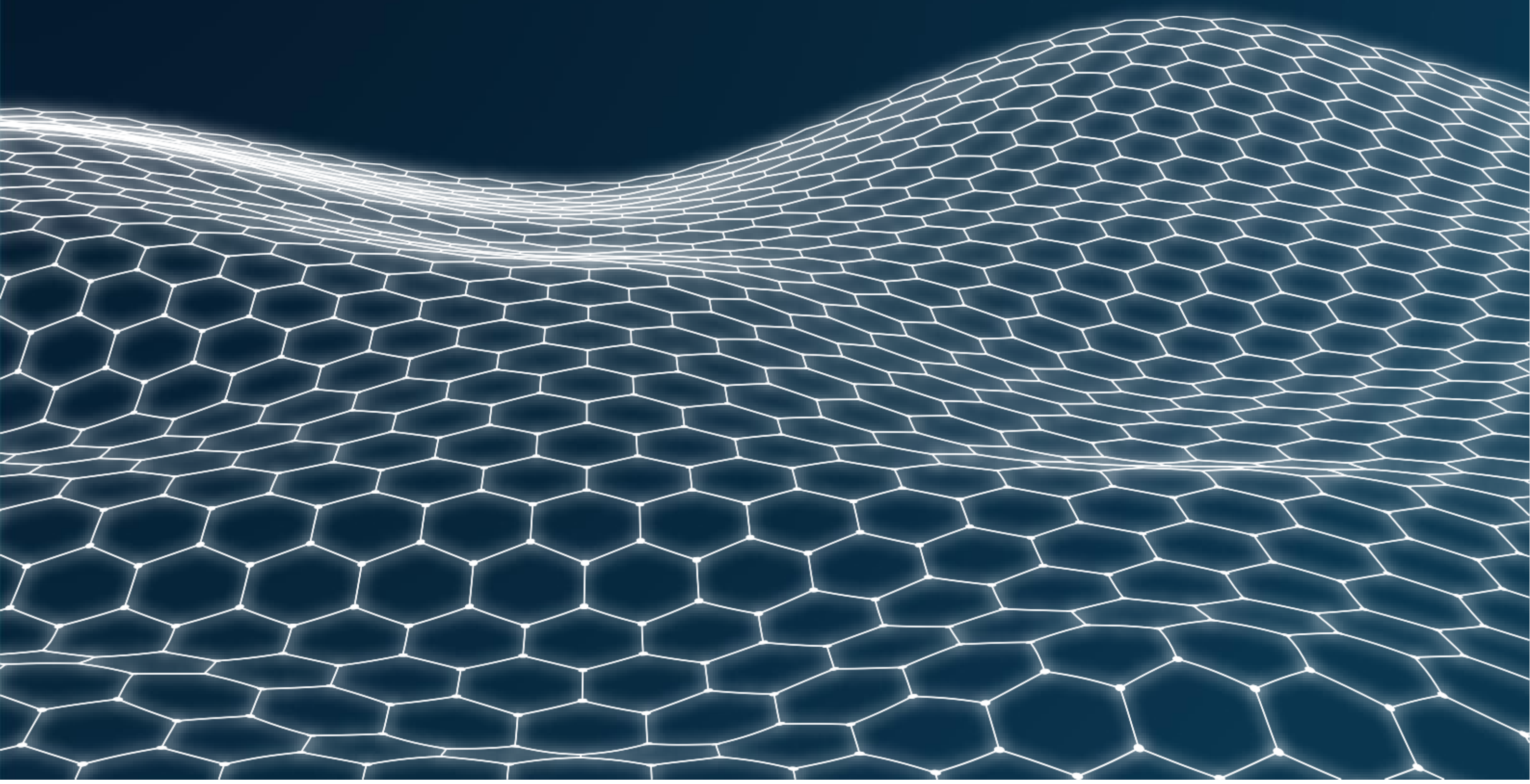

AUTOMATICALLY CALIBRATED WAVE SPECTRA BY THE MIROS WAVEX® SYSTEM – ACCURACY VERIFIED

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Abstract: Sea state measurements are used to secure and optimize operations and activity at sea and in coastal areas. Wavex® provides directional wave spectra and integrated wave parameters based on digitized X-band radar ocean surface images. By means of algorithms that have been significantly improved during recent years, Wavex operates using various radar types under a wide range of measurement conditions, with no need for calibration using external references. The accuracy of the system has been verified by comparing Wavex data with data from reliable reference sensors at a considerable number of sites.

INTRODUCTION

Sea state measurements are useful for many applications:

- considering stress and fatigue on maritime structures and vessels;
- fuel optimization, route planning, cargo safety, and passenger comfort for ships in transit;
- input to bridge and decision support systems;
- input to marine, crane, and loading operations;
- coastal monitoring.

Directional ocean wave spectra and integrated wave parameters can be obtained by processing digitized images from a conventional X-band navigation radar. In the early years of this technology, calibration of such spectra depended on various empirical and semi-empirical methods, requiring an external reference sensor (a wave buoy, for instance) to initially establish calibration parameters. This was associated with additional cost and practical challenges. Incorrect scaling of wave spectra implied that also integrated wave parameters related to wave height, as for instance the significant wave height, became inaccurate.

Now, after several important breakthroughs, fully automatic calibration is supported by the Wavex system, meaning that the user is provided with high-quality spectra and reliable integrated wave parameters for a wide range of radar types and measurement conditions, with no need for calibration using external references.

Furthermore, the new algorithms facilitate a simple procedure for site-specific calibration at sites previously not suited for such radar-based technology. Data from a two-digit number of sites have been used to examine and verify the accuracy of the new algorithms.

BACKGROUND/PROBLEM

Wave sensors based on conventional X-band radars are indirect, meaning there is no direct relation between image intensity and wave height. The radar sea echo is simply a depiction of the gravity wave pattern as seen by the radar, where the slope of the ocean surface relative to the direction of sight is one important factor. Hence, obtaining calibrated wave spectra and integrated wave parameters using such sensors is not straightforward, but requires advanced algorithms or some sort of initial calibration using wave height data from a reliable reference sensor. Calibration is not desirable as it adds cost and is often not practically feasible, for instance for vessels in frequent transit and operation around the world.

SOLUTION

Miros has developed algorithms to automatically calibrate wave spectra derived from gravity wave patterns in X-band radar images. The work has progressed through several stages, covering different parts of the algorithms, resulting in a system that supports automatic calibration. Algorithms used in previous versions of Wavex have been improved. In addition, new methods have been developed to increase the measurement accuracy and to support a wider range of radar types and measurement conditions without having to re-calibrate.

About the technology used in Wavex®

Raw radar images are acquired from a marine navigation X-band radar and digitized by Miros hardware, especially developed for this application. Digitized images can also be acquired directly from radars with digital data feed, commonly known as IP (Internet Protocol) radars, eliminating the need for additional digitalization hardware.

In the context of wave measurement by radar, signals refer to gravity wave patterns visible to the radar, given the radar's spatial resolution in range and azimuth. To obtain optimum performance, an unfiltered signal from a radar operating in short pulse mode is required. In addition, a wind speed of at least 2 – 3 m/s is required to get sufficient electromagnetic backscatter from the ocean surface.

Cartesian image sections, defined during the software configuration, are extracted from the digitized radar images and processed by dedicated algorithms. This provides the user with real-time wave spectra, as well as integrated wave parameters and surface current vectors. The measurement area can be changed by software reconfiguration at any time.

3-D fast Fourier transforms (FFTs) are performed on time series of Cartesian images, giving 3-D spectra with information about the power present at various wavenumbers and frequencies. Ocean image spectra are obtained from these wavenumber-frequency spectra by integrating over frequency. Various sorts of noise filtering are also applied. The dispersion filtering, for instance, is based on knowledge about the relation between wavenumbers and frequencies of ocean gravity waves.

Finally, a transfer function is applied to the image spectrum to obtain a calibrated directional wave height spectrum. The transfer function is relatively complex, relying on several fundamental sub-methods, ensuring that the final wave height spectrum correctly describes the actual ocean surface, both with respect to shape and scaling.

Principal test sites

Table 1 lists essential parameters related to four principal test sites indicated in Figure 1, spanning a wide range of properties relevant for the measurements. Data have been acquired for months at each of these sites, both from Wavex systems and reliable reference sensors.

	#1 Deep Panuke (fixed)	#2 North Sea (fixed)	#3 West Navigator (moving)	#4 Ekofisk (fixed)
Radar brand	Furuno FAR 2117	Sperry Bridge-master II	Sperry Bridge-master II	Terma Scanter 5202
Antenna height (m)	26.0	43.5	23.0	92.0
Antenna length (ft.)	6.5	4	6	12
Antenna rotation speed (RPM)	42	29	29	18
Range resolution in short pulse mode (m)	10.5	7.5	7.5	3.0
Water depth (m)	45	185	850-1100	70
Reference, at distance (km)	Buoy, < 5	RangeFinder, < 1	Buoy, < 1	RangeFinder, 7

Table 1: Essential parameters related to four principal test sites.

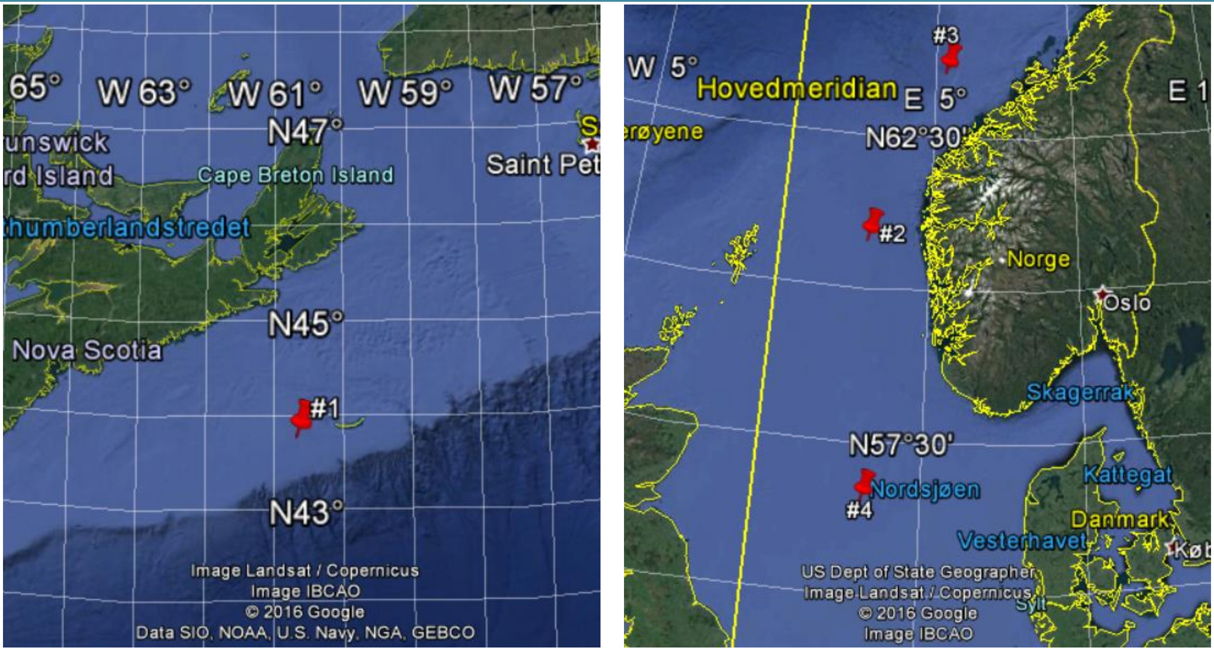

Figure 1: Four principal test sites indicated in Google Earth.

Performance and accuracy

Figure 2 and Figure 3 show time series and scatter plots from the four principal test sites. Correlations and deviations between Wavex and references, with and without site-specific calibration, are shown in Table 2. As can be observed from the statistics, RMS deviations are well within 0.5 m and correlations close to unity for all sites. Performing site-specific calibration has only minor impacts on the results. All available data are used in this study, apart from data automatically tagged by built-in data quality controls relying on the signal-to-noise ratio and other parameters deduced from the data.

The reference sensors are based on measurement principles very different from Wavex. This also includes spatial and temporal averaging strategies used in the sensors, implying that some differences must be expected due to the statistical properties of the ocean surface itself. Furthermore, the accuracy of the reference sensors is not known.

CONCLUSION

The algorithms of the Wavex system have been considerably improved during recent years. The system is now capable of providing high-quality calibrated wave spectra and reliable integrated wave parameters using various radar types under a wide range of measurement conditions, with no need for calibration using external references. Furthermore, new algorithms facilitate a simple procedure for site-specific calibration at sites previously not suited for such radar-based technology. Data from a two-digit number of sites have been used to verify the accuracy of the new algorithms. Results from four principal sites considered in this paper illustrate that RMS deviations between Wavex and reliable references are well within 0.5 m. These deviations also comprise measurement errors in the reference sensors, as well as statistical variance related to differences in measurement principles and the statistical properties of the ocean surface itself.

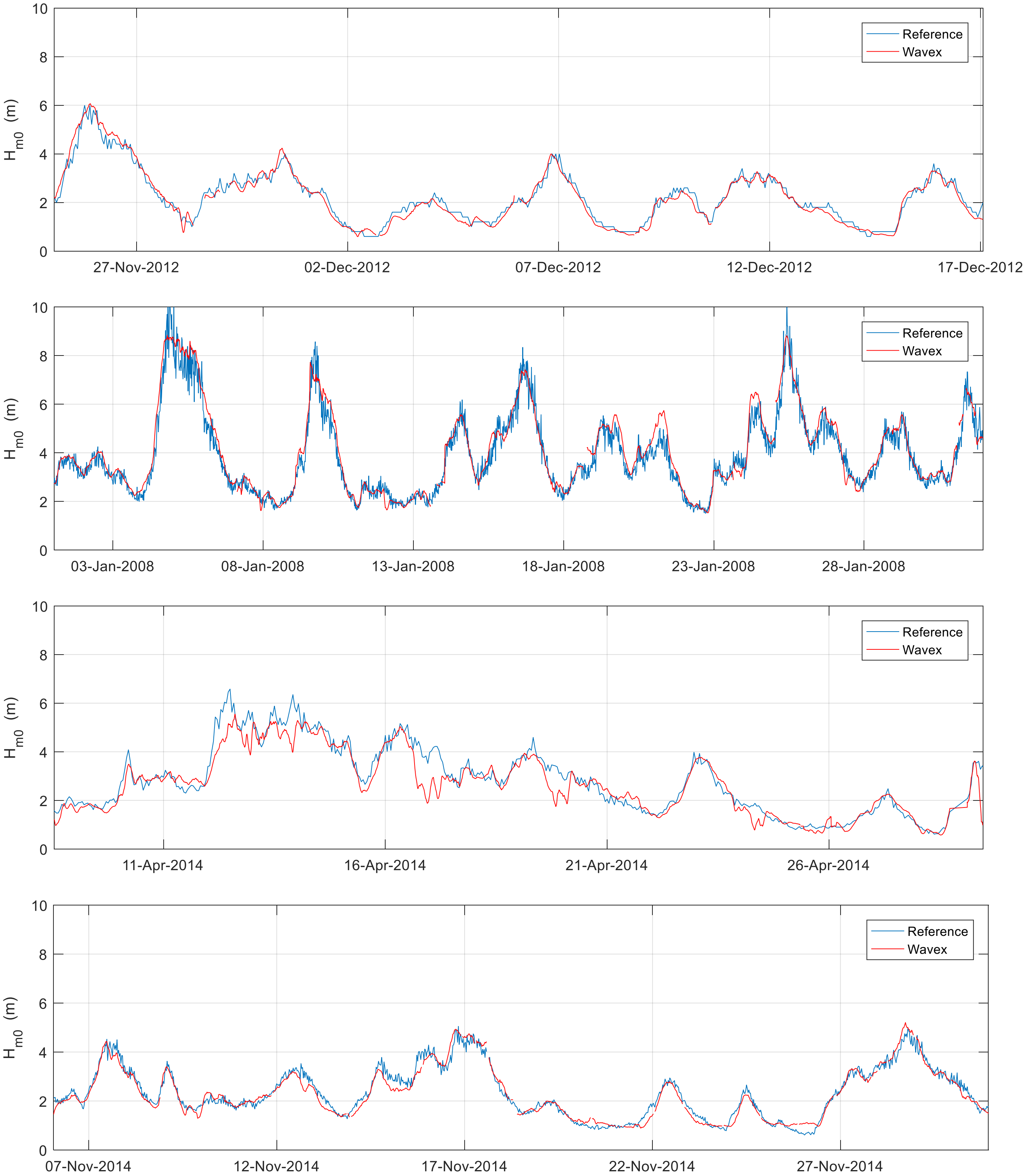

Figure 2: Time series from sites #1 - #4 (#1 on top), comparing significant wave height Hm0 from Wavex and references.

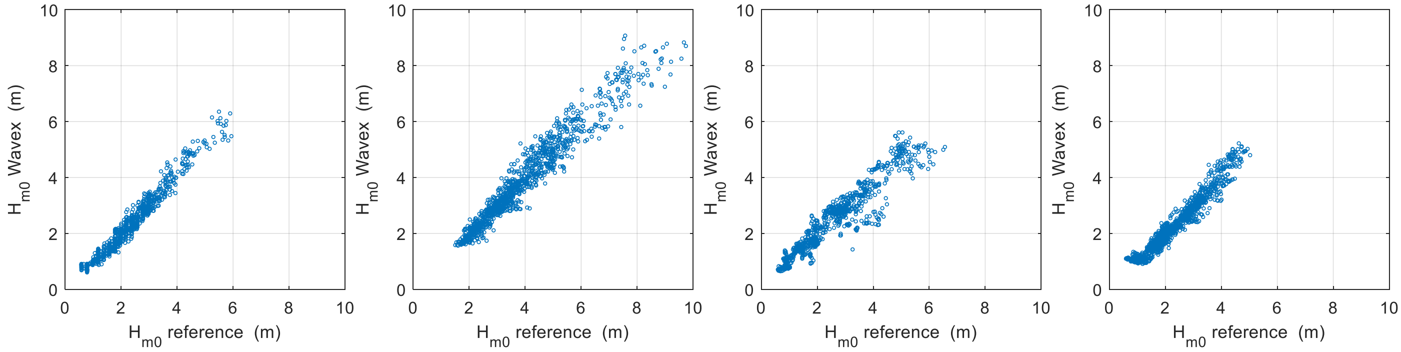

Figure 3: Scatter plots from sites #1 - #4 (#1 to the left), comparing Hm0 from Wavex and references. Data are decimated to improve the readability.

	#1 Deep Panuke	#2 North Sea	#3 West Navigator	#4 Ekofisk
Correlation	0.98 (0.98)	0.97 (0.97)	0.94 (0.94)	0.97 (0.97)
Mean deviation (m)	0.04 (0.00)	0.15 (0.00)	0.19 (0.00)	0.13 (0.00)
RMS deviation (m)	0.22 (0.19)	0.42 (0.38)	0.50 (0.46)	0.26 (0.22)

Table 2: Statistics of performance: Correlation, mean deviation, and RMS deviation between Wavex and references. Numbers in parenthesis represent statistics after performing site-specific calibration.

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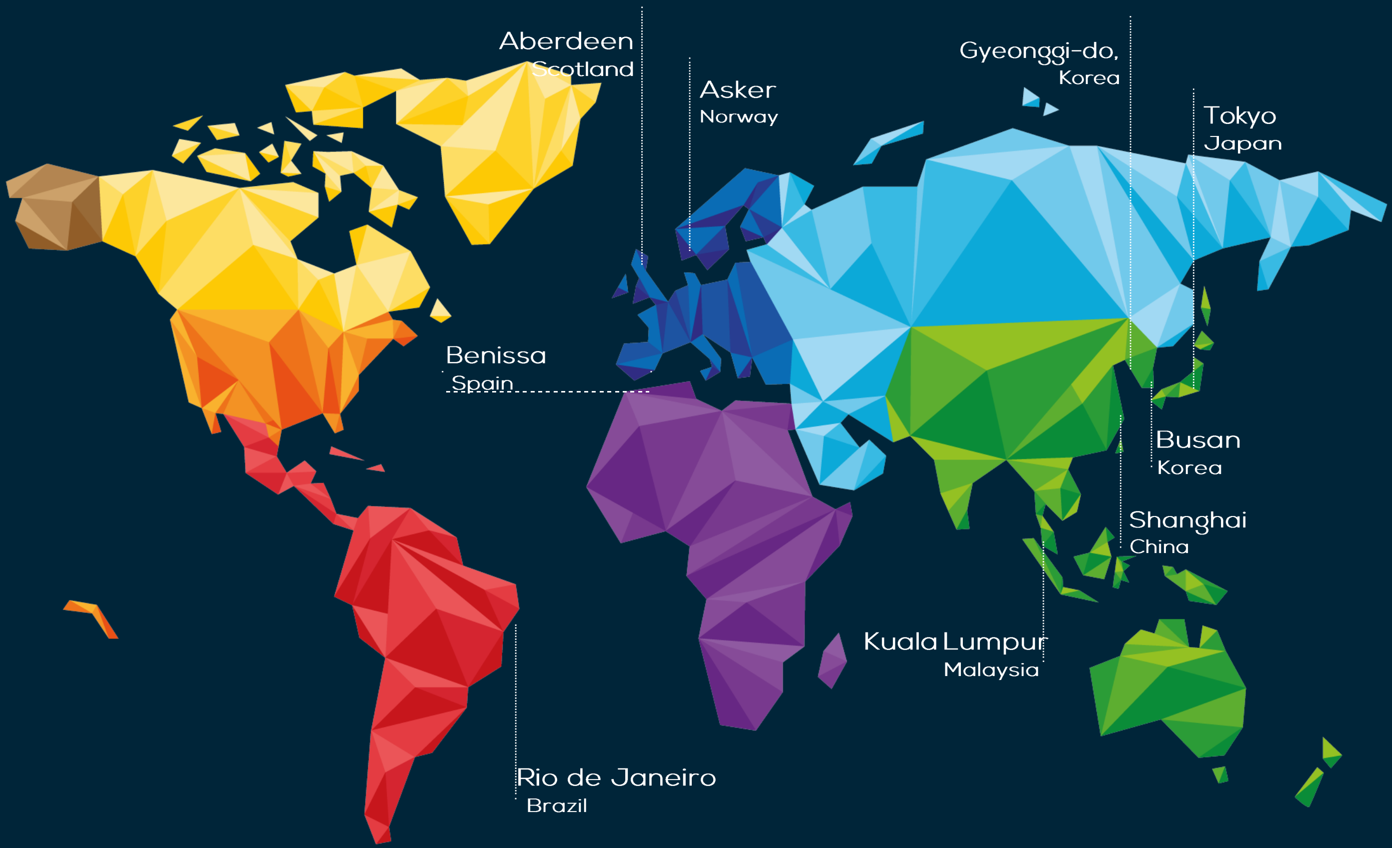

SERVICE AND SUPPORT

Miros has experienced personnel supporting and servicing Miros technologies and installations worldwide. Miros supports customers both on long-term services contracts and with ad hoc services as needed.

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