ECHOSOUNDER OBSERVATIONS FROM AN UNMANNED SURFACE VESSEL IN THE ARCTIC

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\textbf{Abstract:} Two SailBuoys, long endurance unmanned ocean surface vehicles, were deployed in the Fram Strait in June-July 2016. One of the SailBuoys was equipped with a single beam echosounder, and the other with a sensor suite designed to measure ocean acidification. Recordings by the echosounder were converted to echograms. We have developed a system to identify objects by removing noise in the echograms and categorized them by their shape descriptors. Although interpretation of the categorized objects is limited by the lack of ground-truth information, each category is assumed to be an organism type in this study.

Physical and chemical data from the other SailBuoy, XBT profiles taken during the 2016 research cruise, and satellite remote sensing data are available as independent variables. In this study, the relationship between the behaviour of the categorized “organism” data and the independent environmental variables is investigated.

\textbf{Keywords:} SailBuoy, Echosounder data categorization, Ocean acidification, XBT and CTD profiles

1. \textbf{INTRODUCTION}

The Arctic marine ecosystem is sensitive to human-induced changes, such as acidification caused by CO2 emissions. More knowledge is needed of the physical and chemical processes in the region, and their effects on biological production. Two SailBuoys, small autonomous sailing platforms, were deployed in the Fram Strait for three weeks in June-July 2016 to collect in-situ data at high spatial and temporal resolutions. One of the SailBuoys (“SB Nexos”) was equipped with a 200 kHz echosounder for the purpose of detecting marine organisms, and the
other ("SB IceEdge") with a new sensor suite designed to measure parameters relevant to ocean acidification.

A total of 79 echosounder recordings are available for the study. Echosounder data from the upper 100 m are converted to echograms and objects in the images are identified. In this study, all the identified objects are assumed to be organisms and categorized.

Other in situ data (XBT profiles) obtained during the 2016 research cruise, and satellite remote sensing data - chlorophyll and wind speed - are also available as independent variables. Each categorized object data is corresponded to the independent variables with the smallest position or time difference. The relationship between the behaviour of the categorized organisms and the physical and chemical independent variables are then analysed and discussed.

2. DATA ACQUISITION AND PROCESSING

2.1 SailBuOys

The SailBuOy is a remotely controlled surface vehicle that uses wind power to sail towards dynamically defined waypoints [1]. The SailBuOy weighs 60 kg, is 2 m long and has a payload capacity of 15 kg. Waypoints are set using a web interface, and communicated to the SailBuOy via Iridium satellite link. Since the SailBuOy is wind-powered, the acoustic noise generated by the measurement platform is minimal, which is an advantage for the echosounder measurements. In addition, by mounting the transducer in the keel of the SailBuOy (depth about 0.5 m), the blind zone in the surface is significantly reduced compared to conventional vessels. Two SailBuOys were deployed in the Fram Strait from 30 June to 18 July 2016 (see Fig.1). Both SailBuOys were piloted from shore and sailed 106 - 231 km away from the nearest ice edge during their 18 day mission. They followed largely the same track, except for the westernmost part of the journey where SB Nexos did a larger excursion before turning back towards the east.

2.1.1 Echosounder SailBuOy

The SB Nexos SailBuOy was equipped with a Simrad EK15 echosounder, with a single beam 200 kHz transducer, Simrad 200-28CM (28° beamwidth) [2]. The pulse repetition rate was 1 s, and pulse length was 320 µs. To preserve battery, data were recorded on the 5th and 12 - 15th of July. During periods of the operation, data with 15 minutes long were recorded every 30 minutes. A total of 79 such recordings (4.4 GB of data) were available for this study. The volume backscattering coefficient (SV) are calculated from the raw echosounder data, using a range of 1 to 100 m, which is the range we expect biologically significant signals to be present. The SVechograms are then used for the further analysis. The mean speed of the SailBuOy in the echosounder measurements was 24.3 m/min.

It is important to remove various types of noise included in the recordings to characterize the objects seen in the echograms for analyses of biological activities. A semiautomatic system to remove noise from the echograms and then convert to the binary images was developed. The procedure is shown in Fig.2.

The regionprops function in the MATLAB Image Processing Toolbox identified 1770 objects in the 79 binary images (see the last panel in Fig.2) and quantified properties of each object such as central position, area and major and minor axis length. Wide objects in shallow depth likely indicate phytoplankton. Objects in middle depth might represent fishes or swarms of zooplankton, e.g. krill and Themisto gaudichaudii. However, interpretation of the echosounder data is limited because of lack of higher dimensional / ground-truth data [3]. For this analysis we suppose all the identified objects in the echograms are organisms. The 1770 objects are then categorized into 7 types by their depth and shape descriptors using the criteria
in Table1. The total numbers of objects for each type in the 79 echograms are also shown in Table1.

Fig.1: Overview map of the study area showing the surface water temperature (°C) distribution on 18th July 2016 from the operational TOPAZ4 Arctic Ocean system (E.U. Copernicus Marine Service Information). The tracks of SB IceEdge and SB Nexos during the 18 days mission are shown in black and white respectively and the pink line shows the positions from which echosounder data were collected. Stars mark the final positions on 18th July.

Fig.2: 1st from the left: Raw echogram, 2nd: Remove depth (horizontal) noise, 3rd: Delete mechanical noise near the sea surface, 4th: Remove vertical noise and emphasize objects, 5th: Banalize the 4th panel. If two or more objects overlap as shown by the arrow in the 4th panel, they are assimilated during the conversion to a binary image. The objects are then segmented manually as shown in the 5th panel, 6th: Identify objects in the binary image (objects recognition)

2.1.2 Ocean acidification SailBuoy

A new sensor package developed by Aanderaa Data Instruments comprises sensors for temperature, conductivity, pH, partial pressure of carbon dioxide (pCO2), and dissolved oxygen (O2). Most of the sensors are housed in a bulb on the keel of the SailBuoy together with a UV-antifouling device. An O2 and temperature sensor for measurements in air is placed on top of the vessel. Data were recorded every 10 minutes. All sensors functioned well throughout the deployment, giving a total series of ca. 2500 values for each parameter. GPS position and time was logged for each sample. All water measurements are from the near-surface layer, from sensors placed in the keel at about 50 cm depth.
2.2 XBT and CTD profiles

During the research cruise, expendable bathythermographs (XBTs) were deployed from the ship. A total of 153 profiles were done, out of which 20 on a 130 km long line from west to east parallel to the SailBuoy tracks (see Fig. 3, inset). The surface mixed layer depth (MLD), here defined as the depth of the strongest vertical temperature gradient in the upper 100 m, was computed for each XBT profile.

<table>
<thead>
<tr>
<th>Type</th>
<th>ss</th>
<th>sl</th>
<th>ms</th>
<th>ml</th>
<th>ds</th>
<th>dl</th>
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<tr>
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<td>&lt; 20m</td>
<td>&lt; 50m</td>
<td>&lt; 50m</td>
<td>&gt;= 50m</td>
<td>&gt;= 50m</td>
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<td>&lt; 5000</td>
<td>&gt;= 5000</td>
<td>&lt; 50000</td>
<td>&gt;= 50000</td>
<td>width &gt; 10000</td>
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<tr>
<td># of objects</td>
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<td>220</td>
<td>671</td>
<td>534</td>
<td>47</td>
<td>5</td>
<td>88</td>
</tr>
</tbody>
</table>

Table 1: Objects in each echogram are classified into 7 types by the depth (shallow, middle and deep) and area (small and large) / width. For instance, data type “ds” represents deep-small object. The “# of objects” represents a total number of the objects in the 79 echograms for each type.

2.3 Satellite data

Two products from satellite remote sensing are available.

- Chlorophyll data (chl) are provided as Level-2 product, generated from either a Level-1A or Level-1B product of MODIS Aqua or Terra, by OceanColor (https://oceancolor.gsfc.nasa.gov/). The spatial and temporal resolutions are 1 x 1 km and 10-12 times/day respectively.
- Wind speed data (ws) are given by Copernicus marine environment monitoring service (http://marine.copernicus.eu/). Level-4 products provided as 6 hourly mean data with 25 x 25 km spatial resolution are used for this study. The provided data are blended mean wind field based on daily ASCAT (Metop-A and Metop-B) and QuikSCAT (OceanSat2) gridded wind fields with ECMWF analysis.

3. ANALYSIS

3.1 Phytoplankton layer and Mixed Layer Depth (MLD)

The wide type objects were extracted from the categorical data. If there were two or more wide objects in an echogram, they were removed from the analysis to prevent ambiguity. Based on advice from biologists, we presume the extracted objects represent phytoplankton. The MLDs computed from XBT profiles taken on the 14th of July were compared with the phytoplankton data from the 14th and 15th of July. The MLD data were interpolated in space to match the phytoplankton data from the same line (see Fig.3). The depth of the plankton layer varied between 3 and 20 m, with an average of 9 m and a standard deviation of 4 m. The depth of the phytoplankton layer identified in the echosounder data thus roughly agrees with the MLDs, which ranged from 7 to 20 m, with a mean of 13 m and a standard deviation of 4 m. Shallow MLDs of 5 - 30 m are common in the Arctic in summer [4].
3.2 Organisms and ocean environment

Canonical Correlation Analysis (CCA) is the analysis of correlation between two sets with multiple variables, X and Y [5]. The canonical correlation coefficient measures the strength of the relationship between two Canonical Variates (CV). CV is the weighted sum of the variables in each set X and Y. CCA determines the canonical weights (coefficients of CV) so as to maximize the correlation between CV_1 and CV_2 for each set.

923 samples out of 1770 objects, categorized as small objects (ss, ms, ds), were extracted. These small objects likely indicate organisms such as zooplankton and fishes. The organism data were related to 8 physical and environmental variables shown in data set X in Table 2 to make a correspondence table with (8 + 3) columns. The categorical data were paired with the 5 ocean acidification variables based on time. The satellite record closest in time to each categorical data was used, and since the two variables from the satellite data have lower spatial resolution they were interpolated in space to the positions of the echosounder data. A solar elevation angle was calculated for each categorical data based on the time and position of the underlying echosounder recordings.

CCA was applied to the 923 samples to clarify the relationship between the 8 independent variables and 3 depth types of the organisms. Table 2 represents the canonical weights for 1st and 2nd CVs. Wind speed is the most significant variable in CV_1 owing to the largest absolute weight in CV_1. The negative value means decreasing wind speed increases the CV_1 value. pH and pCO2 are the second and third significant variables. Increase of pH and decrease of pCO2 raise the CV_1 value. In the same manner, ss and ms are the first and second significant variables in the CV_2. Increase of ss and decrease of ms raise the CV_2 value. The correlation coefficient between CV_1 and CV_2 is 0.673, i.e., a positive correlation. In brief, it is found out that increased number of organisms near the sea surface coincided with calmer winds, weaker acidity of the surface layer, and lower sea surface pCO2.

Significant variables in CV_2 are temperature in water, pH, and solar elevation angle. Increases of temperature, solar elevation angle and acidification of sea surface raises the CV_2 value. Increase of CV_2 is proportional to increase of ds (organisms below 50 m). Correlation
The coefficient between $CV_{x2}$ and $CV_{y2}$ is 0.511. The number of organisms in the deeper water thus increased with increasing water temperature, solar elevation angle, and sea surface acidity.

<table>
<thead>
<tr>
<th></th>
<th>X</th>
<th>Y</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>ws $^{1)}$</td>
<td>Chl $^{2)}$</td>
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<tr>
<td>1st</td>
<td>-1.57</td>
<td>-0.46</td>
</tr>
<tr>
<td>2nd</td>
<td>-0.70</td>
<td>-0.68</td>
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</table>

*Table2: The first and second canonical weights for the two sets. Bold indicate which values are mentioned in the discussion above. 1)wind speed, 2)chlorophyll, 3)salinity, 4)solar elevation angle*

4. CONCLUSIONS

Two SailBuoys were deployed to record echosounder and ocean acidification data in the Fram Strait in June-July 2016. XBT profiles obtained during the 2016 research cruise, wind speed and chlorophyll data from satellite, and sun elevation angles calculated based on the echosounder recordings, were also available as independent variables.

1770 objects were extracted from the echogram data, and categorized into 7 object types. Each object was related to the other independent variables based on time and position. In the study, the 7 categories of the objects were assumed to be organism types, and relationships between behaviour of the organisms and independent physical and environmental variables were investigated.

5. ACKNOWLEDGEMENTS

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REFERENCES