3D velocity fields for the Burger vortex flow treatments

Website: https://www.bco-dmo.org/dataset/834530
Data Type: experimental
Version: 1
Version Date: 2020-12-30

Project
» Collaborative Research: Navigating through space in turbulence tubes: Copepod responses to Burgers' vortex (Burgers_Vortex_Copepods)

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Abstract
A laboratory apparatus was constructed to physically create a Burgers vortex. Fluid motion is induced by co-rotating two disks while simultaneously withdrawing fluid axially through hollow drive shafts. The technique creates a flow pattern that mimics a Burgers vortex with size and strength consistent with dissipative-scale turbulent eddies in the coastal and near-surface zones. Specifically, the radius, circulation, and axial strain rate of the Burgers vortex were specified to match typical dissipative vortices corresponding to four turbulence intensity levels (described by a mean turbulent dissipation rate of 0.002, 0.009, 0.096, and 0.25 cm2s-3, respectively). Tomographic particle image velocimetry (tomo-PIV) was used to quantify the flow field, calibrate the apparatus, verify that it produces the desired vortex characteristics, and provide a three-dimensional velocity vector field to compare with zooplankton behavioral assays. The apparatus facilitates direct examination of the mechanistic aspects of plankton interaction with a dissipative-scale turbulent eddy. In depth description of the laboratory setting can be found at Webster and Young, 2015, and Elmi et al., 2021.

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Dataset Description

The data files contain the fluid velocity measurements in the Burgers vortex flow field. Vortex orientations are horizontal and vertical, each with 4 levels of intensity, as indicated via the file name. Data were measured using tomographic particle image velocimetry.

Acquisition Description

The tomographic particle image velocimetry (tomographic PIV) technique was used to measure the three-dimensional flow field (Elsinga et al., 2006) and to quantitatively confirm that it matches the target parameters of small-scale eddies in copepod habitats. The tomographic PIV technique reconstructed the volumetric position of small particles suspended in the fluid, the position of which was imaged by collecting scattered laser light via four cameras simultaneously. Particle displacements were calculated via cross-correlation of particle locations in consecutive volumetric reconstructions in order to measure the local three-dimensional velocity vector. Three-dimensional flow measurements were required for this flow since the local velocity vector included three components of motion and the flow field varied in three coordinate directions.

The tomographic PIV system (Murphy et al., 2012) used four high-resolution (Phantom v210, 1280 × 800 pixels), cameras to measure flow fields at the scale of the copepod. Images were captured digitally at a rate of 24 frames per second. To resolve the small length scales in this study, a 105 mm focal length lens (Nikon) was used for each camera. Scheimpflug mounts were used to change the orientation of the lens to correct the plane of focus on the cameras (Murphy et al., 2012). Orgasol polyamide powder (20 micron diameter; specific weight of 1.03 g cm-3; Arkema group) tracked the fluid motion within the tank. An infrared laser (808 nm wavelength) was used to illuminate the tracer particles. Experiments were performed in a dark room to eliminate any light outside the control volume that could increase the level of error in the flow measurements.

Processing Description

The vortex volume was reconstructed in the DaVis software (LaVision DaVis 8.4 - LaVision Inc.) using MART algorithms. A three-dimensional cross-correlation technique calculated the velocity field in the vortex by measuring particle displacements in consecutive reconstructed volumes (Elsinga et al., 2006).

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Related Publications

Elmi, D., Webster, D. R., & Fields, D. M. (2020). The response of the copepod Acartia tonsa to the hydrodynamic cues of small-scale, dissipative eddies in turbulence. The Journal of Experimental Biology, jeb.237297. doi:10.1242/jeb.237297
Methods

Elsinga, G. E., Scarano, F., Wieneke, B., & van Oudheusden, B. W. (2006). Tomographic particle image velocimetry. Experiments in Fluids, 41(6), 933–947. doi:10.1007/s00348-006-0212-z
Methods

Murphy, D. W., Webster, D. R., & Yen, J. (2012). A high-speed tomographic PIV system for measuring zooplanktonic flow. Limnology and Oceanography: Methods, 10(12), 1096–1112. doi:10.4319/lom.2012.10.1096
Methods

Webster, D. R., & Young, D. L. (2015). A laboratory realization of the Burgers' vortex cartoon of turbulence-plankton interactions. Limnology and Oceanography: Methods, 13(2), e10010. doi:10.1002/lom3.10010
Results

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Parameters

Parameter	Description	Units
X	horizontal coordinate	millimeters (mm)
Y	horizontal coordinate	millimeters (mm)
Z	vertical coordinate	millimeters (mm)
V_x	horizontal velocity field	meters per seconds (m/s)
V_y	horizontal velocity field	meters per seconds (m/s)
V_z	vertical velocity field	meters per seconds (m/s)
Flow_field	orientation of the vortex axis: horizontal or vertical	unitless
Level	level of intensity: 1, 2, 3, 4	unitless

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Instruments

Dataset-specific Instrument Name	Tomographic particle image velocimetry
Generic Instrument Name	Particle Image Velocimetry (PIV) system
Dataset-specific Description	Data were measured using tomographic particle image velocimetry
Generic Instrument Description	Measures 2D velocity flow fields, usually by scanning particles with a laser beam and capturing images of the illuminated particles.

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Project Information

Collaborative Research: Navigating through space in turbulence tubes: Copepod responses to Burgers' vortex (Burgers_Vortex_Copepods)

Website: http://www.nsf.gov/awardsearch/showAward?AWD_ID=1537284

Coverage: Coast of Maine

Copepods are ubiquitous animals in marine environments and play a critically-important function in the food web of the world's oceans. The ability of a copepod to sense fluid motion provides an advantage for critical survival tactics such as finding food, finding mates, and avoiding predators. This project will examine the capability of copepods to detect turbulent flow. A turbulent-like flow will be mimicked in a laboratory aquarium as a small vortex (i.e., swirling motion like a tornado), and copepod swimming behavior will be observed in and around the vortex. The goal is to understand the variations in the sensory ecology of three species of copepods with three representative sensor arrays to better explain their temporal and spatial distribution in the ocean in response to turbulence conditions. The project also has a strong education and outreach plan. It will provide interdisciplinary training for graduate and undergraduate students in fields such as engineering, biology, and computational sciences. Further, research results will provide context for planned outreach efforts to educate the general public at local high schools and aquariums.

The project will deconstruct the turbulence-copepod interaction by performing detailed kinematics analysis of swimming in three species of copepods in and around a laboratory realization of a Burgers' vortex that mimics in situ turbulent vortices in the dissipation range of scales. The goal is to test the hypothesis that the copepods Acartia tonsa, Temora longicornis, and Calanus finmarchicus detect hydrodynamic cues related to vortices in turbulent flows and actively respond via changes in swimming kinematics. Using a custom designed and calibrated apparatus, a turbulent-like vortex will be created in the laboratory. By holding the turbulent vortex stable in space, cameras will be focused on a small region of the feature to record the animal behavior relative to well-quantified flow characteristics. The approach has the advantage of eliminating the time-varying and stochastic nature of turbulent flows that make such mechanistic understanding so challenging to achieve. Hypotheses will address questions about the influence of swimming style, setal array architecture, and the interaction of chemical and hydrodynamical cues on the turbulence-copepod interaction. Specifically, the investigators will examine how copepod species with different sensory structures and swimming orientation respond to a stable well-defined laboratory stimulus to determine how copepods exploit the shape and orientation of turbulent features. The species of copepods chosen for this work provide a range of sensory architectures, swimming orientations, sizes, and mate tracking abilities.

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Funding

Funding Source	Award
NSF Division of Ocean Sciences (NSF OCE)	OCE-1537284

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