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A Field Study of Waves in Ice in the Beaufort/Chukchi Sea Fall 2015

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A field study of wave propagation in the marginal ice zone was conducted in the Beaufort/Chukchi Seas from 1 Oct to 10 Nov, 2015. A total of seven experiments over this time span covered an area between 72.5-75N and 151-163W. These experiments were mostly performed in pancake ice fields, a new regime of the Arctic that was found to be prevalent during our study. Three types of buoys were deployed to determine the wave directional spectra. In addition, the ship radar record was also available for analyzing the wave field. In this paper, we describe these experiments and provide sample data sets for the wave and ice conditions. The data will be further processed to calibrate and validate some existing wave-in-ice models. Preliminary analysis of the buoy data and its use for model calibration are presented in an accompanying paper in this Proceedings.

1. Introduction

In the late 1970s and early 1980s a number of field studies were carried out in the Marginal Ice Zone (MIZ) at various locations of the Arctic (Wadhams, 1979; Squire and Moore, 1980; Johannessen et al., 1983, Johannessen and Horn, 1984). Among other important contributions, wave propagation was carefully measured inside different ice covered regions. Two very significant phenomena were identified: wave attenuation and directional spreading. Theories developed prior to and since that series of field studies have relied on those results for validation. A review of the earlier theories is given by Squire (2007). After the 1980s, several other smaller scale field studies were performed in the two polar regions (Frankenstein et al., 2001; Marco, 2003; Doble and Bidlot, 2013). At the same time, investigations of wave propagation under ice covers using remote sensing have begun.

Because of the rapidly declining Arctic ice, the extent of MIZ is expanding both in season and areal extent (Stammerjohn et al. 2012). Increased open water in the Arctic has brought more shipping and potentially more offshore exploration activities. At the same time, there is evidence that storm activities have also increased (Zhang et al., 2004). To enable safe operations through the MIZ in the Arctic, wave-ice interaction is now not only of scientific interest, but also of practical importance.

There are a number of global wave models. In which, the directional wave spectrum is calculated based on a radiative transfer equation (Tolman et al., 2014). This equation solves the propagation of a wave ray provided that factors such as the group velocity and the source/sink of each wave frequency component are known. Under open water conditions, these factors have been studied extensively. For ice covered regions, such study has just begun (Thomson and Rogers, 2014). To account for the wave-ice interactions, each of these factors needs to be re-examined.

The Office of Naval Research initiated two programs to address the changing Arctic. The first is the Marginal Ice Zone Program (http://www.apl.washington.edu/project/project.php?id=miz) (MIZ) started in 2012. The second is the Sea State and Boundary Layer Physics Program started in 2013 (http://www.apl.washington.edu/project/project.php?id=arctic_sea_state) (SeaState). Both programs are 5-yr long with a field component in the 3rd year. The area of study is the Beaufort and Chukchi Seas. The MIZ program focused on the melting season and the SeaState program focused on the formation season. In this paper, we describe the field study conducted under the SeaState program during 1 Oct-10 Nov, 2015 on board the R/V Sikuliaq. We focus only on the wave-ice interaction part of this field study. Other parts of the field study addressing the atmospheric and oceanic fluxes, and the snow and ice mass balance are left out here. The whole field study is documented in the report by the chief scientist Jim Thomson (http://www.apl.washington.edu/project/projects/arctic_sea_state/pdfs/cruise_report.pdf). The scientific background for the SeaState program is provided by Thomson et al. (2013).

2. Study Sites and Data Types

The cruise map is shown in Fig. 1, in which seven separate wave studies conducted over a six-week duration are marked. The ice conditions of two of these studies are shown in Fig. 2. The majority of the ice type found during the entire time was pancake ice. The ice type and thickness were monitored by visual observations using the ASSIST protocol (http://www.iarc.uaf.edu/icewatch) which adapted and expanded the earlier AsPect protocol (http://aspect.antarctica.gov.au/home/conducting-sea-ice-observations). This visual observation was done each hour twenty four hours a day. An ice camera mounted on the side of the ship at the bridge level took a photo once a minute. The images are undergoing orthorectification and then floe size distribution analysis. The ship was also equipped with a camera at the top of the mast, which recorded the ice condition every minute as well. Physical sampling of the pancake ice floes was done during ship transit whenever possible. Data from physical sampling was used to calibrate the visual observations.

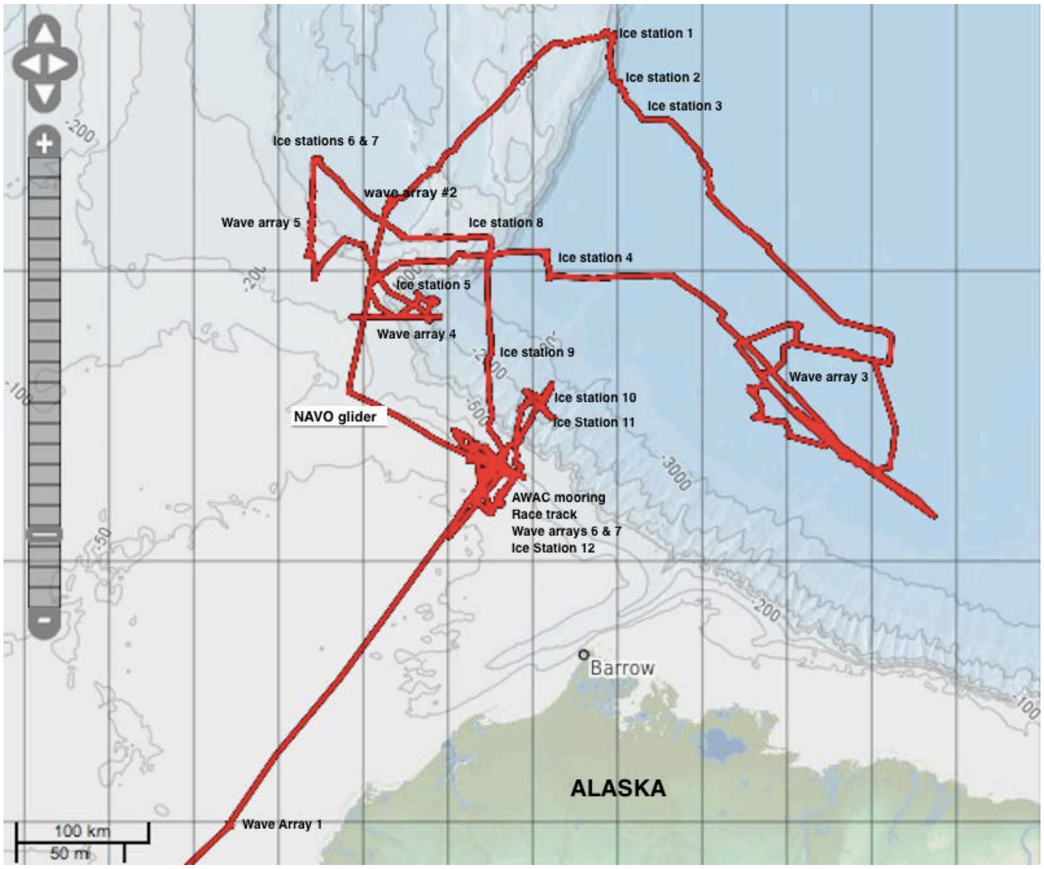

Figure 1. Sikuliaq cruise track. The seven wave tests are shown. Ice stations marked are locations of detailed ice measurements with AUV, LiDAR, and other instruments.


Figure 2. Sample ice conditions of wave array 2 (left) and 3 (right).
The wave spectra were measured by three types of buoys, as shown in Fig. 3. The SWIFT buoys directly measure water particle velocity (Thomson, 2012). They penetrate the ice cover to reach

the water underneath. The NIWA buoy (Kohout et al. 2014) and WB buoy (Doble and Bidlot, 2013) both measure the acceleration of the surface. They may either be floating in water or placed on top of an ice floe. Cross calibration of these three types of buoys were made at the beginning of the cruise before reaching the ice covered sites.

In addition, ship radar images were captured continuously. A sample image is shown in Fig. 4. Wavelengths may be obtained using these images. Such measurements complement buoys, which are great for amplitude but difficult for wavelength measurements. Having both types of instruments will provide complete information for wave conditions.

Figure 3. Three types of buoys used in the experiment: SWIFT (left), WB (middle), and NIWA (right).

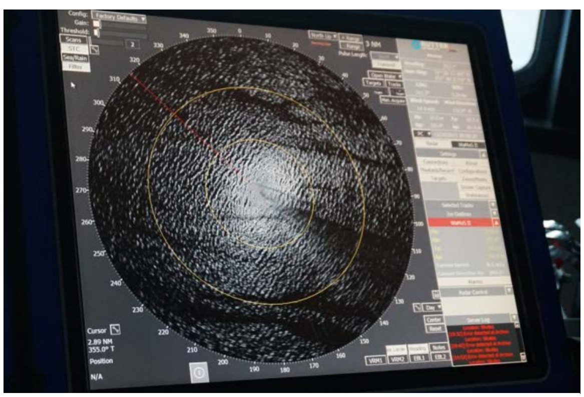

Figure 4. Ship RADAR image.

The above are in-situ measurements. During the field study, there were also daily satellite images captured that overlapped ship track. In addition, Naval Research Laboratory from Barrow flew a Twin Otter on 15, 16, 21, 23, 24 Oct over the region of the ship. LiDAR, SAR, and visible images were obtained during these flights that covered a much larger area than the in-situ observations. These images are being analyzed to determine the ice type, and floe size distribution. The LiDAR images are also being analyzed for wavelengths.

Wave forecast was done daily using WAVEWATCH III® (Tolman et al., 2014). The planning of each of the seven wave tests was guided by these forecasts. Hindcast is now being conducted. For hindcasts, observed ice map from satellite images may be used instead of ice model results as was done on the ship. The hindcast will be compared with in-situ wave data to provide information necessary for different model parameterization and validation.

3. Wave Data from Buoys

Time series of buoys were recorded with built-in data loggers and downloaded after buoy retrieval. Preliminary data analysis was carried out immediately after each wave test. Fig. 5 shows a typical directional wave spectrum obtained with a SWIFT buoy inside an ice cover. The directions of the peak wave period and directional spread at different frequencies are clearly seen. In this example case, there are two waves present: one is a 6s wave from 340^{o} and the other a 3.8s wave from 310^{o}. To determine the wave attenuation, simultaneous data from two or more buoys will be used. The amplitude of waves at different locations and the distance between the buoys in the direction of each wave component may be used to measure the attenuation rate.

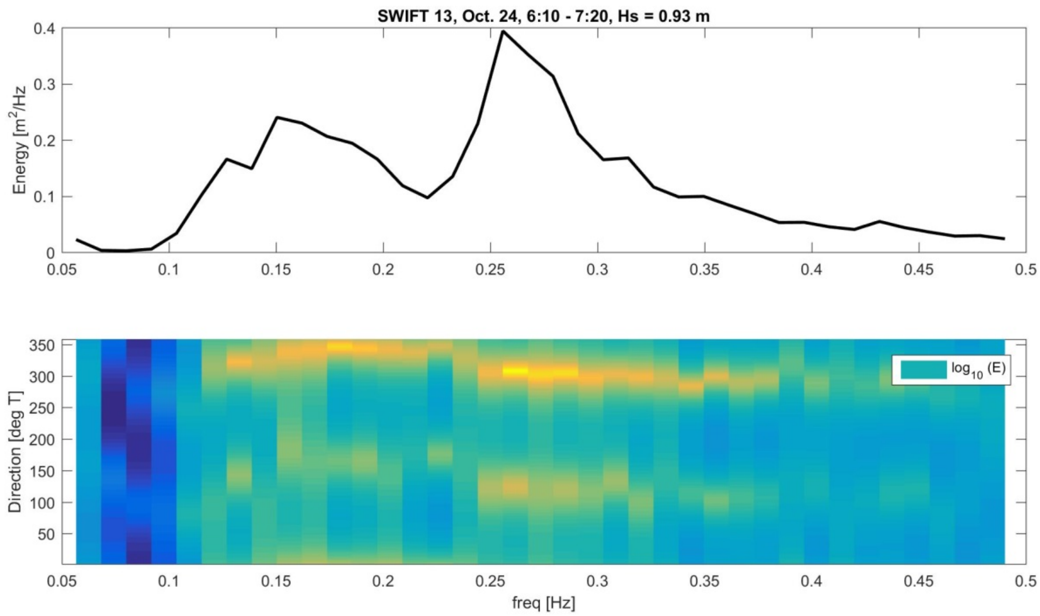

Figure 5. Sample wave energy and directional spectrum.

Wavelength under an ice covered region is much more difficult to determine. Remote sensing can be used for the dominant wavelength by spatial correlation. But the dominant wavelength can result from a selective attenuation, i.e. high frequency waves damp faster, that shifts the spectrum gradually towards long waves. The component by component change of wavelength from spatial signals of the wave profile is difficult to obtain. Advanced analysis may separate the energy into different wavelength components. But without a reliable dispersion relation such spectrum cannot be converted into the frequency domain. On the other hand, shipboard marine Xband radar has the advantage over most satellite borne products that it samples surface waves in space and time. Marine radar therefore allows a direct measurement of wave dispersion (Young et al. 1985). We await the ship radar information to provide us the data which can be compared with buoy and model data.

4. Ice Data

Under the ASSIST protocol, each hour an observer is to visually survey an area about 1nm radius from the ship for about 10-min. The observer then classifies an ice cover into primary, secondary, and tertiary types, based on the thickness. For instance, an ice cover can consists of multi-year ice (primary), brash ice (secondary), and grease ice (tertiary). Each type is given an estimate of concentration, floe size, and average thickness. The floe size classification is coarse: <20m, 20-100m, 100-500m, 500-2000m, and >2000m. The pancake ice category does not have a finer size gradation. Photograph record to be analyzed further will be used for this size information. Since most of the tests were done in pancake ice fields, careful analysis of different pancake sizes and thickness will be useful for checking any potential scaling laws for wave attenuation. At least some field data have shown possible linear scaling of the attenuation with ice thickness (Doble et al., 2015).

Comparing the in-situ ice type with satellite imagery will provide useful information for ice cover classification through remote sensing. This type of study has been ongoing (e.g. Kaleschke and Kern, 2002, Zakhvatkina et al., 2013). Improved resolution of sensors onboard of satellites has given promise to much more sophisticated ice information instead of just ice concentration. This improved information is the basis to enable new physics to be included in both sea ice and wave-in-ice models. Fig. 6 shows a RADARSAT-2 image coincident with a photograph of the ice cover. Combined with hourly observations from visual record and from the ice camera, the information will be used to provide a data bank, to be used for developing an automatic ice type classification.

Figure 6. Superimposed RADARSAT-2 image with photo from Sikuliaq on the same day and roughly the same time. Julian day 2015/10/10, 3:34UTC. Photo location: 73.7^o, -150.8^o. The photo range is approximately 1nm.

5. Summary

We provide a summary of a six-week field study in the MIZ of Beaufort and Chukchi Seas. This paper focuses only on the wave-ice aspect of the study. Simultaneous wave and ice observations using multiple sensors have been made. These data are currently being further analyzed by the PIs and their colleagues in the SeaState program. At present, a short list of scientific inquiries that will be addressed by the data collected is given below:

- How does wave affect the formation of new ice;
- How does pancake ice attenuate waves;
- How does wind generate waves under pancake ice covers;
- What is the upper ocean mixing under ice covers;
- What is the reflection off a pancake ice edge;
- How do different ice dispersion and attenuation models perform against the new data.

A preliminary data analysis and model calibration exercise using a partial set of the buoy data are presented in an accompanying paper in this Proceedings (Cheng et al.).

In addition to the above list, the data set will be, like its predecessors, broadly used by many researchers in the future to address questions that may not even be apparent now.

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