

## **Laboratory Verification of the Optical Turbulence Sensor (OTS): Particulate Volume Scattering Function and Turbulence Properties of the Flow**

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### **LONG-TERM GOALS**

Our goal is an extensive tank validation of the Optical Turbulence Sensor (OTS). This sensor uses a Hartman optical wavefront sensor to determine turbulence characteristics and to characterize the particulate field. In our configuration the wavefront sensor has been able to quantify simultaneously turbulent and particulate scattering for particles larger  $>50 \mu\text{m}$ .

### **OBJECTIVES**

Our laboratory studies were carried out in a well controlled fully turbulent convective tank. The optical measurements have been carried out with a number of neutrally buoyant spherical particles of diameter ranging from between  $0.5$  and  $1000 \mu\text{m}$ .

We have three main objectives:

*Turbulence characterization:* in this part of the effort we have compared thermistor (the temperature dissipation rate and the temperature dissipation spectra) and Particle Imaging Velocimetry (PIV) measurements of the turbulent kinetic energy dissipation rate, with concurrent optical OTS measurements of the same variables.

*Particle field characterization:* we have tested a new Volume Scattering Function (VSF) measurement method where we have used a wavefront sensor (OTS) to calculate large particles (particles larger  $>50 \mu\text{m}$ ) VSF.

*Particle/turbulence interaction:* in this part we have carried out simultaneous measurement of the particle VSF, the flow velocity and flow turbulent quantities using OTS. These optical derived parameters were then compared with same parameters obtained using PIV technique (energy dissipation rate, flow speed, flow shear), fast thermistor (temperature dissipation rate, temperature spectra), nephelometer (particle VSF). In addition we plan on quantifying of particle transport by coherent turbulent structures.

## APPROACH

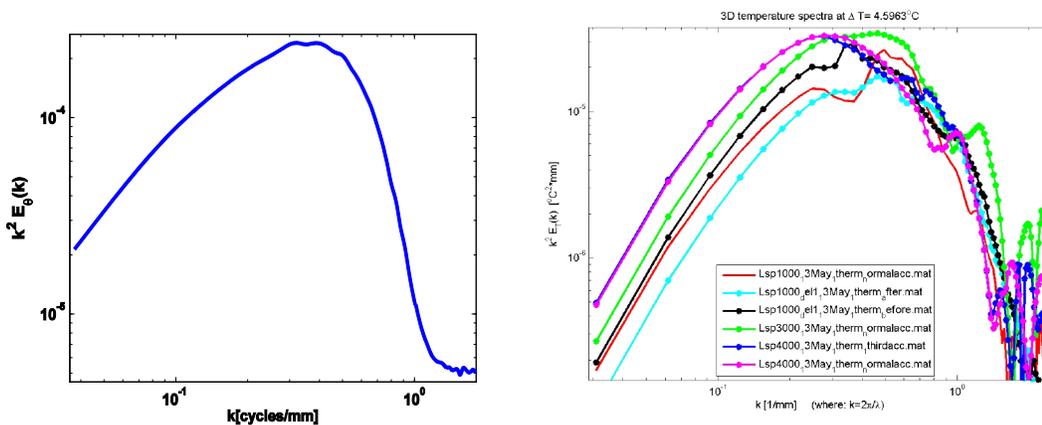
We have carried out rigorous tank testing of the turbulent and optical quantities measured by the OTS and direct compared with standard measurements. Among them we have carried out:

- Using a set of traversing fast thermistors (FP07) we have carried out measurement of temperature dissipation spectra and temperature dissipation rate
- We have carried out a 2D PIV flow measurements to obtain energy dissipation rates, instantaneous flow velocity and flow shear.
- The 0.5 and 1000  $\mu\text{m}$  particulate properties such as VSF were measured by nephelometer and verified the VSF by Mie calculations.
- Concurrently with above measurements we have carried out optical characterization of the flow and particles in the turbulent tank obtaining: temperature dissipation spectra, flow speed, flow shear and particle VSF.

## WORK COMPLETED/RESULTS

### Comparison of optically measured temperature spectra with fast thermistor measured temperature spectra.

We are in process of comparing the optically determined temperature dissipation spectra with the FP07. The Figure 1 presents the comparison between OTS measured 1 second data set and 20 min long thermistor data. Since the fast thermistor becomes noisy and high wavenumbers we have used an ensemble of 20 minute long thermistor measurements and carried out with varied between 2 cm/s to 10 cm/s thermistor speed. The optical measurement generated stable spectra over few milliseconds but for stability for each experimental run we have acquired a 1 second worth of data. The results are presented on Figure 1.



**Figure 1. Three dimensional temperature dissipation spectra –  $k^2 * E_\theta(k)$ .**

**A- The optically measured spectrum - 1 second average**

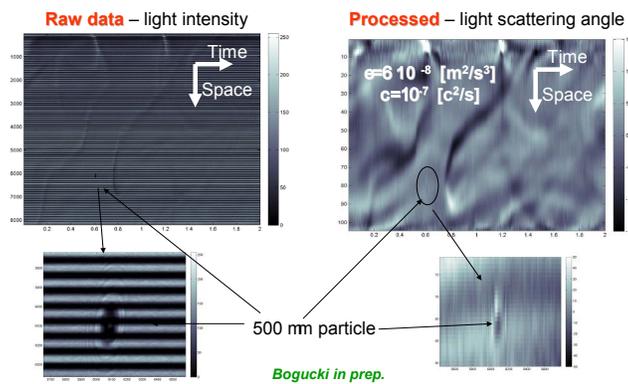
**B- Fast thermistor (FP07) spectra, collected at a different thermistor speed and varying between 2 to 10 cm/s each over 20 min time span.**

The OTS measured - three dimensional temperature dissipation spectra –  $k^2 * E_{\theta}(k)$  compares well with the thermistor spectra – Figure 1. Since the fast thermistor becomes noise at high wave numbers – the effects of that noise are apparent on the Figure 1 – right hand side panel.

In general the OTS measured temperature spectra agree well with ones obtained from the fast thermistor but OTS measurements exceeds the thermistor in accuracy thus allowing for more precise temperature and energy dissipation rates from optical measurements than using the fast thermistor.

## IMPACT/IMPLICATIONS

The goal of this part work is to develop greater understanding of particle dynamics in a turbulent flow. To that end we have carried out a laboratory experiment where a few large particles of know size were inserted into a turbulent flow. The aim was to concurrently characterize particles, temperature dissipation rates and visualize coherent turbulent structures. An example form such experiment is presented in the Figure 2.



**Figure 2. Raw (intensity) and processed (light scattering angle) images acquired for a controlled flow with a single 500  $\mu\text{m}$  particle. The images were acquired over  $\sim 5$  cm aperture in 5 minutes.**

The single particle is visible in the raw data surrounded by its diffraction rings. The scattering angles associated with the 500  $\mu\text{m}$  particles and characterized in terms of the particle VSF show rapid VSF decrease at scattering angles of around 80  $\mu\text{rad}$ .

This is consistent with the Mie calculations for 500  $\mu\text{m}$  particle which predict steep VSF decrease at around  $O(80 \mu\text{rad})$ .

The wavefront particulate measurements yield correct amount of particulate scattering and can be used to characterize large particle ( $>50 \mu\text{m}$ ) VSF.

## PUBLICATIONS

Woods S., W. Freda, J. Piskozub, M. Jonasz, **D. Bogucki**. Laboratory measurements of light beam depolarization on turbulent convective flow. *Applied Optics*, 49(18), 2010.

**D. Bogucki**. Optical properties of oceanic turbulent flows – implication for in situ measurements and the remote sensing. In preparation for *Applied Optics*.

**D. Bogucki**. Wavefront sensor measurements of large particles in the coastal environment - Volume Scattering Function. In preparation for *Applied Optics*.

S. Woods, J. A. Domaradzki, **D. Bogucki**. Laboratory measurements of turbulent momentum and temperature for a convective flow with  $Ra > 10^6$ . In preparation for *Physics of Fluids*.