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Radar Remote Sensing of Ice and Sea State and Air-Sea Interaction in the Marginal Ice Zone

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LONG-TERM GOALS

The goals of this project are to utilize shipborne remote sensing to understand the scattering and attenuation process of ocean waves interacting with ice. A nautical X-band radar on a vessel dedicated to science would be used to follow the propagation of waves into the marginal ice zone (MIZ) and observe the attenuation and scattering of wave modes from the floating ice as well as estimate surface wind and current speeds and directions. This measuring approach will provide a comprehensive local picture of wave scattering and boundary layer flows over floating ice in the MIZ.

OBJECTIVES

To determine the penetration distance of waves in the MIZ and correlate the MIZ width to the surface wave climatology that generated it.

1. To determine the density of ice floes in the MIZ similar to "void fraction" and correlate this parameter to the surface wave climatology.
2. To describe the local momentum transfer during freezing and melting cycles and the transport patterns affected by wind and currents.
3. To follow ocean wave groups into the MIZ to estimate the damping of wave energy based on the ice density and scattering from ice floes.
4. To correlate the open ocean wind and wave climate to the wind and wave climate within the MIZ using satellite SAR imagery and marine radar data.

APPROACH

Boundary layer flows and air-sea fluxes in ice infested waters like the MIZ are very complex compared to the open ocean where surface waves provide the only roughness at the interface. In addition freezing and melting cycles modify both the interface surface and the local transport of heat and mass which can readily be disturbed by the impact of surface waves penetrating the ice floes of different ice types. While obtaining measurements of the boundary layer flows in densely floating ice waters is

challenging, a better approach might be with nautical X-band radar installed on a ship. For example, the new ice breaking capable *R/V Sikuliaq* (Figure 1), recently completed for the National Science Foundation (NSF) will be equipped with a radar dedicated for science. Specifically, the sigma S6 100S6 X-band Radar from Rutter Technologies and the OceanWaves WaMoS II system will be installed in February 2015 that are capable of making real time measurements of directional ocean wave spectra to monitor the sea state surrounding floating ice especially as the vessel enters the MIZ. Figure 2 shows an example of radar image from the *R/V Polarstern* entering MIZ in Antarctica. The raw marine radar image highlights the strong backscatter from the ice edge.

Figure 1: Photo of the R/V Sikuliaq during a recent test voyage in 2014. (Courtesy of Jim Thomson, UW/APL).

Many recent advances have been made using measurements from marine radars of ocean environment variables. For example, single waves and wave groups are retrieved from several WaMoS II image sequences which can be inverted into sea surface elevation maps using the method by Nieto-Borge *et al*. (2004). Lund *et al*., (2014a) has shown that accurate directional wave properties can be derived from marine radar data while the ship is moving and correctly geolocate polar radar images in the time-space geo-reference system. The X-band radar data have also been used to compute the local wind speed and direction (Lund *et al*. 2012). Similarly surface currents and upper ocean current shear can be determined from sequences of radar images using the dispersion relation of high frequency wave modes (Lund *et al*., 2014b). A marine radar would also detect the presence of floating ice and in combination with satellite SAR imagery could provide local validation of the observed wind and wave conditions.

The Wave Monitoring System WaMoS II is an ocean wave and surface current monitoring system designed for operational measurements under harsh environmental conditions. Many offshore operations are critically dependent on the prevailing sea state. To enhance the safety of people, structures and environment, routine sea state as well as surface current measurements are required.

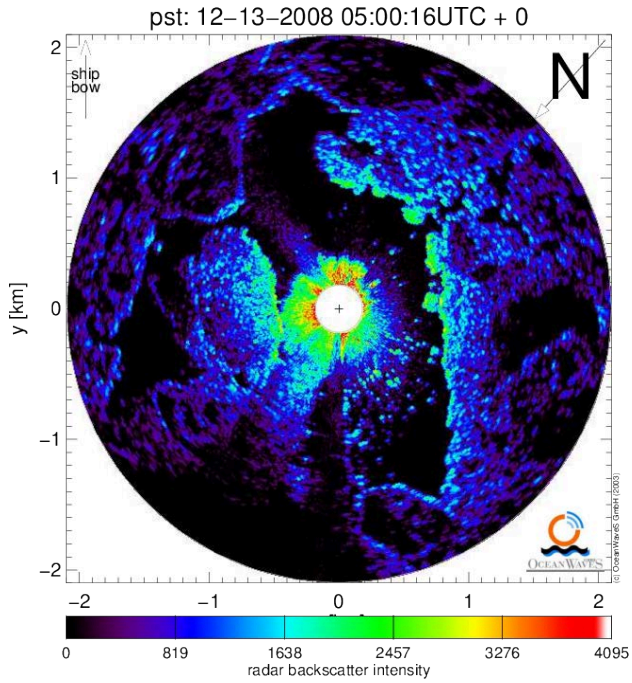

Figure 2: A raw marine radar image from the R/V Polarstern showing the presence of ice floes and open water leads in the Antarctic MIZ.

WaMoS II is an instrument especially designed to measure in real time sea state information such as significant wave height, wave period and wave direction. It can be operated automatically and unattended from moored platforms, moving vessels or coastal sites. As the system is not in direct contact with the sea, it is optimally suited for use under extreme weather and sea state conditions. Standard methods are applied to derive directional wave spectra from a sequence of nautical radar images and then compute standard wave parameters like significant wave height, peak wave period, peak wave direction and peak wave length. The measurement and data analysis takes about 2 minutes for standard, commercial nautical radars and sea state parameters are available in real time. A minimum wind speed of 3 m/s is required to obtain good wave measurements. The intensity of the backscatter will change with height of the waves and the strength of the wind. For example, current products include: a) surface elevation of individuals waves, b) directional wave spectrum, c) wind speed and direction, d) surface current vectors, e) internal wave characteristics, and f) upper ocean current shear. Soon, we hope to add sea ice detection and floating ice distribution.

While the WaMoS II system is capable of making real time measurements of various ocean and atmospheric parameters, this is only possible when the data is correctly georeferenced. So, it is critical for accurate quantitative data analysis which provides winds, waves, currents and ice parameters that the data is properly prepared. This involves first to correctly georeference the polar radar images in the moving time-space coordinate system. Figure 3 shows schematically the approach to georeference a timeseries of marine radar backscatter images in space and time. Subsequent products can then be directly generated from the raw data. The traditional approach is a “Snapshot” assumption which is an analysis limited to small window with no geo-referencing or ramp correction. This leads to inaccurate and limited results. A more advanced approach is geographically and temporally accurate mapping of the polar images per revolution and this analysis would extend over the entire image and includes a 2D ramp correction.

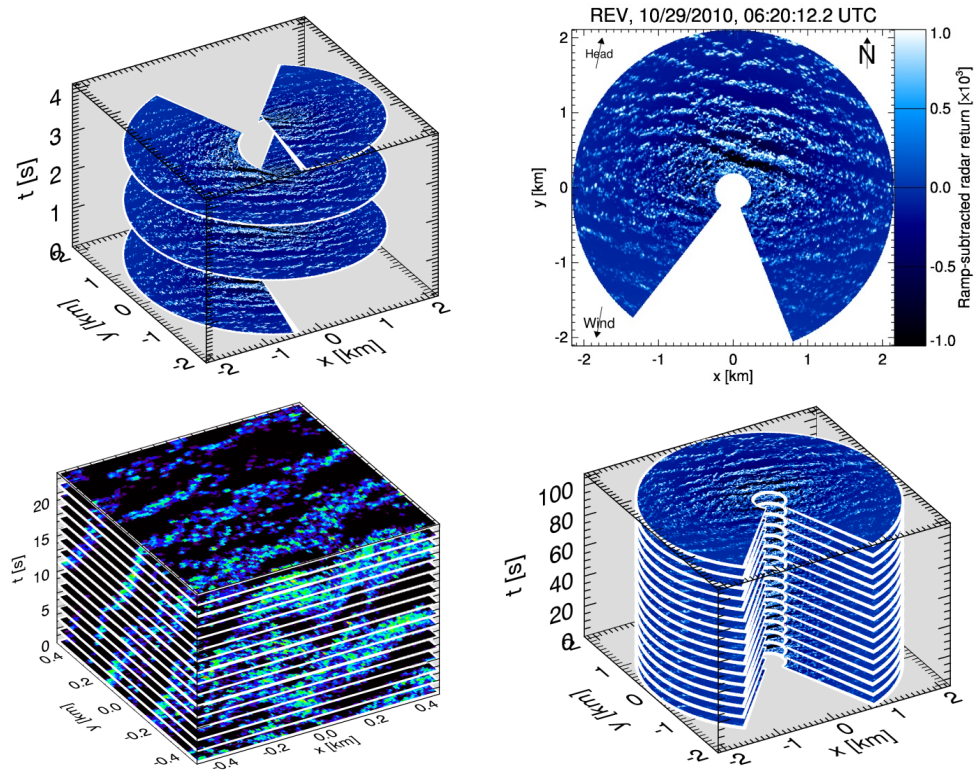

Figure 3: Top left: A marine radar image acquisition spiral. Bottom left: A time sequence of "Snapshot" wave fields which samples a limited, small window of the ocean surface. Top right: A fully reconstructed marine radar image using trilinear space-time interpolation. Bottom right: A time sequence of geographically and temporally accurate mapped polar radar images applying a 2D ramp correction.

Young et al. (1985) were the first to propose a least-squares fitting algorithm that derives the near-surface current speed from the wave spectral coordinates. Their algorithm has since been improved by accounting for aliasing effects and the higher harmonics of the dispersion relation (Senet *et al*. 2001). The higher harmonics are believed to appear due to the nonlinearity of the marine radar imaging mechanism, especially shadowing effects. To estimate the current velocity, Young *et al*. (1985) and Senet *et al*. (2001) assume that the wave signal's spectral coordinates can be discriminated from the nonlinearities (among which the group line, which is believed to be due to modulations by the wave field's group structure, figures most prominently) and the background noise component through a spectral energy threshold. A detailed discussion of the different spectral components can be found in Borge *et al*. (2008); Lund *et al*. (2014b). However, instead of using spectral energy, we identify the wave signal from the 3D spectrum's signal-to-noise (SNR) ratio. This approach requires a good understanding of the background noise's dependency on wavenumber and frequency, but has the advantage that it facilitates the identification of the low-power short-wave signal that experiences the strongest Doppler shift and is therefore particularly important for an accurate near-surface current estimate. Figure 4 illustrates the difference of these two methods. On the left is the traditional approach which shows the detected wave signal within power spectrum derived from a ~12min-long sequence of marine radar images. On the right is the new advanced approach by using the SNR spectrum to better

detect signal from short ocean waves. The dominant signal is located on the Doppler shifted fundamental mode dispersion curve. Group line and higher harmonic contributions are also visible.

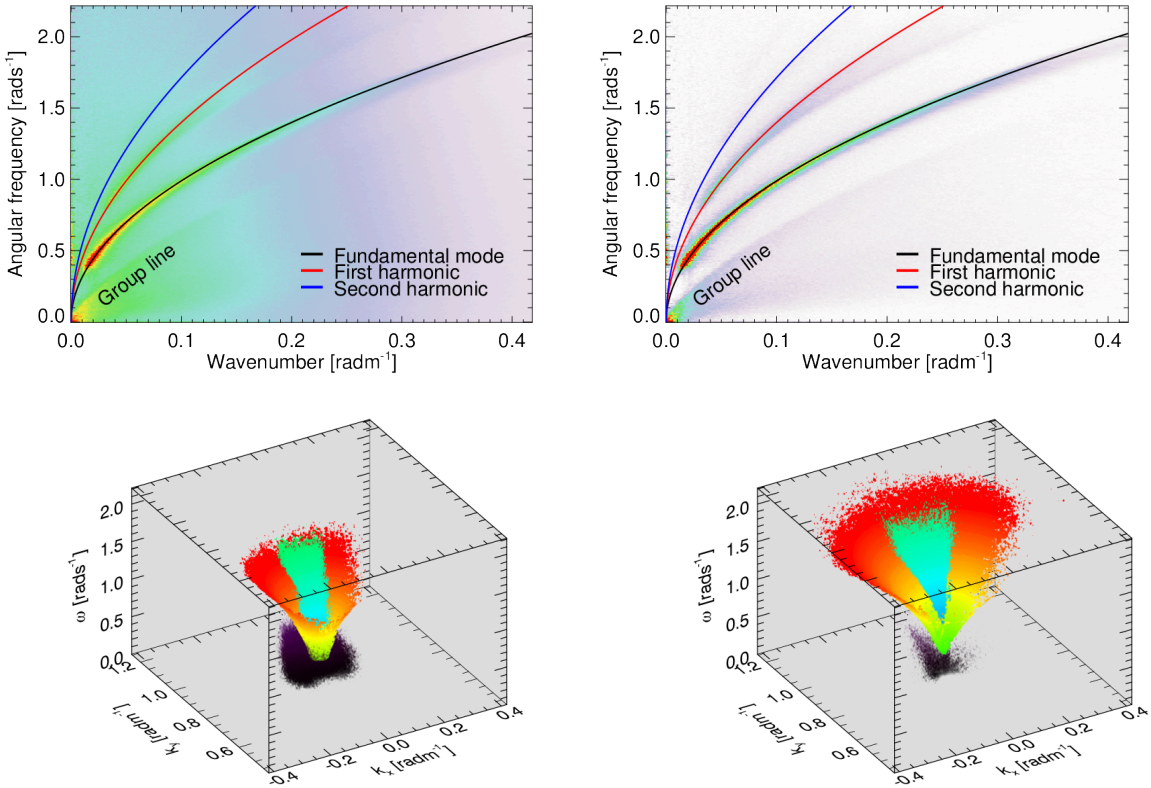

Figure 4: Top row: The 2D dispersion relationship showing curves corresponding to the dispersion relation's fundamental, first harmonic, and second harmonic modes are shown in black, red, and blue, respectively. The white-to-red color scale is logarithmic. Left: Dispersion as derived from the 3D wave spectral components. Right: Dispersion as derived from the 3D SNR components which emphasizes the sensitivity of the higher frequencies. Bottom row: The 3D power (left) and SNR (right) spectra. The sensitivity of the higher frequencies is quite evident in the SNR spectrum.

WORK COMPLETED

Final planning and preparation for next experimental phase is nearly complete. We have reviewed and evaluated existing, off-the-shelf commercial natuical X-band radars best suited for acquisition and implementation on the *R/V Sikuliaq*. The selected radar will be *sigma S6 100S6 X-band Radar* from Rutter Technologies and the *OceanWaves WaMoS II* system.

In lieu of any marine radar data of sea ice to us, we continued to either develop or refine algorithms for winds, waves and currents from data of previously funded ONR projects such as HiRes, ITOP, NLIWI, SW06.

However, most of our effort has been spent on developing calibration techniques for these algorithms that eliminates motion induced errors from a moving ship. Specifically we have explored how errors are introduced in the physical variables and what measurements and sampling strategies are needed to either reduce and/or elimnate such errors in order to improve the accuracy of desired parameters such

as winds, waves and currents. The steps are necessary to detect unambiguously ice and provide more accurate quantitative results.

We also developed a new algorithm for improved retrievals of marine radar near-surface currents and the first ever near-surface current shear measurements from marine radar data.

RESULTS

An advanced algorithm for improved retrievals of marine radar near-surface currents and current shear measurements. A paper has been submitted on this topic.

B. Lund, H.C. Graber, K. Hessner, and N. J. Williams, 2014: On shipboard marine X-band radar near-surface current "calibration". Manuscript submitted to *J. Atmos. Oceanic Technol.*

IMPACT/APPLICATIONS

None yet.

RELATED PROJECTS

Monitoring of Arctic Conditions from a Virtual Constellation of Synthetic Aperture Radar Satellites
N00014-12-1-0448

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