Scientific literature review on the topic of monitoring and modeling seabed evolution rates

Douglas J Schillinger
GaleForce Scientific Consulting Ltd.

This document was prepared as a deliverable under contract W7707-4500979572 by Doug Schillinger of GaleForce Scientific Consulting Ltd, 26 Surrey Way, Dartmouth, NS, Canada.

Scientific Authority: Dr Anna Crawford, DRDC Atlantic. 902-426-3100 x370

The scientific or technical validity of this Contract Report is entirely the responsibility of the Contractor and the contents do not necessarily have the approval or endorsement of the Department of National Defence of Canada.

Contract Report
DRDC-RDDC-2014-C203
October 2014

© Her Majesty the Queen in Right of Canada, as represented by the Minister of National Defence, 2014

© Sa Majesté la Reine (en droit du Canada), telle que représentée par le ministre de la Défense nationale, 2014

Abstract

DRDC is proposing a multi-year research program into development of decision aids for optimal scheduling of survey work in support of Maritime Route Survey operations. The overarching concept behind the project is that in order for a change detection approach to be most effective, an accurate baseline survey database must be maintained. If the local seabed is changing rapidly in response to natural forcing, surveys may be required more frequently. The first step in this research work is to perform an overview literature survey of existing scientific research work into monitoring and modeling of seabed rates of evolution. This work was completed under contract (W7707-4500979572), the present report being the primary deliverable, including a summary of the findings and an extensive bibliography.

Significance for Defence and Security

While this report does not have direct military significance in itself, it provides the necessary background review of existing research reported in scientific literature. The bibliography contains highlights of the best in scientific research published in open literature and in government reports and provides links to online data archives, establishing the state of the art in the field, upon which future research can be based. The topic of the literature review is in monitoring and modeling of rates of change in seabed characteristics, for application in research supporting Maritime Route Survey applications.

Table of contents

List of tables

Acknowledgements

It should be acknowledged here that Nicola Wheatley's Masters Thesis describes an algorithm which should be closely reproduced.

Paul Hill and Tim Milligan confirmed there is a lack of data collected in the near shore zone of Nova Scotia in a personal communication.

Ryan Mulligan offered his assistance with using XBeach, and his comments regarding the model are included in section 2.9

1 Introduction

1.1 Purpose

The purpose of this literature review is to document research relevant to determining the periodicity with which repeat sidescan sonar surveys must be performed for use in automated object detection. In contrast to synthetic aperture radar applications for images of terrestrial environments, SONAR images of the ocean bottom are subject to changes on short time scales. As a result, images collected in subsequent passes decorrelate on time scales from hours to days.

DRDC Atlantic specifically requested information for route survey periodicity for areas along the Nova Scotian coast between the 10m and 20m contour.

1.2 Approach

The contracting agency, DRDC, has significant expertise with sidescan and Synthetic Aperture SONAR (SAS), and repeat pass image referencing, but for completeness the author began with a literature review of these topics. The scientific effort of synthetic aperture data acquisition began with airborne and satellite RADAR (SAR) data. Eventually the process was used in the sea using SONAR; SAS has significant features which differ from SAR. In particular, the ship-mounted SONARs suffer from poor positioning of the ship, motion induced interference, signal losses due to scatterers, often in a layer at a depth which varies with time, and due to steering from depth varying sound speed profiles. With respect to repeat pass applications, these problems are compounded by the rapid rate of decorrelation between subsequent images in time when compared to SAR imagery.

The rapid rate of decorrelation (hours to days) is related to the specular nature of reflections from the ocean-sediment interface, large-amplitude backscatter reflection from benthic-biology; sediment transport, ocean-currents, bio-turbation and episodic forcing events also act with the previously mentioned factors to drive long time-scale (days to weeks) variability of acoustic imagery of the sea-floor.

Moving beyond SAR/SAS related publications, the author expanded the search to include bathymetry and multi-beam survey mapping, sediment type classification, benthic habitat classification, and bedform formation and movement. Rather than focusing on research relating to the physical process of sediment suspension, mobility, settling and bed-load transport, instead, the author search for publications relating to these phenomemon in near-shore locations around Nova Scotia.

Unfortunately, the majority of the research has been focused on the continental shelf, and the various banks on the shelf. There are two reasons for the lack of research between the 10m and 20m contours: 1) operating in this zone is difficult, as the near shore “brown-zone” is subject to bathymetry induced wave-breaking, 2) offshore mineral and oil exploration and fisheries management drive the need for research along the shelf.

With a lack of papers relevant to near-shore bottom type, bottom variability, the author instead searched for databases which might contain relevant information, and for marine policy papers to target potential partner organizations whose purpose is to collect data in this near-shore zone.

Government policy, over the last 10 years, has shifted to marine management and the creation of marine protected areas. Governments are focuses on preserving and promoting recovery of fish-stock, analysing the impact of open pen fish farms, and the effects of human settlement along the coast has on the near shore environment. In Nova Scotia, the government is focused on aquaculture, in-shore fishery, and the development of in-stream tidal power generation. Federally, the Canadian Hydrographic Survey has been tasked with a mapping strategy for benthic habitat and near-shore resources.

In addition to the literature review, a quick cursory search for hydrographic models capable of modeling sediment transport was conducted. A few papers documenting the use of XBeach, by Deltares, are included in this review. Due to time constraints, the author did not make an operational example using the model.

"XBeach [http://oss.deltares.nl/web/xbeach/] is a two-dimensional model for wave propagation, long waves and mean flow, sediment transport and morphological changes of the nearshore area, beaches, dunes and backbarrier during storms. It is a public-domain model that has been developed with funding and support by the US Army Corps of Engineers, by a consortium of UNESCO-IHE, Deltares (Delft Hydraulics), Delft University of Technology and the University of Miami."

While the model can be run using Matlab, the author had a version compatibility issue that prevent a quick setup of the program. Personal communication with University of Queen's professor Ryan Mulligan (Dept. of Civil Engineering) confirmed that the model is well respected in the community, although the functionality is subject to constraints. See section 2.9 for more details

The author must make it clear that this literature search is not intended to be a comprehensive review of SAR, SAS, bathymetric mapping, coastal policy, sediment transport, benthic boundary layer dynamics, image processing, repeat pass interferometry, or ocean dynamics in the littoral ocean. It is very likely that seminal papers on each of these topics have not been included in this review. Rather, this literature review is meant to be a starting point from which the contracting agency can expand on once a test location is confirmed, and coordination with the route survey operators has been explored.

1.2.1 Organization

Academic papers, online reports, and text books have been consulted for written research on the following topics:

- Synthetic aperture radar
- Synthetic aperture sonar
- Object detection/Sea-floor change detection/automated change detection

- Surficial Sediment mapping/bedform development/geomorphology
- Sedimentation measurement techniques
- Benthic sea-floor characterisation
- Coastal Mapping/LIDAR
- Biomass/benthic habitat
- Climatology
- XBeach
- Policy

1.2.2 Addendum

Significant effort has been directed to research on the Scotian shelf, in waters deeper than specified for this contract. As a result, there are few papers documenting the surficial sediment, bedforms, and climatology of the littoral ocean of Nova Scotia. As an addendum to the original contract, the contractor suggested to the technical authority that the scope of research be broadened to include papers on benthic habitat mapping and classification and the effects of bio-turbation. It was hoped that there would be more research directed to the conservation of near-shore benthic habitat threatened by human development along the coast. While multi-beam imaging of near-shore benthic habitat is the focus of many organizations, publications of data have not become readily available.

1.3 Results

The most significant finding of this literature review is the thesis of Nicola Wheatley, written as part of her M.Sc. from the Naval Postgraduate School in Monterey California. In this thesis, Nicola references a model from the British Navy (UKHO) which implemented a weighted GIS based model incorporating physical parameters such as surficial sediment type, ocean currents, and typical wave conditions with external factors like ship traffic to determine the periodicity with which route survey imagery needs to be collected as part of mine counter-measures. Nicola modified this algorithm for use in San Francisco Bay, specifically targeted to mine burial. The author was unable to locate a copy of the original model by UKHO.

However, the DRDC posed a different question for this literature review: at what time scales do baseline imagery de-correlate rendering automated object detection algorithms inoperable? In this case, DRDC is not interested in buried mine detection, but rather the automated recognition of meter scale ($1m^3$) objects on the sea-floor. Given appropriate algorithms to account for registration issues between images collected discreetly in time (i.e. on different route survey passes), how well can an automated detection algorithm perform given changes to the acoustic reflection signal from the bottom? More specifically, DRDC asked which processes act on the ocean bottom in the near-shore littoral ocean, the area beyond the inter-tidal zone but not extending on to the shelf (10m to 20m bathymetric contour).

Working in the near-shore is difficult as the bottom topography induces wave breaking making ship-based operations difficult to conduct. More than that, the shelf region is of interest for offshore fishery and, perhaps more importantly, for mineral/oil exploration.

1.4 Conclusions

The route survey periodicity must be determined for each location based on physical parameters of the location and local climatology. Given the lack of data in the littoral zone beyond the inter-tidal zone, DRDC will need to search the relevant databases for climatological, multi-beam, and bottom type data and compare previously collected images from existing route surveys to determine the periodicity required for the performance of the detection algorithm they implement. This data will likely need to be augmented by wave-rider and bottom mounted ADCP data, as well as bathymetry data and bottom hardness imaging.

As stated in section 2.2, the interpretation of multi-beam data must also be put in context with sub-bottom acoustic information.

1.4.1 Available resources

Natural Resources Canada has an online data base, the Expedition data base, which is a repository for . It can be accessed at http://ed.gdr.nrcan.gc.ca/index_e.php

On online data base of

"Measurements of biomass and productivity of seabed macrobenthic and megabenthic organisms, from studies in eastern North America from New England to the Canadian Arctic dating from 1954 to 2000, have been assembled into a comprehensive, georeferenced, database. Information sources include primary publications, technical reports and unpublished data from scientific studies, commercial fisheries surveys, and monitoring and baseline studies carried out for offshore petroleum exploration" (Stewart et al 2001)

can be accessed at http://www.iobis.org/

Data from three moored buoys stationed in Lunenburg bay from 2000 to 2007 can be accessed at www.cmep.ca

Oceanographic data is provided through DFO at what used to be called MEDS (marine environmental data service). Data hosted here can be accessed at

http://www.dfo-mpo.gc.ca/science/data-donnees/index-eng.html

Environment Canada provides climate data at the National Climate Data and Information Archive http://climate.weatheroffice.gc.ca/Welcome_e.html

Real time data from ocean buoys (providing meteorological and wave data) can be accessed through the NOAA site at http://www.ndbc.noaa.gov/, or for historical data, access Canadian buoys through DFO at

http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/waves-vagues/index-eng.htm

The Nova Scotia Department of Aquaculture and Fisheries is currently undergoing a re-organization. As such, it is severely understaffed, and at the time this report was due, had not responded to a request for access to bottom data around aquaculture sites. Bottom samples are collected around all potential sites, and at active sites as well, and video surveillance of the bottom is also collected. In addition, ADCP data has been collected at sites throughout the province, giving measurements of water currents and a measure of the vertical distribution of scatterers through the backscatter signal.

1.4.2 Sources to collaborate with

The near-shore is becoming of great interest to various government agencies. From the list of resources it is apparent that CHS, and GSC are working with levels of government, both in Canada in States bordering the Gulf of Maine, Bay of Fundy, to produce geological, bathymetric and benthic habitat mapping for use in marine policy. In addition, there are many assets within the province, including Acadia University, who, working through OERA and FORCE are directing research into in-stream tidal power generation in the Bay of Fundy, and at select locations around the province. In conjunction with some of these projects, the Geography department at St. Mary's University (SMU), the Centre for Applied Geomatics Research Group(AGRG) in the Centre for Geographic Sciences (COGS) at the NSCC are actively working in the near shore to monitor shoreline erosion and inter-tidal ecosystems.

Currently, the Halifax Marine Research Institute (HMRI) is overseeing a multi-year, multi-discplinary study called Marine Environmental Observation, Prediction and Response, monitoring coastal environments and their response to global climate change. Specifically, this project is set to measure the sociological and economic impact of increased storm activity, and sea-level changes arising from GCC.

DRDC might consider some networking efforts before it begins collecting data in the littoral ocean. The following is a table listing key players, their institutions, and their interests.

Table 1 *list of local resources for data in the near-shore zone*

Name	Institute	Research
Tim Webster	NSCC, COGS	LiDAR
Danika Proodjst	SMU	Inter-tidal zone
Anna Redden	Acadia, FORCE	In stream tidal power
Doug Wallace	Dalhousie University, HMRI	MEOPAR
Paul Hill	Dalhousie University	Sediment mobility
John Hughes Clark	University New Brunswick	SONAR
	PNS, DFA	Bottom type re aquaculture, in-shore fishery
	PNS DNR	Coastal erosion
	CHS	Bathymetric mapping
	GSC	Bottom sediment classification

2 Literature Review

2.1 SAR

Aperture synthesis is an imaging technique which uses to imaging devices separated by a known distance to improve resolution over a single device by making use of both the amplitude and phase information from the incoming waves. A comprehensive review of SAR is given in Rosen et al. (2000), an invited paper for Proceedings IEEE March 2000 written by several authors from the Jet Propulsion Lab (JPL).

Other titles listed in this review document **decorrelation times** (Zebker et al, 1992; Rignot and van Zyl, 1993; Goldstein, 1995; Ferretti et al. 2001), image **processing techniques** (Weisenseel et al, 1998; Bhanu and Yingqiang, 2003), **image registration** (Reigber and Papathanassiou, 2001; Prats et al., 2005; Câmara de Macedo et al, 2008), and **multi-pass approach** (Gray and Ferris-Manning, 1993; Hagberg et al, 1995). Titles dealing with **change detections from repeat-pass SAR** are topic specific and include (Fiujiwara et al, 1998; Remi and Rignot, 1998; Luckman et al, 2000; Askne et al, 2003; Ouchi et al, 2004)

Ender (1999) outlines using the ground based RADAR technique of moving target indication (MTI) for use with SAR imagery.

An early paper outlining two change detection algorithm for use with repeat pass interferometry is Remi and van Zyl (1993). The two techniques examined for multilook SAR in this paper are difference (ratioing is said to work better than subtracting the amplitudes) and the decorrelation of speckle. Another paper of note is one which uses multi-look SAR data to detect ships by creating a coherence image by cross correlating moving windows of multi-look images (Ouchi et al, 2004).

2.2 SAS

In keeping with the format of section 2.1, this section of the literature review contains several documents summarizing Synthetic Aperture SONAR. A good review, although the later part is specific to applications for mine detection, is van Vossen et al (2008). Barclay provides a review of interferometric SAS for determination of height from SAS in his thesis (2006). Hansen et al (2011) use the word "Challenges" in their review of SAS and Lyons (2011) warns:

"While these systems have been largely successful in achieving their goals of producing high-resolution imagery (on the order of square centimeters), there has been little effort in linking scattering physics to both the mean levels and statistics of the resulting sonar returns seen in the images"

in his review of his model and forward inversion work showing that decorrelation times decrease with increasing frequency.

Banks et al (2001) also present a review of InSAS, while Bellec et al (2005) state that while repeat pass imaging is used in SAR it had not been used for SAS. Synes (2010) investigates coherent processing of HISAS 1030 SAS on a HUGIN 1000-MR AUV. They conclude:

"We believe that the demonstrated ping-by-ping coherent processing will support generation of coherent SAS image pairs. Coherent SAS image pairs opens for coherent change detection, high accuracy bathymetric mapping and other coherent sonar products, which should be a goal of future work."

These papers are but a few of many; for the purposes of this literature review it is assumed the contracting agency has sufficient expertise in SAS that a review of the technology is unnecessary. Further, the contracting agency is far more knowledgeable regarding this topic than this author.

2.3 Object detection/Sea-floor change/Automated Detection

Admittedly, this is a broad classification of papers, and some may find it odd that these papers were not simply listed under the previous section. To begin, a special edition of the IEEE Journal of Oceanic Engineering (2009) contains many papers relating to the SAX 04 (sediment acoustics experiment 2004). The purpose of this experiment is given online at http://www.apl.washington.edu/projects/SAX04/summary.html as

"The overall objective of SAX04 is to better understand the acoustic detection at low grazing angles of objects, such as mines, buried in sandy marine sediments. One component of the SAX04 work is designed to collect data and gain a greater understanding of high-frequency sound penetration into, propagation within, and scattering from the shallow water seafloor at a basic research level. A second component is designed to provide data directly on acoustic detections of buried mine-like objects at low grazing angles."

While only one title from this edition is listed in this literature review, for a serious review of sound scattering from the sea-bed, this edition is a must-read.

It is difficult to decide whether the papers listed here or in section 2.4 are the most important to the question of route survey periodicity. Jackson et al (1996) contrast a sandy area to a silty area and show image decorrelation scales two orders of magnitude more rapid at the sandy site.

Hagen et al (2001) describe a technique for mine hunting using SAS mounted on an AUV.

Gerig et al (2009) work on relating bio-turbation by relating the "decorrelation of scattered acoustic intensity with the decorrelation of seafloor roughness spectral estimates." Jackson et al (2009) also formulate a model for bio-turbation of bedforms and compare to photographic and acoustic data.

Gendron et al (2009) worked on an automated change detection algorithm for SAS data converted to a format similar to existing high resolution side-scan SONAR for use with existing change detection algorithms.

Groen et al (2009) calculated detection rate statistics for a 300 kHz SAS mounted on the MUSCLE AUV in a "variety of seabeds, clutter and vehicle motion."

dePaulis et al (2012) present results from a two year project using SAS to measure altimetric variations in the seafloor.

Lyons and Brown (2012) present a review of temporal variability and confirm that the model of Jackson et al matches well with data, and that

"In both the past work and new analysis, decorrelation was found to be frequency dependent with e-folding times (i.e., decay constants) of hours to days, setting a limit on reasonable time frames for successful repeat–pass coherent change detection."

Kargl et al (2012) show SAS images of known targets, both buried and proud, from the SAX04 experiment.

Midtgaard et al (2011) present results from a trial with an AUV mounted SAS, while Kozak (2012) and Sternlicht et al (2012) both present change detection from side scan sonar for use in port security.

2.4 Surficial sediments/Multi-beam mapping/Geomorphology

Papers described in this section have overlap with those described in section 2.5; the common element is that the movement of surficial sediment creates bedforms, which are the primary interest in route survey periodicity as they present a potential problem for automated diction algorightms. Papers which deal explicitly with the measurement of bedload, transport, and the dynamics of the bottom boundary layer are described in the next section. Those which are more geological in nature, or describe large scale features of bathymetric acoustic imagery are described in this section.

Swift et al (1979) is a specific example of an article which might be more suitably placed in section 2.5. It presents a historical examination of three types of ripples in the mid-Atlantic Bight; the reference papers listed in this journal article are of critical importance to both sections 2.4 and 2.5.

Schwartz (1992) is included in this section particularly because of the following from the abstract: "The sets of sedimentary structures comprising modern washover sand bodies provide criteria for the identification of similar deposits in ancient sediments and for more specific interpretation of the environment"

Other geomorphological examples are: Dickson et al (1994), Li et al (997), Dalrymple and Hoogendoorn (1997), Dellapenna et al (1998), Amos et al (1999), Lyons et al (2002), Werner et al (2004), Shaw (2005), Fenster et al (2006), van Proosdij and Bambrick (2006),

while examples of acoustic imaging are Jackson et al (1996), IEEE Oceans (1998), Todd et al (1999), Locat and Sanfacon (2000), Barclay et al (2003), Pickerill and Todd (2003), Todd et al (2003), Shaw et al (2009), Piper and Campbell (2002).

Papers with a more geological analysis are: Fader (1997), Todd et al (1999), Shaw (2005), Shaw et al (2009), Schafer and Medioli (2009), Piper and Campbell (2002)

Some papers are listed under more than one category based on the topics covered.

One paper which stands alone is Orvain et al (2006) on the effects of Hydrobia ulvae has on sediment cohesiveness.

Other papers which need to be highlighted in this section are Hay (2008) and Jackson et al (2009) which describe the dispersion of bedforms by processes other than hydrological forcing.

Stow et al (2009) work in an inverse fashion, determing maximum past velocity maxima from bedform observations, whil Mosher (2011) provides a warning about geological interpretation of multibeam sonar data without considering data sampling limitations (averaging and beam spreading), subsurface details, and reoccurrence time scales.

Particular interest should be paid to the papers of Shaw, Pickerill, Todd, Mosher, Piper, Fader and Li from the GSC and CHS whose knowledge of the shelf region and geological features of Nova Scotian waters is second to none.

2.5 Sediment deposition/erosion rates: measurement techniques

Soulsby (1983) wrote what is considered to be the handbook on sediment transport. This document should be read in detail, despite the fact that the underlying physics may be beyond the scope of the image processing problem. The document is very relevant for choosing a model to implement, and when trying to analyse any data that may be collated or collected for further study.

Some papers listed in this section examine the physical dynamics related to sediment transport: Sheng and Hay (1995); Ogston and Stemberg (1995); Quinping and Hay (2002);

Others are site specific: Vincent and Osborne (1993);

Papers like Masselink and Pattiaratchi (1998), documenting the effects of a simple yet perhaps overlooked phenomemon like seabreeze on sediment resuspension, or Whitemeyer (2008), where bedforms suggest the possibility of barometrically induced large velocity (80 cm/s) events, show the complicated dynamics in the near-shore zone.

Largely, the papers listed in this section describe deposition or erosion rates, or describe bedforms imaged by acoustic or optical means. In addition, these papers describe the dynamic conditions measured over some period, and relate these physical conditions to the bedform mobility/degradation or formation.

From personal experience, this author has seen multibeam bathymetry data taken in 20-40m of water less than 1 km from shore, bedforms in sand and gravel of unknown origin. At one site, long wavelength ripples are present in what is presumed to be sediment composed of broken shells, tidal velocities exceed 3 m/s. From a non-rigours (and currently unpublished) analysis of repeat pass images the long wavelength ripples seem to be unmoving. At a second site, ripples in what is presumed to be gravel (requires very energetic conditions to become mobile) in predominant low flow (< 20 cm/s) region are likely made during the winter storm season. This author has also seen imagery from a harbour in Nova Scotia prone to meter scale pitting, origin unknown.

The conclusion to draw from these references, and personal experience, and in particular, from Nicola Wheatley's thesis, is that a significant amount of background information must be gathered, and an intensive field program initiated prior to the development of an estimate of route survey periodicity.

2.6 Benthic sea-floor characterisation

The literature was expanded to included benthic habitat given the lack of research effort in the nearshore, and going on the presumption that research efforts in the nearshore littoral zone would be directed towards benthic habitat. While this broadening of the search terms did not result in an expanded list of data collected nearshore it did uncover documents on the efforts for Coastal zone mapping in Massachusetts (Tyrell, 2004).

In addition, papers relating marine habitats to geophysical parameters (Roff et al, 2003, Orpin and Kostylev 2006), as well as mapping of Scotian shelf (Kostylev et al, 2001) and the Gulf of St. Lawrence (Colpron et al 2010) and atlantic Canada (Edinger et al, 2011).

2.7 Coastal mapping/LIDAR

Light detection and ranging (LIDAR) is typically collected from airplanes, although it can also be used in a cart equipped with GPS to map shorelines and cliff faces. The Applied Geomatics Research Group at the Centre of Geographic Sciences, Nova Scotia Community College, uses both these techniques in their research efforts. Air-borne LIDAR is particularly useful in mapping bathymetry on-shore and in shallow water. When it is properly referenced, it can complement bathymetric models by getting bathymetry in areas where ships cannot travel.

Included in this section are papers from the department of Geography at SMU, particularly the research group of Danika van Proosdij, who study the tidal flats, salt-marshes and intertidal areas in the Bay of Fundy.

2.8 Bio-mass

Studies of benthic ecology often involves recovering sediment samples at distributed locations. As a reult, biological studies include not only measures of the benthic macro and micro fauna, but also of sediment type. By expanding the literature review to include benthic biomass, a database of Fisheries data was discovered (Stewart et al 2001). Reports of ongoing data collection are also included in this review (Clark et al 2010, and Clark and Emberley 2011). An esoteric discussion on changing ecosystems is also included in this section, but only to suggest that given overfishing, trawling activities, invasive species, and global climate change, historical analysis of biomass may prove to be unreliable. Although any change in biomass is likely only to have had an effect on bio-turbation, and not on sediment type. Sediment cohesion is know to be affected by biology, so the effects of trophic change on sediment mobility in a sheltered coastal bay may not yet be known.

2.9 XBeach

XBeach is an open source model developed by Deltares (http://oss.deltares.nl/home). Many researchers in the community are actively testing the model. The model incorporates wave breaking (using Swan) and can incorporate other models as well. In addition to wave breaking, XBeach is capable of modeling flow, sediment transport and morphology change. However, the model does have constraints. It does not have vertical layers; rather it is a depth-averaged flow model better suited to shallow and vertically uniform situations.

Model output can be seen online at:

http://www.youtube.com/watch?v=kyvmxl7tdoQ [This video shows XBeach model results for a large scale dune erosion test conducted in the Deltaflume in 2006. the still water level is at 4.5 m above the flume's floor, Hrms = 1.5 m and Tp = 4.9 s. We imposed irregular waves described by a Pierson Moskowitch spectrum. The sand in the flume is characterized by D50 = 200e-6 m.]

Other publications listed in the bibliography are the result of an internet search for "xbeach" using Google Scholar. The titles showcase the various conditions for which the model is used.

2.10 Climatology

This section is perhaps the weakest link in this document, these references do not include near shore measurements in Lunenburg Bay, Mahone Bay, below the cliffs of Louisbourg, or data collected for the province of Nova Scotia's department of Fisheries and Aquaculture. The author is aware that acoustic Doppler current data was collected at these sites, although the results have not been published in academic journals. Additionally, meteorological and wave data can be found online at sites listed in section 2.12. These data are also not published in academic journals.

2.11 Policy

These large documents are not densely populated with relevant data. They are, however, important as they document a change in focus from various levels of government, and also document collaboration between federal and state agencies in the United States with agencies in Canada such as the Canadian Hydrographic Survey. These documents are included in this literature review as possible sources of data, contacts for collaboration, and for to cover additional references not attainable from a search simply limited to topics of geological, physical, or acoustical oceanography.

Bibliography

SAR

Zebker, Howard A., and John Villasenor. “Decorrelation in Interferometric Radar Echoes.” IEEE transactions on Geoscience and remote sensing, Vol 30, No. 5 (1992): 950-959.

Rignot, Eric J. M., and Jakob J. van Zyl. “Change Detection Techniques for ERS-1 SAR Data.” IEEE Transactions on Geoscience and Remote Sensing, Vol. 31,(1993) 4:896-906

Gray, A. Laurence, and Peter J. Farris-Manning. “Repeat-Pass Interferometry with Airborne Synthetic Aperture Radar.” IEEE Transactions on Geoscience and Remote Sensing, Vol. 31 (1993) 1:180-191

Goldstein, Richard. “Atmospheric Limitations to Repeat-track Radar Interferometry.” Geophysical Research Letters, Vol 22 (1995) 18:2517-2520

Jan 0. Hagberg, Jan O., Lars M. H. Ulander, and Jan Askne. ”Repeat-Pass SAR Interferometry Over Forested Terrain.” IEEE Transactions on Geoscience and Remote Sensing, Vol. 33 (1995) 2:331- 340.

Weisenseel, Robert A., W. Clem Karl, David A. Castanon, and Richard C. Brower. “MRF-based Algorithms for Segmentation of SAR Images.” Proceedings of the 1998 International Conference on Image Processing, vol.. 3,(1998): 770-774

Fiujiwara, Satosh, Paul A . Rosen, Mikio Tobita and Makoto Murakami. “Crustal deformation measurements using repeat-pass JERS 1 synthetic aperture radar interferometry near the Izu Peninsula, Japan.” Journal of Geophysical Research, Vol. 103, (1998) B2: 2411-2426

Michel, Remi, and Eric Rignot. “Flow of Moreno Glaciar, Argentina, from repeat-pass Shuttle Imaging Radar images: Comparison of the phase correlation method with radar interferometry.” Journal of Glaciology (1998)

Ender, J.H.G. “Space-time processing for multichannel synthetic aperture radar.” Electronics and Communication Engineering Journal (1999):29-38

Luckman,Adrian, John Baker, and Urs Wegmuller. “Repeat-Pass Interferometric Coherence Measurements of Disturbed Tropical Forest from JERS and ERS Satellites.” Remote Sensing of Environment, Vol. 350–360 (2000)73: 350-360

Rosen, Paul A., Scott Hensley, Ian R. Joughin, Fuk K. Li, Søren N. Madsen, Ernesto Rodriguez, and Richard M. Goldstein. “Synthetic Aperture Radar Interferometry.”Proceedings of the IEEE, Vol. 88, NO. 3 (2000):333:382

Ferretti, Alessandro, Claudio Prati, and Fabio Rocca. “Permanent Scatterers in SAR Interferometry.” IEEE Transactions on Geoscience and Remote Sensing, Vol. 39,(2001) 1:8-20

Reigber, A., and K.P. Papathanassiou. "Correction of residual motion errors in airborne repeat-pass interferometry." Geoscience and Remote Sensing Symposium, (2001)7: 3077 - 3079

Jan Askne, Jan, Maurizio Santoro, Gary Smith, and Johan E. S. Fransson."Multitemporal Repeat-Pass SAR Interferometry of Boreal Forests." Transactions on Geoscience and Remote Sensing, Vol. 41,(2003) 7: 1540-1550

Bhanu, Bir, , Yingqiang Lin. "Genetic algorithm based feature selection for target detection in SAR images." Image and Vision Computing 21 (2003) 591–608

Ouchi, Kazuo, Shinsuke Tamaki, Hidenobu Yaguchi, and Masato Iehara. "Ship Detection Based on Coherence Images Derived From Cross Correlation of Multilook SAR Images." IEEE Geoscience and Remote Sensing Letters, Vol. 1 (2004) 3:184-187

Prats,Pau, Andreas Reigber, and Jordi J. Mallorqui. "Topography-Dependent Motion Compensation for Repeat-Pass Interferometric SAR Systems. " IEEE Geoscience and Remote Sensing Letters, Vol 2 (2005)2:206-210

Câmara de Macedo, Karlus A., Rolf Scheiber, and Alberto Moreira. "An Autofocus Approach for Residual Motion Errors With Application to Airborne Repeat-Pass SAR Interferometry." IEEE Transactions on Geoscience and Remote Sensing, Vol 46 (2008) 10:3151-3162

SAS

Banks, S., T. Sutton, and H.Griffiths. "Interferometric Synthetic Aperture Sonar." London Communications Symposium (2001)

Callow, H.J., M. P. Hayes, and P. T. Gough. "Autofocus of Multi-band, Shallow-water Synthetic Aperture Sonar Imagery using Shear-averaging Change detection." Sydney, Australia: International Geoscience and Remote Sensing Symposium: Scanning the Present and Resolving the Future, 9-13 Jul 2001. In Proceedings of IGARSS 2001, Scanning the Present and Resolving the Future 4: 1601-1603

R. Bellec, R., M. Legris, A. Khenchaf, M. Amate, and A. Hetet. "Repeat-track SAS interferometry : feasibility study" Proceedings IEEE Oceans 2005, Vol 1 (2005): 748 - 754

Barclay, Philip J. "Interferometric Synthetic Aperture Sonar Design and Performance." PhD Thesis, University of Canterbury, Christchurch, New Zealand. August (2006).

Torstein Olsmo Sæbø, Torstein Olsmo, Roy Edgar Hansen, and Alfred Hanssen. "Relative Height Estimation by Cross-Correlating Ground-Range Synthetic Aperture Sonar Images." IEEE Journal of Oceanic Engineering, Vol. 32, No. 4 (2007): 971-982.

van Vossen, R., B.A.J. Quesson, J.C. Sabel "The prospects of SAS interferometry for detection and classification." TNO-DV2008 A176, Netherlands, (2008) Callow, Hayden J., Michael P. Hayes, and Peter T. Gough.Motion-Compensation Improvement for Widebeam, Multiple-Receiver SAS Systems." IEEE Journal of Oceanic Engineering, Vol. 34, (2009)4: 262-268

Sæbø , Torstein Olsmo. "Seafloor Depth Estimation by means of Interferometric Synthetic Aperture Sonar" PhD Thesis, Tromso University, Sept. (2010)

Synnes, Stig A.V., Hayden J Callow, Roy E Hansen, and Torstein O Sæbø. "Multipass coherent processing on synthetic aperture sonar data." Proceedings ECUA 2010 Istanbul Conference, (2010)

Lyons, Anthony P. "Synthetic Aperture Sonar Forward Modeling and Inversion." Technical Report, Pennsylvania State Univ., State College. Applied Research Lab. (2010)

Sæbø, Torstein O., Roy E Hansen, Hayden J Callow, and Stig A V Synnes. "COREGISTRATION OF SYNTHETIC APERTURE SONAR IMAGES FROM REPEATED PASSES." Proceedings of Underwater Acoustic Measurements 2011, Kos, Greece, June (2011).

Hansen, Roy E., Hayden J Callow, Torstein O Sæbø and Stig A V Synnes. "Challenges in Seafloor Imaging and Mapping with Synthetic Aperture Sonar." IEEE Transactions on Geoscience and Remote Sensing, Vol. 49 (2011) 10: 3677 - 3687

Object Detection/Sea-floor change/Automated detection

Hagen, Per Espen, Roy E. Hansen, Kenneth Gade, and Erik Hammerstad. "Interferometric Synthetic Aperture Sonar for AUV Based Mine Hunting: The SENSOTEK project." Unmanned Systems 2001, Baltimore, MD, USA, July-August 2001

Anthony L. Gerig, Anthony L., Anthony P. Lyons, Eric Pouliquen, and Kevin L. Williams. "Comparison of Seafloor Roughness and Scattered Acoustic Temporal Decorrelation." IEEE Journal of Oceanic Engineering Vol. 34, NO. 4, (2009): 423

Gendron, Marlin, Maura Lohrenz and John Dubberley. "Automated Change Detection Using Synthetic Aperture Sonar Imagery." Conference Proceedings, OCEANS 2009, MTS/IEEE Biloxi (2009)

Groen, Johannes, Enrique Coiras, David Williams. "DETECTION RATE STATISTICS IN SYNTHETIC APERTURE SONAR IMAGES." Proceedings of the 3rd International Conference and Exhibition on Underwater Acoustic Measurements: Technologies and Results, (2009)

"Guest Editorial Special Issue on Sediment Acoustic Processes: Part II." IEEE Journal of Oceanic Engineering Vol. 34, NO. 4, (2009)

Midtgaard, Oivind, Roy Edgar Hansen, Torstein Olsmo Sæbø, Vincent Myers, John R Dubberley, Isabelle Quidu. "Change Detection Using Synthetic Aperture Sonar: Preliminary Results from the Larvik Trial," Proceedings OCEANS 2011, Waikoloa, HI, (2011) De Paulis, R., C. Prati, S. Scirpoli, F. Rocca, A. Tesei, P. A. Sletner, S. Biagini, P. Guerrini, F. Gasparoni, C. Carmisciano and M. Locritani. "SAS multipass interferometry for monitoring seabed deformation using a high-frequency imaging sonar." Proceedings, IEEE Oceans 2011 (2011)

Lyons, Anthony P., and Daniel C. Brown. "The Impact of the temporal Variability of Seafloor Roughness on Synthetic Aperture Sonar Repeat–Pass Interferometry." IEEE Journal of Oceanic Engineering (2012)

Kargl, Steven G., Kevin L. Williams, and Eric I. Thorsos. "Synthetic Aperture Sonar Imaging of Simple Finite Targets." IEEE Journal of Oceanic Engineering, Vol 37 No. 3 (2012)

Kozak, Garry. "Side Scan Sonar Target Comparative Techniques for Port Security and MCM Q-Route Requirements." From http://ebookbrowse.com/techniques-port-security-pdf-d16727192

Sternlicht, Daniel D., Tesfaye G-Michael, Cameron A. Matthews. "ADVANCES IN SEABED CHANGE DETECTION FOR PORT AND COASTAL SECURITY." Waterside security conference (2012)

Surficial sediments/multi-beam mapping/geomorphology

Swift, D. J. P., G. L. Freeland and R. A.Young. "Time and space distribution of megaripples and associated bedforms, Middle Atlantic Bight, North American Atlantic Shelf." Sedimentology (1979) 26, 389-406

Schwartz, Robert K. "Bedform and stratification characteristics of some modern small-scale washover sand bodies." Sedimentology (1982) 29,835-849

Dickson, Stephen M., Joseph T. Kelley, and Walter A. Barnhardt. "Geomorphology and Sedimentary Framework of the Inner Continental Shelf of Downeast Maine." Report for the United States Minerals Management Service, Continental Margins Program. Dept. of Conservation (1994)

Jackson, Darrell R., Kevin L. Williams, and Kevin B. Briggs. "High-frequency acoustic observations of benthic spatial and temporal variability." Geo-Marine Letters (1996) 16:212 218

Fader, G.B.J., R.O. Miller, R.C. Courtney. "A geological interpretation of multibeam bathymetry: inner Halifax harbour." GSC Open file 3411 (1997) {found online at: http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/b04f43f4-f0e0-5049-9a83-3597e6acb0ad.html}

Li, Michael Z., Carl L. Amos, and David E. Heffler. "Boundary layer dynamics and sediment transport under non-storm conditions on the Scotian Shelf." Marine Geology 141 (1997) 157-181

Dalrymple, R.W., and E.L. Hoogendoorn. "Erosion and Deposition of Migrating Shoreface-attached Ridges, Sable Island, Eastern Canada." Geoscience Canada Vol. 24 (1997): 25-36

Kearns, T. Halifax Harbour drained: integration of multibeam, elevation, and SAR data, IEEE Oceans 1998

Dellapenna, T. M., S. A. Kuehl and L. C. Schaffner. “Sea-bed Mixing and Particle Residence Times in Biologically and Physically Dominated Estuarine Systems: a Comparison of Lower Chesapeake Bay and the York River Subestuary.” Estuarine, Coastal and Shelf Science (1998) 46, 777–795

Amos, C. L., A. J. Bowen, D. A. Huntley, J. T. Judge and M. Z. Li. “Ripple Migration and Sand Transport under Quasi-Orthogonal Combined Flows on the Scotian Shelf.” Journal of Coastal Research, Vol. 15, No. 1 (Winter, 1999), pp. 1-14

Todd, Brian J., Gordon B.J. Fader, Robert C. Courtney, and Richard A. Pickrill. “Quaternary geology and surficial sediment processes, Browns Bank, Scotian Shelf, based on multibeam bathymetry Marine Geology 162(1999). 165–214

Locat, Jacques and Richard Sanfaçon. “Multibeam surveys: a major tool for geosciences,” Proceedings of the Canadian Hydraugraphics Conference, Montréal, (2000).

Lyons, Anthony P., Warren L. J. Fox, Thomas Hasiotis, and Eric Poulique. “Characterization of the Two-Dimensional Roughness of Wave-Rippled Sea Floors Using Digital Photogrammetry.” IEEE Journal of Oceanic Engineering Vol. 27, NO. 3, (2002): 515

Piper, D.J.W and D.C Campbell. “Surficial geology of the Scotian shelf, Eastern Canada.” Geological Survey of Canada Current Research (2002) E15.

Barclay, P. J. , C. J. Fome, M. P. Hayes, and P. T. Gough. “Reconstructing seafloor bathymetry with a multichannel broadband In SAS using Belief Propagation,” Proc. OCEANS 2003, San Diego USA (2003)

Pickrill, Richard A., and Brian J. Todd. “The multiple roles of acoustic mapping in integrated ocean management, Canadian Atlantic continental margin,” Ocean & Coastal Management 46 (2003) 601–614

Todd, Brian J., Thomas Noji, Susan Snow-Cotter, and Page C. Valentine. “Provisional Strategic Plan: The Gulf of Maine Mapping Initiative GOMMI” February 21, 2003

Werner, S. R., R. C. Beardsley, and A. J. Williams III. “Bottom friction and bed forms on the southern flank of Georges Bank”, J. Geophys. Res., 108(C11), 2004

Shaw, John. “GEOMORPHIC EVIDENCE OF POSTGLACIAL TERRESTRIAL ENVIRONMENTS ON ATLANTIC CANADIAN CONTINENTAL SHELVES,” Géographie physique et Quaternaire, 59(2-3), 2005

Fenster, Michael S., Duncan M. FitzGerald, and Matthew S. Moore. “Assessing decadal-scale changes to a giant sand wave field in eastern Long Island Sound.” Geology, (2006): 89-92

van Proosdij, Danika, and Jillian Bambrick. “Spatial and Temporal Variations in the Intertidal Geomorphology of the Avon River Estuary,” Final report submitted to the Nova Scotia Department of Transportation and Public Works (NSTPW) (2006). Print ISBN: 978-0-415-45363-9

Orvain, Francis, Pierre-Guy Sauriau, Cedric Bacher, Michel Prineau. “The influence of sediment cohesiveness on bioturbation effects due to Hydrobia ulvae on the initial erosion of intertidal sediments: A study combining flume and model approaches.” Journal of Sea Research 55 (2006) 54– 73

Chapter 48: Sand ripple dynamics and degradation under oscillatory flow and turbulence. River, Coastal and Estuarine Morphodynamics: RCEM 2007, Two Volume Set Proceedings of the 5th IAHR Symposium on River, Coastal and Estuarine Morphodynamics, Enschede, NL, 17-21 September 2007, Edited by C . Marjolein Dohmen-Janssen and Suzanne J . M . H . Hulscher Taylor & Francis 2007

Hay, Alex E. “Near-bed turbulence and relict waveformed sand ripples: Observations from the inner shelf.” Journal of Geophysical Research, VOL. 113 (2008)

Jackson, Darrell R., Michael D. Richardson, Kevin L. Williams, Anthony P. Lyons, Christopher D. Jones, Kevin B. Briggs, and Dajun Tang. “Acoustic Observation of the Time Dependence of the Roughness of Sandy Seafloors.” IEEE Journal of Oceanic Engineering Vol. 34, NO. 4, (2009): 407

Shaw John,, Brian J. Todd, Denise Brushett, D. Russell Parrott and Trevor Bell. “Late Wisconsinan glacial landsystems on Atlantic Canadian shelves: New evidence from multibeam and single-beam sonar data,” BOREAS, Vol. 38 (2009) pp. 146–159

Schafer, Charles T. and Franco S. Medioli. “Pilot study of fossil evidence of onshore-directed storm events in estuarine sediments: Chezzetcook Inlet, Nova Scotia,” Can. J. Earth Sci. 46(2009): 193–205

Barrie, J. Vaughn, Kim W. Conway, Kim Picard, H. Gary Greene. “Large-scale sedimentary bed form sand sediment dynamics on a glaciated tectonic continental shelf: Examples from the Pacific margin of Canada.” Continental Shelf Research 29 (2009) 796–806

Stow, Dorrik A.V., F. Javier Hernández-Molina, Estefania Llave, Miriam Sayago-Gil, Victor Díaz del Río, Adam Branson. “Bedform-velocity matrix: The estimation of bottom current velocity from bedform observations.” GEOLOGY, April (2009):327-330

Mosher , David C. “Cautionary considerations for geohazard mapping with multibeam sonar: resolution and the need for the third and fourth dimensions,” Mar. Geophys. Res. Vol. 32 (2011) 25–35

Theroux, Roger B., Roland L. Wigley. “Quantitative Composition and Distribution of the Macrobenthic Invertebrate Fauna of the Continental Shelf Ecosystems of the Northeastern United States.” NOAA Technical Report NMFS 140

Pickrill, R.A. “Implementing Canada’s National Marine Mapping Strategy” Geological Survey of Canada.

Sediment deposition/erosion rates: measurement techniques

Soulsby, R.L., A.G.Davies and R.H.Wilkinson. “The detailed processes of sediment transport by tidal currents and surface waves.” Report No. 152, Institute of Oceanographic Sciences, (1983)

Vincent, C.E., P.D. Osborne. “Predicting suspended sand concentration profiles on a macro-tidal beach.” Continental Shelf Research, Vol. 15, (1995)13:1497-1514

Sheng, Jinyu, and Alex E. Hay. “Sediment eddy diffusivities in the nearshore zone, from multifrequency acoustic backscatter Continental Shelf Research.” Vol. 15, No. 2/3 (1995): 129-147

Ogston, Andrea S., and Richard W. Sternberg. “On the importance of nearbed sediment flux measurements for estimating sediment transport in the surf zone.” Continental Shelf Research, Vol. 15,(1995)13: 1515-1524

Masselink, Gerhard, Charitha B. Pattiaratchi. “The effect of sea breeze on beach morphology, surf zone hydrodynamics and sediment resuspension.” Marine Geology 146 (1998) 115–135

Ridd, P, G. Day, S. Thomas, J. Harradence, D. Fox, J. Bunt, O. Renagi and C. Jago. “Measurement of Sediment Deposition Rates using an Optical Backscatter Sensor.”Estuarine, Coastal and Shelf Science (2001) 52, 155–163.

Zou, Quinping and Alex E. Hay. “The Vertical Structure of the Wave Bottom Boundary Layer over a Sloping Bed: Theory and Field Measurements” Journal of Physical Oceanography. Vol. 33 (2002): 1380-1400

Lee, Guan-hong and Carl T. Friedrichs. “Examination of diffusion versus advection dominated sediment suspension on the inner shelf under storm and swell conditions, Duck, North Carolina.” JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 107 (2002) C7

Dehler, Sonya A. and D. Patrick Potter. “Determination of nearshore geologic structure off western Cape Breton Island, Nova Scotia, using high-resolution marine magnetics,” Can. J. Earth Sci. 39: 1299–1312 (2002)

Smyth, C., Alex E. Hay, and L. Zedel. ”Coherent Doppler Profiler measurements of near-bed suspended sediment fluxes and theinfluence of bed forms.” Department of Physics a Journal of Geophysical Reserach, Vol. 107, (2002)C8

Fernando, Harindra J.S., Sergey I. Voropayev, and Mark W. Schmeeckle. “Ripple Dynamics and Benthic Transformations under Variable Wave Forcing.” Technical Report, Arizona State Univ., Tempe. Dept. of Mechanical and Aerospace Engineering. (2007)

Testik, F.Y., S.I. Voropayev, H.J.S. Fernando and S. Balasubramanian. “Sand ripples dynamics and degradation under oscillatory flow and turbulence.” Proceedings of the 5th IAHR Symposium on River, Coastal and Estuarine Morphodynamics (2007)

Austin, Martin J., Gerhard Masselink. “The effect of bedform dynamics on computing suspended sediment fluxes using optical backscatter sensors and current meters.” Coastal Engineering 55 (2008) 251–260

Whitmeyer, Shelley J., and Duncan M. FitzGerald. ”Episodic dynamics of a sand wave field.” Marine Geology 252 (2008) 24–37

Benthic seafloor characterisation

Kostylev, Vladimir E., Brian J. Todd, Gordon B. J. Fader, R. C. Courtney, Gordon D. M. Cameron, and Richard A. Pickrill. “Benthic habitat mapping on the Scotian Shelf based on multibeam bathymetry, surficial geology and sea floor photographs.” Mar Ecol Prog Ser, Vol. 219 (2001) : 121–137

Roff, John C., Mark E. Taylor and Josh Laughren. “Geophysical approaches to the classification, delineation and monitoring of marine habitats and their communities,” Aquatic Conserv: Mar. Freshw. Ecosyst. 13: 77–90 (2003)

Megan Tyrrell “Strategic Plan for Mapping Massachusetts’Benthic Marine Habitats.” Massachusetts Office of Coastal Zone management Executive Office of Environmental Affairs. May (2004)

Orpin, Alan R., and Vladimir E. Kostylev. “Towards a statistically valid method of textural sea floor characterization of benthic habitats,” Marine Geology 225 (2006) 209–222

Colpron, Emile, Evan Edinger, and Barb Neis. “Mapping the distribution of deep-sea corals in the Northern Gulf of St. Lawrence using both scientific and local ecological knowledge,” DFO Can. Sci. Advis. Sec. Res. Doc. 2010/047. iv + 15 p. (2010)

Edinger, Evan N , OwenA.Sherwood, DavidJ.W.Piper, Vonda E.Wareham, Krista D.Baker, Kent D. Gilkinson, David B.Scott. “Geological features supporting deep-sea coral habitat in Atlantic Canada ,” Continental Shelf Research 31 (2011) S69–S84

Coastal Mapping/LIDAR

Pietersma-Perrott, Barbara, and Dr. Danika van Proosdij. “Shore Zone Characterization for Climate Change Adaptation in the Bay of Fundy,” report submitted to Atlantic Climate Adaptation Solutions Association.

Fedak, Michael. “Hydrodynamic Modelling for Flood Management in Bay of Fundy Dykelands,” Master of Science Thesis, Saint Mary’s University, Halifax, Nova Scotia

Webster, Tim, Nathan Crowell, Kevin McGuigan, and Candace MacDonald. “Mapping Coastal Sections using full 3D Digital Laser Scanning Technology to Monitor the Effects of Climate Change,” report to Climate Change Directorate, Nova Scotia Department of the Environment April, (2011) Webster, Tim, Kevin McGuigan and Candace MacDonald. “Lidar processing and Flood Risk Mapping for Coastal Areas in the District of Lunenburg, Town and District of Yarmouth, Amherst, Count Cumberland, Wolfville and Windsor,” report submitted to Atlantic Climate Adaptation Solutions Association, October (2011)

Tibbetts, Jeremy R. “Assessing Relative Coastal Vulnerability in a Macrotidal Environment to the Increased Risk of Storm Surges due to Climate Change,” Thesis, Masters of Science in Applied Science, Saint Mary’s University, Halifax, Nova Scotia (2012)

Benthic biomass

Stewart, P.L., H.A. Levy and B.T. Hargrave. “Database of Benthic Macrofaunal Biomass and Productivity Measurements for the Eastern Canadian Continental Shelf, Slope and Adjacent Areas.” Oceans and Environment Branch Canadian Technical Report of Fisheries and Aquatic Sciences 2336 (2001)

Frank, Kenneth T., Brian Petrie, Jae S. Choi,and William C. Leggett. “Trophic Cascades in a Formerly Cod-Dominated Ecosystem,” Science 308, 1621 (2005); 1621-1623

Clark, D., J. Emberley, C. Clark, and B. Peppard. 2010. Update of the 2009 Summer Scotian Shelf and Bay of Fundy Research Vessel Survey. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/008. vi + 72 p. (2010)

Clark, D.S. and Emberley, J. 2011. Update of the 2010 summer Scotian Shelf and Bay of Fundy research vessel survey. Can. Data Rep. Fish. Aquat. Sci. 1238 (2010)

XBeach/Models

Li, Michael Z., and Carl L. Amos. “sedtrans96: upgrade and calibration of the GSC sediment transport model.” Geological Survey of Canada, Open file report 3512. (1997)

http://www.youtube.com/watch?v=kyvmxl7tdoQ [This video shows XBeach model results for a large scale dune erosion test conducted in the Deltaflume in 2006. the still water level is at 4.5 m above the flume's floor, Hrms = 1.5 m and Tp = 4.9 s. We imposed irregular waves described by a Pierson Moskowitch spectrum. The sand in the flume is characterized by D50 = 200e-6 m.]

Roelvink, Dano, Ad Reniers, Ap van Dongeren, Jaap van Thiel de Vries, Robert McCall, and Jamie Lescinski. “Modelling storm impacts on beaches, dunes and barrier islands.” Coastal Engineering (2009) 56: 1133–1152

R.T. McCall, R.T., J.S.M. Van Thiel de Vries, N.G. Plant, A.R. Van Dongeren, J.A. Roelvink, D.M. Thompson, A.J.H.M. Reniers. “Two-dimensional time dependent hurricane overwash and erosion modeling at Santa Rosa Island.” Coastal Engineering (2010) 57: 668–683

Brandenburg, Peter. “Scale dependency of dune erosion Models: Performance assessment of the DUROS and XBeach model for various experiment scales.” MSc Thesis, Water Engineering & Management, University of Twente, The Netherlands (2010).

M.I. Vousdoukas†, L.P Almeida‡, and Ó. Ferreira. “Modelling storm-induced beach morphological change in a meso-tidal, reflective beach using XBeach.”Journal of Coastal Research, Special Issue 64, (2011):1916-1920

Hartanto, I.M., L. Beevers, I. Popescu, N.G. Wright. “Application of a coastal modelling code in fluvial environments .” Environmental Modelling & Software (2011) 26: 1685-1695

Almeida,L.P., Ó. Ferreira and A. Pacheco. “Thresholds for morphological changes on an exposed sandy beach as a function of wave height .”Earth Surf. Process. Landforms (2011) 36: 523–532

Silva, Ana Maria Almeida Nobre and Rui Pires Matos Taborda. “Integration of beach hydrodynamic and morphodynamic modelling in a GIS environment.” J Coast Conserv (2012)

Climatology

Loder, John W., Jennifer A. Shore, Charles G. Hannah, and Brian D. Petrie. “Decadal-scale hydrographic and circulation variability in the Scotia-Maine region.” Deep-Sea Research II 48 (2001) 3: 35

Lam ,Frans-Peter A., Patrick J. Haley Jr., Jeroen Janmaat, Pierre F.J. Lermusiaux, Wayne G. Leslie, Mathijs W. Schouten, Lianke A. te Raa, Michel Rixen. “At-sea real-time coupled four-dimensional oceanographic and acoustic forecasts during Battlespace Preparation 2007 .”Journal of Marine Systems 78 (2009) S306–S320

Xu, Fumin, and Will Perrie. “Extreme Waves and Wave Runup in Halifax Harbour under Climate Change Scenarios,” report submitted to Atlantic Climate Adaptation Solutions Association, May (2012)

Coastal Management and Policy

Rutherford, R.J., G.J. Herbert, and S.S. Coffen-Smout. “Integrated ocean management and the collaborative planning process: the Eastern Scotian Shelf Integrated Management (ESSIM) Initiative,” Marine Policy 29 (2005) 75–83

Canadian Science Advisory Secretariat. “IMPACTS OF TRAWL GEARS AND SCALLOP DREDGES ON BENTHIC HABITATS, POPULATIONS AND COMMUNITIES.” Science Advisory Report 2006/025 June 2006

“Resource Development and its implications in the Bay of Fundy and Gulf of Maine.” Proceedings from the 8th annual BoFEP Science Workshop, Acadia University, Wolfville NS, May 2009.

“The State of the Scotian Shelf Report” Context document: Oceans and Coastal Management Division Bedford Institute of Oceanography. ISBN: 978-0-9869437-0-6

Greenlaw, M.E., A.G. Gromack, S.P. Basquill, D.S. MacKinnon, J.A. Lynds, R.B. Taylor, D.J. Utting, J.R. Hackett, J. Grant, D.L. Forbes, F. Savoie, D. Bérubé, K.J. Connor, S.C. Johnson, K.A. Coombs, and R. Henry. A Physiographic Coastline Classification of the Scotian Shelf

Bioregion and Environs: The Nova Scotia Coastline and the New Brunswick Fundy Shore. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/051. iv + 39 p. (2013)

This page intentionally left blank.

List of symbols/abbreviations/acronyms/initialisms

DND	Department of National Defence
DRDC	Defence Research and Development Canada
DSTKIM	Director Science and Technology Knowledge and Information Management
R&D	Research & Development
SAR	Synthetic aperture RADAR
SAS	Synthetic aperture SONAR
NSCC	Nova Scotia Community College
COGS	Centre of Geographic Sciences
AGRG	Applied Geomatics Research Group
SMU	St. Mary's Univesity
UNB	University of New Brunswick
DFO	Department of Fisheries and Oceans
CHS	Canadian Hydrographic Service
GSC	Geological Service of Canada
PNS, DFA	Province of Nova Scotia, Department of Fisheries and Aquaculture
PNS, DNR	Province of Nova Scotia, Department of Natural Resources
HMRI	Halifax Marine Research Institute
MEOPAR	Marine Environmental Observation, Prediction and Response
UKHO	United Kingdom Hydrographic Office