SHALLOW WATER BATHYMETRY WITH AN INCOHERENT X-BAND RADAR USING SMALL (SMALLER) SPACE-TIME IMAGE CUBES

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1. INTRODUCTION

As is well known the velocity of ocean surface gravity waves can be inverted into a map of bathymetry. All of the many implementations of this idea analyze a 3D Fourier transform of an image cube of certain dimensions in xy and time. A minimum length in xy and time span are deemed essential for the algorithms to work. Some examples: Hoogeboom et al. [1], the first group to attempt depth inversion with X-band radar images , used cubes of 750 m (1 dimensional images only) x 90 s; Dugan et al. [2], 256 m x 256 m x 60-120 s; Trizna [3], 192 m x 192 m x 60 s; Senet et al. [4], 110 m x 110 m x 453 s. All past studies used 60 s or more. Piotrowski and Dugan [5] found that depth estimation errors sky rocket when the time dimension is <60 s, increasing five-fold from 60 s to 13 s. In this paper we demonstrate an algorithm that can achieve depth estimation errors with 13 s cubes that are not significantly greater than with 60+ s.

We are researching a modified algorithm that can work with both reduced time span and reduced xy dimensions. Reducing xy dimensions will improve spatial resolution and detection of smaller morphological features. Reducing the time dimension would allow rapid bathymetric surveying on a fast moving platform where we do not have the luxury of long staring time at a fixed patch of ocean. At present we focus on reducing the time dimension.

The main rational for long time spans in the 3D Fourier analysis is the desire for high frequency resolution to filter gravity waves from noise and interference. In the absence of any noise this filtering is not needed and the depth inversion can be done with as few as two image separated by an infinitesimal time increment. If there is some way to achieve high SNR on the gravity waves signal there is no need for long time cubes. One of our earlier studies [6] demonstrated this with a modified algorithm processing a pair of IKONOS satellite images. The 3D Fourier analysis was modified to work with N=2 images rather than the usual N>>2. We refer to this as the 2-image algorithm (details in [6]). Excellent bathymetric mapping was achieved with the 2-image algorithm. The standard errors were ~5% of depth based on comparison of IKONOS results with a side-scan survey. It was established that at least in the IKONOS test case there was sufficient SNR and linearity in the satellite images to map bathymetry with just two images. The interval between the two images was 13 s. In this paper we report on the application of the same method to short time span cubes of X-band radar images.

2. METHOD

The data for our test was acquired on November 12, 2009 with the ISR radar on the Field Research Facility (FRF) pier and processed with the 2-image method slightly modified for radar data. The radar produces one image every 1.25 s. For a given time interval, T, there are N=T/1.25 images. We process them as N-1 image pairs and average the pair-wise results to improve the depth estimation as much as possible. Although no frequency filter is possible we can exploit the wavenumber space for noise filtering. As with the IKONOS processing we include a wave-number filter, *W(k)*. Neito-Burge et al. [7] used such filtering to minimize errors from low wavenumber speckle noise. We extend the idea further to filter any noise mechanism that is outside or overlaps the gravity waves wavenumber support. At a minimum *W* is a directional filter rejecting most of the sensor noise and improving SNR by 6 dB or more. The *W* filter will also reject wavenumbers where there is a coherent signal, such as wind streaks [Dankert et al. 2004], overlapping the linear gravity waves spectrum.

3. RESULTS

Figure 1 are maps with relatively long time cubes. The left panel uses 74 s. The derived bathymetry is in good agreement with the 1% slope (1 m drop per 100 m cross-shore distance from the beach) that is typical of FRF bathymetry. Unfortunately there is no detailed ground truth close in time to the data for more precise validation. As another means of validation we re process the 74 s of data in two disjoint 37 s interval, with results shown in the middle and right panels. The waves in one of those short intervals are completely decorrelated from the other interval. Errors should be independent. The 37 s maps are very similar to the 74 s map, suggesting that the maps accurately depict the bottom morphology. The difference between the two 37 s intervals may be taken to represent twice the depth error variance.

Figure 2 shows maps for still shorter time intervals. Again there is similarity to the 74 s solution. The largest depth errors are in the deep end as expected. Morphological structures appear consistently in cubes of 25 s or greater and several ~1m high sea mounts are detected. In shorter time spans the small sea mounts are lost. More significantly there is excellent agreement between short and long cubes in the very shallow (<6 m, light green to dark blue in the color scale) depths. The 6 m contour is well delineated in all the maps, even the shortest time span. The 6 m depth contour is of special interest for navigational safety.

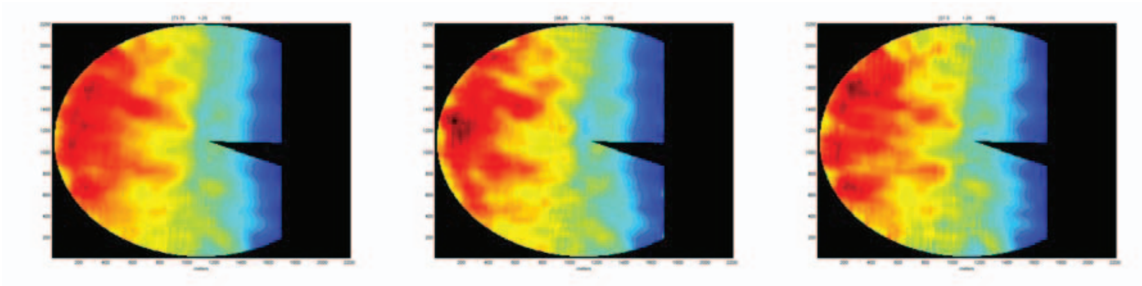

Figure 1. FRF bathymetry with an X-band radar located at the end of the FRF pier and a footprint of 1 km radius. Black is areas with no depth solution, either outside the radar footprint or within the footprint but without a satisfactory solution convergence. The vertical cutoff on the right marks the shoreline. Color is depth from 0 (blue) to 15 m (dark brown). Cube dimensions are 135 m x 135 m x time window which varies. Left panel is the depth map obtained with 74 s cube. The center and right panels are based on the first and last 37 s intervals.

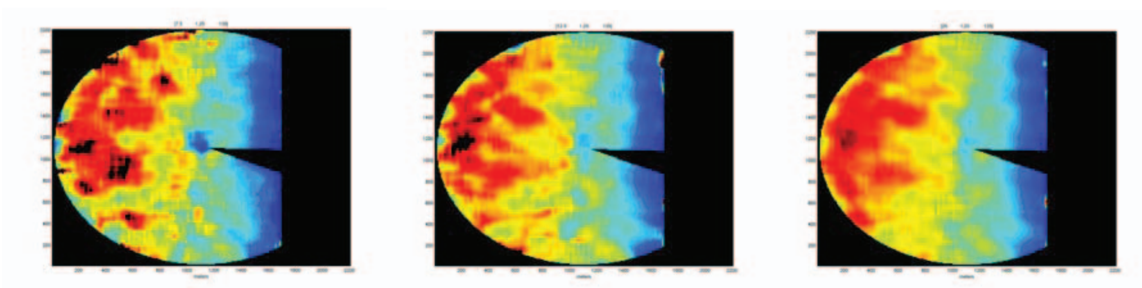

Figure 2. Bathymetry with shorter time spans: 7.5 s, 13 s, and 25 s (right).

4. CONCLUSIONS AND IMPLICATIONS

The conclusion from this test is that there is potential for bathymetry with many fewer images, and less time span, than had been traditionally used. This finding suggest depth inversion is possible with a radar (or camera imager) mounted on a fast moving platform. Some potential applications include the following. The Navy's new littoral combat ships could map bathymetry in a patch 500 m ahead, increasing the opportunity to safely sprint at 40 kts. (With 60 s cubes the ship will have run into a navigation hazard before the processing is completed!) A 20 kts ship can survey a 36 km swath of shoreline in one hour and the entire stretch of a storm battered coastline in one day. An airborne radar or optical imager could similarly cover 360 km swath in one hour and the entire CONUS coastline in a few days.

As this abstract is written there is more analysis to complete for the conference presentation. There will be a more thorough analysis of the depth estimation errors based on both comparison between consecutive independent data cubes and with ground truth. Further tests are planned to explore the limit for smaller cubes: decreasing both the time and xy dimensions. A data set with higher sea state (more wave nonlinearities) will also be analyzed.

5. REFERENCES

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