Digital holography of marine particles in situ during the Arctic Expedition

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***Abstract*—The paper presents the results of measurements of marine particles in situ during Arctic expedition using the digital holographic camera (DHC). Characteristics of various marine particles, including classification and statistics on taxa, depth profiles of plankton concentration were measured. DHC technology may be used without additional sensors to obtain additional information on the medium, such as volume content of methane according to bubble surfacing and water turbidity assessed by the screening coefficient of the suspension taxon.**

Keywords—underwater digital holography; marine particles; plankton; in-situ measurements; field measurements; marine sensors

I. Introduction

Many tasks of oceanology and oceanography require information on marine particles of various origins [1-5]. It is necessary to obtain data on plankton to study the ecosystem biodiversity, assess the ecological state of the water area, data on suspended solids – to build hydrological translation models, and data on particles of various origins of certain sizes – to build mathematical models of light propagation in seawater.

The main research focus of the 82 Arctic Expedition on the research ship *Academician Mstislav Keldysh* (September 28 - November 4, 2020) was a comprehensive study of methane emission processes in the Arctic Seas of the Russian Federation. The feature of one of the research tasks was the need to simultaneously measure plankton, gas bubbles and other particles in the vicinity of methane seeps. Traditionally, for plankton measurements, samples are taken using a net, particles are fixed and then analyzed by an operator under a microscope [6]. Other methods (e.g. sedimentation traps) are used to measure bubbles and other particles.

It was confirmed during the expedition that the classification capabilities of the DHC technology algorithm make it possible to uniquely isolate mesoplankton with the distribution by taxa, phytoplankton, marine snow, terrigenous suspended solid material, gas hydrate methane bubbles. The present paper presents the results of measurements of marine particles in situ using the DHC, provides turbidity indicators, characteristics of various marine particles, including statistics on taxa, depth profiles of plankton concentration.

II. DHC Technology

A. Digital Holographic Camera Description

To obtain information on all particles of the studied medium volume in situ and in real time, we applied the digital holographic method using the submersible DHC sensor (DHC – Digital Holographic Camera) developed by us [7, 8] (Fig. 1, Fig. 2). The DHC technology was developed to extract information on particles of various origins, which records a digital hologram of the medium volume with particles on a CCD/CMOS matrix, followed by numerical reconstruction of holographic images of particles and determination of sizes, shapes, coordinates, speed for each particle, as well as their recognition and classification [9]. The maximum submersion depth of the DHC is 500 m, the volume recorded per one exposure is 0.5-1 liters depending on the DHC modification.

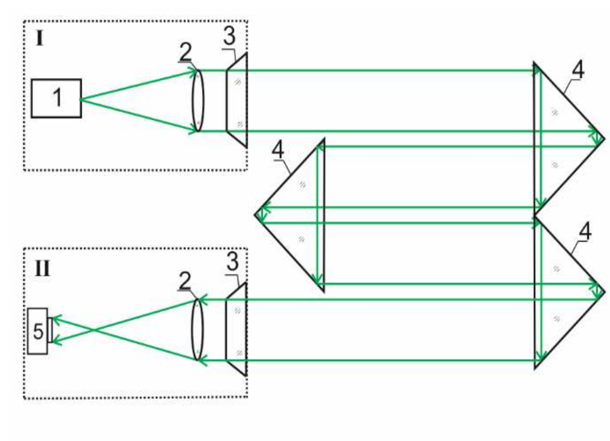

Fig.1. In-line scheme of digital hologram recording with folded configuration of investigated volume. I – lighting module; II – recording module; 1 – semiconductor laser; 2 – collimating/receiving objective; 3 – window; 4 – prism; 5 – CMOS camera

Fig.2. Digital holographic camera (DHC)

B. Images Reconstruction

During the Arctic Expedition, the DHC technology and one of the variants of the DHC sensor were tested when studying particles of various nature both in the background monitoring mode and in the vicinity of the seeps. Figs. 3, 4 show images of plankton and other particles reconstructed from holograms recorded by the DHC sensor at different depths in different Arctic seas.

As we can see from Figs. 3, 4, the reconstructed images allow us detecting and simultaneously processing the images of all particles. Besides, we know the exact spatial location of each particle and can plot the distribution of particles by size, orientation and location in space, etc.

C. Images Recognition

To obtain data on certain particles of the medium and their belonging to various types, the DHC software includes a particle recognition and classification unit.

The DHC classification is based on information on the geometric dimensions of marine particles. Depending on these dimensions (parameter H) and their ratio (parameter M), all marine particles are divided into 10 taxa. They are shown in Table 1, with the first 8 taxa belonging to plankton.

Suspension taxon is used to determine the medium turbidity. It includes particles which size is less than 200 μm and a cross-sectional shape close to a circle, i.e. the ratio of M sides of the circumscribed rectangle equal to ≥0.9. We use their size and concentration to calculate the turbidity of water.

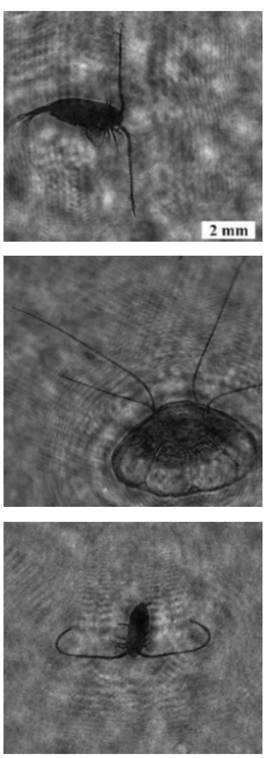

Fig. 3. Images of plankton particles reconstructed from holograms recorded by the DHC during the Arctic Expedition

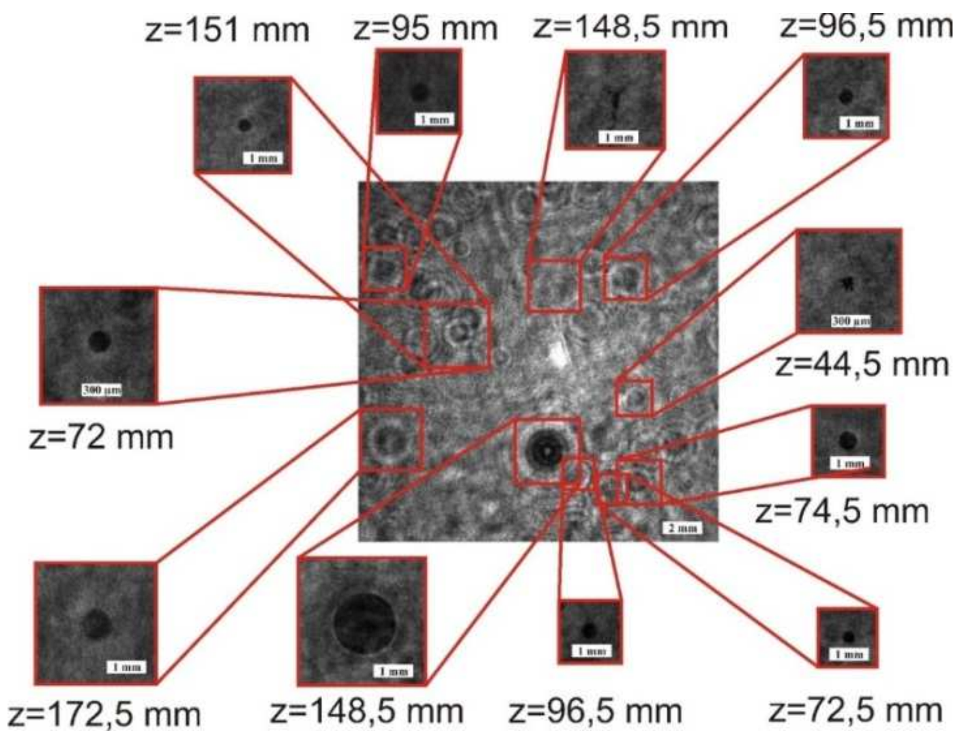

Fig. 4. Digital hologram (in the center) and reconstructed images of planktonic particles, settling particles, methane bubbles

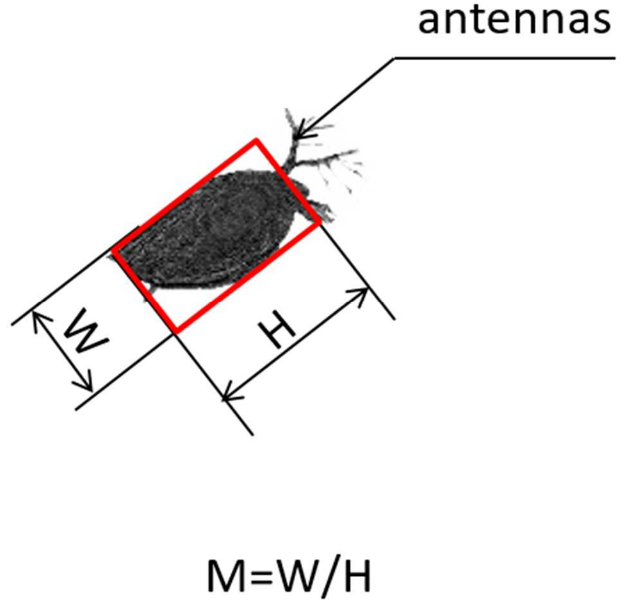

Fig.5. Morphological parameters

TABLE I. DECISION TREE OF AUTOMATIC CLASSIFICATION

Taxa	Presence of antennas	H, µm	M
1. Chaetognatha	YES	>200	0-0.2
2. Copepoda	YES	>200	0.2-0.5
3. Copelata	YES	>200	0.5-0.66
4. Cladocera	YES	>200	0.66-0.9
5. Other	YES	>200	0.9-1
6. Rotifera	YES	≤200	0-0.9
7. Phytoplankton chain	NO	ANY	0-0.25
8. Marine snow	NO	ANY	0.25-0.9
9. Suspension	NO	≤200	0.9-1
10. Bubbles	NO	>200	0.9-1

III. TURBIDITY AND METHAN MEASUREMENT

As a rule, turbidimetric and sedimentation measurements are performed to clarify the hydrological state of the water area (for example, turbidity measurements). Turbidity can also be assessed according to data obtained by the DHC. To do this, it is necessary to form a histogram of the particle size distribution of the Suspension taxon. Turbidity is taken equal to the total fraction of the volume cross-sectional area covered by particle sections, and the formula for its calculation is the following:

$$\alpha = \frac{\sum_{i=0}^{n} S_i}{S_{DHC}},$$

where S_{DHC} – area of the DHC entrance pupil; S_i – area of the i particle; n – number of particles of the Suspension taxon.

To determine the volume content of methane in the DHC software, data on the Bubbles taxon is used. Here we refer to particles which size is more than 200 µm and which cross-sectional shape is close to a circle, i.e. M≥0.9. These may be particles of both anthropogenic origins due to the extraction of hydrocarbons on the shelf and particles of natural gas hydrate origin formed as a result of the degradation of permafrost due to warming.

A data on the size and number of the Bubbles taxon particles are used to determine the volume content v of methane. The formula for calculating the volume density of the Bubbles taxon is used to assess the volume content of methane, and is shown below.

$$v = \frac{\sum_{i=0}^{n} {}^{1}/_{6}\, \pi H_i^3}{V_{DHC}},$$

where V_{DHC} – studied DHC volume; H_i – size of i particle of the Bubbles taxon; n – number of particles of the Bubbles taxon.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

Field measurements took place from September 28 to November 4, 2020 on the *Academician Mstislav Keldysh* research vessel. The map (Fig. 6) shows all the stations of the expedition.

As an example, Fig. 7 shows the hologram recorded at Station No. 6961 at a depth of 2 m in the East Siberian Sea. Besides, it shows the holographic images of some characteristic marine particles contained in the recorded volume of 1 liter.

As we can see, it is possible to distinguish mesoplankton, suspension and bubbles, and to determine their concentration. Fig. 8 shows the results when the DHC records the changes of concentrations of mesoplankton, Sea Snow, Suspension and Bubbles taxa in depth in the waters at two stations. The correlation between turbidity measurements using the DHC and a turbidimeter was 75.5%.

The comparison of diagrams in Fig. 8 shows that the Ob estuary (Kara Sea) is characterized by a quite large emission of river particles, which determines high turbidity of the water area, low plankton content and the absence of gas hydrate methane. In the Laptev sea, the water is more transparent, plankton is larger, gas hydrate bubbles are present.

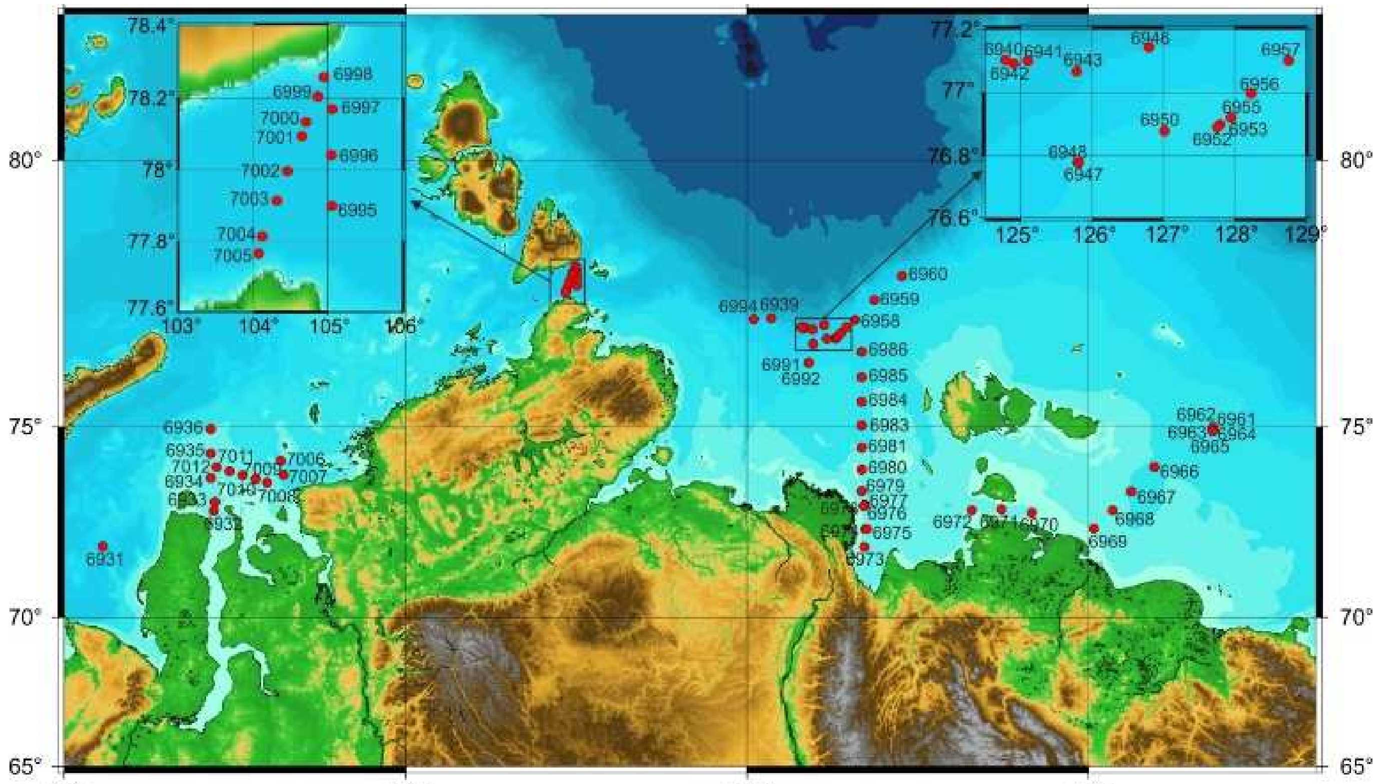

Fig.6. Map of the stations

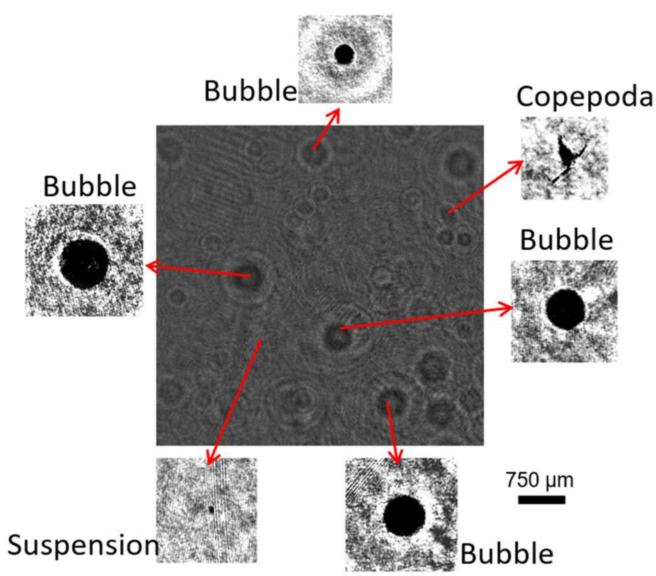

Fig.7. Holographic images of marine particles

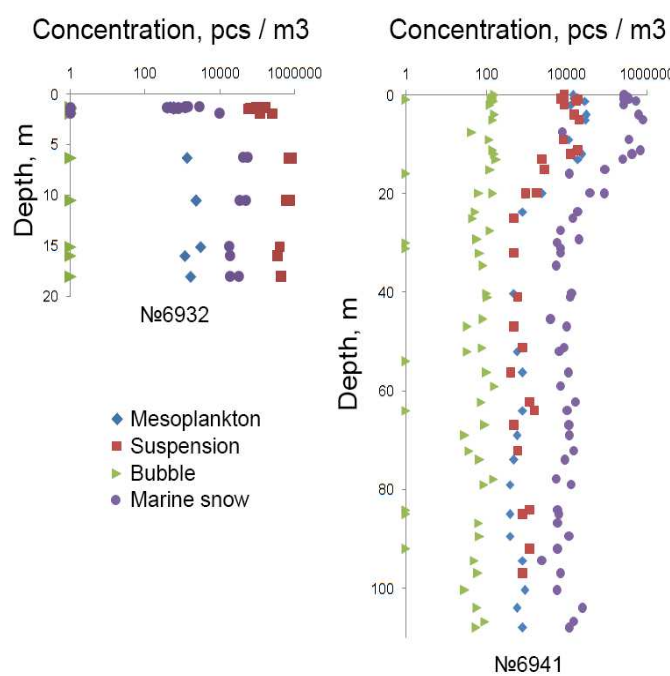

Fig.8. Depth profiles of particles of different origin concentration

Fig. 9 shows data on methane bubbles in the waters of the East Siberian Sea, at the stations No. 6961 and No. 6962. The station No. 6961 is located near the pack ice boundary, on the edge of the fault. There are many bubbles here, which indicates the intense melting of gas hydrates, which is a consequence of global warming processes.

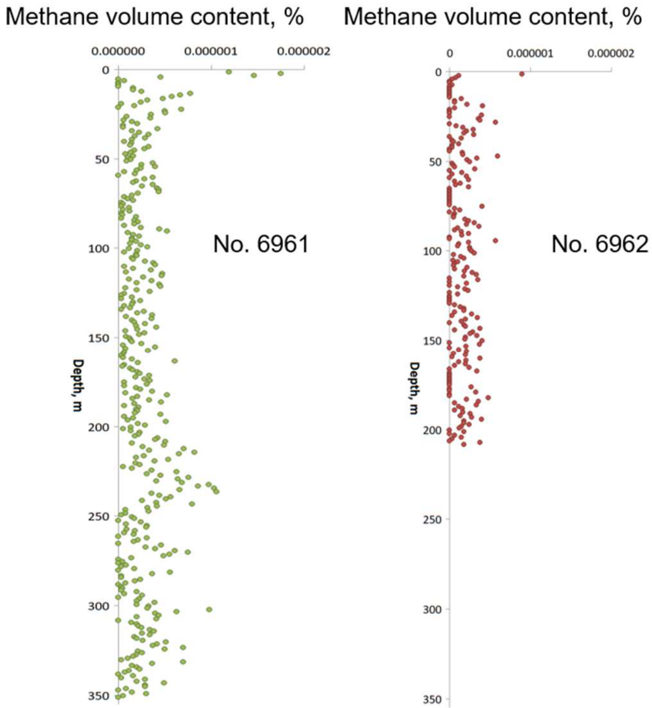

Fig. 9. Assessment of methane volume content

The volume content and flow of methane were measured at two closely located stations in the East Siberian Sea (No. 6961 and No. 6962). The difference in methane flow values of about 20% may be taken as an error in estimate.

V. Conclusion

Classification capabilities of the DHC technology algorithm make it possible to uniquely isolate mesoplankton with the distribution by taxa, phytoplankton, marine snow, terrigenous suspended solid material, gas hydrate methane bubbles.

Therefore, the DHC technology may be used without additional sensors to obtain additional information on the medium, such as the volume content of methane according to bubble surfacing and water turbidity assessed by the screening coefficient of the Suspension taxon.

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