OCTOBER 2006
Single Issue Price $4.50

Sea Technology

THE INDUSTRY'S RECOGNIZED AUTHORITY FOR DESIGN, ENGINEERING AND APPLICATION OF EQUIPMENT AND SERVICES IN THE GLOBAL OCEAN COMMUNITY

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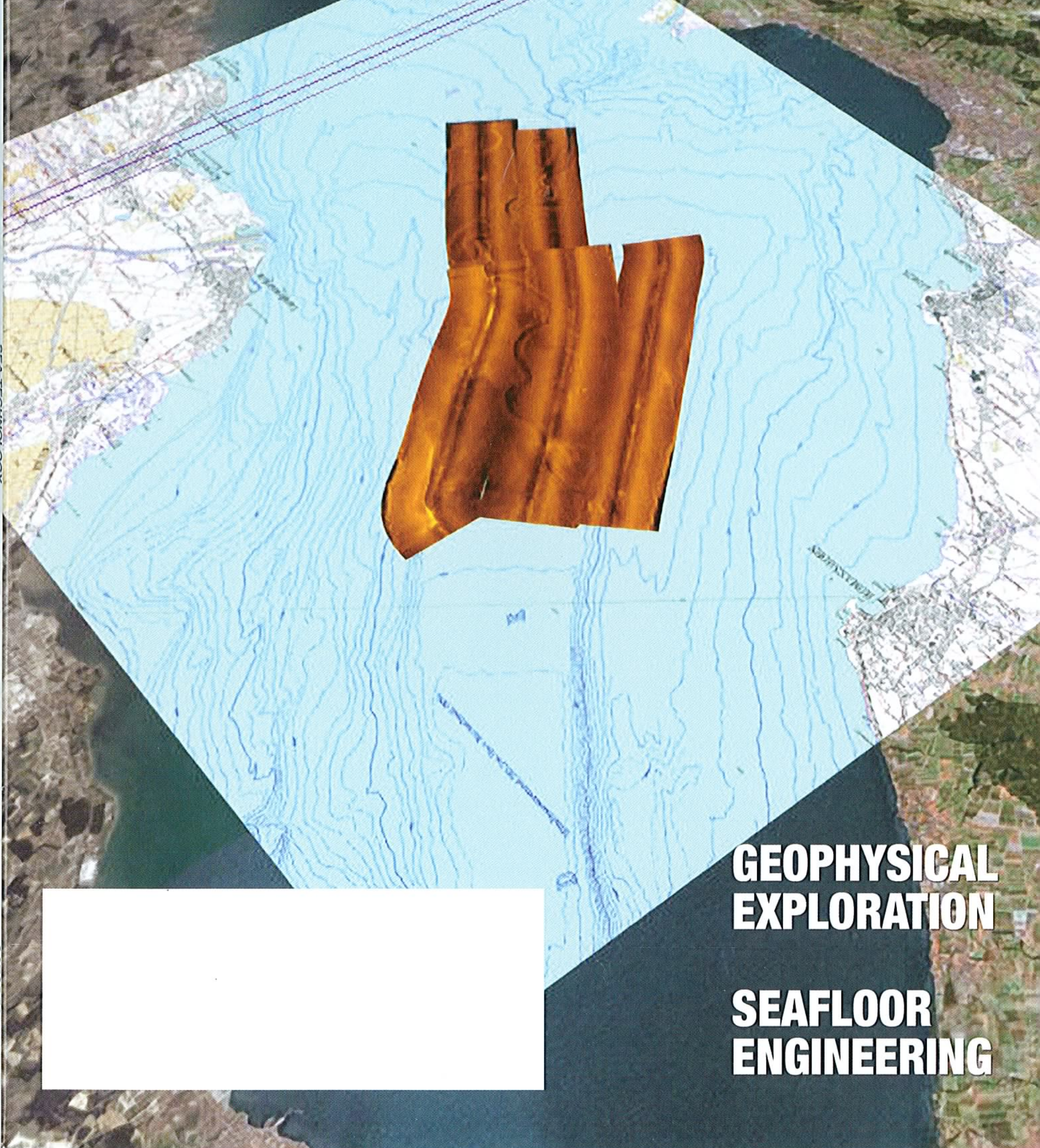


GEOPHYSICAL EXPLORATION

SEAFLOOR ENGINEERING

Wave Radars: Techniques and Technologies

Advantages and Disadvantages of Different Ground-Based Radar Remote Sensors

By Dr.ing. Øistein Grønlie
Technical Manger
Miros AS
Asker, Norway

Miros Wave and Current Radar MkIII installed offshore Brazil.

Surface ocean waves can be measured by a number of different radar remote sensing techniques, and there are a lot of commercially available instruments to help do so. One problem from the user's point of view is that many of these instruments are commonly called simply "wave radars," quite unprecise and often misleading, as their operation may be based on very different principles given the instrument's different qualities. This article gives a brief description of the most common ground-based radar remote sensing techniques available, as well as some of their advantages and disadvantages.

Terms and Definitions

A wide range of radio wavelengths may be used for remote sensing of sea waves, spanning from high frequency via microwave to infrared (IR). There are basically two different classes of radar remote sensors for waves: direct and indirect sensors. The direct sensor directly measures some relevant parameter of the wave system. Indirect sensors observe the surface waves by their interaction with some other physical process. This greatly complicates the interpretation of the measurement results.

Microwave radars may be used in two different modes. In the near-vertical mode, the radar echo is generated by specular reflections from the sea surface. In the low grazing angle mode, the radar echo is generated by Bragg scattering. Hence, wind-generated surface ripples must be present. The backscattered signal will be modulated by the large gravity waves, and the gravity wave information is derived from the modulation of the backscattered signal. An excellent presentation of the theories of microwave remote sensing of the sea surface is given by W. J. Plant and D. L. Shuler.[1]

Radar resolution is determined by the bandwidth of the radar signal and the beamwidth of the radar antenna. The beam of a microwave antenna is dispersive, so consequently, the footprint size becomes a function of range. The beam of an IR radar is non-dispersive, so the footprint size is independent of range.

High-frequency radars also utilize the Bragg scattering mechanism and always operate at very low grazing angles. Due to the low-frequency of operation, the radar waves are backscattered directly from the gravity waves, and wind-generated surface ripple need not be present.

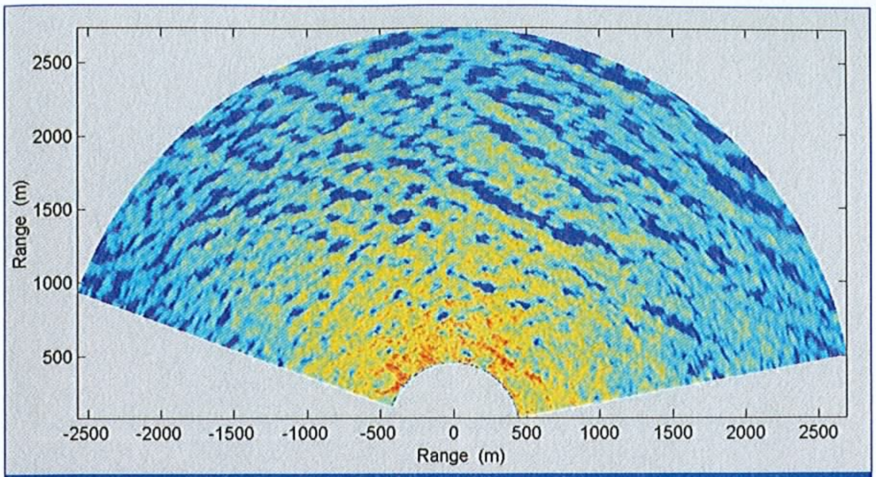
Radar transceivers may either be coherent or non-coherent. Coherent radars measure Doppler modulation and amplitude modulation, while non-coherent radars only measure amplitude modulation. Hence, a non-coherent radar echo contains less information about sea surface properties.

The radar transmitter waveform may be an unmodulated continuous wave (CW), modulated or pulsed. An unmodulated CW radar has no range resolution.

From the above discussion, one may well understand why the term wave radar is not very precise. The wave radar performance is highly dependent on the mode of operation, class of system, frequency of operation, radar waveform, type of transceiver and radar antenna properties.

Remote Sensing Techniques

An excellent survey of different radar techniques for remote sensing of waves is given by M. J. Tucker.[2]



Polar sea echo image of a marine navigation radar shows the gravity wave pattern.

Laser Altimeters. Laser altimeters are small and lightweight, and work in the IR frequency band. They operate in vertical mode and normally use pulsed waveforms to perform direct measurements of sea surface elevation, which can easily be converted to wave amplitude. The laser beam is very narrow and almost non-dispersive. The footprint is small and almost independent of range. Due to the high frequency of operation, laser altimeters are prone to interference from natural sources of IR emissions. Salt and soot deposits on the optical window greatly deteriorate the measurement performance. The sensor easily locks on to fog and water spray, and will frequently be unable to track the sea surface.

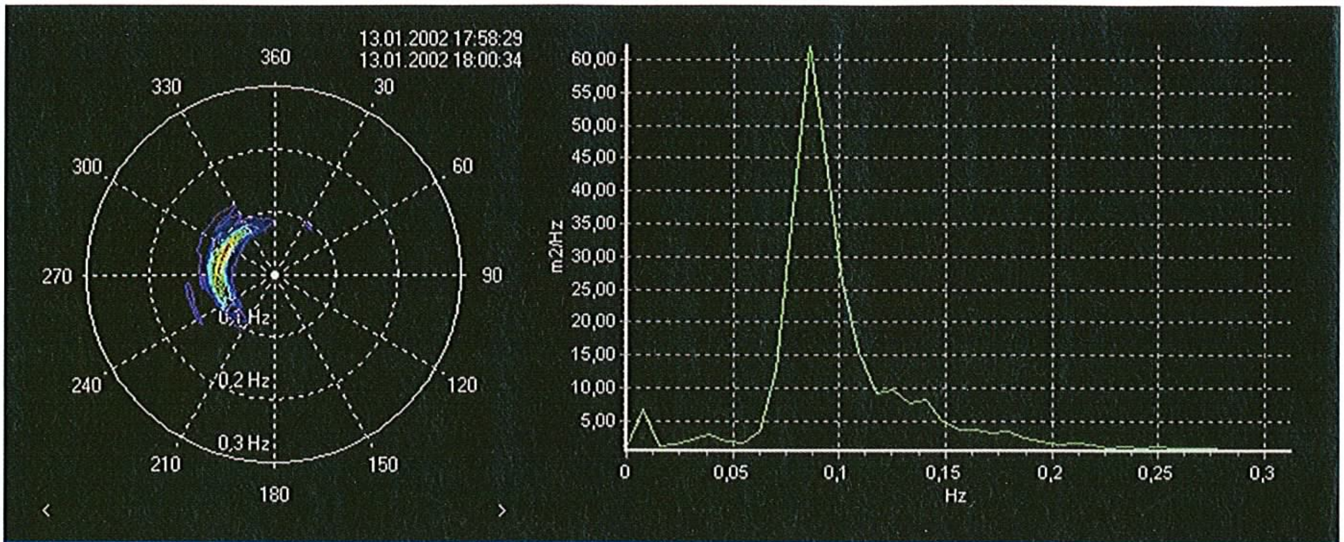
Microwave Range Finders. Microwave range finders also operate in vertical mode at gigahertz frequencies. Due to the much lower frequency, the microwave range finder is not as affected by fog and water spray as the laser altimeter. A continuous wave frequency modulated or pulsed radar waveform is normally used to provide range resolution. The beam is dispersive, so the size of the footprint increases linearly with range.

Low-Cost Vertical Microwave Sensors. These sensors, designed to be used as level gauges, are generally not suitable for wave measurement applications. The main problems are high sensor noise levels, requiring large averaging intervals, and large footprints due to wide antenna beams.

One example of a microwave range finder is the Miros SM-094, which is designed for wave and water-level measurements.

Microwave CW Doppler Radars. These radars operate in vertical mode and use a coherent unmodulated continuous waveform to measure the Doppler shift caused by the vertical velocity of the sea surface.

The Doppler measurement is directly related to wave height by simple integration. This radar has no range resolution, and the antenna footprint is entirely determined by the antenna pattern.



2D wave spectrum (left) and point spectrum (right) measured by Miros Wave and Current Radar.

An accelerometer can be used to remove the ship or platform vertical motion from the Doppler measurement.

An array of three vertical radars in a triangular configuration can be used to measure a directional wave spectrum. Algorithms and signal processing software are similar to what is used in the processing of heave, pitch and roll buoys.

A frequently occurring problem with vertical radars is the effect of the interference on the structure on which they are mounted. The wave field to be measured will be disturbed, and the resulting measurement error will depend on wave direction.

Marine Navigation Radars. These radars provide sea clutter images, which contain a pattern resembling a sea wave pattern. By digitizing the radar video signal, it can be processed by a digital computer. Sea surface parameters may be calculated on the basis of these digitized images. The marine navigation radar operates in low grazing angle mode, and wind-generated surface ripple must be present.

The marine navigation radar is non-coherent and is a typical example of an indirect wave sensor because there is no direct relation between wave height and radar backscatter modulation amplitude. An empirical method of wave spectrum scaling is normally employed. These methods work well under most conditions, but may occasionally fail. It is, therefore, impossible to quote reliable wave height performance figures valid under all conditions. Additional wave height measurements may be required for calibration purposes. Marine navigation radar-based wave sensors are excellent tools for wave direction measurements.

A marine navigation radar may also be a tool for surface current measurements. Point measurements of the current vector, as well as current maps up to a distance of a few kilometers, can be provided.[3]

The Miros WAVEX has been commercially available since 1996. The main area of application is directional wave measurements from moving ships.

Range Gated Pulsed Doppler Microwave Radar. This radar operates the in low grazing angle mode. By using several antennas, it may be used as a directional wave sensor, measuring the directional spectrum of the horizontal water particle velocity. The velocity spectrum is directly related to the wave height spectrum by a mathematical model based on linear wave theory, and accurate measurements of the wave spectrum can be provided under most conditions. As measurements are taken at a distance from the platform on which it is mounted, the wave field is only disturbed by interference from the platform structure to a small degree.

The Miros Wave and Current Radar is the only commercially available wave sensor based on the range gated pulsed Doppler radar technique. This radar also uses the dual-frequency technique to perform point measurements of the surface current vector.

Dual-Frequency Microwave Radar. This radar transmits two microwave frequencies simultaneously. The frequency separation is chosen to give a spatial beat length, which is in the range of the water waves of interest. The dual-fre-

"Radar resolution is determined by the bandwidth of the radar signal and the beamwidth of the radar antenna."

quency radar may be considered a microwave equivalent of the high-frequency radar, and is suitable for the measurement of surface current. As far as wave measurements are concerned, the back-scatter processes are too complicated (and not well enough understood) to allow useful measurement accuracy to be attained.

High-Frequency Radar. This radar is well established as a powerful tool for sea current measurements up to a range of about 30 kilometers. It operates in the megahertz frequency band, corresponding to a radar wavelength in the range of 10 to 300 meters. The Doppler shift of the first order Bragg lines of the radar echo is used to derive sea current estimates in very much the same way as for the dual-frequency microwave radar. Two radar installations are normally required, looking at the same patch of the sea surface from different angles.

For wave measurements, a more complex second order mechanism of backscatter is used. Basic problems are that the range of wave frequencies and sea states that can be measured depends on the selected radar frequency, and that data return is limited by propagation and radio interference effects. A great disadvantage of many high-frequency radars is the size of their phased array antennas. Some systems use compact direction-finding antennas instead, but wave measurements are believed to be more difficult with the compact antennas. Recent work has demonstrated that useful wave measurements in agreement with buoy measurements can be obtained using high-frequency radars.[4]

Conclusions

In this article a number of different radar techniques suitable for ocean wave and surface current measurements have been presented. These techniques are implemented in commercial wave and current sensors that differ in complexity and performance. In order to select the "right" sensor, the user must have an understanding of the requirements imposed by his application and the working principles of the different sensors.

References

For a complete list of references, contact the author at Oistein.Gronlie@miros.no. /st/

For more information on this subject matter, visit our Web site at www.sea-technology.com and click on the title of this article in the Table of Contents.

Dr.ing. Øistein Grønlie received his masters degree in electrical engineering from the Norwegian University of Science and Technology (formerly the Norwegian Institute of Technology) in 1971, and his Ph.D. in communication theory in 1980. Between 1972 and 1982, he was employed as a scientist at the Norwegian Defence Research Establishment. In 1984, Grønlie joined Miros AS, where he is presently a technical manager.