Copy No. _____

Defence Research and Development Canada
Recherche et développement pour la défense Canada

DEFENCE R&D DÉFENSE

Geomagnetic Coherence Trial #3

J. Bradley Nelson
DRDC Atlantic

Dave Marcotte
National Research Council

Prepared for the Office of Naval Research Grant Number: N00014-06-1-0127

Defence R&D Canada – Atlantic

External Client Report
DRDC Atlantic ECR 2006-266
May 2007

Canada

This page intentionally left blank.

Geomagnetic Coherence Trial #3

J. Bradley Nelson
DRDC Atlantic

Dave Marcotte
National Research Council

Prepared for the Office of Naval Research Grant Number: N00014-06-1-0127

Defence R&D Canada □ Atlantic

External Client Report
DRDC Atlantic ECR 2006-266
October 2006

Author

Original signed by J. Bradley Nelson

J. Bradley Nelson

Approved by

Original signed by Dr. Neil Sponagle

Dr. N. Sponagle

H/Underwater Sensing

Approved for release by

Original signed by Jim L. Kennedy for Kirk Foster

Kirk Foster

DRP Chair

Abstract

DRDC Atlantic and the Naval Air Warfare Centre Aircraft Division (NAWC-AD) are developing techniques for modeling and removing geological and geomagnetic noise in magnetic anomaly detection (MAD) systems. The aim of this collaborative work is to improve submarine detection ranges in littoral areas. The Office of Naval Research (ONR) is partially funding this research.

In August 2006, the National Research Council Convair research aircraft was used to gather aeromagnetic data over the continental shelf of the United States. Magnetic basestation data were collected at a number of nearby on-shore sites. The primary objectives were to separate the effects of geology (spatial) and geomagnetic (temporal) noise sources, quantify the degree of geological noise cancellation possible using multiple-passes down the same flight line, measure the coherence of the geomagnetic field from on-shore to off-shore environments as a function of distance and altitude, and thus quantify the geomagnetic noise cancellation possible. The secondary objective was to measure the magnetic anomalies due to non-linear littoral internal waves (NLIWs). Theoretical calculations suggest that these anomalies can have very similar amplitudes and wavelengths as submarine MAD signals and thus can be a source of False Alarms in MAD systems.

This report describes the experiment and the status of ONR Grant N00014-06-1-0127.

R sum

RDDC Atlantique et le Naval Air Warfare Centre Aircraft Division (NAWCAD) des tats-Unis ont entrepris l laboration de techniques de mod lisation et de suppression des bruits g ologiques et g omagn tiques relev s par les syst mes de d tection d anomalies magn tiques, afin d accro'tre la port e de ces syst mes dans les eaux littorales. Mentionnons aussi que l Office of Naval Research (ONR) des tats-Unis contribue au financement de ces travaux de recherche.

En ao t 2006, l a ronef de recherche Convair du National Research Council des tats-Unis a t affect la collecte de donn es a romagn tiques sur la plate-forme continentale des tats-Unis. Des donn es magn tiques ont t recueillies l emplacement d un certain nombre de stations de base c ti res voisines de la zone de collecte. Ces travaux visaient principalement faire la distinction entre les effets des sources de bruits g ologiques (valeurs spatiales) et g omagn tiques (valeurs temporelles), d terminer dans quelle mesure les bruits g ologiques peuvent tre supprim s en effectuant de nombreux passages suivant le m me axe de vol, mesurer l homog n it du champ g omagn tique entre des milieux c tiers et extrac tiers en fonction de la distance et de l altitude, et d ainsi quantifier les bruits g omagn tiques potentiellement supprimables. Ils visaient galement, mais dans une moindre mesure, mesurer les anomalies magn tiques attribuables des ondes internes littorales non lin aires. Des calculs th oriques laissent supposer que l amplitude et la longueur d onde de ces anomalies peuvent s av rer tr s similaires celles des signaux de d tection d anomalies magn tiques sous-marins, ce qui peut produire de fausses alertes.

Le présent rapport comprend la description de l'expérience qui a été réalisée et de l'état de la subvention de l'ONR numéro N00014-06-1-0127.

Executive summary

Background

DRDC Atlantic and the Naval Air Warfare Centre Aircraft Division (NAWC-AD) are developing techniques for modeling and removing geological and geomagnetic noise in magnetic anomaly detection (MAD) systems. The aim of this collaborative work is to improve submarine detection ranges in littoral areas. In August 2006, the National Research Council Convair research aircraft was used to gather aeromagnetic data over the continental shelf of the United States. Magnetic basestation data were collected at a number of nearby on-shore sites. The aims of the experiment were to test various geological and geomagnetic noise reduction algorithms developed by DRDC Atlantic, and to measure the magnetic anomalies due to non-linear littoral internal waves (NLIWs). Theoretical calculations by the Naval Research Laboratory Stennis Division (NRL Stennis) suggest that these anomalies may look very similar to submarine signals and thus may be a source of False Alarms in MAD systems. This report describes the experiment and the status of ONR Grant N00014-06-1-0127.

Significant Results

The experiment was completed in early August 2006, and the data will be passed to NAWC-AD and NRL Stennis in October, thereby meeting all of the deliverable described in the ONR Grant. Data analysis, although not part of the ONR Grant, has started at both DRDC Atlantic and NRL Stennis. Data pre-processing (visual inspection, bad-data correction, aircraft noise removal, time alignment, etc) was completed by 1 September 2006. Algorithms for separating geological and geomagnetic noise have already been developed and applied to roughly half of the flight data. It is expected that the data analysis will be completed by January 2007.

Future Work:

DRDC Atlantic and NAWC-AD are collaborating on the 3MDS (Multi-Mode Magnetic Detection System) Project, also funded by ONR. The goal of 3MDS is to develop an improved MAD and airborne ELF detection system for submarine detection. The noise reduction techniques developed from the data collected with this Grant will be adapted for real-time use in the 3MDS program.

NRL-Stennis has received an ONR Grant to perform the forward modeling of the NLIW magnetic fields based on the SW06 oceanographic measurements. NRL-Stennis has an internally-funded program to investigate a wide variety of ocean-generated magnetic noises, and the results of that work will be made available to both the DRDC Atlantic program in Airborne EM Sensing and the 3MDS program.

Nelson, JB and Marcotte, D. 2006. Geomagnetic Coherence Trial #3. DRDC Atlantic ECR 2006-266. Defence R&D Canada Atlantic

Sommaire

Contexte

RDDC Atlantique et le Naval Air Warfare Centre Aircraft Division (NAWCAD) des tats-Unis ont entrepris l laboration de techniques de mod lisation et de suppression des bruits g ologiques et g omagn tiques relev s par les syst mes de d tection d anomalies magn tiques, afin d accro'tre la port e de ces syst mes dans les eaux littorales. En ao t 2006, l a ronef de recherche Convair du National Research Council des tats-Unis a t affect la collecte de donn es a romagn tiques sur la plate-forme continentale des tats-Unis. Des donn es magn tiques ont t recueillies l emplacement d un certain nombre de stations de base c ti res voisines de la zone de collecte. Ces travaux visaient essayer divers algorithmes de r duction des bruits g ologiques et g omagn tiques labor s par RDDC Atlantique et mesurer les anomalies magn tiques attribuables des ondes internes littorales non lin aires. Des calculs th oriques effectu s par le Naval Research Laboratory Stennis Division (NRL Stennis) des tats-Unis laissent supposer que ces anomalies ressemblent de pr s des signaux sous-marins et qu elles peuvent ainsi entra'her de fausses alertes misses par les syst mes de d tection d anomalies magn tiques. Le pr sent rapport comprend la description de l exp rience qui a t r alis e et de l tat de la subvention de l ONR num ro N00014-06-1-0127.

R sultats significatifs

L exp rience s est conclue au d but d ao t 2006, et les donn es recueillies seront transf r es au NAWCAD et au NRL Stennis en octobre; tous les produits livrer rattach s la subvention de l ONR auront ainsi t fournis. Bien qu elle ne constitue pas un pr alable la subvention de l ONR, une analyse des donn es a t entreprise par RDDC Atlantique et le NRL Stennis. Le traitement pr alable des donn es (examen visuel, limination des donn es erron es , suppression des bruits de l a ronef, alignement chronologique, etc.) tait termin avant le 1er septembre 2006. Les algorithmes servant distinguer les bruits g ologiques et g omagn tiques ont d j t labor s et appliqu s la moiti environ des donn es recueillies en vol. L analyse des donn es devrait tre termin e avant janvier 2007.

Travaux venir

RDDC Atlantique et le NAWCAD collaborent dans le cadre du projet de 3MDS (*Multi-Mode Magnetic Detection System* syst me de d tection magn tique multimode), que l ONR finance conjointement et qui vise mettre au point un syst me plus perfectionn de d tection d anomalies magn tiques et de d tection a rienne d ondes de tr s basses fr quences sous-marines. Les techniques de r duction des bruits labor es d apr s les donn es recueillies gr ce la subvention de l ONR seront modifi es pour permettre leur utilisation en temps r el avec le 3MDS.

Le NRL Stennis a obtenu une subvention de l ONR pour la mod lisation pr visionnelle, selon des mesures oc anographiques prises avec une sonde SW06, de champs magn tiques attribuables des ondes internes littorales non lin aires. Le NRL Stennis a financ son propre programme visant tudier divers bruits magn tiques dans l oc an,

dont les résultats seront fournis aux responsables du projet de 3MDS et du programme de détection aéroélectromagnétique de RDDC Atlantique.

Nelson, JB and Marcotte, D. 2006. Geomagnetic Coherence Trial #3. DRDC Atlantic ECR 2006-266. Defence R&D Canada – Atlantic

This page intentionally left blank.

Table of contents

List of figures

1. Introduction

1.1 Long-Term Goals

The goal of this project is to develop techniques for modeling and removing geological and geomagnetic noise in magnetic anomaly detection (MAD) systems. This will improve submarine detection ranges in littoral areas.

1.2 Objectives

In order to meet the long-term goals, an airborne experiment was conducted off the Eastern coast of the USA with the NRC Convair research aircraft in August 2006. At the same time, magnetic basestation data was collected at a number of nearby on-shore sites. All analysis will be performed in post-processing, but real-time versions of the most successful noise-reduction algorithms will eventually be developed.

The primary objectives were to separate the effects of geology (spatial) and geomagnetic (temporal) noise sources, quantify the degree of geological noise cancellation possible using multiple-passes down the same flight line, measure the coherence of the geomagnetic field from on-shore to off-shore environments as a function of distance and altitude, and thus quantify the geomagnetic noise cancellation possible.

The secondary objective was to measure the magnetic anomalies due to non-linear littoral internal waves (NLIWs). Theoretical calculations suggest that these anomalies can have very similar amplitudes and wavelengths as submarine MAD signals. Thus NLIWs can be a source of False Alarms in MAD systems.

The deliverable for Grant Number N00014-06-1-0127 was simply □releasing the final data set from the experiment to other US Navy researchers identified by ONR□ For the primary objectives, this is Dr. Jon Davis of the Naval Air Warfare Centre □Aircraft Division in Patuxent River, MD. The detailed follow-on data analysis will be performed by Mr. Nelson, with input from Dr. Davis, under an existing collaboration between their respective laboratories (DRDC Atlantic and NAWC-AD). For the secondary objective, this is Will Avera of the Naval Research Laboratory-Stennis. Here most the analysis will be conducted by Mr. Avera and Patrick Gallacher, with input from Mr. Nelson.

2. The Experiment

The experiment consisted of flying along the same track multiple times and correcting/re-sampling the resulting data to the same points in space. Because the magnetic field due to the underlying geology should be the same no matter when the measurement is made, any differences between the co-located magnetic field measurements should be due to aircraft manoeuvres, geomagnetic activity, and various oceanographic processes. The NRC Convair aircraft was equipped with various sensors to monitor aircraft orientation and control surface position. Both time-domain and frequency-domain techniques algorithms using data from these sensors will be used to reduce aircraft manoeuvre noise. Frequency-domain cancellation techniques will be used to reduce the geomagnetic noise as measured at the various magnetic basestations.

Exercise SW06 was an ONR-supported experiment to investigate a number of oceanographic processes on the continental shelf east of New Jersey. A major component of SW06 was to identify and measure the oceanographic parameters related to NLIWs. The Convair aircraft was used to collect aeromagnetic data over the NLIWs that were identified by other SW06 researchers. Mr. Nelson will use the same techniques described above to isolate and identify the magnetic signals from NLIWs from the geological, geomagnetic, and aircraft manoeuvre noise. Mr. Avera and Mr. Gallacher will then model the magnetic anomalies from the NLIWs based on the oceanographic measurements and compare them to the airborne measurements.

3. Status

All Convair flights were completed by August 2, 2006. All basestation data was obtained by August 15, 2006. Data pre-processing (visual inspection, bad-data correction, aircraft noise removal, time alignment, etc) was completed by 1 September, 2006. The final data set has been delivered to NAWC-AD and the collaboration between Mr. Nelson and Dr. Davis for follow-up analysis has begun. Algorithms for separating geological and geomagnetic noise have already been developed and applied to roughly half of the flight data. It is expected that draft reports will be written by January 2007.

The NLIW airborne magnetic measurements will be delivered to Mr. Avera at NRL-Stennis in October, 2006. NRL-Stennis will obtain the SW06 oceanographic measurements shortly, at which point work on the forward modeling can commence.

3.1 Preliminary Results

The operational area is shown in Figure 1. Figure 2 shows an example of the total noise reduction obtained along by comparing two west-to-east flight lines at 1000 altitude, using the basestation at Fredericksburg VA (denoted X in Figure 1) for geomagnetic noise removal.

3.2 Impact/Applications

For the example shown in Figure 2, the standard deviation of the noise was reduced from 0.15 to 0.015 nT (a factor of 10). If we assume a simple $1/R^3$ dependence for the amplitude of the MAD signal due to a submarine, then it implies that the MAD detection range would roughly double using this noise reduction technique.

However, it is interesting to note that the specturm of the final residual (Figure 2, lower trace, shown in Red) is not flat. This means that there is some residual noise that is not being accounted for by our present models. The most obvious candidate for the source of this excess noise is oceanographic processes such as swell, waves, and currents. Detailed analysis of the NLIW data, combined with NRL-Stennis computer simulations based on the oceanographic data and magnetohydrodynamic modelling may shed some light on this phenomenon.

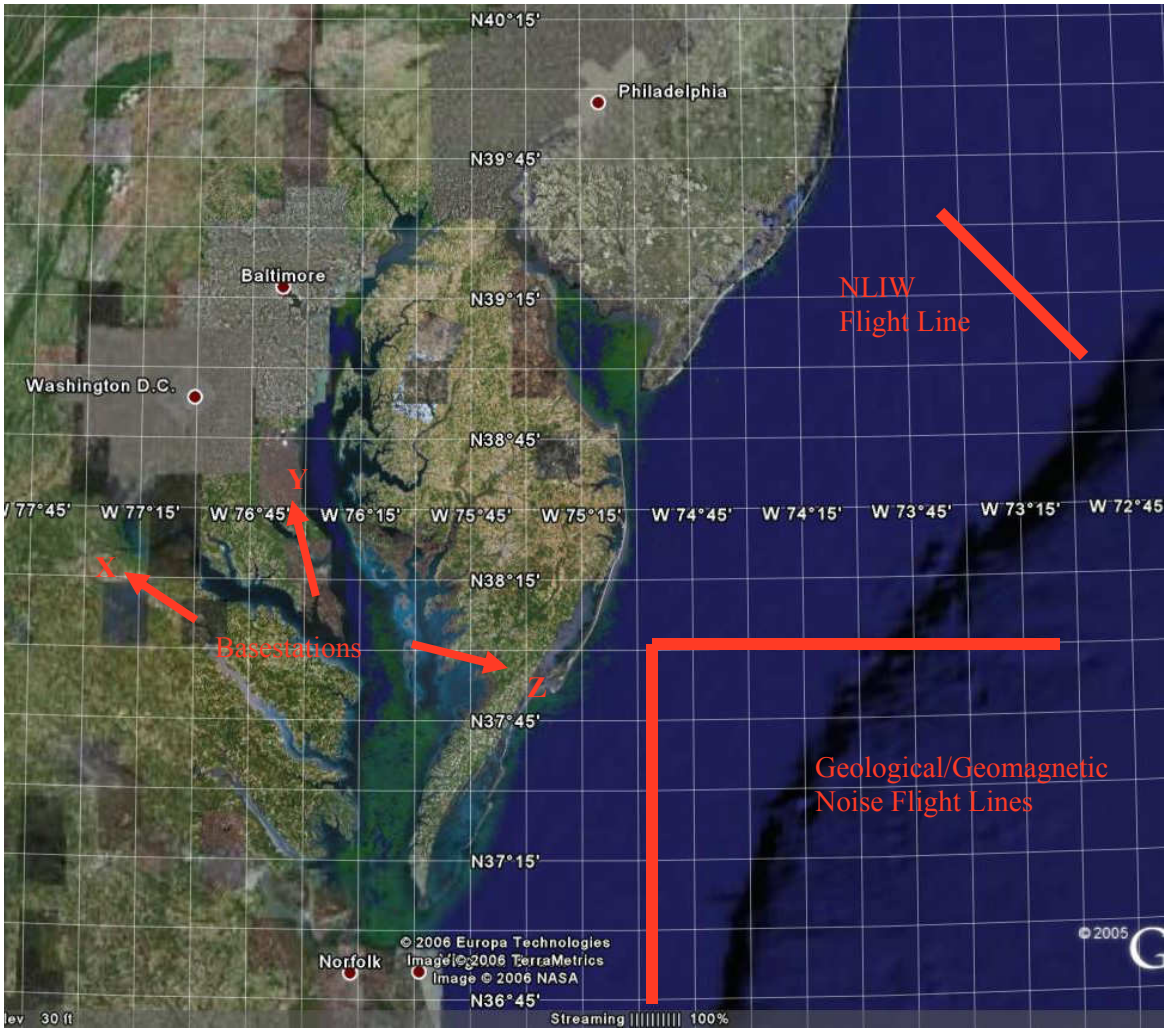

Figure 1. Location of flight lines and magnetic basestations. X = Fredericksburg, VA, Y = Prince Frederick, MD, and Z = Wallops Island, VA.

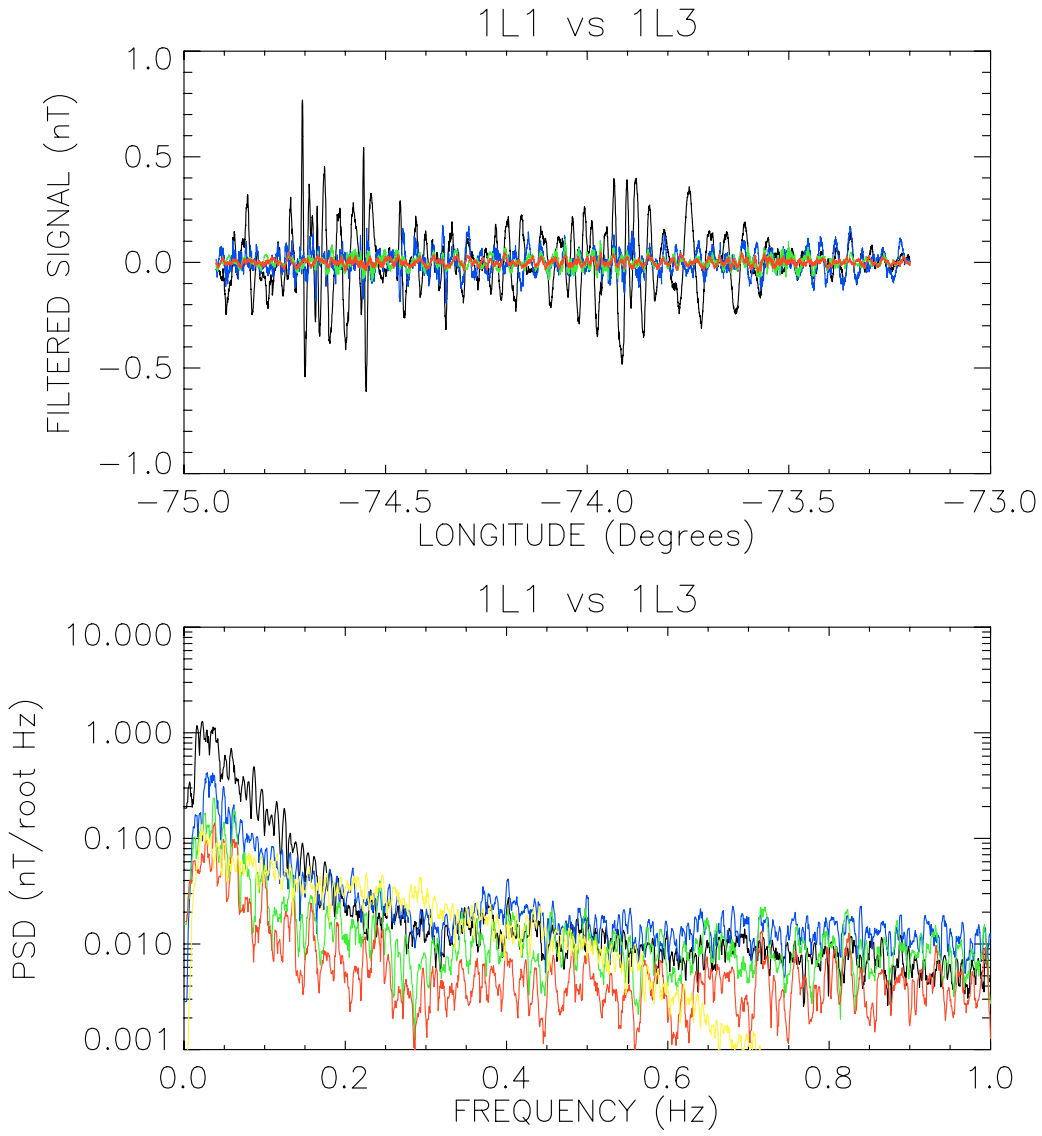

Figure 2. Upper Trace: time series of raw MAD signal (Black), residual after removing geological signal (Blue), residual after removing all aircraft manoeuvre-related noise (Green), and geomagnetic noise (Red). All data bandpass filtered from 0.02-1.0 Hz.

Lower Trace: power spectral densities of signals shown in the upper trace with the same color codes. In addition, the power spectral density of the geomagnetic field measured at the Fredericksburg, VA basestation is shown in yellow.

4. Related Projects and Future Work

DRDC Atlantic and NAWC-AD are collaborating on the 3MDS (Multi-Mode Magnetic Detection System) Project, also funded by ONR. The goal of 3MDS is to develop an improved MAD and airborne ELF detection system for submarine detection. The sensor for this system is the ASQ-233 Helium^3 magnetometer being developed by Polatomic Inc. Although this system is being developed for UAV applications, it may be used on a variety of airborne platforms. The noise reduction techniques developed from the data collected with this Grant will be adapted for real-time use in the 3MDS program.

NRL-Stennis has received an ONR Grant to perform the forward modeling of the NLIW magnetic fields based on the SW06 oceanographic measurements. NRL-Stennis has an internally-funded program to investigate a wide variety of ocean-generated magnetic noises, and the results of that work will be made available to both the DRDC Atlantic program in Airborne EM Sensing and the 3MDS program.

Distribution list

List A (Full Report)

5 - DRDC Atlantic Library

External

2 - DRDKIM

1 - Institute for Aerospace Research
Building U-61, Uplands
1200 Montreal Road
Ottawa, Ontario K1A 0R6
Attn: Mr. J. Bradley Nelson

1 - Office Naval Research
Ocean, Atmosphere and Space Department
800 N Quincy Street
Arlington, VA 22217
Attn: Dana Hesse code 321, rm 407-25

1 - Naval Research Laboratory, Bldg. 1005
Stennis Space Center, MS, USA 39529-5004
Attn: Will Avera

List B (Executive Summary Only)

External

1 - DAEPM(M) 4 / Phil Baxter
1 - DRDC / DSTA 5
1 - DAR 3

This page intentionally left blank.

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (the name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Centre sponsoring a contractor's report, or tasking agency, are entered in section 8.)

DRDC Atlantic

2. SECURITY CLASSIFICATION (overall security classification of the document including special warning terms if applicable).

UNCLASSIFIED

3. TITLE (the complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C,R or U) in parentheses after the title).

Geomagnetic Coherence Trial #3

4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.)

Nelson, J. Bradley, and Marcotte, Dave

5. DATE OF PUBLICATION (month and year of publication of document)	6a. NO. OF PAGES (total containing information Include Annexes, Appendices, etc).	6b. NO. OF REFS (total cited in document)
May 2007	17	0

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered).

External Client Report

8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include address).

Defence R&D Canada – Atlantic
PO Box 1012
Dartmouth, NS, Canada B2Y 3Z7

9a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant).	9b. CONTRACT NO. (if appropriate, the applicable number under which the document was written).
Thrust 1C/11CS10	

10a ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.)	10b OTHER DOCUMENT NOs. (Any other numbers which may be assigned this document either by the originator or by the sponsor.)
DRDC Atlantic ECR 2006-266	

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

(x) Unlimited distribution
( ) Defence departments and defence contractors; further distribution only as approved
( ) Defence departments and Canadian defence contractors; further distribution only as approved
( ) Government departments and agencies; further distribution only as approved
( ) Defence departments; further distribution only as approved
( ) Other (please specify):

12. DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in (11) is possible, a wider announcement audience may be selected).

13. ABSTRACT (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

DRDC Atlantic and the Naval Air Warfare Centre – Aircraft Division (NAWC-AD) are developing techniques for modeling and removing geological and geomagnetic noise in magnetic anomaly detection (MAD) systems. The aim of this collaborative work is to improve submarine detection ranges in littoral areas. The Office of Naval Research (ONR) is partially funding this research.

In August 2006, the National Research Council Convair research aircraft was used to gather aeromagnetic data over the continental shelf of the United States. Magnetic basestation data were collected at a number of nearby on-shore sites. The primary objectives were to separate the effects of geology (spatial) and geomagnetic (temporal) noise sources, quantify the degree of geological noise cancellation possible using multiple-passes down the same flight line, measure the coherence of the geomagnetic field from on-shore to off-shore environments as a function of distance and altitude, and thus quantify the geomagnetic noise cancellation possible. The secondary objective was to measure the magnetic anomalies due to non-linear littoral internal waves (NLIWs). Theoretical calculations suggest that these anomalies can have very similar amplitudes and wavelengths as submarine MAD signals and thus can be a source of False Alarms in MAD systems.

This report describes the experiment and the status of ONR Grant N00014-06-1-0127.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title).

Geomagnetic noise cancellation
Geological noise reduction
Non-linear internal wave
SW06

This page intentionally left blank.

Defence R&D Canada

Canada's leader in defence
and National Security
Science and Technology

R & D pour la défense Canada

Chef de file au Canada en matière
de science et de technologie pour
la défense et la sécurité nationale

DEFENCE DÉFENSE

www.drdc-rddc.gc.ca