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Water wave measurements at Bellsund in the western Spitsbergen

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ABSTRACT

The Arctic region has experienced rapid changes in the last few decades. The Arctic coasts in times of progressing global warming are exceptionally vulnerable to erosion. Arctic sea-ice extent is decreasing dramatically leaving coasts exposed to destructive action of waves. The lack of sea ice causes a dramatic increase of wave energy reaching coastline. In order to provide insight into coastal changes in Arctic areas, field measurements were carried out in the area of Calypsobyen, Bellsund, west Spitsbergen. Data of free-surface elevation, wave orbital velocities, water currents and bathymetry were collected during expedition in the western Spitsbergen. In the frame of this study a detailed analysis of wave field were performed. The collected database constitute unique and valuable source of information on Arctic wave climate.

Keywords: *Field measurements, Arctic, water waves, database.*

1. INTRODUCTION

The Arctic region is very intensively explored in the last few decades and coastal settlements are exposed to great risk. Coastal changes in the Arctic are affected by many environmental factors such as sea-level and sea-ice extend variations, wind, waves and storminess. Also the geology and morphometry of the coastline, permafrost concentration and its ground-ice content have an impact on coastal changes (Zagórski 2011). As a result of costal processes such as sediment transport due to waves and currents and degradation of permafrost, the erosion or accretion occurs affecting biological and human systems (Rachold et al. 2005). The Arctic coasts in times of progressing global warming are exceptionally vulnerable to erosion. The Arctic sea-ice extent is decreasing dramatically. According to the newest studies, sea ice extent in Arctic is decreasing 3.8% i.e. about 400,000 km^2 per decade. The situation is more dramatic when we consider the average winter ice thickness, which decreases about 16 % per decade (Comiso and Hall 2014). Disappearing of natural barrier in the form of sea ice, leaves the coasts exposed to destructive action of waves (Reda et al. 2015, Paprota et al. 2016, Sulisz et al. 2015).

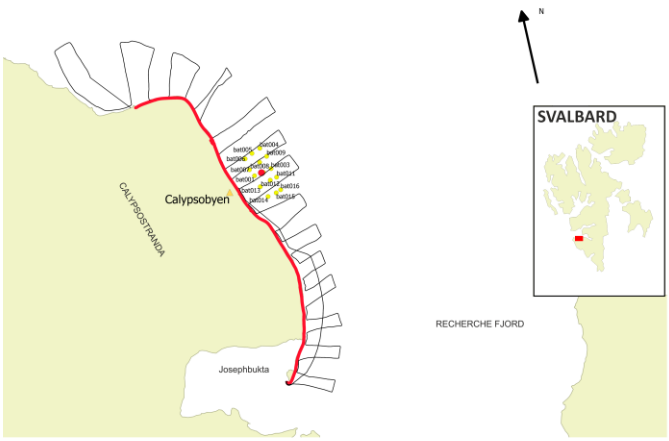

Figure 1. Measurements site at the southern part of Bellsund, Spitsbergen. Red line – coastline position, black line – bathymetry survey tracks, yellow dots – bathymetry survey with CTD probe.

The main objective of this study is to create a database of wave field characteristics in Arctic regions which will be constantly updated. The database will include other parameters useful in the estimation of coastal erosion rates such as bathymetry of nearshore zone, coastline position, and topographic profiles of the beach. This database is going to be used to verify numerical model of marine scour in Arctic conditions. Further work includes the estimation of Arctic coasts vulnerability to wave-induced erosion. In order to estimate wave energy reaching the shoreline, water wave measurements were carried out in the area of Calypsobyen, Bellsund, West Spitsbergen. Field campaign was conducted by the team of researchers from the Institute of Hydro-Engineering and Maria Curie-Skłodowska University (UMCS) during the summer season of 2015 in the vicinity of Polish Polar Station in Calypsobyen (Figure 1). Although measurements of currents, salinity, etc. were conducted in Svalbard archipelago, very little attention has been given to surface waves in that area (Mędrek et al. 2015). The database will also contribute to other fields of science. To provide full insight in the process of coastal erosion, wave measurements were supported by complementary bathymetry surveys and shoreline position tracking. Authors are going to perform second expedition to the Calypsobyen in the summer season of 2016 and supplement the database with new measurements. It will allow to estimate seasonal change of coastal erosion rate in Bellsund. This paper presents analysis of raw measurement of wind waves, currents and bathymetry.

2. FIELD MEASUREMENTS

In the Arctic conditions, a higher possibility of drifting ice and iceberg appearance, makes the use of conventional methods of surface wave measurements impossible. The floating buoy such as WaveRider is likely to be carried away or completely damaged by floating ice. Therefore, the Acoustic Wave and Current (AWAC) measuring system was chosen to be deployed. The advantage of the AWAC system is its sea floor deployment, which makes the system less vulnerable to weather conditions. The system also offers the possibility of current velocity and direction measurements. Taking into account the logistic issues regarding the expedition and morphological characteristic of the Svalbard archipelago (Zagórski 2011), authors decided to choose Calypsobyen, Bellsund, west Spitsbergen as the study area. Desirable place had to be an intermediate or shallow water area, i.e. the ratio of water depth to wavelength is less than 0.5 and the waves are already refracted and tend to propagate perpendicularly to the shoreline. The measurements were conducted from 10.06.2016 to 03.09.2016. The area of planned deployment of AWAC system was initially probed with YSI 600XL-B-M CTD device equipped with the pressure sensor. These measurements are presented as yellow dots in Figure 1. As a result, the position of the system was determined by the distance of 1 km from the coastline and is marked by a red dot in Figure 1. The water depth ranged from 8 to 10 m depending on the tide level. The device was fixed at the bottom on a tripod stand with the head of the device 0.8 m above the bottom. The AWAC was programmed to record free-surface oscillations with the highest available frequency of 4 Hz. One wave record lasted for 1,200 seconds which resulted in 4,800 points per wave record. The interval between wave records was 1,320 s. The gap between wave records lasted only 120 s and was used to register water current profile. The profiles were recorded in 18 vertical cells, every 1,320 seconds for 55 seconds and then the results were averaged. The cell vertical size was 0.5 m and the number of cells was chosen to reach the surface at the highest water level.

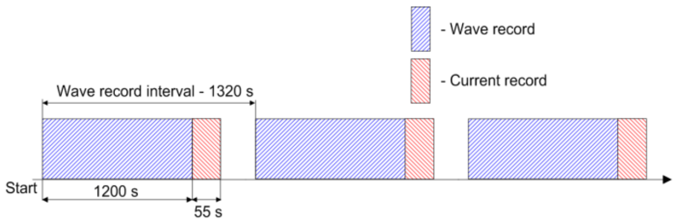

Figure 2. Time schedule of AWAC measurements.

Wave measurements were supported by bathymetry surveys and coastline position tracking. Bathymetry measurements were made from a boat by applying Garmin echoMAP DV50 echo sounder. The black line in fig. 1 depicts the path of depth measurements. The speed of the boat was kept constant to avoid the noise appearance in the bathymetry record. Moreover, archival digital bathymetry that consists of interpolated point data in the array of 10 m by 10 m was available. The position of the shoreline was measured with the Leica GPS System 500 at a known sea level. The track of coastline position is marked by red line in Figure 1. The second record of the coastline position is planned to be performed in the frame of the next expedition and will allow to determine interannual variability. Additionally, meteorological parameters such as temperature, atmospheric pressure, wind speed and wind direction were recorded by four automatic weather stations located in the western Spitsbergen.

3. RESULTS AND DISCUSSION

3.1. Waves

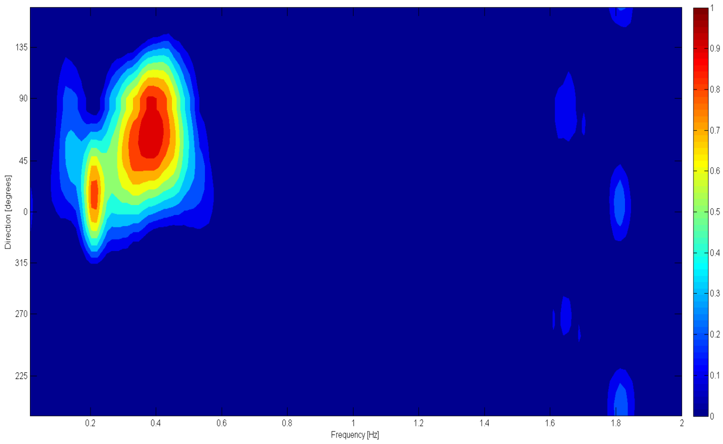

Figure 3. Normalized directional wave energy density spectrum.

Wave measurements collected using AWAC system resulted in more than 5300 wave records. The directional wave energy spectrum $S(\theta, f)$, where θ is a wave direction and f is a wave frequency, were calculated for each 20 minutes wave record. The directional spectra were calculated by applying a directional Fourier series approach which is commonly used in a wave field analysis (Boukhanovsky et al. 2007). The method was originally developed by Longuet-Higgins et al. (1963) and consists of counting first five coefficients of the directional Fourier series expansion a_0, a_1, a_2, b_1, b_2 of the directional wave spectrum $S(\theta, f)$. The spectrum is given by:

$$S(\theta, f) = \frac{a_0}{2} + a_1 \cos(\theta) + b_1 \sin(\theta) + a_2 \cos(2\theta) + b_2 \sin(2\theta) \tag{1}$$

The detailed procedure can be found in Longuet-Higgins et al. (1963) or in Earle et al. (1999). The directional spectrum for the whole period of measurements is shown in fig. 3. It can be seen that the majority of wave energy is focused around 0.2 to 0.4 Hz. The significant wave height H_s was derived with the zero up-crossing method and was compared to its spectral counterpart H_{m_0} to check the results. Differences were less than 2 %. H_{m_0} is the wave height derived on the basis of zeroth-order spectral moment from the following formula:

$$H_s = 4\sqrt{m_0} \tag{2}$$

The significant wave height H_s is plotted in Figure 4. One can distinguish some periods of stormy weather when the significant wave height grew rapidly. The most spectacular storm occurred around 28th of July when the significant wave height grew to over 1 m. The growth in H_s can be also seen on days 06/12, 07/15, 08/18, 08/25. The topography of Bellsund area enforce less wave energy which causes that the significant wave height is lower than in open waters of North-East Atlantic (Vikebø et al. 2003). Peak periods, and dominant wave directions were calculated on the basis of spectral parameters and are also plotted in Figure 4. The distributions of peak periods and wave directions are uneven when the water surface is relatively calm. With increasing H_s, when the storm is developing, the peak periods and dominant wave directions are more stable in time. The directional distribution of dominant wave directions is shown in Figure 5. The dominant wave direction coincides with North-East direction, which is with some deviation, perpendicular to the shoreline in the vicinity of Calypsostranda. Wave directions are in reasonable agreement with wind directions (Figure 6). Wavelengths were calculated according to the linear dispersion relation. Wavelengths corresponding to significant wave height are presented in Figure 7.

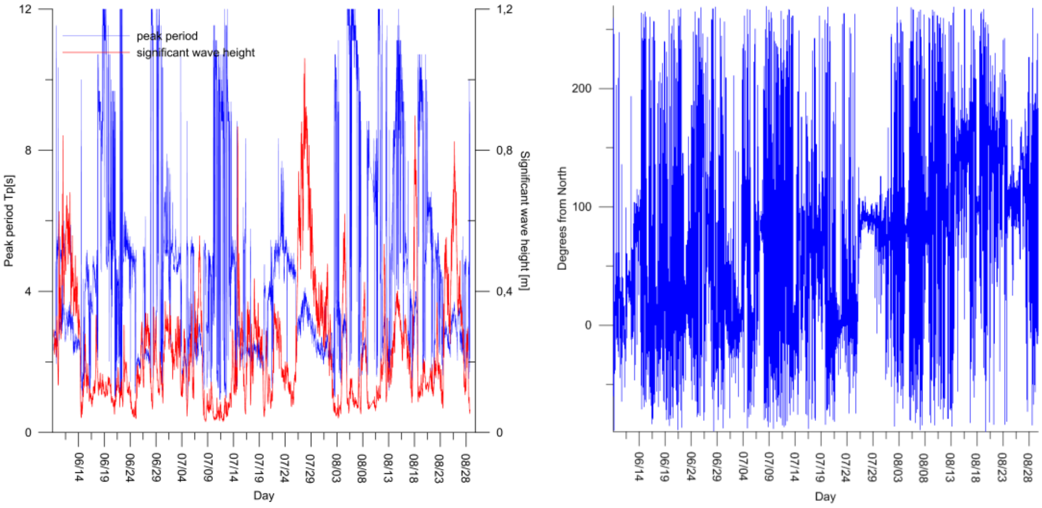

Figure 4. Time distribution of peak period, significant wave heights and dominant wave direction.

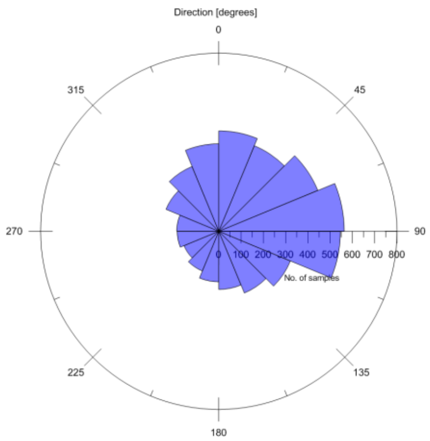

Figure 5. Wave peak directions. Zero degree is N.

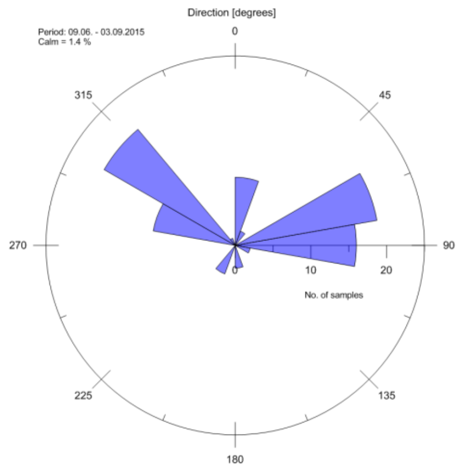

Figure 6. Wind Directions. Zero degree is N.

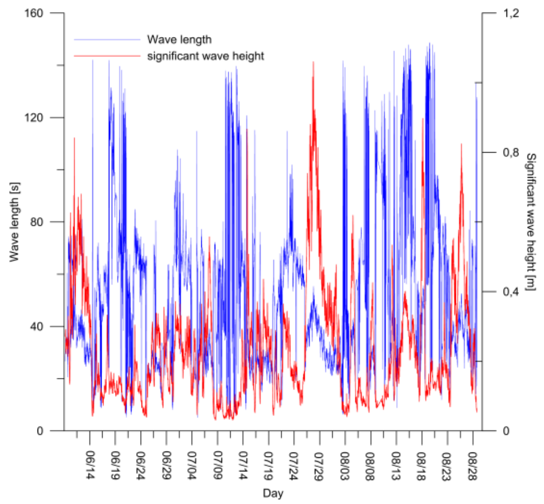

Figure 7. Time distribution of wavelengths and significant wave heights.

3.2. Currents

The current speeds and directions recorded during expedition are shown in Figure 8. Angels on right plot correspond to the real north shown in Figure 1. The plots show that during strong storms, when significant wave height is increased, the current becomes more homogenous over depth and its magnitude increases, as expected. This is especially seen on day 07/28 on both plots in Figure 8. Similar situation can be observed also around days 06/12, 06/28, 08/10, 08/18, 08/25. When the significant wave height decrease and the storms become weak, the upper and bottom layers of the water column move southward, which is consistent with wave directions. The middle layer of water column moves northward, creating a certain circulation pattern. For weak storms the current usually decreases with water depth.

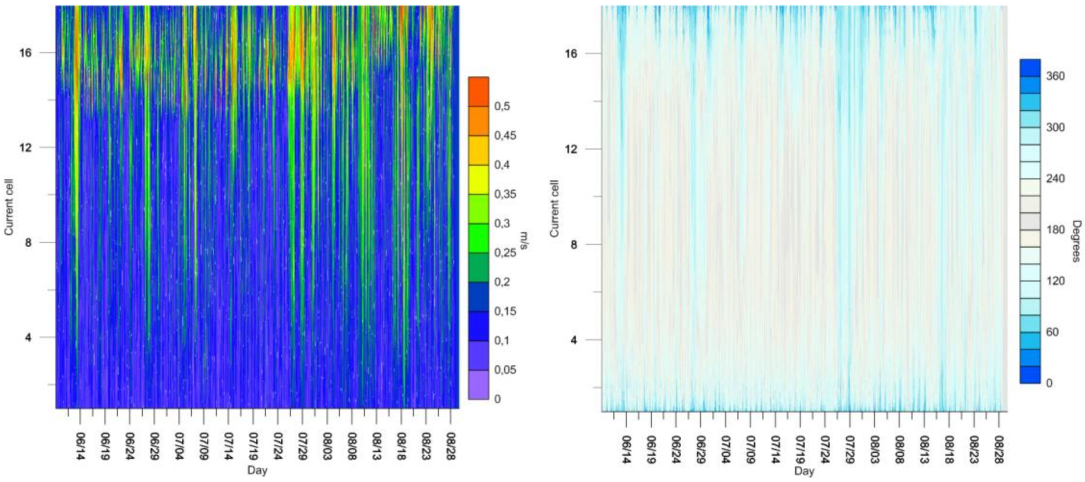

Figure 8. Current speed and current direction profiles.

3.3. Bathymetry

The bathymetry measured during the expedition and the archive data are presented in Figure 9. The archive data were collected by Norwegian Hydrographic Service (NHS) and consist of interpolated data in the grid of 10 m by 10 meters. The comparison of the historical data with the bathymetry recorded in the course of this study showed that the NHS bathymetry is very general and misses many details related to underwater land forms. This can be seen on the chosen profiles taken from both databases (Figure 10). In Figure 10, the profiles were set to be perpendicular to the shoreline and to pass through the AWAC position. Due to large uncertainty in historical bathymetry data, the analysis of changes in depth over time led to unreliable results. Nevertheless, archival bathymetry can be useful as a supplement data collected in the course of this study. Analysis of the bathymetry showed that the coastal zone of Recherche Fjord is composed of two steep slopes and the 1.5 km long relatively flat section between the slopes. The toe of the first steep slope is located at the depth of 10 m, while the second one is located at the depth of 80 m.

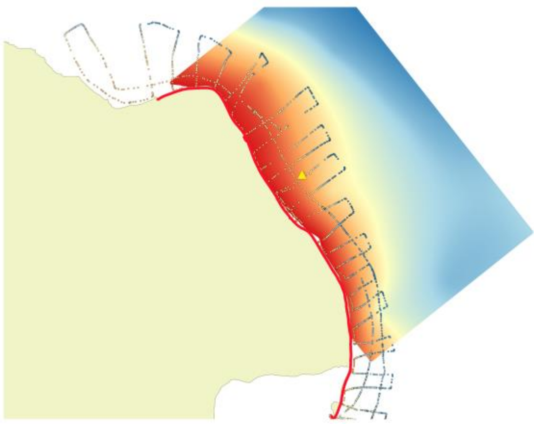

Figure 9. Bathymetry surveys and archival bathymetry data.

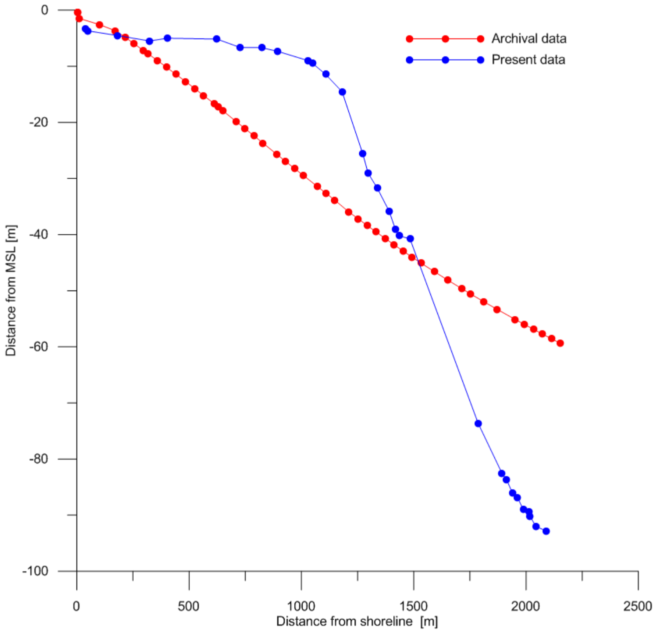

Figure 10. Depth profiles from bathymetry data.

4. CONCLUSIONS

The results of the present work constitute a unique and valuable database of Arctic wave climate parameters. Particularly, wave records of frequency 4 Hz are very rare. Data of free-surface oscillations and wave peak direction are in good correlation with wind directions and show the maximum variance of 50 degrees. Significant wave height is lower than in open waters of North-East Atlantic, which limits wave-induced erosion. Current directions are parallel to the shoreline with some discrepancies during storms. The authors were unable to estimate time dependent bathymetry changes due to inaccuracy of archival data. A detailed analysis will be performed on the basis of measurements collected during presented and future expedition, which is planned to be carried out in the summer season of 2016. Accordingly, an estimation of coast vulnerability to wave-induced erosion will be performed when the data of seasonal changes of the coastline position will be available.

5. ACKNOWLEDGMENTS

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