Extracting Internal Wave Parameters from Marine Radar Data

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LONG-TERM GOALS

The Navy has funded a series of projects to estimate local environmental conditions from Synthetic Aperture Radar (SAR) imagery. Many of those algorithms should be applicable to marine radar systems since these systems measure the same radar cross section as SAR does. This program is a first step to try and convert the SAR algorithms to marine radar applications.

OBJECTIVES

Estimate internal wave parameters (amplitude and mixed-layer depth) and surface wave parameters from a time series of marine radar imagery and validate their performance using test data of marine radar imagery with coincident ground truth information.

APPROACH

Acquire marine radar data with coincident in situ observations (this is being done by a different contractor under a different program). Convert the SAR algorithms for estimating internal wave parameters and surface wave parameters to work on marine radar data. Validate them with in situ observations.

WORK COMPLETED

All the data from the first site has been collected. From that data we have extracted the ones with the strongest internal wave signatures. We have modified the existing code to run on this data, and have used it to estimate the internal wave parameters. Unfortunately the radar was not relatively calibrated, so there is an unknown scale factor to convert it to RCS modulations. Thus we have generated the internal wave parameters for a range of possible radar scale factors to see if they are consistent with the local environment. This was reported on last year.

We have received data from the North Sea sites; one set off of land and one from an offshore platform. These contained data collected while the radar was rotating, and data collected with the radar stationary. These radars are coherent, so we get but radar cross section data and radial velocity data. We have developed the tools to analyze the time series data and divide it into dispersive and non-dispersive components, and to perform spectral estimation on each component.
We are working on algorithms to estimate wave height from both radar cross section and radial velocity data using both linear and non-linear wave theory (from radial velocity) and scattering theory (from the radar cross section). We are also developing algorithms to calculate the phase shift between radar cross section and radial velocity for breaking and non-breaking data.

RESULTS

The internal wave data analysis from the first collection site is finished and was reported in detail last year.

This year we have been working on data collected from the North Sea sites. This consists of data from two locations: a radar located on the shore at Bunker Hill and a radar located on the offshore platform known as Fino-3. Both of these radars are coherent, so that they record the complex-valued return. From this we can estimate both radar cross section and radial velocity for each patch of the ocean surface. In addition, the radar can be operated either in normal mode, where they are rotating in a circle, or in stationary mode, where the antennas are kept fixed and just record pulses over time pointed at the same piece of ocean. The latter, stationary, mode provided significantly improved estimates of radial velocity because it proved a much longer dwell over the same ocean location. For the rotating mode, the amount of dwell over any piece of the ocean is much shorter.

Figure 1 shows an example of the data from the shore-based Bunker Hill site. This is for the radar operating in rotating mode. The upper, left image is one full rotation of the radar; the ocean is in the bottom half of the image and the land is in the top half. The image has been flattened so that the land turns into a flat noise region. Since we have set of such images in time, we can take a 3D Fourier transform and generate the w-k image from the spectral values. This is shown in the upper, right where the white, dashed line is the dispersion relation of ocean waves. Note that one can clearly see energy that exists along this dispersion relation and energy that is off of it. We can then take a subset of the ocean image from the full image, and decompose it into the radar cross section values that are on the dispersion curve (the Dispersive Energy) and those that are off of the curve (Non-Dispersive Energy). The three images at the bottom of the figure show this decomposition; the left image is the original fill radar cross section (RCS) image, the middle image is the energy on the dispersion curve, and the right image is energy off the dispersion curve. Note that the waves falls within the dispersive energy, but the breaking events (the bright blobs at the top of the image subsets) falls mainly in the non-dispersive image. However, note that this is a bright response, smaller in extent, at the breaking location in the dispersive image. It is interesting that this may represent bright RCS values that are still traveling at the phase speed of the surface waves.

Figure 2 shows the same set of images, but for the off-shore platform Fino-3. In this case the platform is in the middle of the image and one can see waves throughout the image. There is very little non-dispersive energy, because there is no breaking going on in this scene. Note that the non-dispersive sub-image contains mainly noise effects for these cases.

As mentioned above, we also have data where the radar is kept stationary. This data provides the best estimate of radial velocity due to the longer dwell. Figure 3 shows an example of the radar cross section data in this mode for Bunker Hill. Since the radar is stationary, it just records one range record as a function of time; this is shown as the upper, right image. The ω-k image for this data is shows to its left. Note that for this case we are showing both positive and negative values of wavenumber, k.
Figure 1: Example data for the rotating radar for the shore-based Bunker Hill site. Upper, left is the full image, upper, right is the w-k image derived from the 3D Fourier transform of the data. The bottom images are for a subset of the full image and shows the full RCS (left), the RCS that has dispersive energy (middle), and the RCS that has non-dispersive energy (right).
Figure 2: Same as Figure 1 except for the off-shore Fino-3 site.
Figure 3: Example results from the stationary radar operations for the shore-based Bunker Hill site using radar cross section data. Top images are for the full data, middle are for dispersive energy, and bottom are for non-dispersive energy.

The upper values represent wave moving toward the radar, these will be “stripes” with a positive slope in the image data on the right. The energy in the lower half of the $\omega$-$k$ image represents wave that are moving away from the radar (and thus away from shore) and are “stripes” with a negative slope in the imagery. Note that there is a faint hint of this in the image. The top images in Figure 3 are the full radar cross section data. The middle image is for energy on the dispersion curve, and the bottom images are for energy off of the dispersion curve. It is interesting to note that the non-dispersive radar cross section image contains local peaks of bright values, which represents large radar cross section events that are not moving with the phase speed of the waves; perhaps these are tilted Bragg scattering events. Note that they become more prominent at larger range values, and thus larger incidence angles, where tilted ocean facets will be closer to a specular orientation.

Figure 4 shows the same data but for the radial velocity estimates. Note that the waves traveling away from the shore are slightly more prominent here than in the radar cross section data, and there is not the same amount of local bright responses in the non-dispersive energy image.
With these tools in place, we are now building algorithms to:

- Convert radar cross section and radial velocity modulations into wave height characteristics, using both linear and non-linear wave theory (for the radial velocity data), and both MTF-based and tilted-Bragg scattering models (for the radar cross section data). Ideally, they should both provide a similar wave height characterization for the same data set.

- Automatically detect breaking events in the data (via thresholding of the radial velocity data) and determine the phase shift between radial velocity peaks and radar cross section peaks (both in breaking and non-breaking regions).

For the latter analysis we have looked at generating breaking threshold by forming the histogram of the radial velocity data, and fitting the lower half to a Gaussian density function. Where the upper half of the data histogram differs from the Gaussian fit is where the breaking events are starting to occur. The top plot in Figure 5 shows an example where the blue curve is the radial velocity data from Figure 4, and the orange curve is the Gaussian fit to the lower half of the data. Note that the data has a large tail that represents the breaking events; where this tail deviates from the Gaussian fit will be the threshold. Also note that the mean value of the radial velocity is not zero. The sensor has some biases in the
Figure 5: Top plot shows a histogram of radial velocity data (blue) compared to a Gaussian fit to the lower half of the histogram (orange). The deviation from this fit at the higher end is due to breaking events in the imagery and provides a threshold to locate those events. Bottom plot shows a comparison of radar cross section (RCS) and radial velocity where the dots indicate a breaking event based on thresholding of the radial velocity, and the phase shift between the two can be seen.
radar phase estimates that need to be removed as part of the calibration step, however for this application that is not relevant since we are thresholding the data as is. The bottom plot in Figure 5 shows radar cross section and radial velocity as a function of range for one time slice of the stationary radar case. The dots on the plots indicate breaking events as evidenced by thresholding the radial velocity data. Note that phase shift that is apparent between the RCS and radial velocity peaks, where the RCS peaks at a nearer range than the radial velocity, and thus is peaking at a forward location of the wave surface tilt.

IMPACT/APPLICATIONS

This program is funding a tool development that, if successful, will improve the ability of marine radar systems to estimate oceanic properties; in particular internal wave parameters.

TRANSITIONS

When completed, the components will be transitioned to operational systems as indicated by ONR.

RELATED PROJECTS

There are no ongoing related projects that are closely identified with this project.