Marelec 2009 Speaker Abstracts

Day: Tuesday **Session:** Plenary **Time:** 10:45 **Location:** Spegelsalen	**Wiring the underwater environment** **Professor Nigel Edwards, Professor of Physics, University of Toronto, Canada**
Day: Tuesday **Session:** Plenary **Time:** 11:25 **Location:** Spegelsalen	**Title to be confirmed** **Dr Geoff Garnett, dstl Winfrith, United Kingdom**
Day: Tuesday **Session:** 1: Environmental Noise **Time:** 13:30 **Location:** Spegelsalen	**Coastal Mixing and Magnetics Project A Quantified Approach to an Accelerated Research Initiative** **Dr. John Holmes, Senior Scientist, Naval Surface Warfare Center, United States** The Coastal Mixing and Magnetics (CMM) project is designed to be an Accelerated Research Initiative (ARI). The site for the CMM experiment is at the Naval Surface Warfare Center, Carderock Division South Florida Ocean Measurement Facility on Florida's southeast coast. The ocean test site is located at the narrowest point of continental shelf and extends from shore to 300m of water. This region is characterized by high currents and tides, which lead to internal waves, strong shear, and vertical mixing which act to redistribute temperature, salinity and density that affect magnetic and electric fields within and about the ocean. The study concerns the investigation of physical oceanographic and magnetic relationships via measurable physical and magnetic properties. The overall research objective is to determine how magnetic and electric fields respond to physical forcing under various oceanic conditions on a narrow continental shelf (deep water close to shore) off the east coast of the United States. The paper establishes the requirement for the test, provides the reader the information necessary to determine the validity of the test and how it relates to the overall magnetic signature measurement problem, and provides the information necessary for the experiments initial planning, funding and scheduling. Specific detailed calculations are provided to justify the sensor methodology and overall approach to modeling and measuring the physical oceanographic and magnetic relationship.
Day: Tuesday **Session:** 1: Environmental Noise **Time:** 13:55 **Location:** Spegelsalen	**Influence of Internal Wave Ocean Dynamics on Magnetic Surveys** **Mr. Will Avera, Geophysicist, Naval Research Laboratory, United States** Previous work has predicted the magnitudes of induced magnetic fields generated in the ocean by surface waves, small amplitude internal waves, and tides. While platform, geologic, and ionospheric noise sources are large low frequency contribution for magnetic surveys, progress has been made in reducing these contributions to the data. Oceanographic features are also a major contributor to the ambient noise environment, and the contribution has not been adequately recognized so that successful removal could be accomplished. New magnetic sensors and data analysis techniques have reduced the system and platform noise to the point that ocean noise sources are important components of the residual magnetic fields. In this paper, a high resolution non-hydrostatic model is used to hindcast the circulation within the coastal ocean. The circulation includes mesoscale and submesoscale dynamics and large amplitude internal waves. The ocean flow fields are re-gridded into smaller cells and represented by three perpendicular electric current elements scaled to the velocity and earth field. The magnetic field contributions from each of the elements are combined to produce an estimate of the observed magnetic field at points along profiles across the model area. The ocean hindcast is computed for a shallow region off the coast of New Jersey over the shelf and slope in the summer of 2006. Predictions of the associated magnetic field are generated for an airborne magnetic sensor in a region roughly 90 km square. The resulting fields are analyzed to determine an estimate of the ocean contribution for an airborne magnetic survey using a total field magnetic sensor. Preliminary results

	indicate variations on the order of more than +/- 0.5 nT across the model region associated with the ocean flow. These results are significantly greater than the noise levels of modern day magnetic survey equipment and can be an important source of noise in surveys.
Day: Tuesday **Session:** 1: Environmental Noise **Time:** 14:20 **Location:** Spegelsalen	**<u>Ranging in electromagnetically noisy environments</u>** **Dr Samantha Davidson, Research and Software Team Leader, Ultra Electronics PMES, United Kingdom** The Earth's magnetic field contains not only dc and slowly varying components but also ac components including ionospheric and magnetospheric effects. This can be especially true nearer the poles. At some range locations and for some periods it is found that the level of magnetic noise is sufficiently large to downgrade range performance. Noise can also arise from man-made sources, e.g. trains and power systems, which can impact both magnetic and electric signatures of multi-influence range systems. The standard method of improving magnetic range performance and removing a proportion of this noise is with the use of an Earth's Field Reference (EFR) sensor. However there are many practical problems in finding an appropriate location for the EFR sensor away from the range and any other sources of magnetic field e.g. other passing ships. Also the effects of magnetic noise arising from wave motion and local magnetic anomalies can produce non-coherent effects that are different to those measured at the range. Given that the advantages of not using an EFR are both practical and financial, an alternative method is proposed. In this paper, the effects of coherent and non-coherent noise on the performance of an Ultra Electronics Transmag modelling range are investigated. An alternative method of removing coherent noise is described which utilises only the sensors of the range, with no separate EFR.
Day: Tuesday **Session:** 2: Underwater Surveillance **Time:** 15:30 **Location:** Spegelsalen	**<u>Application of target-based and noise-based methods in magnetic anomaly detection systems</u>** **Dr Boris Ginzburg, Senior Researcher, SOREQ NRC, Israel** The magnetic anomaly detection (MAD) technique started during the World War II for the anti-submarine warfare. A major progress was made during the 'cold war' where each side spent efforts to detect the underwater vessels of the opponents. Assuming a magnetic dipole field for the target, its signal decreases with the cube of the distance from the sensor which results in a relatively short detection range. On the other hand, MAD is a passive technique that enables the searcher to stay unexposed, which is beneficial over active sensing methods. The static magnetic field is practically transparent to many sorts of soils as well as water. The advantages of MAD make it attractive for detection of ferromagnetic targets. MAD can be used either as a single detection technique or as a part of multi-channel/multi-sensor system, through data fusion with other methods. In this work we analyze two different approaches in building of effective MAD algorithm. The first one is based on a certain assumption concerning mutual sensor-target movement. It is a typical situation for magnetic search systems when a path of sensor-carrying platform is preprogrammed and its spatial location is continuously measured by positioning system while a target is quasi-static. For MAD-based warning systems with fixed sensors position this pertains to the cases where a target movement obeys specific track-time pattern. We demonstrate this approach with an example of differential magnetometer which comprises a couple of three-axis magnetometers. External Earth's magnetic field components along each magnetometer axis are removed either by analog high-pass filtering or digitally. Then the total field is calculated separately for each three-axis magnetometer. Afterwards, the total field obtained from one magnetometer is subtracted from the other, resulting in a differential (gradiometric) signal. We address the case of a static differential magnetometer (gradiometer) aiming to detect a moving ferromagnetic target. Note that the analysis for opposite case (static target, moving gradiometer) is similar. We use several assumptions regarding the movement of a ferromagnetic target in the vicinity of the gradiometer: target magnetic field can be correctly represented as being produced by a single magnetic moment; target magnetic moment is fixed; target moves along a straight line track with a constant velocity. Under these assumptions we decompose the variety of target signals into a set of principal components. We obtain these components by means of computer simulation followed by principal component analysis (PCA). These principal

	components are the basis functions (BF) used to construct an efficient detector. The detector was tested by numerous computer simulations proving high detection probability. Simulation results were supported by real-world acquired magnetic signals. Similar PCA technique can be successfully used for any other path-time pattern of target movement, for instance, for targets moving along a non-straight line track. Another approach to MAD algorithm should be applied in the situation when no tentative assumption concerning mutual target-sensor movement can be made. In this case, in contrast to methods that rely on possible target signal waveforms, we use methods based on statistical analysis of magnetometer noise. We analyze proposed adaptive minimum entropy detector (MED), which detects any change in the magnetic noise pattern. Statistical evaluation of the magnetometer noise is implemented in a moving window. The anomaly in the measured magnetic field which is produced by a ferromagnetic target changes the pattern. We use entropy function value for quantitative description of the change in magnetic noise statistics. Existence of a magnetic anomaly is revealed by a drop in the entropy value below a predetermined threshold. The MED was tested on a real-world magnetic noise acquired by a fluxgate magnetometer and proved good detection characteristics. Appreciable advantage of the MED over the BF-based detector is shown, when the target does not move according to the assumed pattern.
Day: Tuesday **Session:** 2: Underwater Surveillance **Time:** 15:55 **Location:** Spegelsalen	**Electromagnetic signature feature extraction by time-frequency domain analysis for ship underwater identification** **Dr Odara Thongsamouth, Scientist, Royal Military Academy, Belgium** In the scope of mine countermeasure and ship underwater detection, we have taken a great interest in signature analysis. One of the influences that can be used by a smart mine is the electromagnetic field. The alternative magnetic and electric signatures of a ship can be represented in a temporal or a spectral form. In the temporal representation, the most common parameters examined in the mine algorithms are the amplitude, the rate of rise or the time intervals between different points of the signal. In the frequency representation, one can have a closer look at the position and the amplitude of the spectral lines. In this paper we propose to compare the spectrogram of the ships. We use a time-frequency domain analysis of the measured electromagnetic signals combined with a concept of center of field and singular value decomposition to tell apart two ships. The concept of center of field is an analogy with the concept of center of mass. The idea is that the source distribution is unique, in intensity and frequency, for each ship and similar for two ships of a same class. The center of mass of a system is a mass average weighted by distances. By analogy we compute the field average weighted by specific variables considering a given system of reference. The variables are the registration period and the frequency range. The singular values are another kind of features that we extract from the spectrogram matrix for comparison. The magnetic and the electric sources do not necessarily coincide in a vessel. The magnetic and the electric signatures are then considered independently.
Day: Tuesday **Session:** 2: Underwater Surveillance **Time:** 16:20 **Location:** Spegelsalen	**Surface effects of in-water turbulence resulting from flow over shallow variable seabed topography** **Dr Neil Stapleton, Principal Scientist, Dstl, United Kingdom** Our present understanding of the processes that lead to the appearance of shallow bathymetry and internal waves in radar images cannot adequately explain all observations. Standard imaging models under-predict observed modulations in radar image intensity, where the radar look (range) direction is aligned parallel to crests of sandbanks and internal waves. For the case of shallow, submerged sandbanks imaging models also predict very weak modulations, regardless of the radar-look direction, when tidal flow is aligned with the crests of sandbanks. Notably, these models neglect turbulent and secondary flow effects. However, it has been shown that turbulence interacts with surface waves and this can alter radar image intensity. It is now possible using Large Eddy Simulation (LES) techniques to model turbulence down to sub-metre scales over a 3-D domain that is sufficiently large to represent the effects of real, operationally significant, variations in bathymetry. LES is used to simulate the tidal flow over small, realistically sized, sandbanks and the effect of free surface turbulence on short surface gravity waves travelling initially along the sandbank crest, in the direction of the mean flow, is investigated. This geometry corresponds with the case where radar imaging models are known to grossly under-predict radar intensity modulations. The results obtained confirm that surface waves interact strongly with and are scattered by the turbulent velocity field. In

	particular, short waves appear to propagate about large angles with respect to the initial propagation direction aligned parallel with the sand wave crests.
Day: Wednesday **Session:** 3: EM Fields **Time:** 09:30 **Location:** Spegelsalen	**<u>Basic Study of Underwater Laser Propagation for High Speed Underwater Vehicle Communication</u>** **Dr Hiroshi Yoshida, Researcher, JAMSTEC, Japan** The evolution of electrical and electronic engineering technology over the last decade has led to improvements in the development of autonomous underwater vehicles (AUVs) and wireless remotely operated vehicle (wireless ROV) enabling them to go where tethered vehicles or manned vehicles have trouble reaching, such as under the ice, other dangerous zones, and into the deepest depths. These vehicles frequently have more effective and high resolution observation tools, such as high definition (HD) cameras, mega pixel snap shot cameras, multi-beam echo sounders, and synthetic aperture sonars. The high resolution observation devices output huge image data. The recorded image data are uploaded by cables on a mother ship after recovering the vehicles because underwater communication has limited to acoustical communication which can transmit data with transmission rate of up to a few hundreds kbps. If the data are retrieved without cables during the vehicles cruising, we can save many steps of underwater survey operation. The underwater laser communication is one of its solutions. In 2008, underwater laser propagation measurement started to design an HD camera image transmission system for AUVs. There are some underwater laser propagation data but less data of laser propagation in deep sea. We, first, have developed measurement tools: devices for transmission loss measurement on board and in deep sea and beam scattering measurement devices. It is well known that in some deep sea environment much marine snow blocks thin laser beam. To avoid this we have developed a beam expansion system. We have measured laser propagation and scattering characteristics in sea water by using the on board measurement devices. Sea water samples were gathered from around Japan but sample depths were limited to surface area until now. We obtained propagation loss of 0.6 dB/m with sea water sampled in open ocean. Mitsubishi Electric has developed small semiconductor blue and green laser modules with output power of 10 Watts. We can develop a small laser communication system by using this module, and estimate communication range of about 100 m if bit rate is 20 Mbps or less. In this March, we carry out a deep sea experiment of laser propagation in depth of up to 1000 m. In the conference we will report concept of the laser communication system, experimental system developed, and measurement results.
Day: Wednesday **Session:** 4: Underwater Surveillance **Time:** 09:30 **Location:** Bellmansalen	**<u>Capacity of an electromagnetic gantry to protect an underwater access against intruder</u>** **Mr Hugues Henocq, Underwater Electromagnatics Engineer, DCE/GESMA, France** In this article, we present a method we have simulated in order to evaluate the capacity of a submarine “electromagnetic gantry” to detect the presence of an intruder (diver, UUV…) in an underwater access to protect. We show that the impedance variation of the sea medium generated by this presence could be observable on the variation of the currents circulating between 2 bidimensional grids, one of injection and one of reception, placed on each side of the underwater access to be protected. Several detection methods, taking into the effects of tide and swell, were developed. We got encouraging results even on weak variations. In particular, a technique of detection of movement using 2D intercorrelation coming from image signal processing has been developed. This approach can allow to detect a moving object slightly visible and, also, to deduce its speed.
Day: Wednesday **Session:** 3: EM Fields **Time:** 09:55 **Location:** Spegelsalen	**<u>Multipole representation of the magnetic field vector and gradient tensor of extended magnetic sources: Conventions, expansion through hexadecapole order, simplified formalism, and an alalysis of the inverse problem</u>** **Dr Mike Wynn, Distinguished Scientist, Naval Surface Warfare Center, United States** In many applications of magnetic sensors the source is seen at distances of several times the major dimension of the source, and the source can conveniently be modeled as a point magnetic dipole. There have been extensive treatments of this type of source, and much effort has been devoted to tracking moving dipole sources with stationary sensor arrays and localizing

	stationary dipole sources with mobile magnetic sensors. There are applications in which the source is too close to the sensor array to be modeled as a point dipole, but too far away to make a detailed map of its internal structure. It is desirable to have a well-founded treatment of such sources that will allow extension of the existing dipole tracking and localization algorithms to moderately extended sources. This paper documents a detailed development of the magnetic multipole representation of moderately extended magnetic sources up to and including hexadecapole contributions. It includes details of the definition of the multipole moments and the reduction of the moment tensors to their symmetric traceless Cartesian forms. The paper then develops explicit expressions for the magnetic field vector and gradient tensor for each order of multipole, in terms of the minimum number of parameters necessary for that order expressed as a column matrix. Here, n ranges from 1 for the dipole source to 4 for the hexadecapole source. The mappings between the minimal parameter sets and the full symmetric traceless Cartesian tensor representations are given in the form of simple sparse matrices. The well-known issue of defining unique multipole moments above the lowest non-vanishing order is dealt with by introducing the concept of centroid of magnetization for a distribution of magnetic material. This report provides an explicit construction of the centroid and the symmetric traceless Cartesian multipole tensors for a finite collection of point magnetic dipoles, and then uses the representation to precisely test the theoretical derivation of the dipole and octupole moments of a fully ellipsoidal permeable shell in a uniform background magnetic field. (Provided in a companion paper presented at this conference). We conclude the paper with an analysis of the inverse problem, in which a magnetic source is observed in time from an array of magnetic sensors, and the data is used in a least squares model, with singular value decomposition, to find the optimal multipole moment set and location by means of gradient search. We compare the resulting multipole set and location to the forward computation of magnetic centroid and multipole moments for the known source distribution, and discuss the significance and utility of the inverse process.
Day: Wednesday **Session:** 4: Underwater Surveillance **Time:** 09:55 **Location:** Bellmansalen	**<u>Magnetic Sensors Operated from Autonomous Underwater Vehicles For the Application of Buried Target Identification</u>** **Dr Ted Clem, Magnetic Sensor Technology Manager, Naval Surface Warfare Center, United States** The Office of Naval Research (ONR) currently has programs to develop, test, and demonstrate sensors to detect, classify, and localize (DCL) buried targets while operating onboard autonomous underwater vehicles (AUVs). Under the current concept of operations, search-classify-map (SCM) operations with a relatively high area search rate are performed by an AUV hosting sonars actively generating low-frequency acoustic pulses to penetrate the bottom sediments and to receive return signals scattered back by a target. The DCL of buried targets is obtained either through interpretation of images or through the interpretation of the frequency response of the scattered return. Based on results from the SCM mission, contacts of interest are then reacquired at close range by AUV-based systems with suites of acoustic, magnetic, and electro-optic sensors to provide confirmatory classification of the SCM contacts. Fusion of data from these sensors is being pursued to increase the confidence that a target classified as a mine in the initial SCM operation is, in fact, a mine or not. The ultimate goal is to establish statistical confidence high enough that the Fleet is willing to declare the SCM contact as a mine; i.e., to reacquire and identify (RI) buried contacts in cases where optical imaging is not sufficient. Under the ONR Program, two prototype Buried Mine Identification (BMI) Systems have been integrated with suites of magnetic, acoustic and electro-optic sensors, one onboard a Bluefin12 AUV and a second onboard a REMUS 600 AUV. Both systems have participated in multiple tests, including ONR-sponsored AUV-Fest demonstrations in 2007 and 2008. The Bluefin12 BMI System features the Real-time Tracking Gradiometer (RTG), which is a multi-channel tensor gradiometer using conventional fluxgate technology with a novel electronic feedback system to increase sensitivity for mobile operations. The RTG consists of four fluxgate vector triads, three of these triads are used to construct six rank-2 tensor gradient components of which five are independent. The magnetic-field components measured by the fourth triad are used in the feedback system to drive coils that null the magnetic fields around the primary triads and are used additionally as reference sensors to further cancel noise through software correction. The REMUS 600 BMI System features a high-performance passive magnetic Laser Scalar Gradiometer (LSG). This sensor

	measures changes in the light absorption of helium-4 gas that arise from changes in magnetic field. It features a laser as the light source in order to obtain a significant increase in sensitivity over that obtained in similar sensors employing incoherent light as the light source. The LSG consists of four volume-filling helium-4 cells, which provide the measurement of the vector gradient of the local scalar magnetic field along with the local scalar field. Although the magnetometers for these two sensors measure different physical quantities, vector-field components in the case of the RTG and scalar components for the LSG, their signal processing is similar, providing estimates of the position and magnetic moment for targets that can be modeled as magnetic dipoles. In this paper, we will provide an overview of the two BMI systems. Then we discuss the RTG and the LSG technologies, their respective system configurations, and their data analysis and products. Then we will present results obtained from testing of these two systems, providing examples of the combined data products obtained by fusing the magnetic data along with the acoustic and optical data. Finally, we will discuss our future plans, specifically to implement a capability for embedded data processing operating autonomously in near real time.
Day: Wednesday **Session:** 3: EM Fields **Time:** 10:20 **Location:** Spegelsalen	**General treatment of a fully ellipsoidal permeable shell in a uniform magnetic field: Field vector, gradient tensor, multipole moments, and a test of a general multipole formalism** **Dr Mike Wynn, Distinguished Scientist, Naval Surface Warfare Center, United States** The problem of a solid dielectric ellipsoid in an external electric field is a textbook solution developed in, for example, Stratton's Electromagnetic Theory. Why would anyone write a paper for Marelec on the extension to a permeable magnetic shell in a uniform magnetic field? We argue that the additional information we present in this paper is not available elsewhere, and provides a number of useful results for applications, both theoretical and practical. We use Stratton's ellipsoidal coordinate conventions, but we write the potential everywhere in a form that bypasses the Cartesian coordinate sign ambiguity. We develop expressions for the "scattering coefficients" in all three regions that are simple, physically transparent, and directly usable for all cases, including axisymmetric (prolate and oblate shells) and the spherical shell. We compute the magnetic field vector and gradient tensor everywhere by means of implicit Cartesian differentiation of the defining ellipsoidal equation, followed by explicit factorization and singularity removal (producing results valid in the symmetry planes of the fully ellipsoidal shell). We develop explicit expressions for the magnetic dipole and octupole moments of the shell (higher moments are computed relative to the magnetic centroid, as discussed in a companion paper on magnetic multipole analysis presented at this conference). The multipole moments are calculated by an identification process that requires an implicit expansion of the inverse powers of the spherical range coordinate r in terms of the ellipsoidal "radial" coordinate ξ. The quadrupole and hexadecapole moments, defined and discussed in the companion paper, are identically zero due to the symmetry of the ellipsoidal shell relative to its magnetic centroid. The dipole and octupole moments for the axisymmetric cases follow directly from the general ellipsoidal result, and all moments above dipole order vanish for the spherical shell, as expected. As a powerful test of the complicated development in this paper and in the companion paper on magnetic multipoles, we generate a discrete representation of the ellipsoidal shell, using exact volumes and centroids for the elements in ellipsoidal coordinates. We then use the exact solution for the shell magnetization at each element centroid to produce a magnetic dipole cluster representation of the shell. We then show that the multipole moments calculated for the cluster, using the formalisim in the companion paper, agree precisely with the theoretical results discussed above. Numerical work is done using powerful algorithms from Numerical Recipes, including Ridder's method for root finding, and Carlson's iterative method for incomplete elliptic integrals. All of the computational tools for this paper are written in MATLAB code, and the documented source code will be available on DVD disk for any interested attendees.
Day: Wednesday **Session:** 4: Underwater Surveillance **Time:** 10:20	**Detection of fresh groundwater bodies within the Mediteranean sub-marine coastal aquifers offshore Israel using marine geoelectromagnetic methods** **Dr Mark Goldman, Head of the Geoelectric Department, The Geophysical Institute of Israel, Israel** The existence of relatively fresh sub-marine groundwater bodies extending offshore to distances between a few meters

Location: Bellmansalen	(submarine groundwater discharge – SGD) to several tens of kilometers (either SGD or trapped paleo-groundwater) was reported all over the world. Recent onshore time domain electromagnetic (TDEM) measurements carried out in Israel close to the shoreline showed the existence of fresh groundwater underlying seawater intrusion into the coastal aquifer (hydrologic reversal). In order to delineate the possible extension of fresh groundwater within the sub-bottom sediments, both onshore and offshore TDEM measurements were carried out near the city of Ashdod using grounded transmitter line located at the sea bottom. The induced transients were picked up by a horizontal coil also located at the sea bottom at different distances varying from 50 m to 500 m from the shoreline. All measurements showed the existence of relatively resistive structure within the seawater saturated sub-bottom sediments. Due to a low sensitivity of the measured signal with regard to geoelectric parameters of the target, both the resistivity and the thickness of the latter are poorly resolved. In order to increase the resolution of the signal, multi-component field measurements accompanied by joint inversion of the data will be carried out in the next stage of the research.
Day: Wednesday **Session:** 5: EM Fields **Time:** 11:40 **Location:** Spegelsalen	**<u>The Development of FRP-Propellers in the RNLN</u>** **Mr Piet v.d. Gaag, Naval architect, DMO, Netherlands** The Defence Materiel Organisation (DMO) started in 2000 a feasibility study for replacing the bronze propellers of the “Alkmaar” class Tripartite Mine hunters (MCMV) of the Royal Netherlands Navy (RNLN) to propellers of fibre reinforced plastic (FRP). A technical demonstration of the design, production and application of two fibre reinforced plastic (FRP) rudder propellers, having a six bladed fixed pitch, has been undertaken during the years 2001 to 2005. The aim was to reduce Life Cycle Costs (LCC), the electromagnetic signature and eliminate the cavitation-erosion phenomena caused by electric corrosion currents; so the acoustic ship signatures will be reduced as well. In the 2005 a feasibility study for the main propeller, a five bladed controllable pitch propeller, of the “Alkmaar” class MCMV’s has been performed by the company Airborne Development and the institute MARIN in the Netherlands. Based on this study a detailed engineering phase was executed and in 2007 the production of the first FRP-propeller blade started. Last year strength and stiffness tests with the first blade were carried out in the laboratory. End 2009 the five FRP-propeller blades will be delivered to be mounted on a MCMV to start sea trials and electromagnetic and acoustic signature measurements. In this document the LCC will be discussed, the electric signature reduction ratio will be presented and test results of the FRP propeller will be evaluated.
Day: Wednesday **Session:** 6: Underwater Surveillance **Time:** 11:40 **Location:** Bellmansalen	**<u>Recursive Bayesian method for magnetic dipole localization with a tensor gradiometer</u>** **Dr Marius Birsan, Defence Scientist, DRDC Atlantic, Canada** This paper describes a numerical method that may be used to efficiently locate and track magnetic targets using data collected by a tensor gradiometer. A target containing ferromagnetic material can be adequately modeled at a distance by an equivalent magnetic dipole. This magnetic target can be observed by means of a magnetic gradiometer that measures a symmetric, traceless gradient tensor as a function of time. Of interest is the inverse problem of the determination of the magnetic parameters of the target, and its position and velocity relative to the sensor at each time step. The previous method (W.M. Wynn et al.) of direct inversion of the non-linear equations of the magnetic gradient tensor provided multiple solutions, and the results can be highly sensitive to noise in data. In this study, the determination of target magnetic moment, position and velocity is formulated as a Bayesian estimation problem for dynamic systems, which could be solved using a sequential Monte Carlo based approach known as the ‘particle filter’. These filters represent the posterior distribution of the state variables by a system of particles which evolve and adapt recursively as new information becomes available. In addition to the conventional particle filter, the proposed tracking and classification algorithm uses the unscented Kalman filter (UKF) to generate the prior distribution of the unknown parameters. The proposed method is then demonstrated by using it to locate and track an automobile over a period of time using real data collected with a magnetic gradiometer. The automobile was moving either on a straight or a curved track.

Day: Wednesday **Session:** 5: EM Fields **Time:** 12:05 **Location:** Spegelsalen	**The ELF magnetic field generated by the rotation of the NAB propeller** **Dr Marius Birsan, Defence Scientist, DRDC Atlantic, Canada** The non-acoustic signatures are widely recognized as an important component of the underwater detection. In addition to the ferromagnetic effect, other sources of electromagnetic (EM) signature are taken into consideration, such as UEP, ELF, corrosion related magnetic (CRM) and eddy currents due to the pitch and roll. This paper presents a source of ELF magnetic signature not previously described in literature. Galvanic currents flowing in the water around the hull and in the hull generate underwater electric potentials (UEP). These potentials are responsible for both the CRM and ELF signatures. The rotation of the shaft(s) modulates the galvanic current passing through the shaft-bearing-hull and thus an AC EM signal (ELF) is generated into the water. Analysis of the recorded signals shows that the ELF EM components correspond closely to the fields excited by a horizontal electric dipole source moving with the ship. This signature is usually eliminated by (passive or active) shaft grounding. The ELF EM signal from several ships was analyzed using the cross wavelet transform and wavelet coherence. The phase angle statistics demonstrated the presence of an additional ELF magnetic signature component that was identified as being generated by a rotating vertical permanent magnet. The only vertical part of the ship rotating with the same frequency as the shaft is the Nickel Aluminum Bronze (NAB) propeller, which also contains 3-5% of iron. The paper presents the measurements and the investigation methodology that led to the separation of the additional ELF component and to the calculation of the magnetic moment that caused it. Due to its source, this signal cannot be eliminated by shaft grounding, so that other measures to reduce it are needed.
Day: Wednesday **Session:** 6: Underwater Surveillance **Time:** 12:05 **Location:** Bellmansalen	**Development and applications of a universal dipole model** **Mr Cye Waldman, Senior Scientist, ISL, United States** Development of a Universal Dipole Model—Part I: Theory **Dr. Cye Waldman, ISL** A universal dipole model has been developed for a horizontal electric dipole in a layered medium. The analytic (closed-form) solution contains a single range parameter that defines the complete morphology of all the vector components in addition to the attenuation of the field with range. The range parameter can vary between 2 and 3. The solution is exact at these limits and gives the two- and three-dimensional solutions for a dipole, respectively. Physically, the two-dimensional solution is approximated in the case where the dipole is in a conductive medium bounded on both sides by very low conductivity media and the observer is at a range greater than the thickness of the medium. This has important implications for dipoles in littoral waters. The analytic nature of the solution reveals many properties of the dipole field. In particular, it is shown that a moving dipole exhibits similarity solutions that are dependent only upon the range parameter and the characteristic time of the transit. Moreover, in the two-dimensional case, the horizontal components, E_x and E_y are not independent but can be derived, one from the other, through the Hilbert transform. The universal dipole can be expressed in both similarity and physical space coordinates. This paper (Part I) presents a physical and mathematical description of the problem leading to the universal dipole solution. The model is developed heuristically as an ansatz solution, and then it is shown how it is formally derived as an approximate solution to Maxwell's equations under certain simplifying assumptions. Development of a Universal Dipole Model—Part II: Signal Processing Applications **Dr. Michael Larsen, ISL**

	In this part of the paper several examples of using the universal dipole model for underwater electromagnetic signal processing applications are provided along with comparisons of predicted theoretical results and observed performance from experimental data. The model lends itself well to development of signal processing algorithms for detection, localization, tracking, matched filters, lateral range performance, and receiver operating characteristics. A simplified matched filter bank which utilizes the analytic solution for the detection of underwater anomalies is detailed along with multi-component detection algorithms which exploit the correlated nature of the horizontal field components. Several independent localization algorithms which also exploit the properties of this model are also presented. Results are supported with Monte Carlo simulations using experimentally measured background data and validated with data collected using a towed electric field source.
Day: Wednesday **Session:** 5: EM Fields **Time:** 12:30 **Location:** Spegelsalen	**<u>Magneto-mechanical effects under low fields and high stresses Application to a ferromagnetic cylinder under pressure</u>** **Mr Antoine Viana, PhD student, ENSE3, France** This study focuses on the effects that a ferromagnetic material undergoes when subjected to high stresses under low magnetic fields. In order to predict the magnetic signature, the Jiles-Atherton law of approach is used, and an analytical solution is derived in the case of our prototype, a ferromagnetic cylinder subjected to an internal pressure up to 100 Bars. Measurements using magnetic sensors were led at the LMMCF (Laboratory of Magnetic Metrology in Weak Fields – Grenoble France). Comparison between the model predicted signature and the measurements shows the error is less than 1%. The magnetic signatures expose all ferromagnetic vessels to risk from mines. Given the risk to seamen, the military handicap borne when a defense vessel is hit, and the economical costs, magnetic signature reduction for warships is essential. Research in magnetic silencing is directed towards designing magnetically quiet vessels and on reducing the magnetic signatures of currently operational vessels. In view of the service lifetime of vessels, the latter aspect has perhaps received more attention. Deperming methods and degaussing systems are used, but are unable to deal with the drastic variations of the permanent magnetization induced by high level of stresses. In order to investigate such effects, a ferromagnetic cylinder under internal pressures in a 0-100 Bars range was designed. Magnetic signature was measured using sensors. The objective consists in exhibiting a predictive model for the variations of magnetization expected after the application of pressure under a vertical or longitudinal inductor field. Our study is based on the Jiles-Atherton law of approach. We show this model can be used to derive an equation for the signature measured by sensors, and an analytical is solution is found for the cases where the inductor magnetic field is either vertical or longitudinal. Measurements show good agreement (error < 1%) with the expected behavior in both cases.
Day: Wednesday **Session:** 6: Underwater Surveillance **Time:** 12:30 **Location:** Bellmansalen	**<u>The Method of Auxiliary Sources for Marine EMI scattering problems</u>** **Prof. Fridon Shubitidze, Assistanat Professor, Dartmouth College, United States** Electromagnetic induction (EMI) sensing has been identified as one of the most promising technologies for detecting and discriminating underwater Military Munitions (MM). However, in order to achieve a high (~100%) probability of detection, and to distinguish MM from non-MM items accurately and reliably, first the underlying physics of EM scattering phenomena in marine environments needs to be investigated in great detail. This can be achieved by modeling EMI scattering phenomena in a conducting environment using an accurate 3D numerical code. One of the high fidelity models for studying the EMI scattering phenomena from a highly conducting and permeable metallic object is the method of auxiliary sources (MAS). The MAS is a numerical technique, originally designed for solving various electromagnetic radiation and scattering problems. It has been demonstrated that the MAS is a robust, easy to implement, accurate and sufficient method for studying a wide range of electromagnetic problems, such as investigation of waveguide structures, antennas , scattering , electromagnetic wave propagation in complex media, etc. Later MAS was successfully applied for analysis of low frequency electromagnetic

	induction scattering phenomena from highly conducting and permeable metallic objects placed in free space. In standard MAS for EMI, boundary value problems are solved numerically by representing the electromagnetic fields in each domain of the structure under investigation by a finite linear combination of analytical solutions of the relevant field equations, corresponding to sources situated at some distance away from the boundaries of each domain. The "auxiliary sources" producing these analytical solutions are chosen to be elementary currents/charges located on fictitious auxiliary surface(s), usually conforming to the actual surface(s) of the structure. In practice, at least as the method is realized here, we only require points on the auxiliary and actual surfaces, without resorting to the detailed mesh structures as required by other methods (finite element method (FEM), boundary element method (BEM) etc). The two auxiliary surfaces are set up inside and outside the penetrable scattering object. Specifically, the fields outside of the structure are considered to originate from set auxiliary sources placed inside the object, and the fields penetrating inside the object arise from a set of auxiliary sources placed outside the object. The fields constructed inside and outside of the object are required to obey the continuity of the tangential magnetic field components and the jump condition for the normal magnetic field component, at an array of selected points on the physical surface(s) of the structure. The results are matrix equations in which the amplitudes of auxiliary sources to be determined. Once the amplitude of auxiliary sources is found the solution is complete; the magnetic or electromagnetic field and related parameters can easily be computed throughout the interior and exterior domains. Numerical experiments are conducted for homogeneous and multilayer targets of canonical (spheroidal) shapes subject to frequency- or time-domain illumination as well as for heterogeneous MM like targets, to demonstrate how marine environments change EMI sensor performance and associated processing approaches for detecting highly conducting and permeable metallic objects underwater. Particularly, the results illustrate coupling effects between the object and its surrounding conductive medium especially at high frequencies (early times for time-domain sensors). The results also suggest that this coupling depends on the objects material properties, and the distance between the sensor and the object's center.
Day: Wednesday **Session:** 7: Inverse Modelling **Time:** 14:00 **Location:** Spegelsalen	**Closed Loop Degaussing System Applied to a Double Hull Submarine Mock-up** **Dr Yannick Vuillermet, Research Engineer, Grenoble Electrical Engineering, France** One of the most efficient way to ensure the magnetic discretion of a vessel would consist in setting up a closed loop degaussing system on board. The principle is based on a real-time anomaly evaluation by using internal magnetic sensors. As a consequence, current in degaussing coils can be adjusted to compensate any change in magnetization. The Low Magnetic Field team of G2Elab (previously Ship Magnetism Laboratory - LMN), the DGA and the DCNS are particularly involved in the development of a closed-loop degaussing system dedicated to ferromagnetic hull ships [1][2][3][4], in particular submarines. The present study deals with a specific double hull submarine structure (figure 1). Sensors are located between the two ferromagnetic hulls, very closed to ferromagnetic material. An inverse problem is solved to obtain the hull magnetization from measurements. Then the submarine signature is evaluated. A specific algorithm has been developed and validated by measurements. A submarine mock-up, of about 3.5 meter length, has been designed, built and set inside our magnetic metrology facility (LMMCF, [5]). It has been instrumented with 80 fluxgate sensors (figure 1 an figure 2). For a given magnetic state, the two hull magnetization is obtained by inverse problem (figure 3). Then, the predicted signature is compared to the measured one: it shows a very good agreement (figure 4).
Day: Wednesday **Session:** 7: Inverse Modelling **Time:** 14:25 **Location:** Spegelsalen	**3D focussing inversion of multi-transient EM data in the frequency domain** **Mr Johnathan Linfoot, Project Manager: Processing and Inversion, PGS, United Kingdom** We have produced an inversion code for frequency-domain controlled source EM data based on the 3D MT focussed inversion method developed by the Consortium for Electromagnetic Modelling and Inversion (CEMI). Broad-band frequency-domain data are easily determined from a knowledge of the earth's impulse response obtainable using the transient EM approach. The data are recorded by profiling an inline source and receiver spread resulting in measurements of the inline field

	at a series of offsets along the survey line. A rigorous integral equation (IE) based forward modeller and regularized focussing inversion are employed. The method is efficient since Green's tensors need to be precomputed only once and saved for multiple use at every iteration of inversion. The saved Green's functions are then available to be used for the Fréchet derivative calculation required for every iteration. In addition, forward modeling is required only once for each iterative step, resulting in a relatively fast but rigorous inversion method. To obtain a stable solution for blocky geological structures, we apply a regularization method based on a focussing stabilizing functional (Zhdanov 2002, Zhdanov et al. 2008). This stabilizer helps generate a sharp and focussed image of the anomalous resistivity distribution. The methodology is tested on a synthetic marine EM data set which presents a typical offshore petroleum scenario.
Day: Wednesday **Session:** 7: Inverse Modelling **Time:** 14:50 **Location:** Spegelsalen	**3-D Time-lapse modelling and inversion of multi-transient EM data over the North Sea Harding field** **Mr Johnathan Linfoot, Project Manager: Processing and Inversion, PGS, United Kingdom** We present results of a 3-D time-lapse multi-transient electromagnetic (EM) modelling experiment conducted over the North Sea Harding field. The reservoir model petrophysical parameters of porosity and fluid saturation were converted to resistivity using Archie's law and the model was regridded for input to Pie3D EM modelling code. Synthetic data were calculated for different states of the reservoir from the initial state in 1996, through predominantly oil production to 2011, and finally through gas production to 2016. Unconstrained 1-D full-waveform Occam inversions of these data sets show that Harding should be detectable and its lateral extent should also be well-defined. Resistivity changes caused by hydrocarbon production from initial pre-production state to production of the oil rim in 2011 are discernible as are more signifcant changes from 2011 to 2016 during a modelled gas blow-down phase.
Day: Wednesday **Session:** 8: Inverse Modelling **Time:** 15:50 **Location:** Spegelsalen	**Ship Corrosion Diagnosis And Elf Prediction From Electrical Measurements** **Mr Arnaud GUIBERT, PhD Student, G2ELAB, France** To fight against corrosion reactions on a ship hull, two well known solutions exist, which have to be coupled with an efficient painting of the structure: the first one is the Sacrificial Anode Cathodic Protection (SACP) which introduces a metal less noble than iron. This metal is then the new anode of the reaction. The second one is the Impressed Current Cathodic Protection (ICCP) where new anodes (in platinum, gold, etc…) inject current in the electrolyte to passivate the iron. In both cases the reactions makes electrons spreading in the electrolyte from the anodes to the cathodes (the known noble areas and the unknown defects), inducing an electromagnetic field called ELF (Extremely Low Frequency). One purpose of this article is to present an original corrosion diagnosis method from electric potential or field measurement. From the knowledge of an underwater steel structure geometry and its different locations of anodes (SACP or ICCP), an algorithm based on the BEM method gives clues about the state of the hull. This diagnosis, also called "inverse problem" meet difficulties to obtain a solution fitting real measurements. Actually, getting a physical solution is quite complicated to get although mathematical equalities are verified. Some injection of information and regularization techniques is needed to make it work. This method provides boundary conditions on the hull: the electric potential and current density, synonymous of the corrosion repartition. Moreover, finding these boundary conditions permits an electromagnetic field computation anywhere in the domain by a further reconstruction with the BEM method. In concrete terms, from a signature measurement, the discretion prediction at all depth is available by calculation. Experimentations have been made in Grenoble laboratories to check those algorithms: mock ups under cathodic protection are drowned in a bowl, electrical measurements are performed in the water and a corrosion diagnosis is performed with successful results. Signature reconstructions at other depth are then carried out with results fitting to the real measurements.
Day: Wednesday **Session:** 8: Inverse Modelling **Time:** 16:15 **Location:** Spegelsalen	**On the modelling of electromagnetic soundings of Marine environments applied to electromagnetic ranging and surveillance in an Archipelago** **Mr Fredrik Silfverduk, Scientist, Swedish Defense Research Establishment - FOI, Sweden** We present a numerical study of the 3D transmission loss effects on an electromagnetic range and surveillance array in an

	archipelago. The objective here is to be able to perform a de-convolution of the data from the sensors with respect to environmental effects. In order to study this problem we generate synthetic survey data with the finite difference solver FDMX2D for an archipelago with islands, underwater ridges and variable sediment thicknesses. This data set is used to mimic different experimental configurations with bottom-mounted and towed sources and sensors. The problem is then formulated in terms of recovering a piecewise continuous spatial conductivity distribution from measurements of the electromagnetic fields in the water. This inverse problem is reformulated as a non-linear optimisation problem. Sub-bottom conductivity profiles are then determined using global as well as restarted local optimisation techniques. In particular, we compare the results obtained using stitched 1D models for the environment with the results obtained solving the 2D inverse problem along a survey-line. In order to test the solutions we define a figure of merit (FOM) in terms of the average dB difference between the measured and predicted fields. Finally, we compare the results of modelling with experimental data for a selected set of applications.
Day: Wednesday **Session:** 8: Inverse Modelling **Time:** 16:40 **Location:** Spegelsalen	**Recent Work at FOI on the Modelling of Controlled Source Electromagnetic (CSEM) Sounding of Oil Reservoirs** **Mr Jan-Ove Hall, Scientist, FOI - Swedish Defence Research Agency, Sweden** We present recent work on the modelling of Controlled Source Electromagnetic (CSEM) sounding of an oil reservoir. The problem is formulated in terms of recovering a piecewise continuous spatial conductivity distribution from measurements of the electromagnetic fields in the water. This inverse problem is reformulated as a non-linear optimisation problem and solved using local as well as global techniques. In order to study the CSEM technique, synthetic data is generated with the 3D electromagnetic solver PEMRAD for a set of reservoirs. This data set is used to mimic different experimental configurations with towed sources and sensors. Sub-bottom conductivity profiles are then determined using global as well as restarted local optimisation techniques. In particular, we compare the results obtained using stitched 1D models for the environment with the results obtained solving the 2D inverse problem along a survey-line. Here we analyse the stability and robustness of the estimated parameters and look at the behaviour of the 1D solution as the transmitter and receiver pass over the edges of the reservoirs. Finally, we compare these results with a full 3D solution of the inverse synthetic reservoir problem.
Day: Wednesday **Session:** 8: Inverse Modelling **Time:** 17:05 **Location:** Spegelsalen	**Forward magnetic ranging with towed sensors** **Bradley Nelson, Defence Scientist, DRDC - Atlantic, Canada** Magnetic ranging refers to the measurement of a naval vessel's magnetic signature at a standard depth below the keel to determine if it will trigger enemy mines. The results from this ranging can consist of a simple Pass/Fail criteria, (i.e. is the ship signature below some threshold and thus will not trigger a mine, or is it above the threshold so the vessel needs magnetic treatment), or it can be used to determine what treatment should be done to minimize the vessel's signature. Both types of ranging are usually conducted at dedicated facilities equipped with sea bottom-mounted sensors at known locations, and require the vessel to make multiple passes over those sensors on various headings. Electrical currents are adjusted in the vessel's degaussing system, or de-perming treatments are applied, until the signature threshold criterion is met. This requires the vessel to sail from its theater of operations to a friendly, dedicated facility which may be thousands of kilometers away. DRDC Atlantic is investigating a number of forward ranging systems including towing the Mobile Integrated Sensor Technology (MIST) system on the sea surface past the vessel. The concept of operations is to make multiple passes with the MIST system around the vessel on each of several vessel headings. The measured data are then used to model the permanent and induced magnetic sources on the vessel. The source model is then used to predict the magnetic fields at the standard depth below the keel. The developmental MIST system consists of two total-field magnetometers, four fluxgate vector magnetometers, and two GPS receivers mounted on a floating tow-platform. The system is towed on a 30 m cable by a small boat, where the associated electronics and data recording systems are located. Finally, two GPS antennas are mounted on the vessel to determine its position and heading. The MIST system has been used to measure the magnetic signature of the research ship *CFAV*

	QUEST with the degaussing system both ON and OFF. A magnetic model consisting of numerous permanent and induced dipoles, as well as degaussing coil effects, has been developed to fit the measured signatures. The magnetic fields predicted from that model have been compared to measurements taken at a Canadian degaussing range. This paper briefly describes the MIST system and the results of the latest experiment.
Day: Thursday **Session:** 9: Marine Electromagnetics and the Search for Hydrocarbons **Time:** 09:30 **Location:** Spegelsalen	**<u>Magnetic tensor gradiometry in the marine environment: correction of electric and magnetic field and gradient measurements in a conductive medium and improved methods for magnetic target location using the magnetic gradient tensor</u>** **Mr David Clark, Principal Research Scientist, CSIRO Materials Science and Engineering, Australia** The CSIRO Division of Materials Science and Engineering is developing sensitive magnetic tensor gradiometers, based on high-T SQUID technology, for deployment in the marine environment. The applications include gradient measurements as an adjunct to E and B field measurements in marine CSEM surveys, UXO detection in shallow water, and exploration for seafloor mineralization. Electric and magnetic fields within a conductive medium are perturbed by the measurement process. In particular, sensors located within or around an insulating measurement capsule measure fields that are modified by the diversion of conduction currents around the capsule. In air or free space the gradient tensor is symmetric, as well as traceless. In the presence of conduction currents the curl of B is non-zero and the gradient tensor is asymmetric. This raises the question of what is actually measured by magnetometers and gradiometers immersed in the electrically conductive ocean. In particular, how does the signal measured within a sealed capsule (within which the gradient tensor is symmetric) relate to the field components and the asymmetric gradient tensor that existed in the surrounding medium prior to insertion of the measurement package? This paper presents theoretical relationships between measured electric and magnetic fields and gradients and the corresponding quantities that would exist in the unperturbed medium, for a variety of geometries, including ellipsoidal measurement capsules. For example, for a small spherical cavity within an initially uniform horizontal quasistatic electric current distribution, bounded above and below by horizontal surfaces: the electric field within the cavity is parallel to the unperturbed applied field and larger by 50%, and the magnetic field at the centre of the cavity is equal to the unperturbed magnetic field that existed at the same point in the conductive medium, prior to insertion of the measurement capsule. The symmetric magnetic gradient tensor within the cavity is uniform. The only non-zero components are Byz = Bzy. These components are each equal to half the value of Byz that is produced by the unperturbed current flow in the conductive medium. Another important application of magnetic sensors is the detection, location and classification (DLC) of magnetic objects, such as naval mines, UXO, shipwrecks, and archaeological artefacts. A number of methods have been proposed for locating dipole targets from magnetic gradient tensor data and for dealing with the inherent four-fold ambiguity in obtaining solutions for dipole location and orientation of its moment from point-by-point analysis of gradient tensors. This paper presents a new, simple and efficient method for uniquely determining the location and magnetic moment of a dipole source from a short segment of gradient tensor data that is relatively free of contamination from background gradients, such as those of geological origin. A separate algorithm, which deconvolves gradient tensor data along a profile by separating scalar and vector aspects of the dipole inversion problem, will be described. This enables contamination from background gradients to be estimated and removed, thereby improving estimation of dipole parameters.
Day: Thursday **Session:** 9: Marine Electromagnetics and the Search for Hydrocarbons **Time:** 09:55 **Location:** Spegelsalen	**<u>New joint modeling and inversion approach of 3-D marine MT and CSEM data for hydrocarbon exploration</u>** **Prof Pascal Tarits, Professor, UBO-IUEM, France** With the rapid growing interest for marine control source electromagnetic soundings (CSEM) in hydrocarbon exploration, large CSEM data sets are acquired now routinely that needs to be modeled accurately to provide structural information and ultimately position and extension of possible hydrocarbon targets. When the geological background is not perfectly known, CSEM data are difficult to interpret uniquely and thin resistors such as hydrocarbon layers are difficult to identify and position. In order to improve the CSEM modeling, marine magneto-telluric (MT) data is used to provide the electrical structure

	background for CSEM to retrieve fine details not recoverable with MT, hence the increasing use of marine MT acquired in parallel with the CSEM. Very few forward and inverse modeling tools of 3-D CSEM and MT exist on the market and the appropriate combination of MT and CSEM data to provide detailed information on hydrocarbon has not yet been fully explored, in particular in a joint inversion approach. We developed a successful approach of the full 3-D MT inverse problem that we are now extending to CSEM. Here we report on our current developments of CSEM 3-D modeling and joint inversion with MT. Two forward solutions, one for MT and one for CSEM are combined into a single non-linear iterative procedure that minimizes a weighted joint misfit function. The joint inversion approach was first tested for a series of examples of 1-D layered models containing one or more thin resistors, for different water thicknesses and different CSEM responses combining1-3 electrical and/or 1-3 magnetic receiver components at different offsets. The testing approach is then extended to 3-D situations with a 1-D background and thin resistors of limited extension.
Day: Thursday **Session:** 9: Marine Electromagnetics and the Search for Hydrocarbons **Time:** 10:20 **Location:** Spegelsalen	**Applying Marine EM Methods to Gas Hydrate Mapping** **Dr Steven Constable, Professor, Scripps Institution of Oceanography, United States** In 2004 we carried out pilot study at Hydrate Ridge, offshore Oregon, USA, to assess the use ofmethods and equipment developed for deep hydrocarbon exploration in seafloor gas hydrate characterization. A single 15 km line of 25 seafloor instruments was deployed and one pass of the Scripps Undersea Electromagnetic Source Instrument (SUESI) wasmade using a 5 Hz square wave. At that time we lacked 2D inversion codes that could handle bathymetry, so we presented the data as apparent resistivity pseudo-sections. Recent 2D inversion of these data shows that the pseudo-section approach provides useful, quasi-quantitative, results, and that the artifacts of this projectionmethod are predictable. However, the inversion was able to discriminate resistive regions above the seismic BSR, inferred to be hydrate, and resistive areas below, inferred to be free gas, partly as a result of the richer geometrical complexity of the hydrocarbon exploration approach. The Hydrate Ridge pilot study provided the basis for mounting a much more extensive experiment in the Gulf of Mexico (GoM), funded by a small consortium of companies, the US Department of Energy, and University of California Shipfunds Committee. In October 2008 we collected data sets over four geologically disparate areas in the GoM in water depths of 900 to 3,000 m water. A fleet of 30 seafloor OBEM recorders was deployed a total of 94 times, and the Scripps Undersea Electromagnetic Source Instrument (SUESI) was towed along 18 lines during a cumulative period of 100 hours. Transmission was 200 amps on a 50 m dipole at heights of 70 to 100 m above seafloor. All seafloor instruments recorded both horizontal components of electric and magnetic fields as well as vertical electric field. During all tows, a new 3-axis electric field recorder was flown at a fixed offset of 300 m behind the transmitter. We broadcast a compact (2-second long) binary waveform having significant (at least 10% of peak amplitude) harmonic content from 0.5 Hz to 30 Hz. First results will be presented at the meeting.
Day: Thursday **Session:** 10: Marine Electromagnetics and the Search for Hydrocarbons **Time:** 11:40 **Location:** Spegelsalen	**Multi-transient EM repeatability experiment over Harding field** **Dr David Wright, Senior Research Geophysicist, PGS, United Kingdom** We present results of a multi-transient electromagnetic (EM) repeatability experiment conducted over the North Sea Harding field in 2007 and 2008, as part of a collaborative research project between MTEM Limited (now PGS), BP and the UK Department of Trade and Industry (now DECC) under project number H0531E. The objectives of the experiment were (1) to determine the repeatability of the multi-transient electromagnetic method (Wright et al., 2002; Wright et al., 2005; Ziolkowski et al. 2007) in a marine environment, and (2) to evaluate the potential of the method for identifying resistive hydrocarbon-saturated reservoir compartments in sub-sea fields in water less than 200 m deep. Data acquisition Harding is a medium-size field about 1700 m below the sea floor in block 9/23B in the central North Sea about 320 km north-east of Aberdeen. It comprises a high net:gross, high quality, Eocene (Balder) reservoir with a thick gas cap and a thin remaining oil rim. First oil production was in 1996, with gas being re-injected into the reservoir. Figure 1 shows the position of the lines relative to an outline of Harding Central. The 2D line was acquired to tie a well (9/23b-7) across the thickest part of the hydrocarbon reservoir and a second well 9/23A-3 which is outside closure. The line was orientated

	away from platform infrastructure or operations. The position of each source and receiver was measured during each survey using acoustic transponders. The average difference in source-receiver offset between the two datasets was 9.8m or 0.25%. Data processing The two data sets were acquired with the same parameters and processed with the same processing flow. Processing involves deconvolution to recover the impulse response of the earth, magnetotelluric (MT) noise removal and amplitude scaling to account for small changes in amplitude between the two surveys based on the 5 /1 r offset dependence in amplitude for a half-space. Figure 2(a) shows 2007 and 2008 impulse responses for the same source-receiver pair; (b) shows the corresponding step responses, obtained by integration; the 15 m difference in offset results in an amplitude difference of the peak in (a) of 3.7%. After correction the amplitudes differ by only 0.1%, as shown in Figure 2(c), and similar improvement in the step response, as shown in 2(d). Conclusions We have achieved our first objective and have established that the data are very repeatable. The next step is to invert the data and to see if there are any observable differences in the data over the reservoir. The results of constrained inversion, using available seismic and well data, will be presented at the meeting if this paper is accepted.
Day: Thursday **Session:** 10: Marine Electromagnetics and the Search for Hydrocarbons **Time:** 12:05 **Location:** Spegelsalen	**Effects of VTI anisotropy, data coverage, and initial models on marine CSEM 3D data inversion** **Dr. Len Srnka, Chief Research Geoscientist, ExxonMobil Upstream Research Company, United States** Offshore controlled-source electromagnetic (CSEM) surveying emerged in this decade as a new tool for petroleum applications (Constable and Srnka, 2007). These data provide new information on subsurface rocks and fluids independently from the industry-standard reflection seismic method, although at significantly lower resolution. More than 450 marine CSEM surveys have now been acquired worldwide by industry, about 12% of these by ExxonMobil. Several commercial vendors now offer full marine CSEM services, from survey design to final interpretation, using both frequency-domain and time-domain processing and interpretation methods. Acquisition continues, but at a reduced pace from the 2006 peak. Improved data acquisition, processing, and interpretation techniques have extended the effective depth range to more than 3000 meters sub-mud, depending on the area and target. Three-dimensional nonlinear inversion is becoming an effective tool for interpreting marine CSEM data. Full-physics 3D imaging has become practical using improved nonlinear inversion algorithms on high-performance cluster computers (Commer et al. 2008). Such inversion (imaging) has increased target detectibility and data interpretability. Resistivity anisotropy, especially vertically transverse isotropy (VTI), is now recognized as an important parameter in marine CSEM and is beginning to be included in survey design, data processing, imaging, and interpretation. Wide-azimuth (off the source line, or "offline") CSEM data are essential for reducing interpretation ambiguity related to VTI. We used a frequency-domain finite-difference method (Newman et al., 1997) on a large parallel computer to synthesize 3D data over an offshore earth model containing a hydrocarbon reservoir, to test imaging sensitivities to anisotropy, data coverage, and starting (background) models (Figure 1). These tests reveal resistivity artifacts when anisotropic data are forced through isotropic inversion, and when offline data are excluded from anisotropic inversions. Similar artifacts also appear when the starting model differs too much from the true model. Inadequate attention to anisotropy and/or inadequate data coverage can produce serious misinterpretation of the subsurface resistivity structure. Anisotropic imaging with good data coverage, accurate seafloor receiver orientations, and good initial resistivity models are necessary to quantitatively image resistive anomalies in an anisotropic earth (Jing et al. 2008).
Day: Thursday **Session:** 10: Marine Electromagnetics and the Search	**A fast method for estimation of approvimate sub-bottom resistivity models from electric field data** **Dr Johan Mattsson, Managing Director, PGS Technology AB, Sweden** A boundary value formulation in combination with an integral representation of the electric field is used for fast estimation of

for Hydrocarbons **Time:** 12:30 **Location:** Spegelsalen	sub-bottom resistivity structures. In particular, an inverse problem of frequency sounding is reformulated using the simplified elliptic system method to a boundary value problem (BVP). This means that the resistivity structure dependency is removed and is only implicitly contained in the boundary conditions. As a result, the resistivity structure can be explicitly given from an approximate expression containing the first and second order spatial derivatives of the solution to the BVP. Once a solution for the BVP is obtained, an estimation of the 1D resistivity profile is straight forwardly calculated. In order to obtain an approximate 3D resistivity structures, the spatial derivatives are estimated from the corresponding electric field integral representation. This means that the unknown resistivity values in each cell in the computational grid are calculated by using the explicit resistivity expression from the BVP formulation. The approximate resistivity structure is then preferable used as a starting solution to the corresponding inverse problem solved by a standard conjugate gradient optimization method. This approach is demonstrated on detection of sub-seafloor hydrocarbon accumulations using an in-line configuration of an electric dipole source and receiver system deployed in the sea-water. In particular, a towed electromagnetic system configuration is used along a survey line crossing a 3D model of a reservoir like sub-bottom structure. The 3D structure is then built from the “foot prints” at the common mid-points along the line by using modeled data for the sensitive offsets and frequencies.
Day: Thursday **Session:** 11: Field Computation **Time:** 14:00 **Location:** Spegelsalen	**TEMCaPro - a tool for electromagnetic signature prediction of the cathodic protection system** **Dr Eugene Lepelaars, Researcher, Radar & EW, TNO The Hague, Netherlands** The cathodic protection system is one of the main contributors to the electromagnetic underwater signature of ships. To accurately determine the field distribution due to the cathodic protection system is important from both a military as well as from a corrosion protection point of view. For this purpose, we developed our own calculation model TEMCaPro, based on the Boundary Element Method (BEM). The model assumes that a ship hull is immersed in the seawater of a three-layer configuration consisting of air, seawater and seabed. The underwater surface of the ship hull and propellers is subdivided in triangular elements and for each node a non-linear potential relation is defined. The system of equations that results from this procedure is iteratively solved using a Conjugate Gradient method. The development has been carried out in close cooperation with the Eindhoven University of Techonolology. Two students in Computer Science graduated on the implementation of the BEM. Furthermore, an associate professor in Graphics developed the Graphical User Interface using C++, the Visualization ToolKit library (VTK) and the WxWidgets library. The result is an application with full 3D visualization of electric and magnetic field distributions. The calculations are carried out in the background of the GUI by calling separate executables, originally written in Fortran. The application has been validated using a scale model. The scale model has the shape of a shoe box and only contains non-magnetic materials, i.e., zinc, copper and insulation on the outside. The validation was carried out in a basin with magnetic and electric field sensors. In our presentation we will demonstrate the use of TEMCaPro and devote particular attention to the visualization of electric and magnetic field distributions. The results of the validation measurements will be addressed as well.
Day: Thursday **Session:** 11: Field Computation **Time:** 14:25 **Location:** Spegelsalen	**Recent work at FOI on the computation of static electric signatures and the corresponding corrosion related magnetic signature** **Mr Henrik Claesson, Senior Scientist, FOI - Swedish Defence Research Agency, Sweden** We present recent work on the computation of the static electric- and the corrosion related magnetic signature. The electric potential and the corrosion related magnetic in the water are calculated using an integral representation based on greens formula and greens functions for horizontally stratified media. The Green’s function is approximated with a set of Chebyshev polynomials for fast high accuracy evaluations. The corrosion properties of the hull material, characterized by the non-linear polarization curves, serve as boundary condition to the resulting integral equation. The hull surface is discretized into curved

	triangular faces with a quadratic basis function spanning each triangle. The resulting sets of equations are solved with an iterative method. We will show the performance of the Chebychev interpolation technique; we will present results using our CRM formulation; and we will compare the signatures obtained using non-linear polarization curves and piecewise linear polarization curves for a generic submarine model.
Day: Thursday **Session:** 11: Field Computation **Time:** 14:50 **Location:** Spegelsalen	**Boundary Layer Control Using an Oscillatory Lorentz Forcing** **Professor Manhar Dhanak, Department Chair and Director of SeaTech, Florida Atlantic University, United States** The weak conductivity of saltwater means that the generation of sufficiently strong Lorentz force for boundary layer control requires action of both magnetic and electric fields. Researchers [see for example, Kim (1997) and Crawford and Karniadakis (1997)] have considered various configurations of the electric and magnetic fields to generate appropriate force to control either (a) skin friction, or (b) flow separation. Here we use direct numerical simulation to explore skin friction control through interactions between a magnetic field aligned normal to the flow and an electric field in the form of a travelling wave aligned to the streamwise direction, resulting in an oscillatory Lorentz force normal to the surface. The particular case of axial flow along the length of a circular cylindrical body is considered. A magnetic field is applied so that it is oriented in the azimuthal direction and an electric field is applied so that they it is oriented parallel to the axis of the cylinder, with the lattter varying in the form of a travelling wave along the surface of the cylinder lead to a radial Lorentz force that oscillates spatially and temporally. The direct numerical simulation was carried out using the vorticity-stream function formulation of the Navier-Stokes equations. The model flow is considered to be axially symmetric. A parametric study is conducted involving consideration of the variation of the flow Reynolds number, strength of the Lorentz force, and phase speed of forcing for boundary layer control. Under optimum forcing parameters, it is shown that sustainable Lorentz induced coherent vortex structures in the form rings (Figure 1) can travel along the cylinder at a speed equivalent to the phase speed of forcing. The wall stress is shown to locally change sign in the region adjacent to the vortex, considerably decreasing net viscous drag. Adverse flow behaviors include complex vortex configurations found for suboptimal forcing resulting in an increase in wall stress. An estimate of the power balance between required power supply and benefit associated with lower skin friction (Figure 2) will be discussed.
Day: Thursday **Session:** 11: Field Computation **Time:** 15:15 **Location:** Spegelsalen	**Magnetic signature model for rough design: Asynchronous machines and three phase transformers** **Berend Evenblij, Senior Scientist, TNO D&V, Netherlands** Due to increasing power of electric power and propulsion systems on board warships, the magnetic signature generated by these systems has become a significant design aspect because of mine threats. In the conceptual design mode of a ship, it is important to have a rough idea of expected signature. This paper reports on progress that has been made on the modeling of rotating machines and three phase transformers. The magnetic field distribution in the space around an 11kW asynchronous machine was measured under different load conditions. These measurements could be reproduced by a simple rotating magnetic dipole in the centre of the machine. In order to prove this, a three dimensional way to depict the results was developed. This method allows of visualizing the field of an arbitrarily chosen rotating magnetic dipole with finite (i.e. nonzero) sizes. From an analysis of the magnetic circuit within the machine it was shown that such a simple magnetic dipole model is likely to exist. A provisional recipe to parameterise the model from machine data was proposed. The model of a two phase transformer has previously been shown to be a magnetic dipole proportional to the magnetizing current. This led to the expectation that a three phase transformer could have an external field that is practically zero, because the sum of magntizing currents is zero. Due to asymmetrical magnetic circuit (windings on the outer legs “see” a different magnetic resistance than the middle leg) this is not the case. Field measurements on a 36kVA three-phase transformer were explained on the basis of an analysis of its magnetic circuit. This led to a model that consists of two single-phased

	transformers, with magnetizing currents that are 90 degrees shifted in phase.
Day: Thursday **Session:** 12: Computational Methods **Time:** 16:10 **Location:** Spegelsalen	**<u>Modelling eddy current effects using physical and numerical techniques</u>** **Mr James Ashton, Scientist, QinetiQ, United Kingdom** Eddy currents induced by the rolling motion of a steel or aluminium hulled ship are thought to have a significant effect on its low frequency magnetic signature; however this phenomenon can be very difficult to measure directly. Work has been done to investigate eddy current effects, using small-scale physical models and numerical techniques, in an attempt to further understanding of the subject and aid the prediction of full-scale signatures. Because of the difficulty in numerically modelling complex thin-shelled structures such as ships, this has been done using simplified geometries, and by developing approximate computational techniques. These numerical results compare favourably with laboratory measurements which have been made of small-scale physical models exposed to alternating magnetic fields. The results from this work have shown that small-scale experiments and numerical models can both be used to predict eddy current signatures of ships with reasonable accuracy. This paper details the techniques developed, the results obtained, and discusses the benefits and limitations of each technique.
Day: Thursday **Session:** 12: Computational Methods **Time:** 16:35 **Location:** Spegelsalen	**<u>Part 1: Modelling UEP and CRM signatures generated by corrosion and corrosion control in ships, with detailed representation of the ICCP circuit and propellers. Part 2: Simplified modelling of UEP in electrolyte with depth-varying conductivity</u>** **Dr Cristina Peratta, CP Simulation Engineer, CM BEASY Ltd, United Kingdom** This work is focused on the 3D simulation of CP systems for ships, with detailed representations of the ICCP circuit and the geometry of the propellers. Each transformer-rectifier unit in the ICCP system is represented in a circuit which includes the TRU, supply cabling connecting the TRU to one or more anodes, and return cabling connecting the hull to the return of the TRU. The cable resistances and any connection resistances may be included in the circuit, for example between the propeller shaft and the ship hull. The output of the TRU is defined either as a voltage difference (supply to return) or as current supplied by the TRU. The electrical circuit equations are solved to determine current flow and electrical potential throughout. Current flow from the surfaces of the anodes into the surrounding electrolyte is described using a polarisation curve. Current flowing through the electrolyte is determined by solving the Laplacian equation, using the boundary element method with dual elements used to represent each side of thin structures, such as the propeller blades. The entire solution process is non-linear, and is solved iteratively. The results of the mathematical modelling include current flowing from each ICCP anode, current density and protection potentials on all wetted parts of the ship; potentials at reference electrodes; power loss, current and potential throughout the circuit; and potential, electric field and magnetic field at any number of positions in the electrolyte. For a given ICCP system, the aims of the simulation are to predict the level of protection against corrosion on the ship, and to identify the resulting electric and magnetic signatures. The detailed representation of the ICCP circuit allows investigation into the effects of deficiencies in the system for example failure of an anode, or into effects of variable resistance in a shaft grounding system. The use of dual elements to represent the propeller allows use of the real (thin) geometry of the blades. This in turn makes it meaningful to investigate the effects on signatures of movement (or at least changed position) of the blades as the shaft rotates. Examples are presented which investigate these effects. Where appropriate, comparisons are made with the more simplified approaches normally used, and benefits are discussed.
Day: Thursday **Session:** 12: Computational Methods **Time:** 17:00 **Location:** Spegelsalen	**<u>Elements of the tsunami precursors' physics: Seismo-hydro-electromagnetics</u>** **Dr Oleg Novik, Head of Lab, Institute for Terrestrial Magnetism, Ionophere & Radio Wave, Russian Federation** Basing on the formulated (in accordance with main physical principles and geophysical data) mathematical model of seismo-hydro-electromagnetic interaction the authors investigated the algorithm and traced numerically generation and propagation of ultra-low frequency (ULF) electromagnetic (EM) signals in a seismically disturbed moving model medium with a lithosphere

	zone, a marginal sea and an atmosphere zone up to the lower boundary of the ionosphere. Demonstrated are sequential stages of the physical process of transformation of a seismic excitation in geological structures beneath the sea bottom into EM signals in the atmosphere: generation of an ULF EM wave in a seismically deformed conductive domain of the ocean lithosphere (similar domains are known to be typical for tectonically active lithosphere zones, both continental and oceanic ones); a spatial modulation of the generated long EM wave by the seismic wave , “freezing” of the EM wave (arrived at the top of the marine sedimentary layer) before going over from the lithosphere into the sea depth with its high electric conductivity (4 S/m); the delayed seismic P wave’s shock into the deep part of the sea bottom, arising of a vertical hydrodynamic flow and a surface long (about 150 km) tsunami wave of a small (up to 20 cm amplitude far from the shore) amplitude, EM emission from the sea surface. As a result, it is shown that measurable ULF EM signals (hundreds of pT at the sea bottom and the sea-atmosphere interface by the frequency spectrum similar to one of the initial seismic excitation) do arise in atmosphere during development of a seismo-hydro-EM process initialized by a rather moderate (precursory) seismic excitation in the form of elastic displacements with main frequencies 0.1 to 10 Hz and the amplitude and duration of the order of a few cm and sec respectively in the upper mantle under the sea bottom. The quantitative characteristics of the computed seismo-hydro-EM process (e.g. amplitudes of the EM, temperature and tsunami waves, the delay of the EM signal in regard to the beginning of a seaquake etc) are of the orders observed. The recommendations for a multilevel multifunctional tsunami monitoring system are given.