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Scientific Committee on Oceanic Research

CANADIAN OCEAN SCIENCE NEWSLETTER

LE BULLETIN CANADIEN DES SCIENCES DE L'OCÉAN

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Mixing rates, mechanisms and impacts in the Arctic Ocean: Highlights of recent work by a new research group at UBC

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Department of Earth, Ocean & Atmospheric Sciences, University of British Columbia

The Arctic Ocean is a rapidly changing environment that is tightly linked to changes in the Earth's climate. Historically the Arctic Ocean interior has been quiet, and the heat contained in sub-surface waters has been sequestered from contact with the surface by strong stratification and weak mixing rates. However, as more ice melts, we expect the ocean to become increasingly turbulent owing to increased exposure to wind forcing at the surface. The accompanying enhanced mixing rates are expected to result in important changes in Arctic Ocean stratification, dense water formation rates, and the properties of the waters exported from the Arctic to the global overturning circulation. Further, there exists the potential for the increased mixing intensity to be sufficient to mix the Artic Ocean's deep heat upward, which could warm surface waters, accelerate the rate of ice melt, and increase turbulent energies further.

A primary focus of our group at UBC is to better understand turbulent mixing rates, mechanisms and impacts in the Arctic Ocean in the past, present and future. To do this, we and our collaborators are collecting pioneering ocean glider-based measurements of turbulence, mapping the space and time variability of internal wave energy levels from historical and contemporary observations, and exploring sensitivities to mixing rates and patterns in realistic models of the circulation in the region. In all these approaches, we aim not only to quantify turbulent mixing rates and their space-time variability, but also the physical mechanisms that underpin them and the impacts they have on how the Arctic Ocean 'works' and plays its role in the climate system. In this way, we can better understand the feedbacks associated with current and future changes in the Arctic Ocean system. Highlights of our recent work, all still very much in progress, follow.

A centrepiece of our research at UBC is the collection of direct measurements of ocean turbulence, dissipation, and mixing from a turbulent microstructure-equipped ocean glider, a high-endurance, autonomous drone that carries sensors to study ocean physics, biology and chemistry (Figure 1). The glider's specialized capability to autonomously measure turbulent dissipation rates via on-board turbulent microstructure sensors is novel; the first-ever study to use a microstructure-equipped glider in a realistic setting was reported only in 2014 [1]. Gliders are nevertheless proving to be an ideal low-noise platform for turbulence measurements. They provide turbulence measurements of a quality comparable to that of the best free-falling instruments, with the added critical advantage of delivering the sustained, highly-resolved autonomous sampling needed to correctly characterize the episodic nature of ocean turbulence. The UBC instrument is the one of the first worldwide to be used specifically to study mixing rates and mechanisms in the Canadian Arctic.

In summer 2015, as part of the Canadian Arctic GEOTRACES Program and in collaboration with Jeffrey Carpenter and his team at the Institute of Coastal Research HZG, we successfully used a microstructure-equipped glider to collect 345 quasi-vertical profiles of multi-scale measurements of the ocean circulation in the Amundsen Gulf in the south-eastern Beaufort Sea (Figures 2, 3). The 345 profiles of turbulent microstructure collected over the glider's 10-day mission represent the densest microstructure sampling scheme in the western Arctic Ocean to date, and the first data set to statistically demonstrate the natural variability of turbulence in this region. These uniquely-resolved observations afford us a unique view into mixing rates, mechanisms and impacts in this climatically critical, yet vastly under-sampled region.

Figure 1: The UBC turbulent microstructure-equipped ocean glider. The microstructure probes are mounted above and to the front of the instrument, at the end of the black cylindrical housing. Photo credit: Tara Howatt.

Figure 2: Deployment of a turbulent microstructure glider in the Amundsen Gulf from the science barge of the CCGS Amundsen during the Canadian Arctic GEOTRACES Program cruise in summer 2015. Photo credit: Lantao Gang.

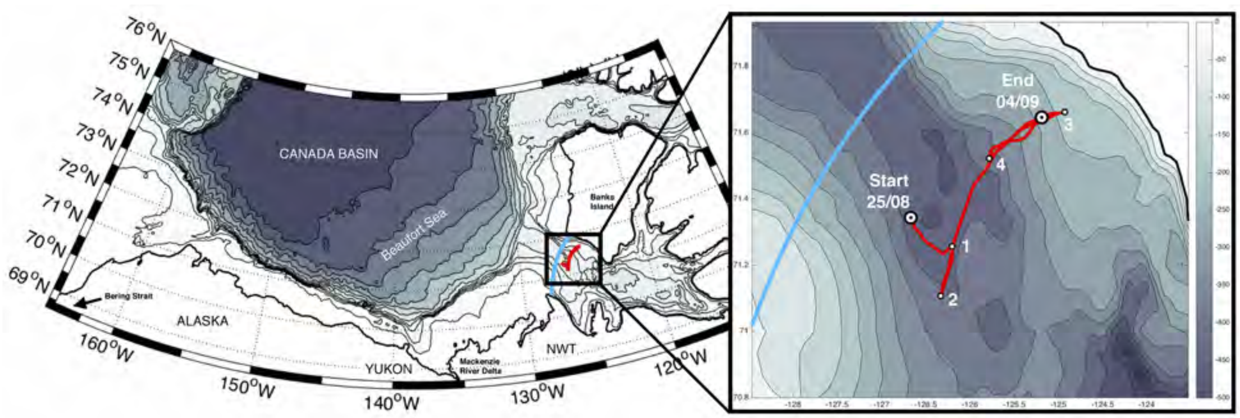

Figure 3: The glider's 10-day path in the Amundsen Gulf along which it measured 345 quasi-vertical CTD and microstructure profiles in summer 2015. Shown are the start and end points/dates, as well as the location of four intermediate waypoints.

Preliminary analysis of the glider's measurements, led by Ph.D. candidate Benjamin Scheifele, shows that the water mass structure in the Amundsen Gulf, despite being at the geographic margins of the Arctic Ocean, exhibits the same primary features that define the structure in the central Canada Basin. These include a seasonal thin, fresh and warm surface mixed layer, a strong near-surface pycnocline resulting from summer sea ice-melt, a colder temperature minimum below the surface mixed layer associated with Pacific inflow, and a warm Atlantic Water temperature maximum at ~350-400 m depth. In addition, the strong stratification above 300 m, the presence of a distinctive warm-core mesoscale eddy, and the clear signature of isopycnal displacement due to internal waves seen in the data set are all representative of features found more widely across the region (Figure 4). Preliminary analysis of the glider's microstructure shear measurements indicate that turbulence is generally very weak, but also variable and patchy

(Figure 5). A histogram showing the distribution of the 48,857 unique dissipation rate estimates (Figure 6) highlights 3 important characteristics: (i) the remarkably large variability of dissipation rates spanning four orders of magnitude; (ii) the disproportionately high probability of observing low dissipation rates; and (iii) the sufficiency of our measurements to define robust statistical averages, a rarity for ocean microstructure measurements especially in the Arctic Ocean. Perhaps the most striking result to date is demonstrated in the distribution of the so-called turbulence intensity parameter, I, a non-dimensional number that characterizes the strength of the turbulent mixing to the stabilizing effects of the stratification (Figure 6c). This shows that an overwhelming majority (89%) of our measurements occur at values of $I \leq 10$. Such low values of this parameter indicate that turbulence is generally not energetic enough to drive a meaningful buoyancy flux in light of the stabilizing effect of the stratification, and that the diffusion coefficient for heat is most frequently near its molecular value and is only occasionally enhanced by turbulent mixing. Such a low diffusion coefficient implies a heat flux of only order 0.01 W/m^2 through the steepest part of the thermocline, and such values of I suggest that the energy of the background turbulent state would have to increase by at least an order of magnitude to drive a meaningful buoyancy flux.

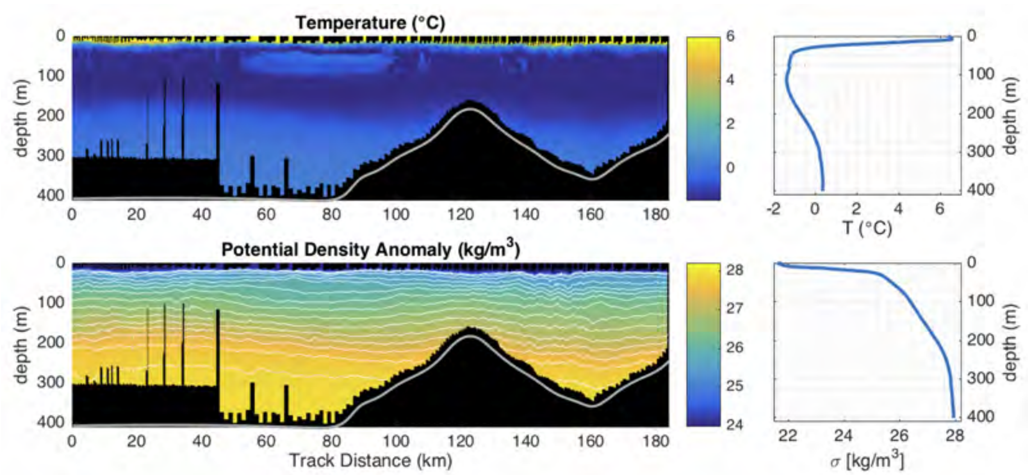

Figure 4: (Left) Temperature and density sections along the glider track shown in Figure 3. Isopycnals in 0.2 kg/m3 increments are shown in white in the lower figure. The approximated bathymetry is shown in grey for reference. (Right) Section mean temperature and density profiles.

In addition to collecting new observations, we are also engaged in gaining new insights into mixing mechanisms, their spatial variability, and temporal trends by consolidating historical observations across the Canadian Arctic. Current efforts involve using these measurements to create a comprehensive and coherent survey of the spatial and temporal variability of internal wave energy and inferred wave-driven mixing across the region. Most previous Arctic Ocean studies have tended to be geographically limited in scope, with measurements that are sparse in space and time. Our efforts seek to address the need for broader analyses to better characterize and explain changing patterns in Arctic internal wave energy levels and associated mixing rates in order to ultimately arrive at a better understanding of the potential for change of wave-driven mixing in an evolving Arctic Ocean.

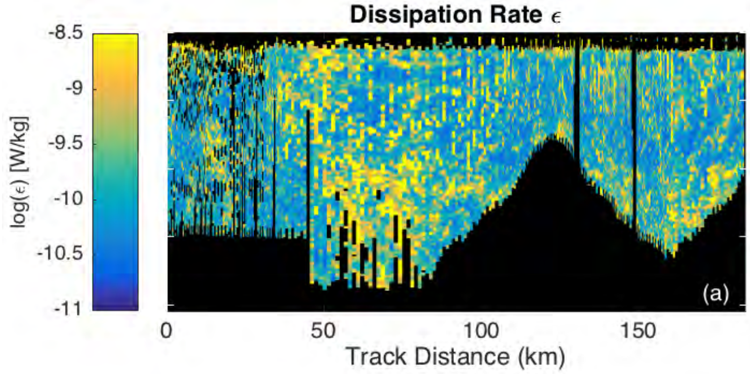

Figure 5: A cross-sectional view of the dissipation rate of turbulent kinetic energy along the glider track shown in Figure 3. Contoured is $\log_{10}(\varepsilon)$, as measured by one of the two shear probes.

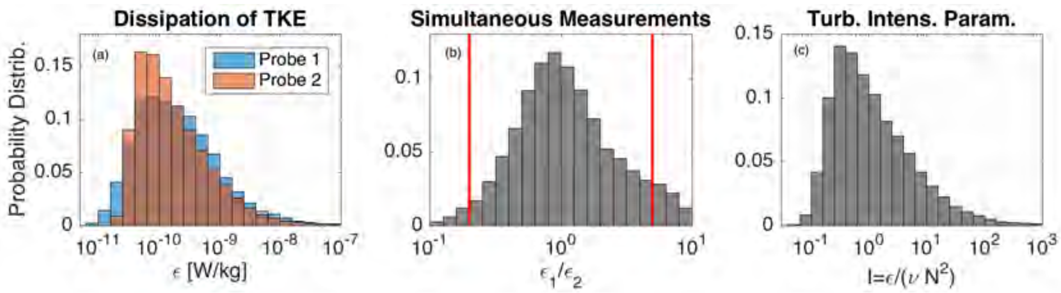

Figure 6: Probability distributions of (a) the dissipation rate of turbulent kinetic energy from the two shear probes; (b) the ratio of simultaneous ε measurements from the two shear probes the region between the red lines indicates where measurements from the two probes agree to within a factor of five; and (c) the turbulence intensity parameter, I.

There exists an abundance of geographically wide-spread vertical profiles of ocean temperature and salinity that has been collected since 1997 by the Network of Centres of Excellence of Canada *ArcticNet*. Together with Yves Gratton (Institute National de la Recherche Scientifique) and ArcticNet, we are consolidating, exploring and interpreting this extensive dataset as a whole. Specifically, we are using the data to 1) quantify the energy in the internal wave field by characterizing the density fluctuations that result from internal wave oscillations; 2) consider the implications for internal wave-driven turbulent kinetic energy dissipation and diapycnal diffusivity through the use of finescale parameterizations [4]; and 3) map the trends in the strength of the stratification across the Pacific, Atlantic, and surface water layers to consider how these will affect the suppression of mixing for a given turbulent energy level. An additional goal is to contribute to our understanding of the variability in internal wave energy and wave-driven mixing rates by exploring links to the underlying mechanisms that may drive it. To this end, we are examining correlations of diagnosed wave energy levels and mixing rates with variability in wind forcing, tidal energy, and bottom roughness in attempts to assess the relative importance of the dominant internal wave forcing mechanisms.

This analysis, led by M.Sc. candidate Melanie Chanona, is still in its preliminary stages. However, already the exercise is providing some thought-provoking views of the large-scale geographic patterns of large-amplitude internal wave activity and its evolution over the last two decades. Further, our analysis of correlations between wave energy and indications of wave energy sources promises to shed new light on the current debate on the likely response of the Arctic to changing conditions [*e.g.* 3,4].

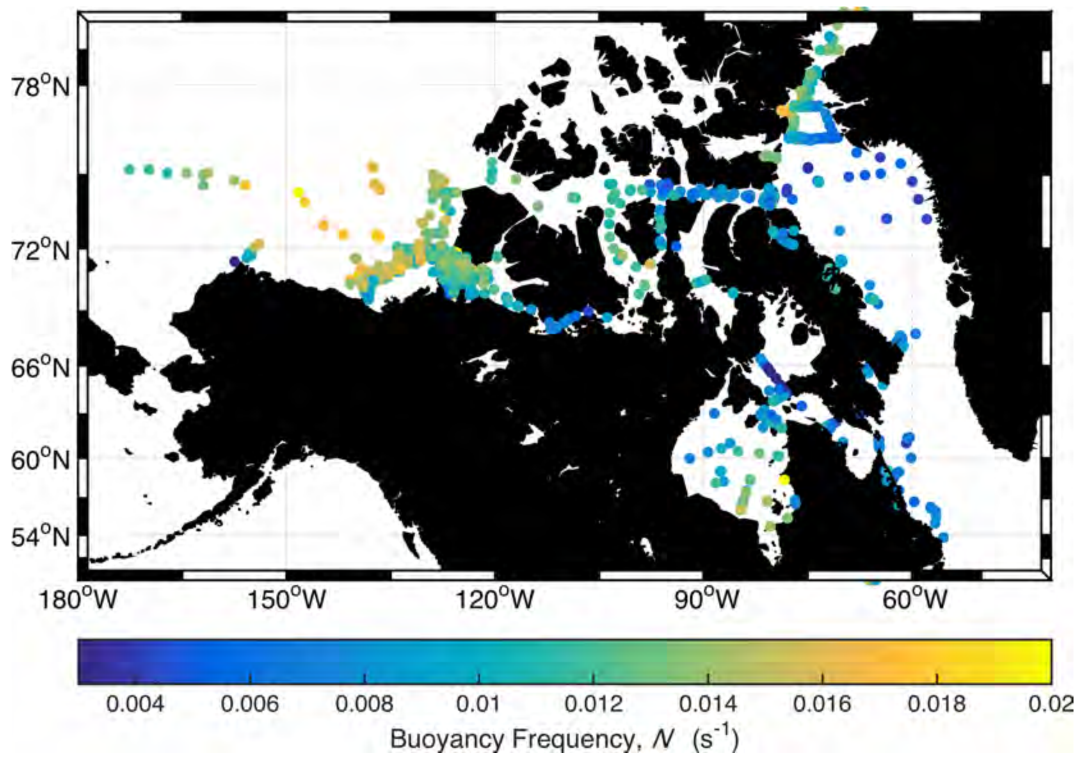

Figure 7: Locations of 3003 vertical profiles of ocean temperature and salinity collected by ArcticNet in the period 2002-2014 (dots). Colour indicates the magnitude of the stratification, as measured by the buoyancy frequency N, averaged between 50 and 100 m representative of the stratification in the main pycnocline above the Atlantic Water layer.

Finally, in addition to observational studies, we are also working to quantify and better understand the sensitivity of the Arctic's response to changes in mixing rates and mechanisms via experiments with a state-of-the-art climate model. Presently, we rely heavily on realistic numerical models of the Arctic Ocean circulation to study Arctic Ocean processes in ways not possible with sparse observations, and to make predictions for present-day operational needs and future climate projections. However, how best to represent mixing in these models, and further how to understand the impact of our mixing representations on model Arctic Ocean functioning and its role in the climate system, remain important, on-going challenges.

We are working with Paul Myers and his group at the University of Alberta (U of A) to investigate the impact of diapycnal mixing rates and mechanisms in NEMO (Nucleus for European Modelling of the Ocean) 1/4° and 1/12° regional models of the Arctic Ocean developed by the U of A group. The NEMO model framework is a widely used oceanographic model in the Canadian and international research communities, as well as by the Canadian government for operational purposes. The specific focus of our study is to quantify the impact of including an additional parameterization of mixing due to the breaking of internal tides [5] on Arctic dense water formation and shelf-basin dense water exchange.

Work on the project, led by M.Sc. candidate Jacquie-Lee Thibault, is also still in its early stages, but preliminary results are promising. Our first attempt to add the enhanced tidal mixing parameterization to the model shows that it has a significant impact on both the magnitude and spatial patterns of model mixing intensity (Figure 8). It thus is almost certain to have important implications for the model's representations of Arctic shelf dense water formation, the shelf-basin exchange of dense water, and the heat flux from the Atlantic water layer. Much work still needs to be done, but at present we are cautiously optimistic that these simulations will deliver useful insight into the sensitivity of the rates and nature of Arctic dense water formation and exchange in both the model and in nature. Utimately, these results will inform an understanding of how dense water formation on Arctic shelves will react to a changing Arctic environment.

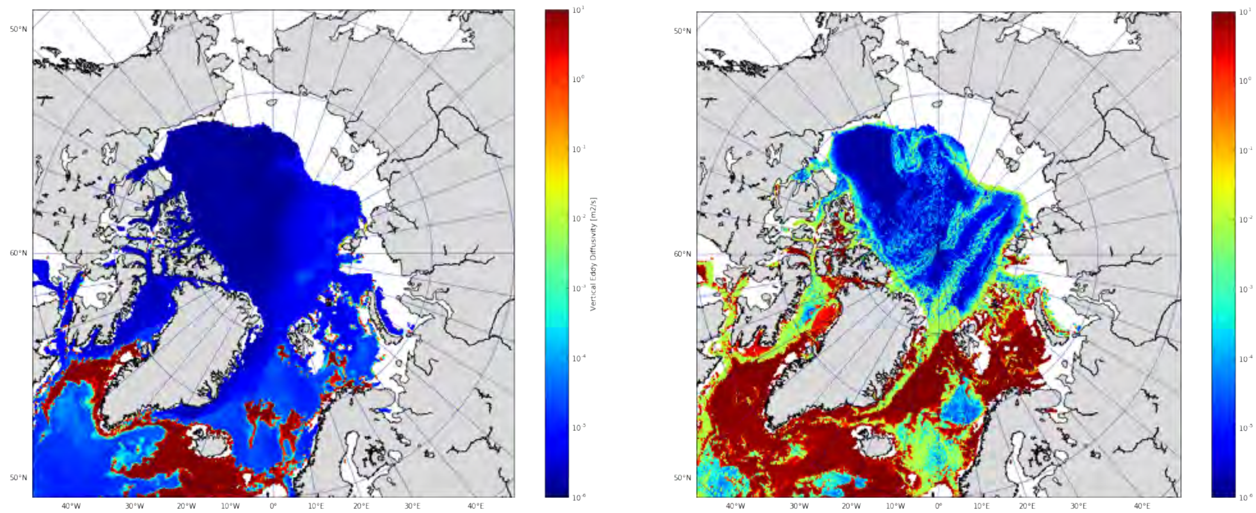

Figure 8: Model vertical eddy diffusivity, κ_v, at 170 m depth in (left) a control NEMO model simulation with a standard mixing scheme; and (right) a NEMO model simulation with the standard mixing scheme plus an additional parameterization of mixing due to the breaking of internal tides.

Stephanie Waterman is a physical oceanographer with interests in both observational and theoretical oceanography. Her specific research interests include geophysical fluid dynamics, in particular the dynamics of jets, eddies and scale interactions; western boundary current jets and their recirculation gyres, in particular the role of eddy fluxes in these systems; and Southern Ocean dynamics, in particular the role of mesoscale and submesoscale processes. Since moving to the University of British Columbia as an Assistant Professor in 2014, she has also worked to build a research program focussing on Arctic oceanography, with a specific focus on the rates, mechanisms and impacts of lateral and vertical mixing in the deep basins and on the continental shelves. She is the inaugural winner of the CNC-SCOR Early Career Scientist Award, an award presented to an early career oceanographer/marine scientist (within 10 years of completion of a Ph.D) for an outstanding contribution to marine sciences within Canada.

ACKNOWLEDGMENTS:

We acknowledge the invaluable contributions of our collaborators, Jeff Carpenter and members of the Small-scale Physics and Turbulence Group at the Institute of Coastal Research, Helmholtz-Zentrum Geesthacht, Geesthacht, Germany, Yves Gratton at Centre Eau Terre Environnement, Institute National de la Recherche Scientifique, Quebec, Quebec, and Paul Myers and members of his group at the University of Alberta. We also thank the Ocean Tracking Network Group at Dalhousie University, ArcticNet Canada, and the crew of the CCGS Amundsen for their invaluable help with glider operations. We gratefully acknowledge support from the Canadian Arctic GEOTRACES Program, the UBC Killam Doctoral Scholarship, NSERC CGS M, CGS D and Vanier Scholarships, the UBC Four Year Fellowship Program, and the Northern Scientific Training Program.

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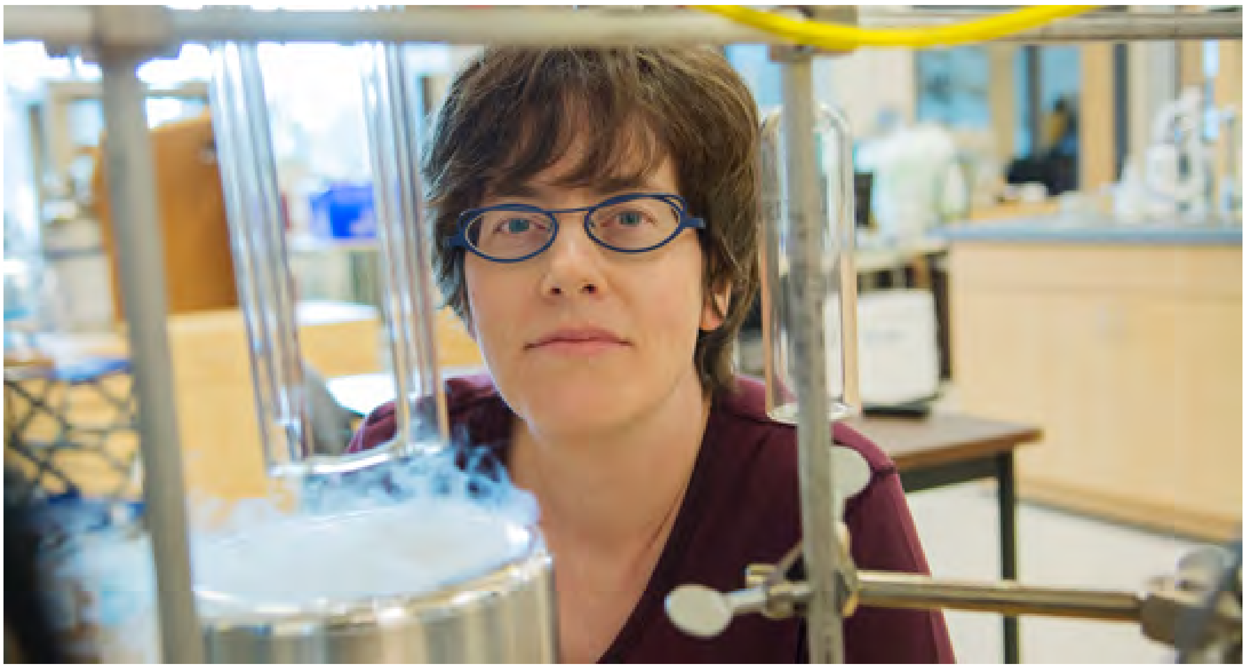
CNC-SCOR Eastern Tour Speaker Roberta Hamme from University of Victoria

Each year CNC-SCOR selects someone from the West coast to give a lecture tour heading East, and someone from the East to give a lecture tour heading West. The person heading East gives talks, over about 1 week at some combination of eastern oceanographic institutes and schools. The 2015 Eastern annual CNC-SCOR tour speaker is Dr. Roberta Hamme from the University of Victoria. She will presenting a talk titled: *Using dissolved gases to diagnose the ocean's carbon pumps.*



Roberta Hamme, Canada Research Chair in Ocean Carbon Dynamics, University of Victoria

Dr. Hamme is a chemical oceanographer who studies the marine carbon cycle. She works on understanding and quantifying the natural mechanisms that transport carbon from the surface ocean to the deep, reducing atmospheric carbon dioxide levels. Her main tools are high precision measurements of dissolved gases, both bioactive gases like oxygen and inert gases like neon, argon, and krypton. Ongoing projects include developing methods to quantify the effect of water mass formation on gases, measuring biological carbon export through oxygen mass balance, and determining amounts of denitrification (the transformation of bioavailable nitrate to unavailable nitrogen gas). She holds a Canada Research Chair in Ocean Carbon Dynamics at University of Victoria's School of Earth and Ocean Sciences.

Exact dates and venues of the eastern tour have not been settled, but the lecture tour will take place between November 1 and 10. Check with your local CMOS chapter to see if and when Roberta might be speaking in your area. http://web.uvic.ca/~rhamme/

Benjamin Halpern of UCSB to receive 2016 AG 2016 A.G. Huntsman Award

The A.G. Huntsman Foundation is pleased to announce that the 2016 A.G. Huntsman Award will be presented to Dr. Benjamin Halpern of the University of California Santa Barbara. The award ceremony will take place at 2:00 pm on Thursday 17 November 2016 at the Bedford Institute of Oceanography in Dartmouth, Nova Scotia. Following the ceremony, Dr. Halpern will present a distinguished lecture entitled “Opportunities and Challenges for Aquaculture to Feed the Planet”.

Benjamin Halpern is Director of the National Center for Ecological Analysis and Synthesis and widely recognised for his work on marine conservation and resource management. His research on marine protected areas transformed our understanding of where, why and how protected areas affect marine species and systems and helped catalyze the explosion of MPA creation around the world in the past decade. His research on measuring and mapping the cumulative impact of human activities provided a new way for governments and organizations to implement conservation plans and marine spatial planning. His research developing the Ocean Health Index (OHI) has transformed how oceans are measured and managed. After the launch of this Index, governments and organizations from 28 different countries on every continent have developed or are developing regional OHI assessments, various United Nations assessment and reporting bodies include OHI as a main metric of ocean health, and many global conservation NGOs and Foundations are using the Index to track progress and inform investments.

The A.G. Huntsman Award was established by the Bedford Institute of Oceanography in 1980 to recognize excellence of research in, and outstanding contribution to, the marine sciences. The award honours those men and women, of any nationality, who have had, and continue to have, a significant influence on the course of marine scientific thought. The award was created to honour the memory of Archibald Gowanlock Huntsman (1883–1972), pioneer Canadian oceanographer and fishery biologist.

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

Drivers of dynamics of small pelagic fish resources, Mar 6-11, 2017, Victoria, BC

The goal of the 2017 symposium is to revitalize global international cooperation on investigations of SPF and to identify, discuss and develop a framework to address unanswered questions such as the impact of climate and/or fishing pressure on the resilience of small pelagic populations using a comparative approach. Because of the importance of environmental and anthropogenic drivers on small pelagic resources, the participation of experts in physical oceanography, climate, and socio-economics is essential.
http://meetings.pices.int/meetings/international/2017/pelagic/scope

October 1, 2016
Abstract submission deadline,
Financial support application deadline,
Early registration deadline

ArcticNet 12th Annual Scientific Meeting, December 5-9, 2016, Winnipeg, MB

ArcticNet will host its 12th Annual Scientific Meeting from 5 to 9 December 2016 at the RBC Convention Centre in Winnipeg, Manitoba to discuss some of the many issues surrounding climate change and modernization in the Arctic. The ASM2016 will welcome researchers, students, Inuit, Northerners, policy makers and stakeholders to explore the latest findings in Arctic research, from dwindling sea ice and changing wildlife habitats to community health and education, northern geopolitics and resource exploitation. ArcticNet is a Network of Centres of Excellence of Canada, the ASM is Canada's largest annual Arctic research gathering.

October 3rd
Abstract deadline
October 31
Early bird registration deadline

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

National Research Council undergraduate and postgraduate programs

Research Associate Program

The Research Associate Program provides promising scientists and engineers with the opportunity to work in a challenging research environment during the early stages of their career. Applicants will be selected competitively and must demonstrate the ability to perform original, high-quality research in their chosen field.

Research Associates will be offered appointments to the staff of the National Research Council on a term basis and will be offered salaries and benefits currently available to Research Officers. Salaries commensurate with experience are taxable and subject to other deductions.

Further information

NRC Co-op Program

The NRC Co-op Program provides practical career-related experience work terms to promising students in science, engineering, and technology. Work terms are also offered in the business, public relations, communications, library sciences, marketing and administration fields.

NRC, Canadian universities and colleges and cégep co-op offices jointly administer the NRC Co-op Program. The program runs throughout the year and is divided along the academic schedule into fall, winter and spring/summer terms. Each term lasts for a period of 16 weeks (four months).

Salaries are based on the number of work terms a student has completed. Students will also be reimbursed for their travel expenses to and from their educational centre and their employment centre.

Further information

Post-doctoral Position in the Salish Sea Marine Survival Project (SSMSP)

We are seeking applicants for a post-doctoral research scientist position to study larval and juvenile salmon migration in the Strait of Georgia. The successful applicant will work on adjusting an individual-based-model (IBM), representing larval and juvenile salmon, into an existing Salish Sea plankton ecosystem ROMS model to simulate their migration and feeding behaviour in the Strait of Georgia. Research will be conducted at the Institute Ocean Sciences in Sidney, British Columbia, Canada.

Applicants should have a PhD in oceanography or related science. Candidates would have experience with ocean science, a good understanding of plankton dynamics and fish larvae, and the ability to analyze simulations by making use of model output and oceanographic datasets. A demonstrated ability to work across physical and biological disciplines is preferred, and the incumbent will be expected to interact with fisheries biologists and ecologists within the SSMSP. Marine ecosystem and oceanographic modelling experience is desirable.

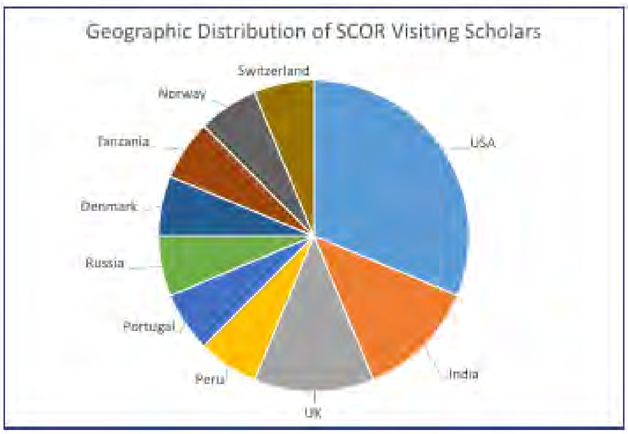
The position, for one-year, renewable for a second year, and available immediately, will be administered through the University of Victoria. Applicants should send a CV, letter of research interests, and list of references to Angelica Peña (Angelica.Pena@dfo-mpo.gc.ca).

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

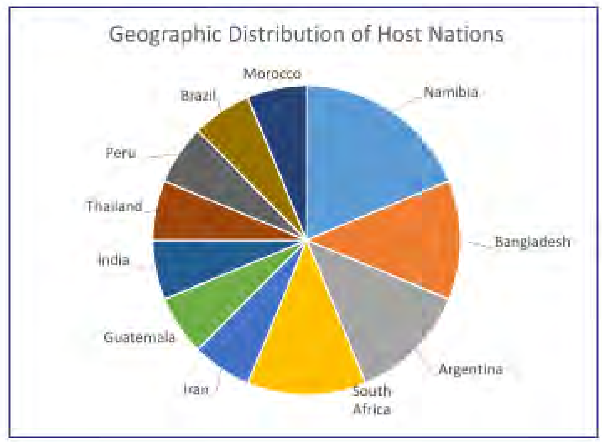
GENERAL

SCOR's Visiting Scholar program

SCOR's Visiting Scholar program is in its 8th year, thanks to funding from the U.S. National Science Foundation. The 16 Visiting Scholars from the first 7 years of the program were sent a questionnaire to assess some demographics of the pool of Scholars and to solicit feedback about the program.



Scientists from 10 different countries have served as Visiting Scholars so far.



Scholars have served in 11 developing countries.

SCOR Visiting Scholars have interacted with approximately 200 students and other trainees. Support from SCOR and host institutions was generally adequate and Scholars appreciated the experience of teaching and mentoring in a developing country. Since most of the host institutions were not in countries that are currently participating in SCOR, it was not surprising that only 65.25% of the institutions were aware of SCOR before the visit of a SCOR Visiting Scholar. So, SCOR Visiting Scholars make SCOR more visible in institutions and countries where SCOR is not well known.

The call for the 2017 Visiting Scholar program is expected on 15 October, with a deadline for applications on 1 December. Check the *Capacity Building* tab on the SCOR website for the latest information. SCOR has noted that there have been no Canadian Visiting Scholars and hope that that will change.

People wishing to obtain regular updates on SCOR activities can subscribe to their newsletter by clicking a button on the right of the SCOR homepage.

SCOR Annual Meetings in 2016, 2017 and Beyond

SCOR recently completed its 2016 annual meeting. This was an interesting and productive meeting held September 4-7 in Sopot Poland. As well as the usual SCOR business matters and discussion on new Working Groups, a session on Polish Oceanography was also held.

More information about meeting outcomes will be included in the next *SCOR Newsletter* and the next Canadian Ocean Sciences Newsletter. The SCOR Executive Committee has accepted invitations for the 2017 and 2018 annual SCOR meetings:

2017: SCOR will meet in or near Cape Town, South Africa on 4-6 September 2017, following the IAPSO-IAMAS-IAGA Assembly. A symposium related to the second International Indian Ocean Expedition (IIOE-2) will be held as part of the assembly. **The call for SCOR working group proposals will be issued around 10 February 2017**. SCOR will celebrate its 60th anniversary at the SCOR meeting with a special evening event. Watch the SCOR Web site in early 2017 for more information about the meeting.

2018: SCOR has accepted an invitation from the UK SCOR Committee to meet in Plymouth, UK in Autumn 2018.

2019 and Beyond: SCOR has received inquiries from three nations about hosting SCOR annual meetings in 2019 and beyond. The SCOR Executive Committee and Secretariat will work with these countries to select locations for meetings in 2019, 2020, and 2021.

SCOR appreciates the enthusiasm of national SCOR committees to host our annual meetings!

CANADIAN OCEAN SCIENCE NEWSLETTER

LE BULLETIN CANADIEN DES SCIENCES DE L'OCÉAN

Previous newsletters may be found on the CNC/SCOR web site.	Les bulletins antérieurs se retrouvent sur le site web du CNC/SCOR.
Newsletter #91 will be distributed in November 2016. Please send contributions to David Greenberg david.greenberg@dfo-mpo.gc.ca	Le Bulletin #91 sera distribué en novembre 2016. Veuillez faire parvenir vos contributions à David Greenberg, david.greenberg@dfo-mpo.gc.ca
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