Guest Editorial
Special Issue on Marine and Maritime Radar Remote Sensing

MARINE and maritime remote sensing encompass monitoring natural phenomena and human activities at sea. The marine environment is the Earth's largest habitat and hosts a vast part of the Earth's biodiversity. With its about 1.35 billion cubic kilometers of water, it plays a key role in the Earth's ecosystem, weather, and climate. Routine marine remote sensing is at the core of operational weather services. Human activities at sea are on one side an economic benefit, but on the other side present potential environmental risk. Monitoring the human impact is very important to enforce environmental laws and mitigate their adverse effects. Development of maritime industries such as oil and gas exploration and production in deep/ultradeep water and extreme environments, offshore wind, tidal and wave energy, offshore aquaculture, shipping, etc., is continuing worldwide. Monitoring such phenomena and activities in a non-invasive and effective way is very important for safety and security reasons. Remote sensing addresses this need.

Radar remote sensing is fundamentally based on how electromagnetic waves propagate and interact with the ocean, i.e., how the electromagnetic wave is modified by the interaction with the ocean's surface [1]. From a methodological point of view, radar remote sensing is composed of three fundamental steps: measurement, modeling, and an inverse problem. The measurement step embodies the sensor design to provide users with (high quality) observation of physical quantities. The second step, also known as forward modeling, is the study of the relationship between the geophysical quantity of interest and the observable quantity. The inverse modeling step is the extraction of the required information from the observation, i.e., estimation of the geophysical quantity of interest from the measured data. The inverse problem solution is generally very challenging since the forward model is often nonlinear, and even high-quality measurements are noisy. Needless to say, data and information are not synonymous; hence, acquiring more data does not automatically ensure access to more information.

Remote sensing of the sea by radars can be done by ship-based radars, ground-based coastal radars, or satellite radars [1]. Ship-based and coastal radar can monitor a limited area in a continuous manner, while satellite radars provide wide area, but limited temporal coverage. Multiple satellites enable shorter revisit times and provide denser spatial coverage. A large number of satellite radars are currently deployed with additional systems planned for launch.

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Radars can be designed for both large-scale and small-scale monitoring and may have fine or coarse spatial capability. Satellite radars such as altimeters and scatterometers are designed for large-scale wide-area observation [2], while synthetic aperture radar (SAR) provides fine-scale but more limited-area observations. The typical marine application of satellite altimetry is for significant wave height (SWH) mapping, while a scatterometry provides measurements of the near-surface wind speed and direction. SAR is well suited for measuring the ocean wave spectrum and for monitoring oil spills and ships [1]. High-frequency (HF) radar operating from the shore receives sea echoes predominantly from Bragg waves that are in the stable part of the wind-wave spectrum. Because the Bragg lines are well resolved in the spectra, these coastal radars can produce accurate maps of surface currents and wave parameters [3]. Shore-based microwave radars produce wave spectrum data at ranges up to a few hundred kilometers.

Recent technology trends in radar remote sensing are motivated by confidence in new applications and improved added-value products can be obtained by new radar operating modes. With reference to SAR, the most important technological trends are related to polarimetric mode observation and new digital beamforming techniques. Radar polarimetry was originally of limited interest in marine and maritime applications but in recent years polarimetry has demonstrated increasing utility. For example, oil spill monitoring is greatly improved by polarimetric mode operation and modeling at a variety of microwave frequencies [4].

Present satellite SAR polarimetric modes suffer from reduced swath and spatial resolution compared to a classical single-pol mode. To circumvent this drawback, compact polarimetry can be used [5], which is a suboptimal measure of the full-polarimetric mode that requires careful calibration [6]. The actual impact of polarimetry on added-value products depends on the specific case. Compact polarimetric modes are currently operated onboard the Japanese Space Exploration (JAXA) ALOS-2 L-band SAR, and the Indian Space Research Organisation RISAT-1 C-band SAR, and are planned for operation on the Canadian Space Agency RADARSAT Constellation Mission C-band SAR.

New SAR techniques for maritime monitoring are based on the digital beamforming concept. For example, in [7], a new staggered mode that allows the use of fine-resolution polarimetric mode with a wide swath of operational interest is proposed. Satellite SAR performance is also improved by bistatic modes that can be operated by sister satellites [8]. This new technological trend is being promoted in connection with the design of new small satellite platforms and miniaturized sensors. However, it must be noted that such miniaturization is physically limited by antenna size and use of frequencies not severely impacted by atmosphere.

This Special Issue on Marine and Maritime Radar Remote Sensing is made up of eight papers. Additional papers still in review will be published in Part II of the Special Issue. The eight papers published here cover a very wide range of applications and types of radars.

In "Megi typhoon monitoring by X-band synthetic aperture radar measurements," two satellite *X*-band SAR sensors, i.e., the Italian Space Agency CosmoSkyMed and the Deutsches Zentrum für Lüft- und Raumfahrt TerraSAR-X, are exploited to monitor typhoon Megi in the Pacific Ocean in 2010. It is shown that typhoon structure is well defined through the appearance of low-backscattering areas due to attenuation bands enhanced at *X*-band. The attenuation bands are exploited to retrieve geometrical features associated with the typhoon and to estimate the eyewall extension. Rain rate estimation is undertaken exploiting the scattered signal in the attenuation bands using an empirical relationship. Violent rainfalls apply within the typhoon characterized by a rain rate of up to 50 mm/h.

In "High-frequency radar ocean surface cross section incorporating a dual-frequency platform motion model," the first- and second-order HF radar cross sections of the ocean surface are derived for an antenna on a floating platform. The simulation study shows that motion-induced peaks appear symmetrically in the Doppler frequency and have less energy in the second-order radar cross section than those in the first-order radar cross section. The magnitude and width of the Bragg peaks are seen to decrease and broaden, respectively, as compared to the case for a fixed antenna. The platform motion modulates the radar signals as a frequency modulator, and the modulation indices are related to the amplitudes of the platform motion.

In "Bistatic high-frequency radar ocean surface cross section incorporating a dual-frequency platform motion model," the bistatic development of the study presented in the previous paper is reported. It is shown that the bistatic angle affects both the power of the second-order received Doppler spectra and the modulation level of the platform motion on the radar cross sections. The size of the modulation level has a relevant effect on the energy of the Bragg peaks in the radar cross sections.

The paper "Assessment and enhancement of SAR noncoherent change detection of sea-surface oil spills" examines an important marine hazard: an oil spill due to the wreck of an oil rig. The case of the 2010 Deepwater Horizon accident in the Gulf of Mexico is studied by considering a time-series L-band ALOS SAR images. The image processing approach is based on a change detection algorithm that best performs on the intensity ratio.

The paper "Normalized scalar product approach for nearshore bathymetric estimation from X-band radar images: An assessment based on simulated and measured data" investigates the capability of *X*-band radar operated on fixed or moving platforms to estimate the near-shore bathymetry. A sensitivity analysis is performed to evaluate how sea-state conditions affect bathymetric estimates. The bathymetric reconstruction is performed through the normalized scalar product (NSP) estimation strategy, exploiting a spatial partitioning of the radar data. The approach is tested over one real data set and other simulated ones. The tests over the simulated data sets show the robustness of the estimation procedure with respect to sea-state conditions. Furthermore, the tests over real and simulated data show that the adaptive partitioning procedure proposed to drive the NSP method as a function of the space-varying behavior of the sea wavelengths evolving in the shoaling region performs better than classical methods.

The paper "Theoretical performance of space-time adaptive processing for ship detection by high-frequency surface wave radars" analyzes the performance of the full or reduced versions of space-time adaptive processing (STAP) algorithms applied to coastal HF surface wave radars for marine target detection to verify whether this family performs better than the standard moving target indication (MTI) algorithms. The analysis is performed on the performance and conditioning (since operational detection needs to invert the covariance matrix) points of view. The study considers a sea clutter model for pulsed and chirp radars centered around the 5- and 12-MHz frequencies. To make the model more realistic, radio frequency interference is also considered. It is shown that the STAP algorithms improve the capability of target detection (compared to the usual MTI algorithm). The main difference is provided by the matrix conditioning of these two approaches. The matrix of successive space-time whitening has a condition number close to that of the MTI, but the performance levels are good only in the 12-MHz band. Thus, the detection improvements do not result in a loss of accuracy in the matrix inversion and can be operationally applied. The main improvement in the full STAP algorithm is provided by increasing the number of antennas, since the MTI approach does not perform any azimuthal/slow time whitening. But for reduced versions, performance does not significantly increase with the number of pulses or antennas. Results apply for Gaussian sea clutter.

In "Ship classification in TerraSAR-X images with convolutional neural networks," the satellite *X*-band SAR on-board TerraSAR-X is exploited to monitor ships. The approach followed by the authors falls within the "deep learning" methods. In particular, the convolutional neural networks (CNNs) are cross evaluated on a common data set composed of five maritime classes, namely, cargo ship, tanker, windmill, platform, and harbor structure. The experimental results show that CNNs are efficient in performing maritime target classification in SAR images, and the combination of different input resolutions in the CNN model improves its ability to extract features, increasing the overall classification score.

Finally, in "An adaptively truncated clutter-statistics-based two-parameter CFAR detector in SAR imagery," Ai *et al.* focus on satellite SAR where they use multilook C-band Envisat SAR and *X*-band TerraSAR-X images to test an improvement of the constant false alarm rate (CFAR) to design a ship detection filter. The two-parameter CFAR detector is based on a log-normal background statistical model for the sea clutter and by an adaptive threshold.

Following the discovery in 1955 that sea surface waves produce coherent Bragg echos [3], there were several decades of technological development of ocean radars. As new applications were developed, the literature began to focus more on practical applications that benefit humanity. This process is still going on and is illustrated in this Special Issue where there are five papers that report technology development and three papers that focus on applications. This indicates that marine and maritime radar remains a young but vibrant field of technology that is still developing new concepts and methodologies with a wealth of applications to current issues.

We hope you will find these papers interesting. We would like to thank the IEEE Society of Oceanic Engineering for approving this special issue and the reviewers that contributed to the selected papers.

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