Methods in Oceanography 11 (2014) 39–58

Contents lists available at ScienceDirect

Methods in Oceanography

journal homepage: www.elsevier.com/locate/mio

Full length article

A novel platform to study the effect of small-scale turbulent density fluctuations on underwater imaging in the ocean

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ARTICLE INFO

Article history:
Received 16 August 2014
Received in revised form
12 January 2015
Accepted 20 January 2015
Available online 6 March 2015

Keywords:
Underwater optics
Optical turbulence
In-situ measurements
Turbulence measurements

ABSTRACT

Optical signal transmission is an important component of numerous underwater applications, including visibility and electro-optical (EO) communication. In addition to the well-studied effect of particle backscatter, underwater optical signal transmission can be limited by changes in the index of refraction (IOR) due to small-scale variations in temperature and salinity, sometimes called "optical turbulence". These variations in IOR, which are associated with oceanic turbulence, can lead to the blurring of an underwater optical target, particularly at high spatial frequencies, thus reducing target detail. The 2011 Bahamas Optical Turbulence Experiment (BOTEX) was conducted to investigate this impact of turbulence on underwater optical signal transmission. Investigating naturally occurring "optical turbulence" requires a platform held at depth, capable of concurrent measurements of optical impairment by turbulence, which requires a significant optical path length, as well as associated physical and optical background conditions of the ambient environment. Our novel platform consisted of a high-speed camera and optical target mounted on a 5*m*-long frame, along with several Nortek Vector Acoustic Doppler Velocimeter (ADV) and PME Conductivity–Temperature (CT) probes, to estimate

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http://dx.doi.org/10.1016/j.mio.2015.01.001
2211-1220/Published by Elsevier B.V.

turbulent kinetic energy and temperature variance dissipation rates experienced by the frame. Data on the background turbulence was collected with a Rockland Oceanographic Vertical Microstructure Profiler, to aid in analysis and guide error estimates of the ADV/CT measurements. This study was the first effort attempting to collect turbulence measurements on a frame designed for the investigation of the effect of density microstructure variations on optical signal transmission in the open ocean. Our results highlight the numerous challenges associated with studying this phenomenon in the dynamic oceanic environment. Here, we present the interpretation of the high-resolution velocity and temperature measurements collected on the frame and discuss the associated difficulties. Despite the numerous challenges, the investigation of the effect of microstructure on underwater optics is needed for efforts aimed at mitigating the impact of "optical turbulence" on underwater EO signal transmission and may help advance optical methods to quantify oceanic microstructure.

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1. Introduction

Optical properties of coastal and open ocean water and their impact on electro-optical (EO) imagery are important for a wide range of applications. Diver visibility, mine detection, search and rescue, and optical communications all depend on underwater optical signal transmissions. Underwater imaging has been shown to be affected by absorption and scattering due to suspended particles (Hou et al., 2007). However, recent evidence suggests that, in addition to particle scattering, underwater EO imagery may also be significantly affected by turbulent temperature and salinity microstructure in the water. Turbulence is ubiquitous in the world's oceans and fresh-water environments and the associated small-scale temperature and salinity variations can lead to localized changes in the index of refraction, which in turn impacts underwater optical properties. It has been demonstrated that this so-called "optical turbulence" can be a limiting factor in natural environments, affecting optical signal transmission that impact various applications, from diver visibility to active and passive remote sensing (Hou et al., 2012b; Bogucki et al., 2004). The recent Skaneateles Optical Turbulence Experiment (SOTEX) conducted in a lacustrine environment confirmed that optical turbulence may significantly contribute to image degradation (Hou et al., 2012b; Woods et al., 2011). To quantify this impact of turbulence on optical signal transmission in an oceanic environment, the Bahamas Optical Turbulence Experiment (BOTEX) was conducted in the summer of 2011 (Fig. 1) (Hou et al., 2012a). Measuring turbulence in the ocean has long been known to be a challenging task, and thus studying naturally-occurring optical turbulence in the open ocean is rife with difficulties. Among these are the deployment strategy, as well as ambient atmospheric and oceanographic conditions that can also affect the measurement method. The goal of this paper is to describe and address the challenges encountered while working to measure turbulence parameters with an experimental array that is geared towards optics measurements and different from the traditional turbulence profiling or fixed mooring approach. Since turbulence is patchy and highly variable in both space and time, it is important to have a type of turbulence sensor on the same structure that is also measuring information on the optics. This limits what turbulence sensors can be used. Shear probes, such as used in traditional Vertical Microstructure Profilers (VMP) and generally deployed at a free-fall from the vessel, would not be useful on a tethered frame drifting with the boat. The requirements on optical path length further complicate the setup. An optical path length of several meters is desirable in particle-laden natural waters, since the effect of image distortion due to turbulence is cumulative and often less pronounced than that of blurring due to particle scattering (Duntley, 1963; Preisendorfer, 1986; Hou et al., 2007). This puts certain size requirements on the frame to measure the optics, which in turn limits the ability to let