Turbulence instruments measure anthropogenic effects in coastal ocean waters

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Astronauts have given anecdotal reports that they can see with the naked eye from space deep sea structures such as continental depth contours. How is this possible? What mechanism communicates the information of submerged structures or other hydrodynamic disturbances to the sea surface? Russian Academicians V. Bondur and A. Savin reported to Norris Keeler in 1992 sensitive remote methods for detecting submerged structures. This led to the remarkably successful Remote Anthropogenic Sensing Program (RASP, Keeler et al., 2004, Sea Technology Vol. 45-4) with the mandate to determine how a sewage outfall at a depth of ~~75~~ 70 m affects the glint pattern of surface waves observed from an optical satellite traveling at an altitude of 680 km. Can subsurface ocean turbulence be detected from space?

To provide "sea truth" for the satellite sensing of submerged turbulence and to explore mechanisms of the observed surface brightness anomaly signatures, Rockland Oceanographic Services Inc. (Canada) and ISW Wassermesstechnik (Germany) were selected by Professor Gibson for the RASP project to provide the microstructure instrumentation and assist with the sea truth microstructure measurements, experiment planning, and data interpretation. The Sand Island municipal outfall injects highly treated wastewater into the clear, kelp-free waters of Mamala Bay, Honolulu, Hawaii. This location was selected rather than California for the RASP tests to eliminate possible surface brightness effects due to surfactants. The work is coordinated by Directed Technologies Inc. and funded by NAVAIR contract NBCHF010272. Measurement campaigns were carried out in Aug-Sept 2002 and 2003 and another is planned for the same period in 2004.

The selected RASP turbulence microstructure instruments were two Sea and Sun Microstructure Turbulence Systems (MSS) modified to include turbidity and microconductivity sensors. One MSS was for vertical profiling with a special winch and the other was for towed horizontal profiling. The MSS detects variations of velocity (turbulence), temperature and electrical conductivity (microstructure stratification), and turbidity over spatial scales between approximately 5 mm and 1 m. Based on the MSS measurements conducted so far, signatures, locations, and turbulent state of the buoyant wastewater plume were identified directly over and a few km from the outfall area. Possible mechanisms for the generation of the observed surface brightness anomalies caused by the plume are provided by Leung and Gibson (2004) and Gibson and Leung (2004).

System Description

The MSS is a multi-parameter system for the measurement of microstructure and turbulence in marine and limnic waters, jointly designed and manufactured by ~~of~~ Sea & Sun Technology GmbH and ISW Wassermesstechnik, Germany. It is based on developments carried out at the former Institute of Marine Research in Rostock-Warnemünde (Germany) and in the framework of European Commission research and development projects. The complete system consists of the MSS profiler with CTD and microstructure sensors, a probe interface for power supply and transmission to a PC, and a portable ship winch SWM2000 (Figure 1).

The MSS carries up to nine sensors that are directly mounted on the forward end of the cylindrical pressure case (Figure 2). The standard sensor equipment of the MSS consists of high resolution turbulence sensors (temperature, current shear) and standard CTD sensors (temperature, electrical conductivity, pressure). An acceleration sensor monitors high frequency vibrations (1-100 Hz) of the profiler itself. Additional sensors can be added and a total of 16 channels are available with the resolution of 16 bit and a sampling rate of 1024 per second. Data are transmitted as a serial stream through the tether cable. The turbulence sensors (i.e., high-resolution temperature, conductivity, and turbulent velocity), are placed on slim shafts extending approximately 15 cm in front of the other sensors. This ensures that the turbulence signals are not affected by flow blockage from the instrument or turbulent eddies generated by the guard cage or other parts of the instrument. For the detection of the wastewater in Mamala Bay, the MSS profiler was equipped with a high-resolution combined light scattering/fluorescence sensor by Alec Electronics Co. Ltd. and a microstructure conductivity sensor.

Operation

During normal use, the MSS is operated as a loosely tethered free sinking instrument. The profiler sinks at a rate of approximately 0.7 m/s and the sinking rate can be adjusted by a combination of weights and buoyancy elements. With a total length of approximately 1.4 m, diameter of 90 mm and a weight in air of approximately 12 kg, the MSS is easy to handle and can be operated from small ships or even manually from rubber boats (e.g., for measurements in small lakes or rivers). The smooth cylindrical housing is designed to minimize flow separation and eddy shedding, which cause vibrations that can obscure the turbulent velocity measurements. Low vibration levels are most important for accurate measurements of natural turbulence in ocean conditions, where the dissipation rate of turbulent kinetic energy (–ε) is often below 10^{-9} W/kg.

The tether cable has four 24-AWG electrical conductors and Kevlar strength members with a total breaking strength of approximately 190 kg. The cable is designed to be strong and extremely flexible so that the profiler can sink freely without feeling the influence of the tether. To facilitate measurements directly below the sea surface, the profiler buoyancy can be adjusted so that the instrument will rise, with the turbulence sensors directed upward.

The tether cable is managed with the SWM winch, which is a special winch that mounts on the ship's gunwale (Figure 1). During the profiling operation, the winch operator pays out cable at a rate slightly faster than the separation between profiler and the ship. This ensures that there is always a small amount of slack cable in the water, so that the profiler is decoupled from any motion of the ship. The operator controls the rotation rate of the winch drum with a small hand-held control. At the end of the profile the instrument is reeled back to the surface at a fast rate. The SWM winch is a portable electrical winch designed specifically for slack-tether deployments. The winch drum is pivoted and can be swivelled 360^o, which is useful during deployment and recovery. The spring loaded outrigger compensates for ship and wave motions to avoid spike loading of the deployment cable during the up haul of the profiler.

Velocity Shear Sensors

The key sensor of for the direct measurement of small scale turbulence is the so-called shear probe. This sensor has the shape of the rotationally symmetric airfoil and it detects lift forces that are generated by the cross-stream velocity component of the oncoming flow. These cross-axial forces are detected by a piezo-ceramic bending element connected to the airfoil. The voltage output of the piezo-ceramic beam is proportional to the lift force at the airfoil.

During the RASP campaign two types of shear probes were used simultaneously. The PNS probe (manufactured by ISW) and the SPM shear probe (manufactured by RGL Consulting Ltd.). In the SPM probe, the piezo-ceramic bending element is mounted inside the airfoil; for the PNS, the lift forces are transmitted via 20-mm long cantilever to the piezo-ceramic bending element, which is recessed and sealed into a Titanium shell. Compared with the SPM, the airfoil of the PNS is smaller (length and diameter are 3.5 mm and 3 mm, respectively), which give a higher spatial resolution. The RASP data set has shown that the measurements of the dissipation rate obtained from both shear probes agreed within approximately 10%, which is roughly the accuracy of the calibration procedure of the shear probes. Details of this comparison between PNS and SPM sensors will be published in a separate paper.

Operations during RASP

The MSS measurements carried out during RASP 2002 and 2003 were focused on the detection of the suspended waste water plume directly above the outfall pipe, as well as the identification of possible mechanism of the observed surface manifestation up to 10 km south of the diffuser. For this purpose, two MSS units were used alternating (and sometimes simultaneously): a vertical operating profiler (as described above) and a towed profiler. The towed profiler was mounted into a small tow sled for horizontal measurements in different depths. Both profilers provided excellent data and information about the waste water distribution in the near-field of the diffuser. The waste water plume is identified by its low salinity, high turbidity and enhanced turbulence level. This behavior is evident in both the vertical measurements (Figure 3) and the horizontal measurements (not shown). With respect to the identification of possible mechanism of the observed surface manifestation, during RASP 2003 we collected an enhanced data set consisting of vertical and horizontal MSS measurements in the far-field of the diffuser. Since the high variability in the hydrographic fields in the Mamala Bay and the intermittency of turbulence requires a large data set to identify any significant properties in the turbulence parameters in the area of the far-field of the diffuser, ongoing data collection using the MSS systems is scheduled for the measurement campaign in August/September 2004.

Conclusions

The RASP field work was the first application of a microstructure profiler to study the propagation of waste water and dynamic processes generated by a sewage outfall. The final results of the investigation require further data analysis and additional data collection using the MSS system. So far, the MSS performed extremely well during the RASP campaigns of 2002 and 2003. Since the MSS is small, compact, and easy to handle, the measurements were easily carried out on the relatively small vessels that were available during the campaign. Furthermore, the sensor equipment of the MSS was easily adjusted to the specific needs of the RASP experiment (e.g.,—.: additional turbidity/fluorescence sensor). The flexibility of the sensor configuration, together with the easy handling, makes the MSS to a very suitable tool for various biological or physical investigations in the ocean, but also in enclosed waters like lakes, rivers, and water reservoirs.

References

For a complete list of references, please contact author Fabian Wolk at fabian@rocklandocean.com.

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Short CVs

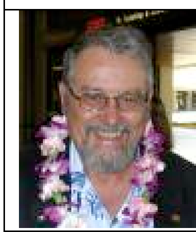
	Fabian Wolk holds a M.Sc. degree in Physical Oceanography and has been developing oceanographic instruments since 1995. He has been involved in the development of several microstructure turbulence instruments in North America, Europe, and Asia. He is the founder and president of President of Rockland Oceanographic Services and is still enjoys being actively involved oceanographic field work.
	Hartmut Prandke is president of ISW Wassermesstechnik, Germany. He works in physical oceanography and has been developing oceanographic instruments since 1973. He has more than 80 publications in refereed journals and books and holds 10 patents on a variety of measurement technologies. Prandke has a Ph.D. in oceanography from the University Rostock (Germany).
	Carl H. Gibson is professor of engineering physics and oceanography at the departments of Applied Mechanics and Engineering Sciences, and Scripps Institution of Oceanography at the University of California at San Diego. He has worked in the areas of theoretical and experimental studies of turbulence and turbulent mixing since 1962.

Figure Captions:

(Note to technical editor: the figures shown here are low-res. Look for 300 dpi TIFF files on CD)

Figure 1: MSS profiler (lying on its side below the railing) and SWM2000 winch in Honolulu Harbour, August 2002.

Figure 2: Sensor head of the MSS profiler. The microstructure sensors are mounted on shafts in front of the other sensors. This arrangement guarantees undisturbed measurements of the micro-scale stratification and velocity fluctuations.

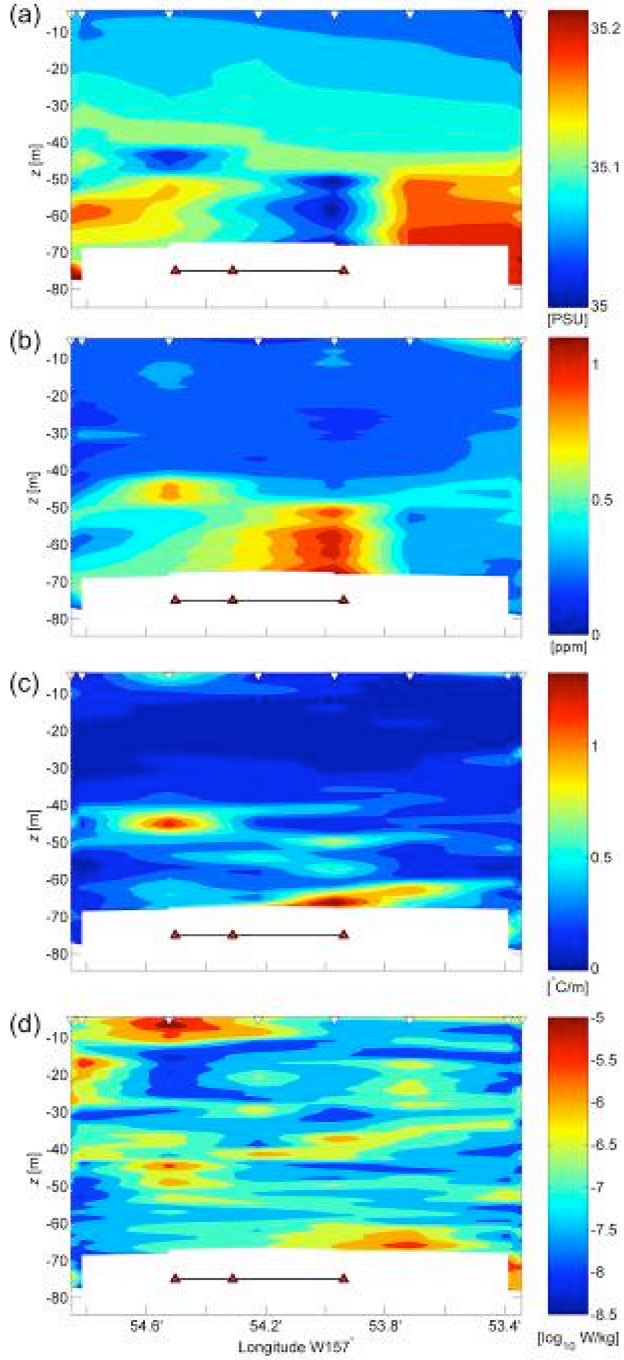


Figure 3: Distribution of waste water discharged from the diffuser in the Mamala Bay, measured with the vertical sinking MSS profiler at a transect over the diffuser pipe (September 2, 2002). The location of the outfall pipe is indicated by the bold line connecting three red triangles at 75 m depth. The discharged waste water is characterized by lower salinity (a), elevated turbidity (b), and enhanced levels of turbulence intensity as indicated by the local temperature gradient (dT/dz)rms (c) and the dissipation rate ε (d).