Real-time Surface Wave Information by Coherent Radar

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Introduction: The technique for extracting wave period and wave direction from radar backscattering intensity reached a mature stage by the 1980s,[1] but the determination of wave height has been hindered by the complex nature of the modulation transfer function relating the radar return to surface wave properties. In contrast to backscattering intensity, the coherent radar Doppler signal characterizes the radial velocity of the surface roughness that scatters back the radar waves. The oscillatory component of the Doppler signal is dominated by the surface wave motion. The principal wave period can be derived from the peak frequency of the Doppler spectrum and the significant wave height from the Doppler variance. Analyses of coherent radar measurements collected from the ocean show that with radar range coverage on the order of ten dominant wavelengths, the spectral peak wave period and significant wave height can be determined from as little as 1 s of data.[2] This new development offers rapid acquisition of critical surface wave information for naval operations and research of the ocean environment.

Doppler Processing: Two approaches can be used to derive the Doppler velocity from the coherent radar return. The first is to obtain the signal phase through Hilbert transformation of the radar return and then compute the time derivative of the signal phase. This method is basically the covariance approach to spectral moment estimation from pulse pairs, thus is called the "pulse pair" approach. The second is by spectral processing of short segments of the complex radar return signal, typically through fast Fourier transformation (FFT), and is called the "FFT" approach. The Doppler frequency computed by the pulse pair method is the equivalent of the mean Doppler frequency defined by the first moment of the Doppler frequency spectrum derived from the FFT method. Figure 1 shows an example of the spatio-temporal images of the Doppler velocity fields of the surface roughness modulated by large-scale ocean surface waves using the coherent radar returns processed by the two methods.

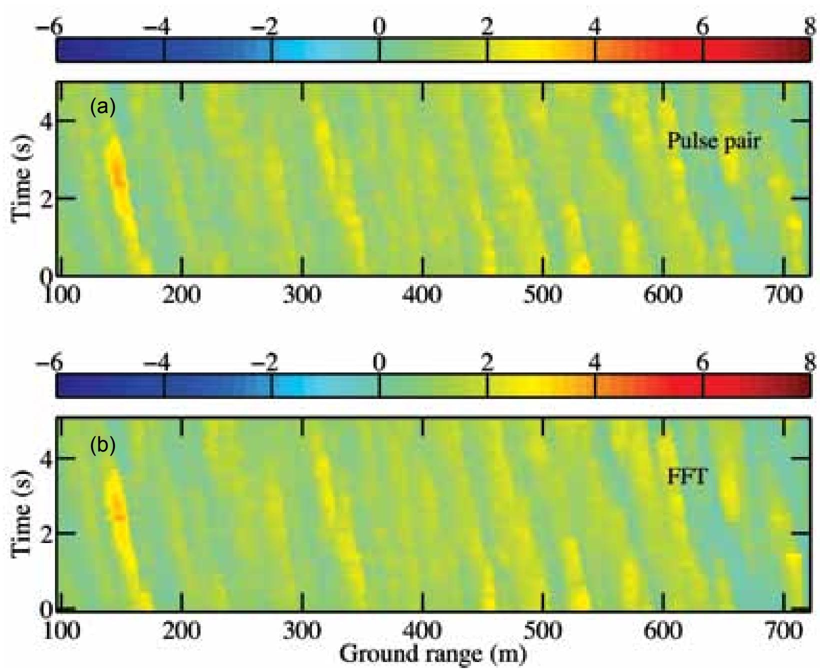

FIGURE 1
An example of the spatio-temporal images of the Doppler velocity field derived from (a) pulse pair and (b) FFT approaches. The unit of the colorbar scale is m/s.

Wave Analysis: Applying spectral analysis to the spatial series of the Doppler velocity record yields a wave number spectrum of the surface wave velocity. The surface displacement spectrum is related to the wave velocity spectrum in a deterministic fashion following the surface wave theory. Figure 2(a) shows examples of the wave number spectra processed with the Doppler velocity using 1 and 5 s of radar data. For comparison, the corresponding spectrum computed with 20 min of accelerometer data measured by a nearby wave buoy is also shown. Interestingly, the Doppler velocity spectra computed with 1 and 5 s of radar data are very similar; both are in good agreement with the buoy measurement, especially in the energetic spectral peak region.

For naval operations in the sea, as well as for ocean surface wave research involving air-sea interaction, the key parameters of the surface wave field are the significant wave height and spectral peak period. Together with the wind speed, the three environmental variables form the dimensionless parameters quantifying ship response, maneuvering, wave impact, growth of wind-generated waves,

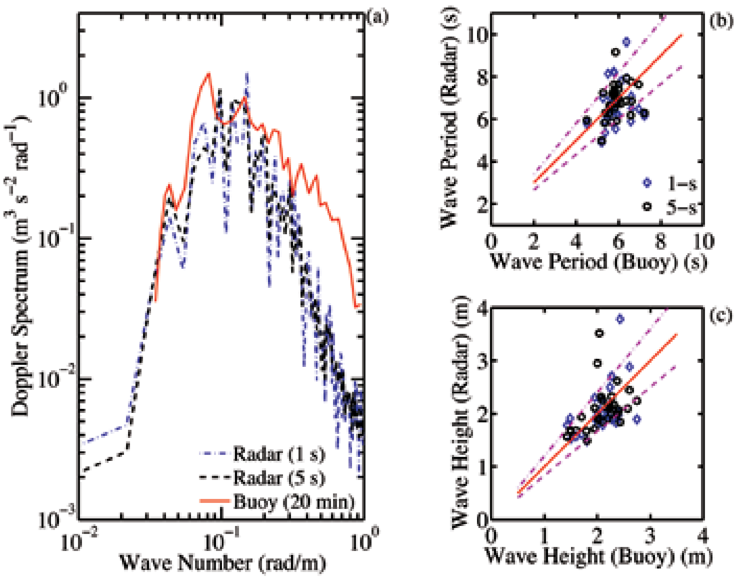

FIGURE 2
Comparison of (a) wave number spectra, (b) peak wave period, and (c) significant wave height, obtained by radar (1 and 5 s of data) and wave buoy (20 min of data). Line segments of 1:1, 1.2:1, and 1:1.2 slopes are superimposed for reference.

and air-sea exchanges of momentum and energy. The spectral peak wave period is readily obtained from the Doppler spectrum. The significant wave height can be computed from the fluctuation component of the radar Doppler velocity. The results are presented in Figs. 2(b) and (c). The peak wave period derived from the present procedure is about 1 s longer than in situ buoy measurements. Accounting for this bias, most wave period and wave height results are confined within the envelopes bounded by ±20% from perfect agreement. For reference, line segments of 1:1, 1.2:1, and 1:1.2 slopes are superimposed in the figure.

[Sponsored by ONR]

References

[1] I.R. Young, W. Rosenthal, and F. Ziemer, "Three-dimensional Analysis of Marine Radar Images for the Determination of Ocean Wave Directionality and Surface Currents," *J. Geophys. Res.* **90**, 1049–1059 (1985).

[2] P.A. Hwang, M.A. Sletten, and J.V. Toporkov, "A Note on Doppler Processing of Coherent Radar Backscatter from the Water Surface: With Application to Ocean Surface Wave Measurements," *J. Geophys. Res.*, **115**, C03026 (March 2010) doi:10.1029/2009JC005870.

Shipboard AIS and Radar Contact Reporting (SARCR)

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Background: Guarding coastal approaches has always been a national priority but the events of September 11, 2001, have heightened the emphasis on filling important gaps in our ability to secure the nation against various threats. A key element of the national strategy for improving security is to provide enhanced Maritime Domain Awareness (MDA). The strategy is aimed at ensuring that decision-making authorities have information necessary to identify and react to potential threats to national security arising in the maritime domain. Threats must be identified as early and as far offshore as possible, requiring awareness of activity not only in our territorial waters, but also in the Contiguous Zone (from 12 to 24 nautical miles from the coast), in the Exclusive Economic Zone (EEZ — out to 200 nautical miles), and even on the high seas. The paucity of dedicated sensors to provide persistent coverage of our coastal waters and commercial shipping lanes hampers the development of in-depth maritime domain situational awareness.

The Naval Research Laboratory recognized that to meet this MDA challenge, new approaches need to be explored. The approach taken by the Mission Development Branch of the Space Systems Development Department was to explore the possibility of using nontraditional sensor sources, i.e., those being used by commercial vessels during their normal transits. NRL proposed the Shipboard Automatic Identification System (AIS) and Radar Contact Reporting (SARCR) system to the U.S. Department of Homeland Security (DHS) Science and Technology Directorate, Borders and Maritime Security Divisions, Maritime Security Technology Program, which funded this effort in FY09. The effort proposed was to design, develop, integrate, test, and install 15 rapid prototype systems. These systems are capable of capturing the ship's onboard radar-generated tracks and simultaneously collect radiated AIS messages and relay all the collected data via a commercial Iridium satellite communications (SATCOM) link to the John A.

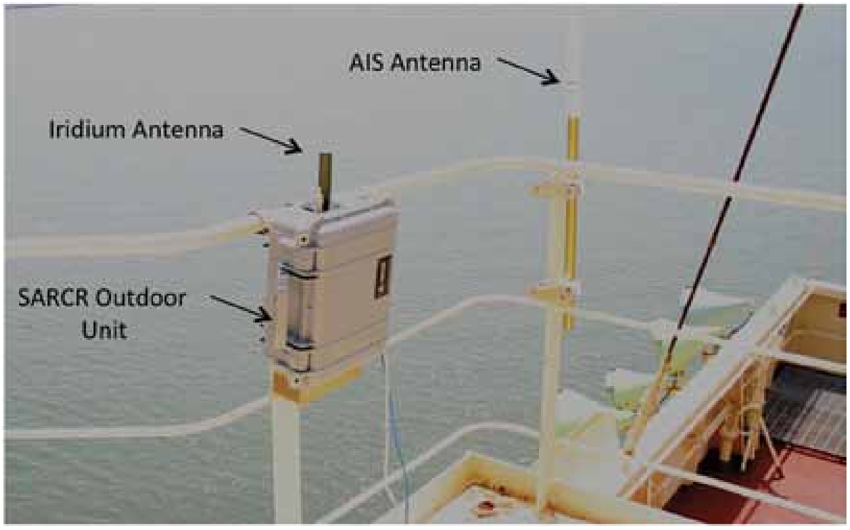

FIGURE 3
The SARCR Outdoor Unit deployed.

Volpe National Transportation Systems Center for distribution to Government and commercial users via the Maritime Safety and Security Information System (MSSIS).

System Overview: The SARCR system consists of two subunits, an Indoor and an Outdoor Unit, built with off-the-shelf hardware. The Indoor Unit interfaces to the ship's radar Automatic Radar Plotting Aid (ARPA) tracker via an International Standard International Electrotechnical Commission (IEC) 61162-1 RS-232/422 interface[1] and to the Outdoor Unit (Fig. 3) via either an Ethernet or an internal ZigBee wireless card located in each unit. The Outdoor Unit is fully integrated, containing an AIS receiver, a GPS receiver, an Iridium modem, and the associated antennas for each system.

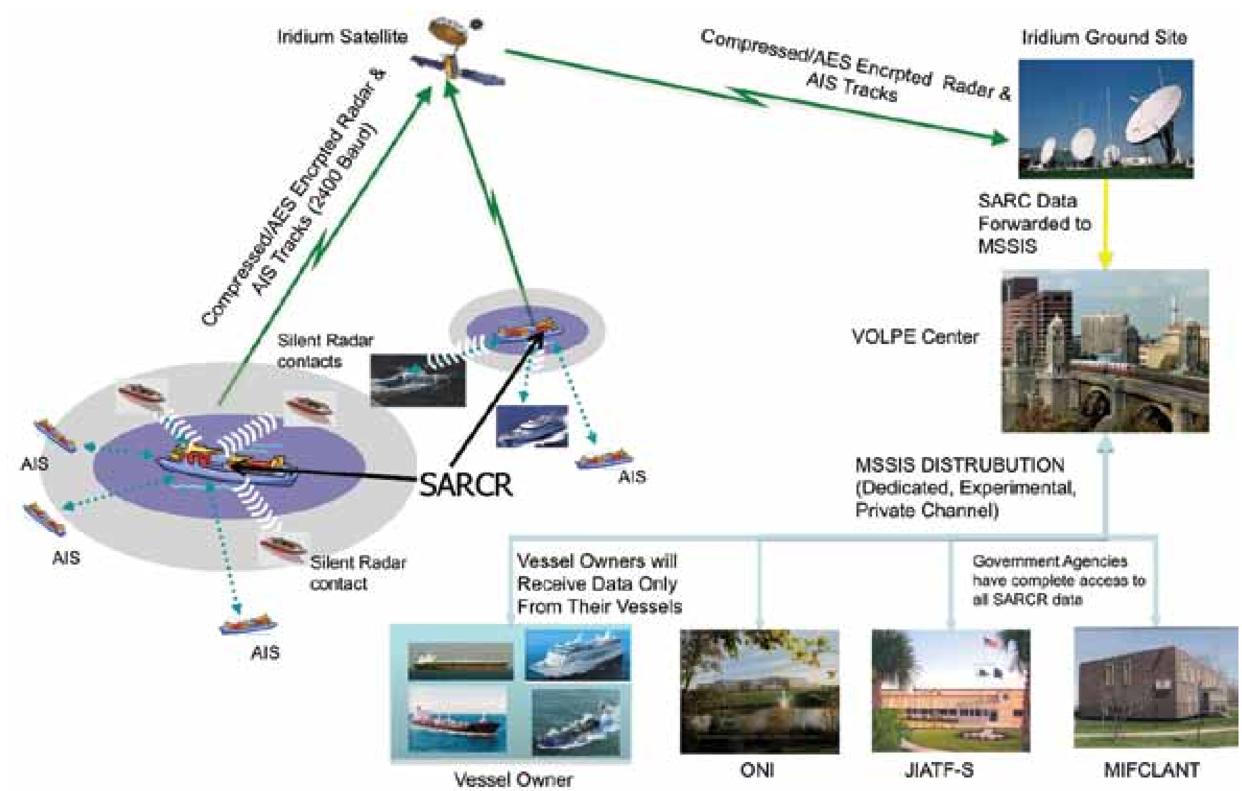

FIGURE 4
SARCR concept of operations.

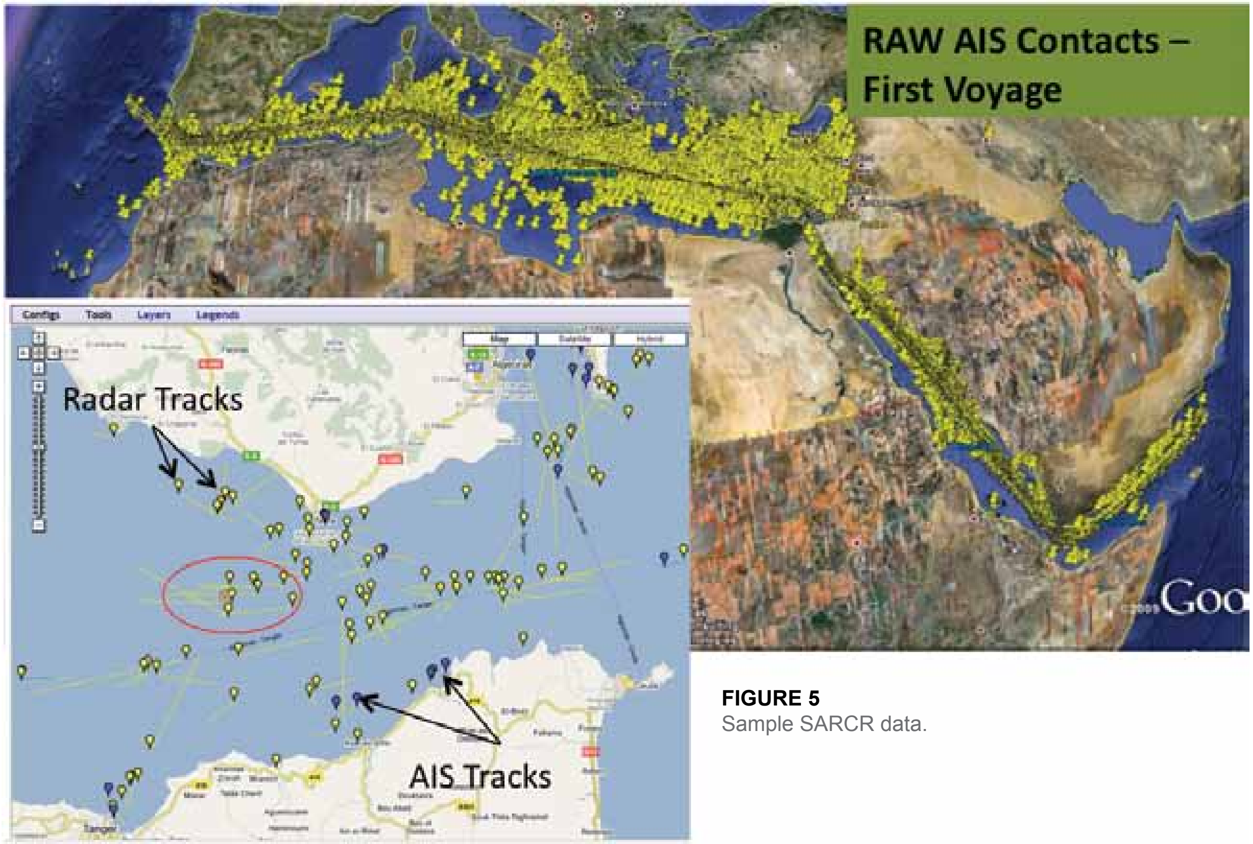

FIGURE 5
Sample SARCR data.

Functional Description: IEC-61162-1-formatted target track messages (TTM) from the ship's radar ARPA tracker are collected by the Indoor Unit and forwarded to the Outdoor Unit. The Outdoor Unit then extracts a target's range and bearing along with time data from the TTM message and converts the data into latitude and longitude. Once the position has been calculated, a modified IEC-61162-1 message containing the positional data and time is created. This message is forwarded to the communications software module in the Outdoor Unit. The Outdoor Unit's communications module then evaluates it as either a new track or an update track. At the same time, the Outdoor Unit is receiving AIS messages and forwarding them to the communications module to undergo the same evaluation.

Every minute, the communications module builds a series of data packets containing all the new radar and AIS tracks and track updates, which are compressed, software-encrypted using 256 bit software encryption, and transmitted continuously (24/7/365) via a 2400 baud Iridium satellite modem link to land-based processing centers. To maintain connectivity across the Iridium satellite link to the land-based processing center, NRL developed an ACK-NAK and a packet-tracking scheme that has allowed for an average data loss of less than 3%. The land-based processing center decrypts, decompresses, and distributes the received data via the Internet to the owner of the participating vessel from which the data originated and to U.S. agencies, Office of Naval Intelligence (ONI), Joint Inter-Agency Task Force South (JIATF-S), and U.S. Coast Guard's Maritime Intelligence Fusion Center – Atlantic (MIFCLANT). The team has installed one unit on a commercial vessel (as shown in Fig. 3), and will have installed the remaining units by the end of FY10. The concept of operations and a sample of data are seen in Figs. 4 and 5, respectively.

[Sponsored by DHS S&T Directorate, Maritime Security Technology Program]

Reference

[1] International Electrotechnical Commission 61162-1, International Standard Third Edition 2007-04, *Maritime Navigation and Radiocommunication Equipment and Systems - Digital Interfaces; Part 1: Single Talker and Multiple Listeners* (2007).