Canadian National Committee for SCOR
Comité national canadien pour SCOR

Scientific Committee on Oceanic Research

CANADIAN OCEAN SCIENCE NEWSLETTER
LE BULLETIN CANADIEN DES SCIENCES DE L'OCÉAN

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Le Comité national canadien du Comité scientifique de la recherche océanographique (SCOR) favorise et facilite la coopération internationale. Il reflète la nature multidisciplinaire de la science océanique et de la technologie marine.

The Canadian National Committee of the Scientific Committee for Oceanic Research (CNC-SCOR) fosters and facilitates international cooperation. It is a non-governmental body that reflects the multi-disciplinary nature of ocean science and marine technology.

Disparate acidification and calcium carbonate desaturation of deep and shallow waters of the Arctic Ocean (Condensed Version)

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Build-up of anthropogenic CO_2 in the atmosphere is acidifying seawater, which will modify the carbonate chemistry of the Arctic Ocean. The Arctic Ocean is already exhibiting signs of such acidification [1], and this may be strengthened upon the disappearance of sea-ice, which will enable more efficient ocean-atmosphere gas exchange.

Pre-industrial waters of the deep Arctic basins were largely supersaturated with respect to aragonite [2], the more soluble of the $CaCO_3$ polymorphs, due to modest metabolic CO_2 production in these waters from low rates of organic matter re-mineralization; nevertheless, decreasing deep-water $CaCO_3$ saturation states and aragonite under-saturation now occur [3] – also see data below.

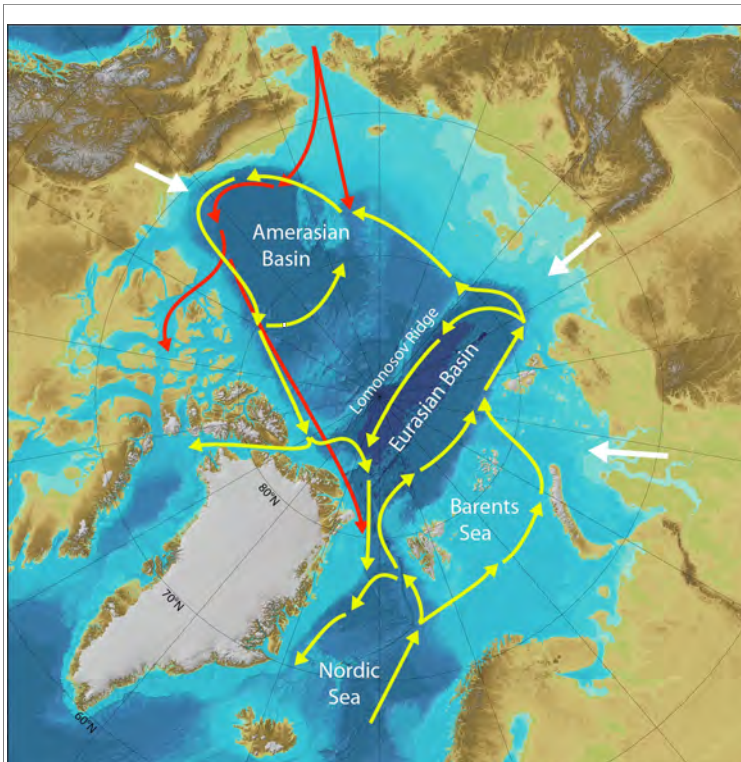

Figure 1. Map of the Arctic regions and major currents/water flows. IBCAO map of the two major deep basins, the Amerasian Basin and the Eurasian Basin, as separated by the Lomonosov Ridge. Red and yellow arrows indicate schematically Pacific water and Atlantic inflow waters, respectively. White arrows represent major river run-off from continents to the Arctic Ocean.

Considering the potential consequences of these changes to this vulnerable marine eco-system, it is paramount to be able to predict accurately the future evolution of the carbonate system of the Arctic Ocean. Models offer a means to reach this goal. Steinacher et al. [4] and Frölicher and Joos [5] have predicted, using a 3D circulation-biogeochemical model, that acidification will spread into the deeper waters from initially acidified surface waters. Nevertheless, the data presented by Miller et al. [3] and calculated from Key et al. [6] indicate the recent development and expansion of aragonite undersaturation in deep water, a feature not found in the 3D model predictions (see below).

Spurred by this discrepancy, we developed an alternative carbonate-dynamics box model for this system. Our model (Figure 2) represents both the Amerasian and Eurasian Basins, separated by the Lomonosov Ridge. Each basin is divided into surface (0-200 m), intermediate (200-700 m) and deep (>700 m) water boxes, and there exist flows between these boxes and with external sources, i.e., rivers and Atlantic and Pacific Oceans. Boxes are also included to account for sediment accumulation and benthic $CaCO_3$ dissolution. Our model equations predict the changes in total dissolved CO_2 ($\sum CO_2$) and carbonate alkalinity (CA) in each of these boxes, as forced by the increasing CO_2 in the atmosphere and in waters feeding into the Arctic. Time-varying $\sum CO_2$ and *CA* of the Pacific surface and high-latitude Atlantic waters that enter the Arctic are obtained from a previously published global carbon-system model [7]. The increase in atmospheric pCO_2 is driven with an *extended* version of the IS92a emission scenario [7].

CO_2 absorption from the atmosphere into the surface Arctic Ocean (dark blue $E_{S,A}$ and $E_{S,E}$ in Figure 2) is thought to be hindered by persistent ice cover. Thus, as global warming reduces the extent and duration of ice cover, CO_2 adsorption may increase, and we include ice-melting and corresponding increased CO_2 uptake in our model.

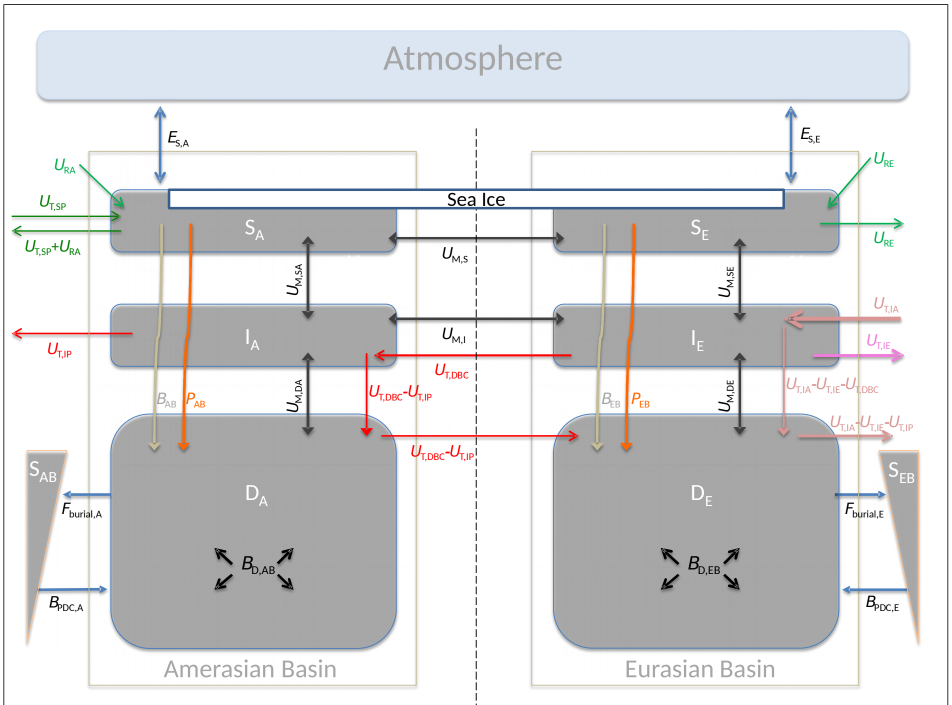

Figure 2. The box model for the carbonate system of the Arctic Ocean. The model divides the Arctic Ocean into a collection of 6 boxes, i.e., Surface Amerasian Basin (SA), Intermediate Amerasian Basin (IA), Deep Amerasian Basin (DA), Surface Eurasian Basin (SE), Intermediate Eurasian Basin (IE), Deep Eurasian Basin (DE), as well as an atmospheric box and 2 sediment reservoirs connected to the deep water boxes. Water flows between boxes are designated by capital U's, the capital E's indicate gas exchanges, the B's stand for internal fluxes of CaCO3, and the F's are the fluxes of CaCO3 to the sediments. Subscripts refer to the particular ocean (A and E), the different depth-boxes (S, I and D), and the nature of the flux, e.g., T for thermohaline, M for mixing, D for dissolution, etc.

Whereas the model results are in the form of $\sum CO_2$ and *CA*, we are primarily interested in the evolving saturation state of the Arctic waters with respect to aragonite, Ω_a,

$$\Omega_a = \frac{[Ca^{2+}][CO_3^{2-}]}{K_{sp}^*} \tag{1}$$

where $[Ca^{2+}]$ is the calcium concentration, $[CO_3^{2-}]$ is the carbonate ion concentration, and K^*_{sp} is the stoichiometric solubility product at in situ conditions. $[Ca^{2+}]$ is calculated from the known salinities of the Arctic Ocean basins. $[CO_3^{2-}]$ is calculated from $\sum CO_2$ and *CA*. Irrespective of the water chemistry, the aragonite saturation state changes with depth in response to increasing K^*_{sp} with pressure.

The aragonite saturation horizon, Z_{sat}, is the depth above which the waters are supersaturated with respect to aragonite ($\Omega_a > 1$) and below which waters are undersaturated ($\Omega_a < 1$) and in which aragonite will dissolve. To predict the position of that horizon, we coupled our box model to an explicit formula for Z_{sat},

$$Z_{sat} = Z_{sat}^0 \ln\left(\frac{[Ca^{2+}][CO_3^{2-}]}{K_{sp}^1}\right) \tag{2}$$

where Z^1_{sat} is a characteristic depth calculated from the solubility equations for aragonite and K^1_{sp} is the value of K^*_{sp} at 1 atm.

Central to our interests are the relative roles of atmospheric CO_2 forcing (*E*) and the input of waters from the Atlantic and Pacific Oceans ($U_{T,IA}$, $U_{T,SP}$ in Figure 2) in changing Ω_a of the Arctic Ocean. To facilitate this analysis, we created a hypothetical reference state wherein the pCO_2 in the Arctic atmosphere follows our prescribed CO_2 emissions scenario, but $\sum CO_2$ and *CA* of the inflowing Atlantic and Pacific waters do not change with time, labeled "constant source" in our figures; these particular inflows are set to year 2010 values. In contrast, a more realistic model results by allowing Atlantic and Pacific water chemistries to change as dictated by the evolving atmospheric CO_2, and those results are labeled "variable source".

To test our model, we compare our output to available saturation data. Figure 3A is a contour plot of the aragonite saturation state for the Amerasian Basin calculated from the data compilations of Jutterstrom et al. [2] and Key et al. [6]. These data indicate a rise of about 500 m over the 1995-2009 period. Figure 3B reproduces the saturation isopleths produced by the 3D model used by Frölicher and Joos [5], which are essentially flat over the 1995-2009 time frame. Finally, Figure 3C displays our model predictions of Ω_a isopleths for that same period and reveals that the isopleths are sloped by an amount similar to the data in Figure 3A, with an upward displacement of ~300 m, based on the Ω_a = 1.2 isopleth. Our model predicts slightly more acidic deep water in year 1995 than the data, but the observed and modeled isopleths below 2000 m are roughly at the same depth in 2009. Finally, Figure 4 displays our prediction of the long-term evolution of the aragonite saturation horizon (red lines) and that made by Frölicher and Joos [5] (black lines). These plots are explained and analyzed futher below.

The 500 m rise in Ω_a isopleths below 2000 m depth over the sampling period (Figure 3A) is not contained in the Frölicher and Joos [5] model results (Figure 3B), which implies that the 3D model does not (properly) represent the process(es) responsible for early, deep-water, desaturation. Our box model results (Figure 3C) provide superior data-prediction, which we principally attribute to a better accounting of Atlantic deep-water penetration ($U_{T,IA}$).

Over a longer time-scale, i.e., millennia, the position of the aragonite saturation horizon can be predicted with equation (2). Our modeled location of Z_{sat} and that from Frölicher and Joos [5] are illustrated in Figure 4A&B as red and black lines, respectively. To aid in the interpretation of this figure, arrows have been added to show the direction of time on a line segment. The black line for Frölicher and Joos [5] must be read in two parts: for the period of years 1850 to 2030, Z_{sat} is positioned at about 3250 m depth; it then also appears at the base of the mixed layer by the year 2030, as surface waters acidify. With time, the near-surface Z_{sat} moves deeper, while the deep Z_{sat} initially stays constant at 3200 m. Around the year 2200, Z_{sat} also starts to migrate

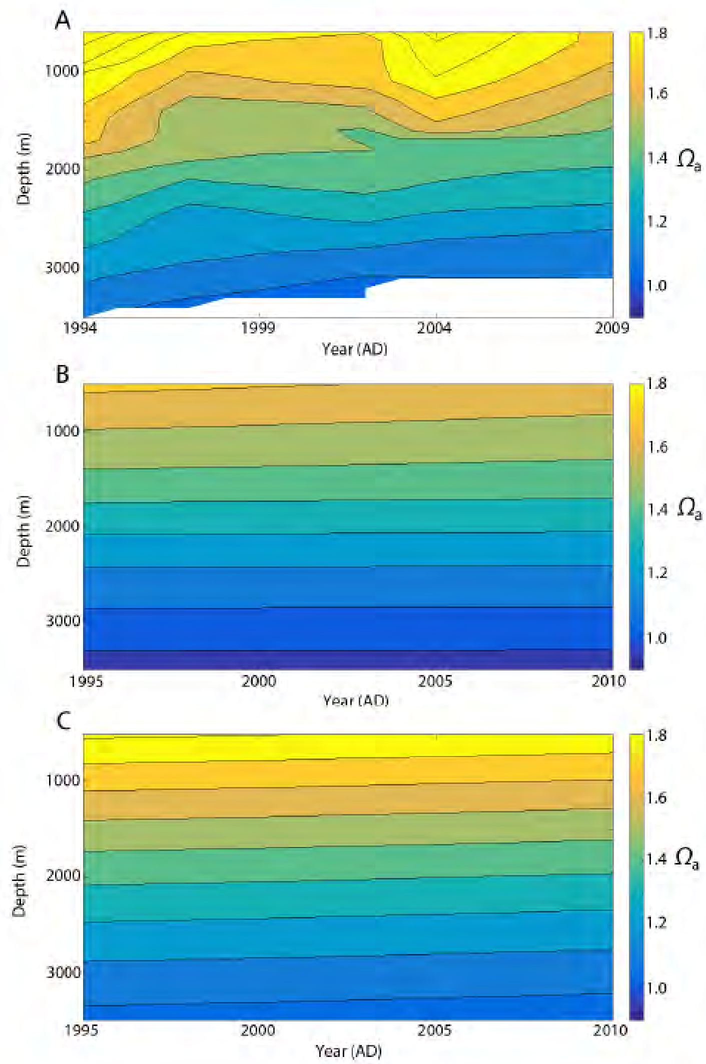

Figure 3. Contour plots of aragonite saturation in the Arctic Ocean. Lines are isopleths of constant Ωa. A Calculated from the data in Jutterstrom et al. [2] and Key et al. [6]. B Calculated with a 3D ocean circulation-biogeochemistry model by Frölicher and Joos [5]. C Calculated with equation (2) and the carbonate chemistry from our model (Figure 2). (Note the one-year time shift in the plot for data compared to the plots of the model results; this is an artifact of the contour.m function in Matlab.)

upward, indicating increasing deep-water acidification. The two horizons meet at about year 2325 at a depth of ~2400 m, and the entire deep Arctic Ocean is undersaturated thereafter.

In contrast, our model, solid red lines in Figure 4A&B, predicts that deep-basin waters were supersaturated to depths closer to 4000 m in pre-industrial times. Anthropogenically linked undersaturation then appears before year 2000 in the bottom waters of both basins because of deep Atlantic inflow. The saturation horizon should then move monotonically upward, without any indication of significant penetration from above the halocline. Z_{sat} will reach the base of the surface mixed layer by about the year 2275 and stay there until ~2970. The red dashed lines in Figure 4A&B illustrate the evolution of Z_{sat} if the entering North Atlantic waters were not to acidify beyond today's conditions ("constant source"). A comparison of the solid and dashed red lines shows that continued acidification and input of Atlantic waters dominates saturation changes in the deep Arctic Ocean.

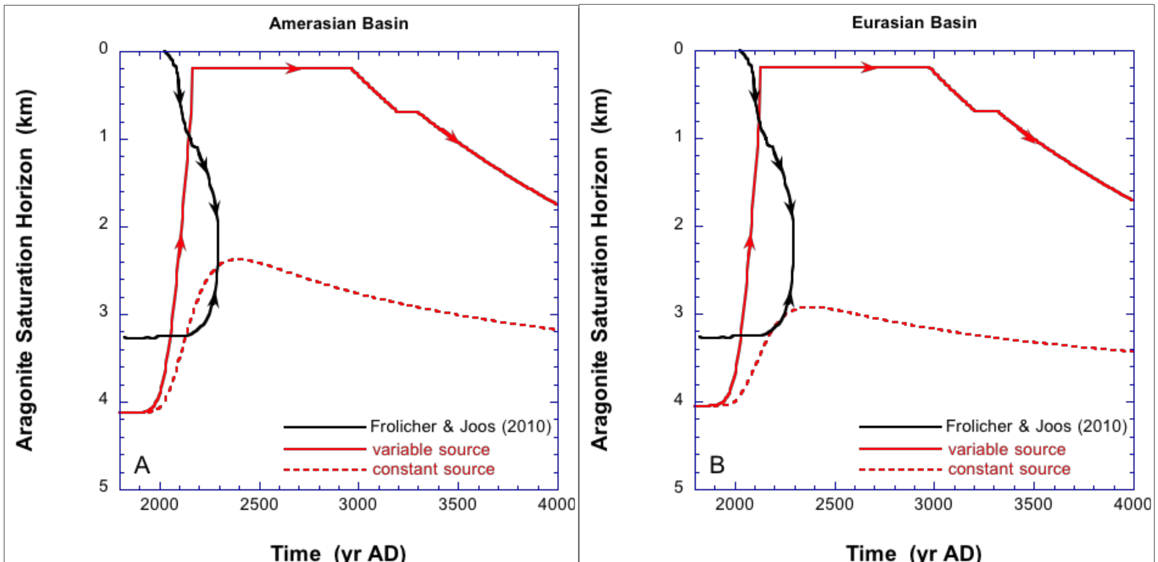

Figure 4. Predicted evolution of the aragonite saturation horizon. The arrows indicate the direction of change on a given line segment. **A** (left) The position of Z_{sat} in Amerasian Basin with our model (red lines) and that predicted in Frölicher and Joos [5] (black line). **B** (right) The position of Z_{sat} in the Eurasian Basin from our model (red lines) and that predicted in Frölicher and Joos [5] (black line).

In conclusion, our investigation of future Arctic acidification-desaturation reveals that both the Amerasian and Eurasian Basins will experience severe undersaturation with respect to aragonite and that acidification of the surface and intermediate/deep waters will be driven by the atmosphere and intermediate-depth Atlantic Ocean water inputs, respectively. Thus, our results reiterate the pressing need to fully apprehend the role of inter-oceanic flows in changing the carbonate chemistry of the Arctic Ocean. In addition, once established, aragonite undersaturation may persist for several millennia in deep and intermediate waters (Figure 4).

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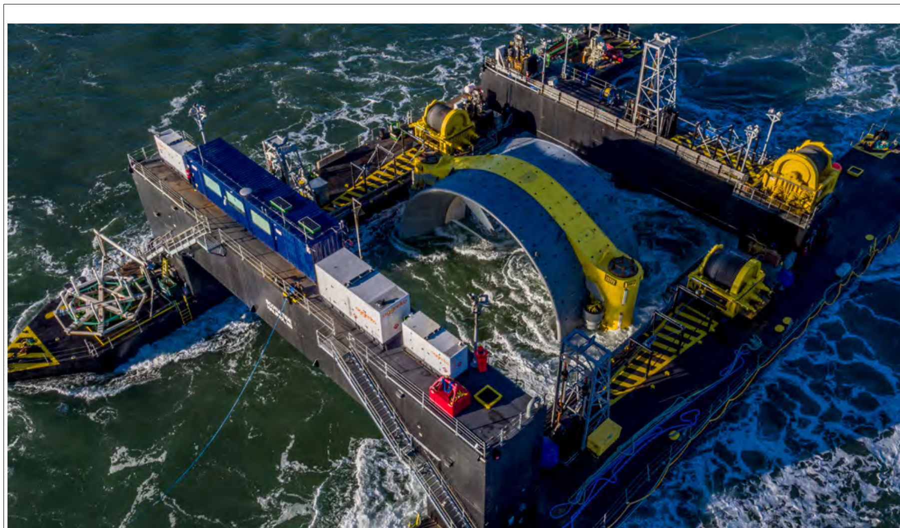
Tidal turbine placed in Upper Bay of Fundy



The Cape Sharp Tidal turbine enters the water.

On November 7 at 10:40 AM, Cape Sharp Tidal deployed the first OpenHydro Open-Centre turbine at the Fundy Ocean Research Centre for Energy (FORCE) near Parrsboro, Nova Scotia. The operation was completed in one attempt, in one tidal cycle, while holding station in the Crown Lease Area. The cooperative effort involved Nova Scotia companies Atlantic Towing (Dartmouth), Seaforth (Dartmouth), Mike Huntley (Kentville), RMI (Dartmouth) and more than 25 local crews. Support from local fishermen who lent their knowledge and understanding of the Minas Passage and local Parrsboro businesses who extended their operating hours around the time of the operation helped keep keep within a tight schedule.

Connecting the cable to transmit power and data to shore.

The next day, Cape Sharp Tidal's marine operations team safely connected the turbine cable tail with the 300-metre interconnection cable installed in the Minas Passage last winter. That cable attaches the turbine's power and data systems to an existing 16MW subsea export cable connected to the onshore substation at the FORCE site near Parrsboro. Throughout the next few weeks, the commissioning program will test the connection, communications and electrical systems to confirm energy production and communications with monitoring devices.

Data collected will be integrated with baseline studies started earlier. In particular they will be trying to better understand the turbine near-field interactions and potential effects turbines may have on the environment. Included in the studies will be monitoring for marine fish, marine mammals and turbine sound.

This section of your newsletter provides an opportunity to highlight your research programs to the Ocean Science Community. *Your are invited to send contributions to David Greenberg, david.greenberg@dfo-mpo.gc.ca*	*Mettez en valeur vos programmes de recherche en publiant un article dans cette première section de votre bulletin.* *Faites parvenir vos contributions à David Greenberg, david.greenberg@dfo-mpo.gc.ca*

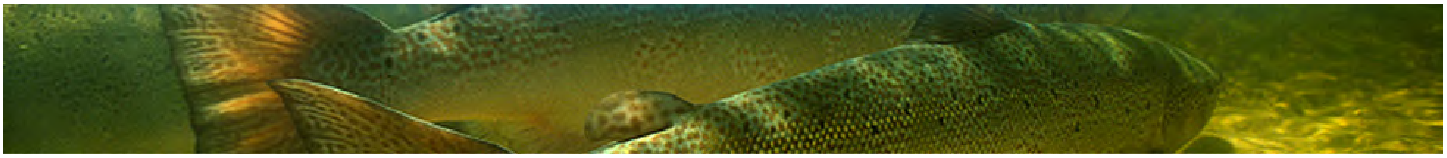
MEETINGS

51st CMOS Congress

Toronto June 4 - 8th, 2017
Future Earth: Weather, Oceans, Climate

The preparations for the next CMOS congress are well underway. On-line abstract submissions will be accepted between December 19, 2016 and February 12, 2017. Scientific and plenary sessions of the Congress will take place from Monday, June 5th through Thursday, June 8th, 2017. In addition, time and venue space have been set aside on Sunday, June 4th for related workshops, business meetings, courses and other Congress-related events, as well as an icebreaker reception to be held that evening.
Congress website

ASCF & CRI Webinar Series



The ***A**tlantic **S**almon **C**onservation **F**oundation* and the ***C**anadian **R**ivers **I**nstitute* have an annual series of webinars dedicated to fish and freshwater issues. Registration and participation in the series is **free**. You are encouraged to register early as space may be limited. Detailed instructions will be emailed to registrants before each webinar. You can take part through your computer or through a toll-free phone line, also at no cost to you. To register, please follow the appropriate link. If you have questions, you are invited to contact: arla@salmonconservation.cad or circourses@gmail.com. Among the webinars offered is: ***The incredible recovery of salmon populations in the northern Baltic Sea: learning from the past and facing new research challenges***, to be presented by Atso Romakkaniemi from the Luke Natural Resources Institute, Finland, on Feb 1 at 10:00 AST. Register

IEBS 2017

Rimouski, 4-8 June 2017

International Symposium on Estuarine Biogeochemistry

Estuaries: Biogeochemical Reactors in the Land-Sea continuum

IEBS returns to Rimouski in 2017 for its 14th annual meeting focused on estuarine biogeochemical processes. We hope to bring together a diverse group of participants to discuss biogeochemical interactions across the land-sea continuum and how they shape the functions of estuarine and coastal ecosystems. The 2017 symposium will engage participants in an international dialogue with a unique mix of keynote and contributed talks, poster sessions and group discussions. This meeting will contribute to the advancement of our field as we seek to understand a wide variety of estuaries and bays of different morphology, in distinct climate regions, facing various natural and anthropogenic pressures. We seek contributions that address any aspect of biogeochemical connectivity between or among the mosaic of systems that characterize this continuum, particularly those that take a multidisciplinary approach. We especially welcome studies of the causes and effects of present and past hypoxia and acidification; nano- to system-scale approaches to estuarine biogeochemistry; biogeochemical processes in permeable estuarine sediments; and the sources, effects, and biogeochemical cycling of technology-critical elements.

Dates: Abstract deadline **January 31.** Early registration ends **April 15.**

Conference Website

Please send meeting announcements to David Greenberg, david.greenberg@dfo-mpo.gc.ca	*SVP faites parvenir vos annonces de réunion à David Greenberg, david.greenberg@dfo-mpo.gc.ca*

CANADIAN JOBS and TRAINING

Assistant Professor in Global Biogeochemistry

The Department of Earth and Planetary Sciences at the University of California, Santa Cruz (UCSC) invites applications for a tenure track faculty position in biogeochemistry. We are especially interested in applicants who integrate and apply computer modeling and/or field and laboratory observations to investigate the interactions of biogeochemical systems/processes across or at the interface of marine and terrestrial environments on regional to global scales, and on human to geologic time scales.

Review of applications will begin on December 1, 2016. The position will remain open until filled, but not later than 6/30/2017. Details

Looking for work? Try the CMOS site (click).	*Vous recherchez un emploi? Visitez le site SCMO (click).*

GENERAL

2017 Massey Medal

Established in 1959 by the Massey Foundation, the Massey Medal is awarded annually by the Society. Its purpose is to recognize outstanding career achievement in the exploration, development or description of the geography of Canada. Eligibility is restricted to Canadian citizens, although in special circumstances, the Medal may be awarded to a non-Canadian, subject to agreement by the Massey Foundation. It is always awarded to an individual, never a group.

The presentation of the Massey Medal is usually made at Rideau Hall by the Society's Patron, the Governor General, when His/Her Excellency's schedule permits. In years when this is not possible, a special award ceremony is held at the College of Fellows Annual Dinner in Ottawa, with the President of the Society presiding.

All nominations must be submitted on-line and must be received by 11:59pm EST on January 15, 2017. The Committee will retain nominations under consideration for a period of three years.

The 2016 Massey Medal winner was Dr. Steve Blasco, recently retired from the Geological Survey of Canada at the Bedford Institute of Oceanography.

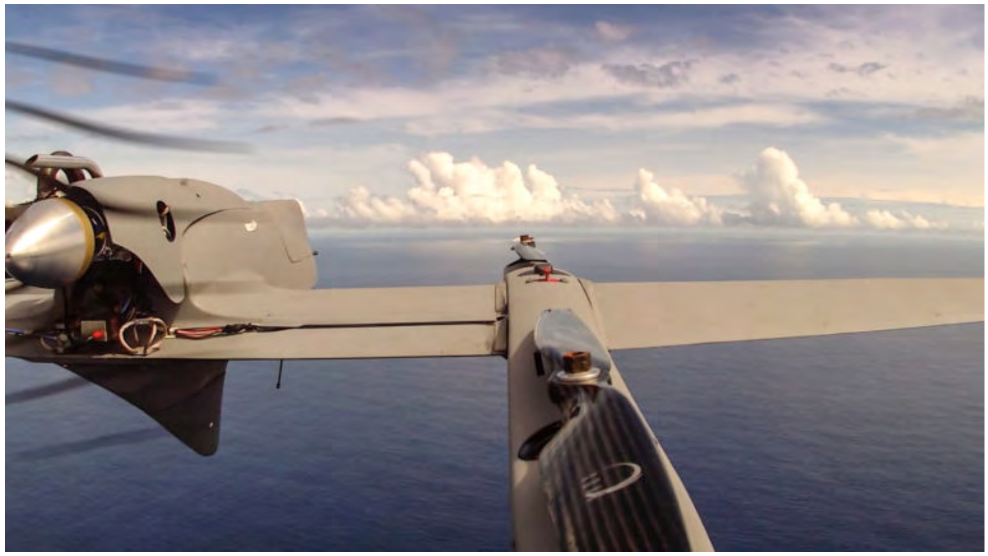
ACUNS-CNST Awards and Fellowships in Northern Studies

The Canadian Northern Studies Trust (CNST) is the awards program of the Association of Association of Canadian Universities for Northern Studies (ACUNS). It was established in 1982 to further ACUNS' mandate to advance knowledge and understanding of Canada's North by offering student awards for exceptional, northern-based research. The purpose of the CNST is to foster scholars and scientists with northern experience and at the same time enhance educational opportunities available for northern residents to obtain post secondary education at Canadian colleges and universities. Among the grants available are multiple awards for northern natural science research by Masters students ($15,000), PhD students ($50,000) and postdoctoral fellows ($50,000). All components of the application must be received by ACUNS **before January 31, 2017**.

Future of the Ocean and its Seas: Non-governmental input to the G7

The International Association for the Physical Sciences of the Oceans (IAPSO), the International Union of Geodesy and Geophysics (IUGG), and SCOR--three groups of the International Council for Science (ICSU)--prepared input for the G7, which is available here.

Two new cruises related to SCOR working groups set sail



An HQ-60B drone flies over the Pacific Ocean, away from the effects that Falkor or clouds could have over data being collected. The aircraft flies an average of two hours in each mission carrying a payload of radiation, hyperspectral or infrared cameras.

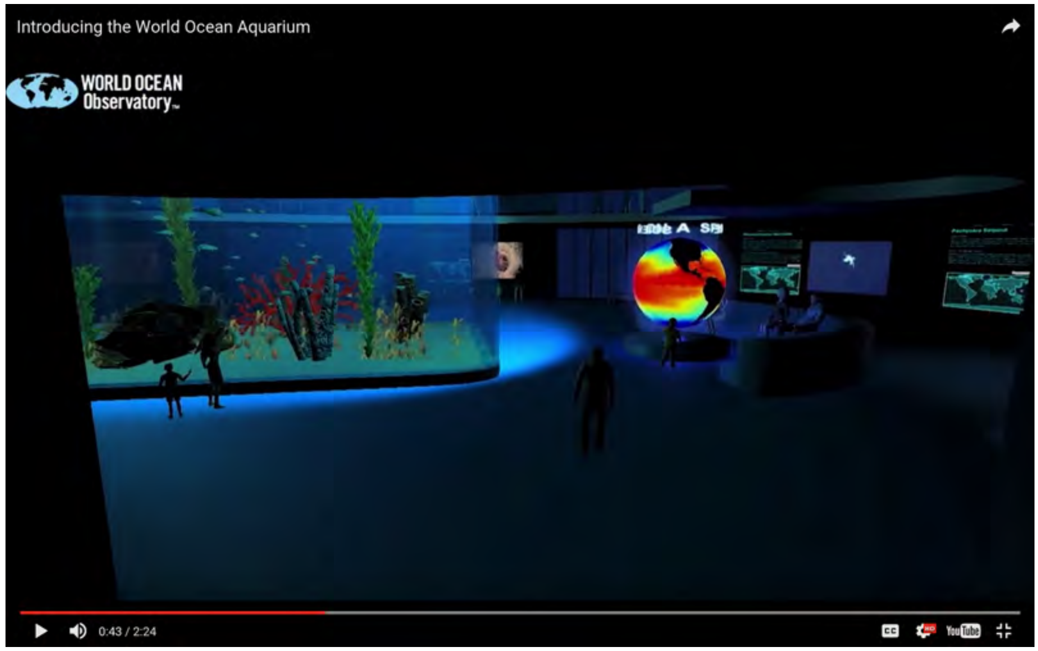
SCOR WG 141 on Sea-surface Microlayers is leading a cruise on the Schmidt Ocean Institute's R/V *Falkor.* The cruise left Darwin, Australia on 10 October for the first international research cruise dedicated to study of the sea-surface microlayer and air-sea interactions. The cruise will finish in Guam in mid-November. Experience gained from the cruise will be used to update the best practices manual produced by the group. More information about the cruise can be obtained from the Schmidt Ocean Institute's Web pages for the cruise.

SCOR WG 143 on Dissolved N2O and CH4 measurements: Working towards a global network of ocean time series measurements of N2O and CH4 is leading a one-week cruise of the *Elisabeth Mann Borgese* from the Leibniz Institute for Baltic Sea Research Warnemünde. The cruise will be conducted on the Baltic Sea beginning on 15 October to conduct an on-board comparison of six systems that measure methane (CH4) and nitrous oxide (N2O) while the ship is underway. The results of this cruise will be used by WG 143 to recommend how such systems could be used routinely to monitor these important greenhouse gases in ocean surface waters. Press releases in English and German are available for more information.

The modest funds that SCOR working groups receive for their meetings is not adequate to support research cruises, but WGs 141 and 146 were successful at finding additional funds to complement the funds from SCOR to extend their work. SCOR appreciates all those WG members involved in obtaining the funds for the cruises and for the sponsors of these activities.

World Ocean Aquarium

The [World Ocean Observatory](#) is pleased to announce the development of a [World Ocean Aquarium](#), a virtual gaming experience, based on realistic aquarium design and presentation, that will enable visitors on any internet-connected device to engage with the marine environment and the many educational services, goal-oriented activities such as operating an ROV, collecting species samples, visiting hydrothermal vents, exploring NOAA's Science on a Sphere, and watching documentaries and short films in a virtual aquarium theater.



Through computer gaming software and method of delivery to appeal to contemporary users, WOA [simulates the presentation and purpose of physical aquariums](#), showcasing species and habitat in both the Northern and Southern Hemispheres not otherwise available for display in an aquarium.

For school and maritime museum settings, the inclusion of the World Ocean Aquarium will allow for the addition of the natural ocean context to its educational programs and outreach through a digital visit by visitors, students, or a guided tour led by an educator. Access would be enabled through any device into homes, classrooms, and other venues – including projection in physical spaces – that would enhance the understanding of the relationships between the ocean and human endeavor.

CMOS looking for nominations

February 15th is the deadline for nominations for the **CMOS Prizes and Awards**. Visit http://www.cmos.ca/site/awards for a list of the eight awards, for instructions on how to make a nomination and then submit something on behalf of one of your colleagues or students. CMOS has a rich history recognizing deserving persons (members and non-members) through its awards programs. But regrettably, there are many deserving candidates who go unrewarded each year because we were too busy to work up a nomination. Don't wait - do it now!

March 15th is the deadline to recognize your colleagues by nominating one or more of them to be a CMOS Fellow or **CMOS Honorary Fellow**. It may seem far away, but it always arrives faster than we expected. The titles "CMOS Fellow" and "Honorary CMOS Fellow" may be granted for exceptional long term service and support to the Society and/or outstanding contributions to the scientific, professional, educational, forecasting or broadcasting fields in atmospheric or ocean sciences in Canada.

Please take a moment to visit http://www.cmos.ca/site/fellows for information about these designations and instructions on how to submit a nomination.

Note that any inquiries and all nominations are to be forwarded to the CMOS Awards Coordinator (Denis Bourque) at awards-coord@cmos.ca .

CANADIAN OCEAN SCIENCE NEWSLETTER

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Previous newsletters may be found on the CNC/SCOR web site.	Les bulletins antérieurs se retrouvent sur le site web du CNC/SCOR.
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