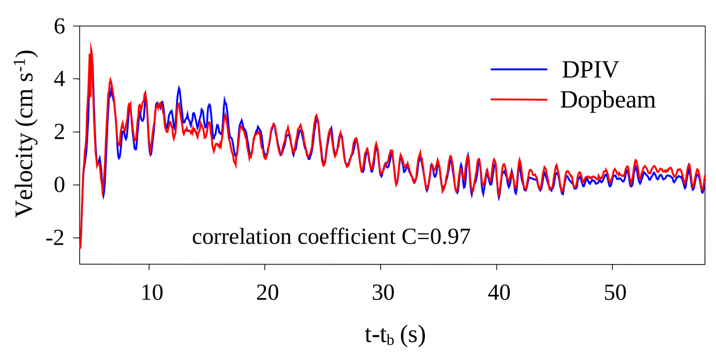
2- LABORATORY MEASUREMENTS

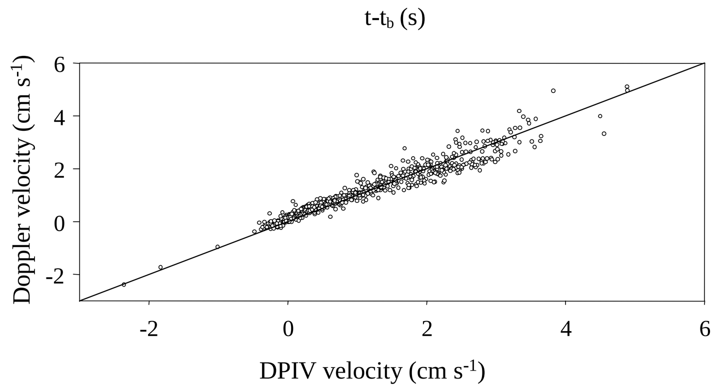


Photograph of a 1.7 MHz single beam coherent sonar profiler. It is capable of measuring along-beam fluid velocity with a O(1) cm resolution along a O(1) m long profile

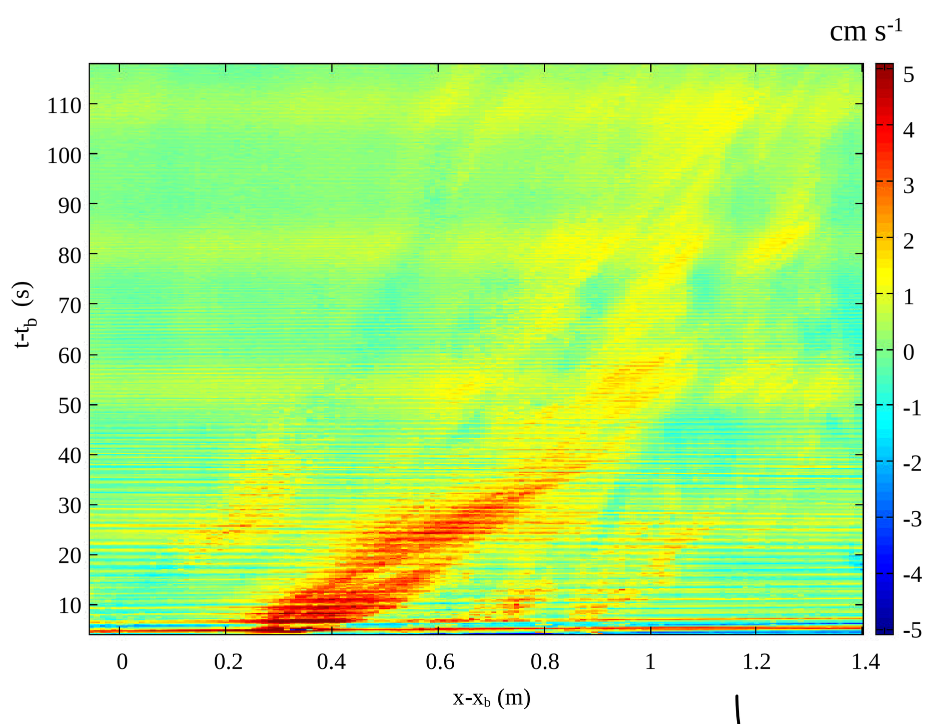


Wave channel at the Scripps Institution of Oceanography. A packet of waves was sent by a hydraulic paddle such that the packet focuses and breaks in the working section. The Doppler sonar was placed at a depth of 10 cm, facing upstream and a Digital Particle Image Velocimeter (DPIV) imaged the breaking region for additional velocity measurements.





Along the common range of the two instruments, the simultaneous velocity time series measured by the Doppler and the DPIV agree very well.

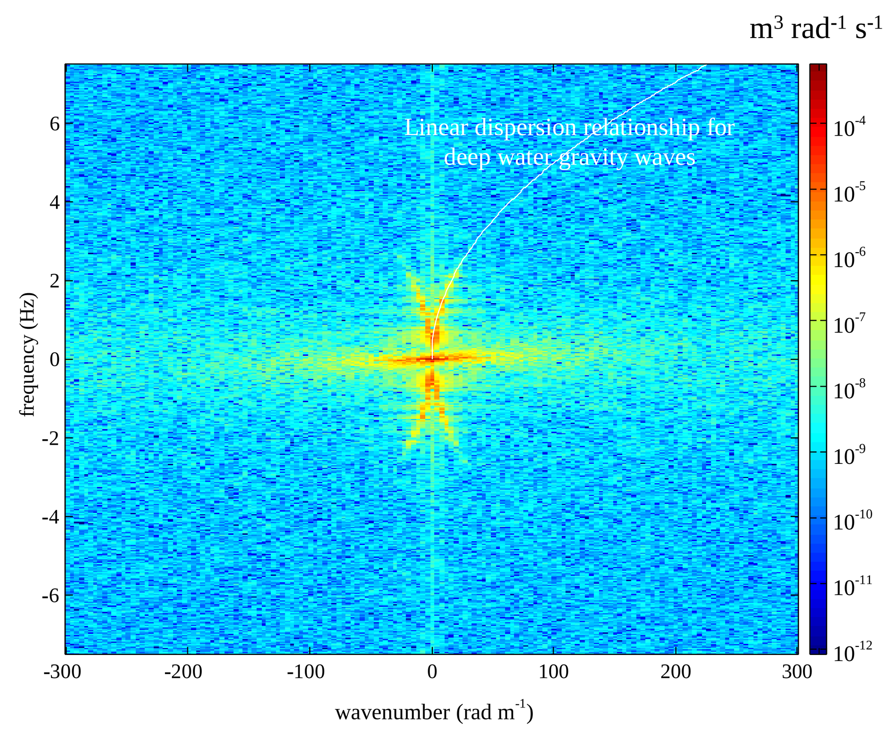


Example of the velocity field recorded by the Doppler sonar. The time-range velocity data can be separated into two dominant features:

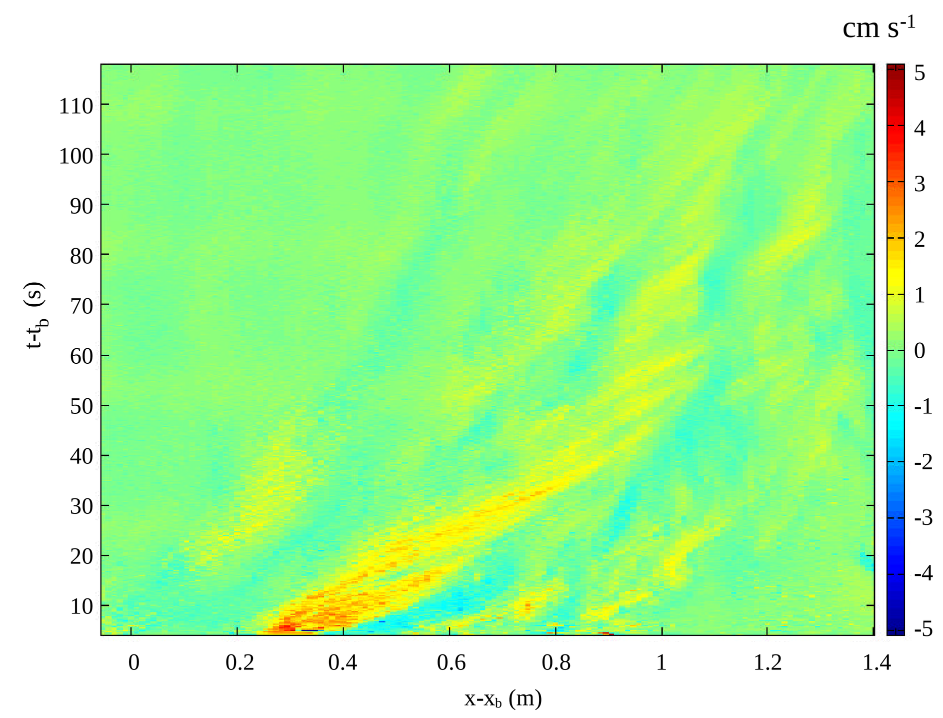
• the orbital motion due to surface waves appears as nearly horizontal lines.

• the plume of turbulence injected by the breaker appears as a primary eddy which, with time, propagates downstream and breaks down in smaller eddies.

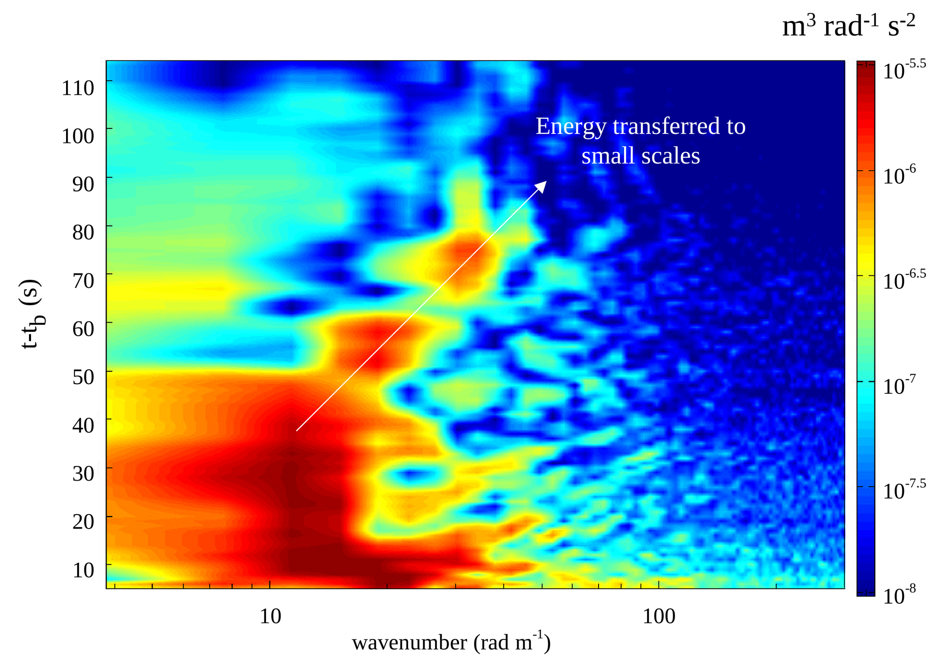
A two-dimensional Fourier transform of the velocity field shows a clear separation of the surface waves (given by the dispersion relationship) and the turbulent motion. The latter appears as a low frequency, broad wavenumber signal, mainly propagating in the downstream direction.



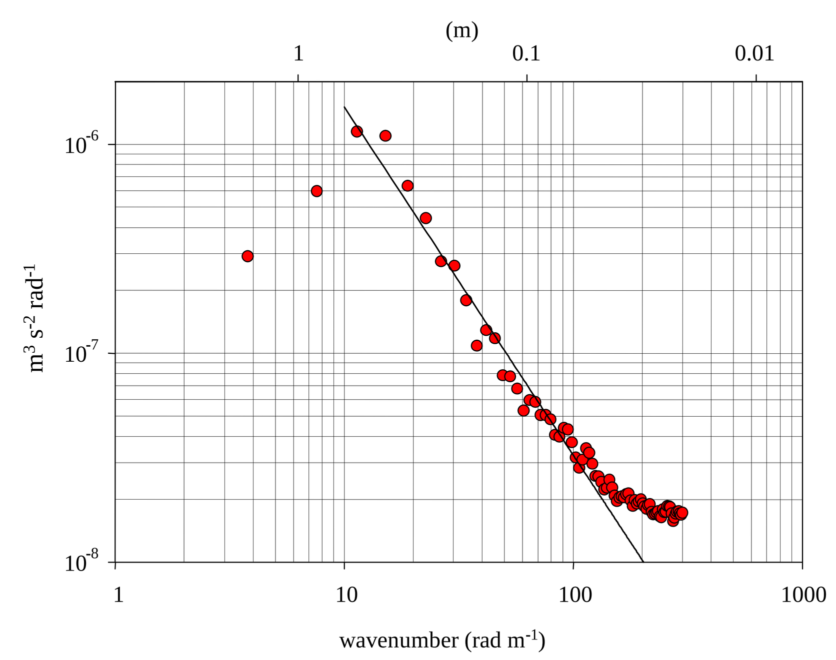
Removing the signal which falls in the neighborhood of the surface wave dispersion relationship (i.e. filtering out the orbital motion), and inverting the result back into real space gives the velocity field dominated by the turbulence generated by the breaking wave.



Individual velocity profiles can be used to calculate wavenumber spectra of the turbulence as a function of time. This gives a *wavenumber spectrogram* of the turbulent velocity generated by the breaker

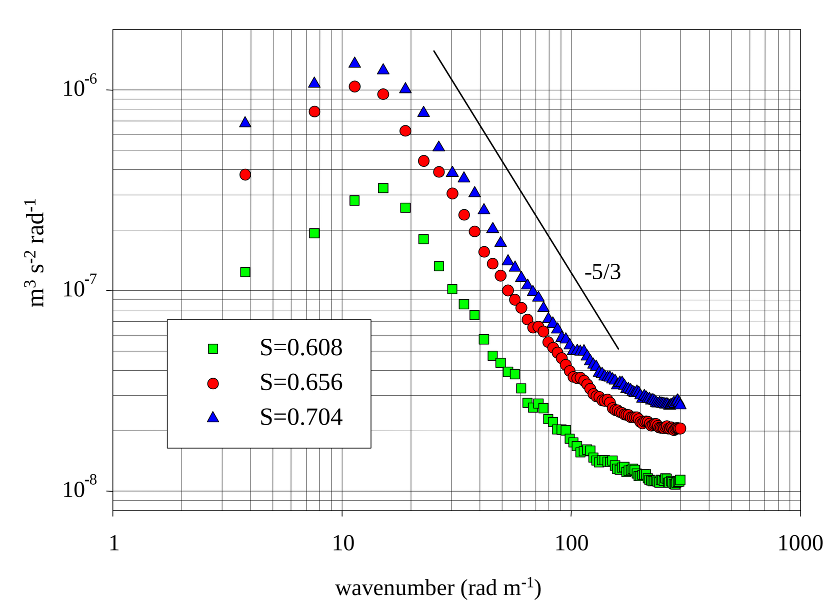


Averaging the wavenumber spectrogram in time gives a wavenumber spectrum on a single breaking event basis. The wavenumber spectrum exhibits a well defined inertial subrange as shown by the solid line of -5/3 slope The presence of an inertial range makes it possible to directly measure the kinetic energy dissipation ε without the need for a time-space transformation through the use of Taylor's hypothesis.



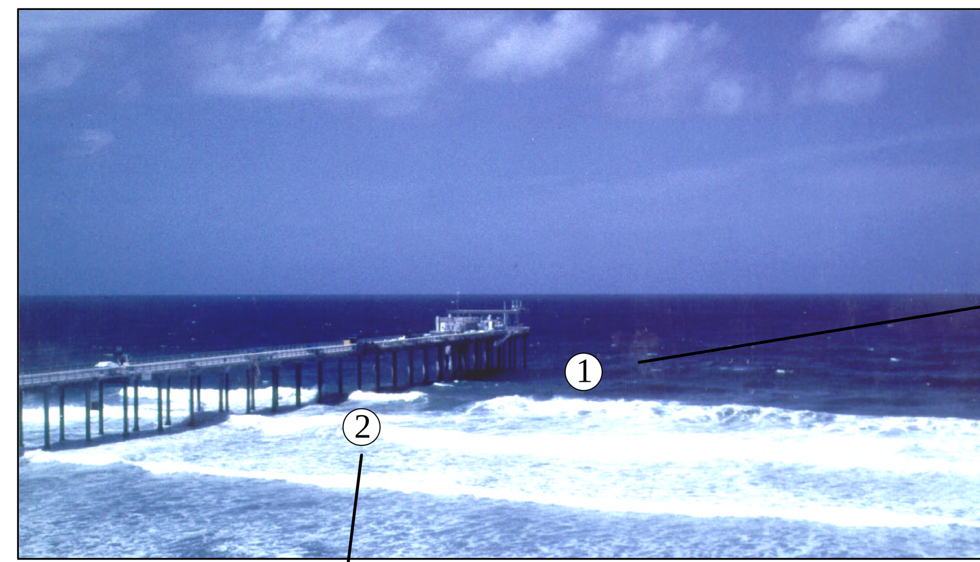
In the laboratory, it is possible to generate a breaking wave in a very repeatable manner. Three different breaking waves were studied with different characteristic surface wave slopes S. Eight repeats of the same breaking event were performed and wavenumber spectra from individual events were ensemble averaged in order to obtain a single wavenumber spectrum for each breaking type.

Shown here is the result of such an ensemble average for a gentle spiller, a strong spiller and a gentle plunger, respectively S=0.608 0.656 and 0.704.



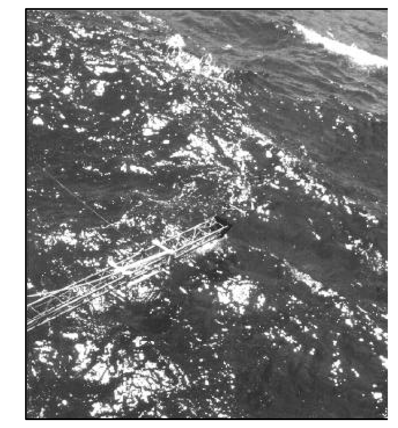
3- FIELD MEASUREMENTS

Some preliminary experiments were conducted from Scripps Pier both seaward and shoreward of the breaker zone.



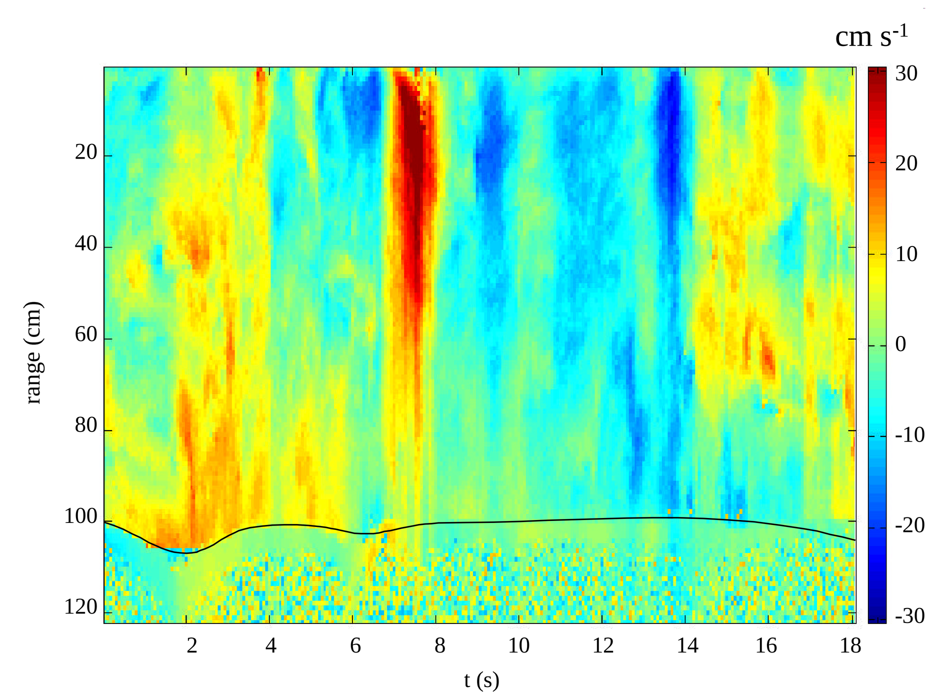
The profiler was fixed to a 10 m long boom at the end of Scripps Pier at an approximate depth of 40 cm. Two orientations of the profiles were tested: along shore horizontal, and vertical. The data shown here illustrate two days with different wind and wave conditions.

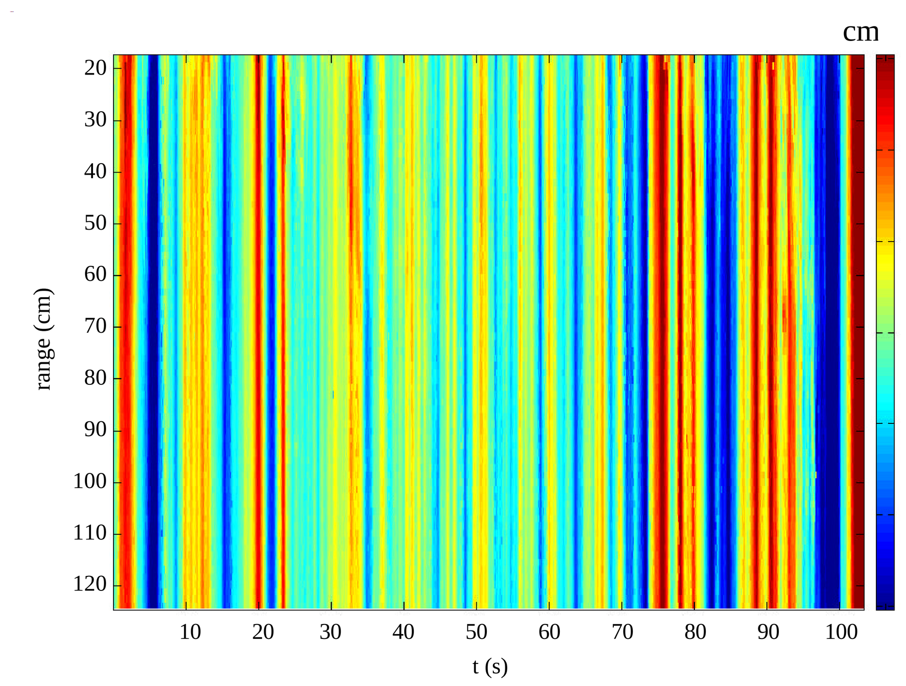
March 28 1997.
Significant wave height : 0.7 m
Wind speed : 13 kts



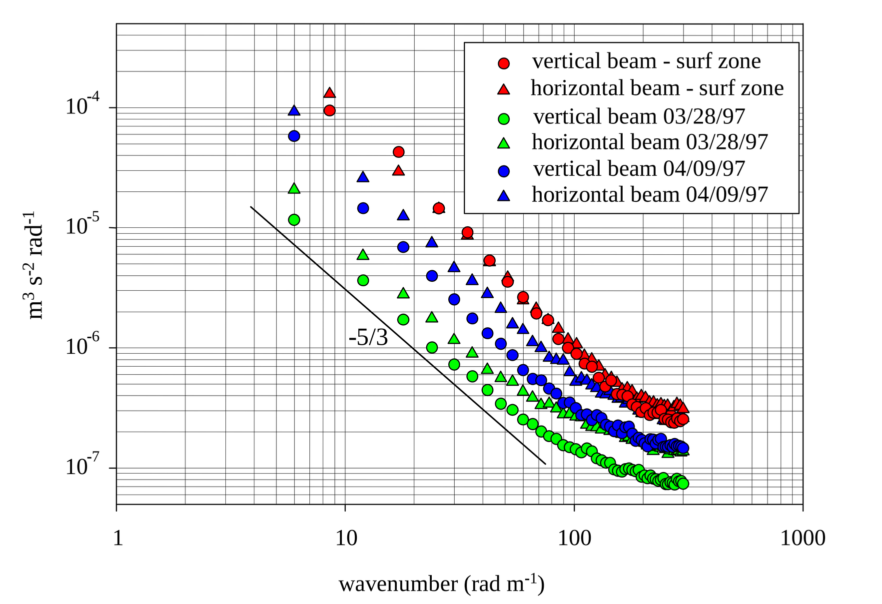
April 09 1997.
Significant wave height : 1.8 m
Wind speed : 20 kts

In the surf zone, the Doppler profiler was fixed to a float at a depth of 40 cm. Again, data were acquired with the beam oriented horizontally and vertically. Below is an example of the vertical velocity in the surf. Only 18 seconds of data are shown since the rest of the record is corrupted due to extremely high velocities and large concentrations of bubbles and suspended sand. The velocity field exhibits large structures with several injections, and also shows the sand bottom at a depth of 1m.





Above, the along-shore horizontal velocity record for March 28 appears to be dominated by waves. However, because of the exponential decay of the orbital velocity with depth, these waves have a wavelength comparable to the profile length and thus will affect the wavenumber spectra only in the low wavenumber dom leaving the turbulent scales at large wavenumbers unaffected.



Wavenumber spectra calculated from velocity profiles similar to those shown above and averaged over 40 s. As expected, the spectral level of the turbulence generated on March 28 is weaker than that on April 09, which in turn is weaker than the turbulence in the surf zone. Note the well-defined inertial subrange with an increasing departure from the expected -5/3 slope as the energy level increases.

4- CONCLUSIONS

• We have presented tests of a 1.7 MHz pulse-to-pulse coherent acoustic Doppler sonar both in the laboratory and in the field.

•In the laboratory, comparison of Doppler measurements with DPIV measurements are very good.

➡ Preliminary analysis of the data shows that the instrument can directly measure wavenumber spectra over wavelengths of O(0.01-1 m), without the use of Taylor's hypothesis.

➡ Thus, in the presence of an inertial subrange, the instrument may prove useful for direct measurements of the turbulent dissipation in the upper mixed layer of the ocean and other natural water bodies.