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Branden Walker Launching the EBEE RPAS to map snow depth at the Trail Valley Creek Research Basin, NWT. *Story Inside p. 16.*
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CMOS Bulletin SCMO
"at the service of its members / au service de ses membres"

Editor / Rédactrice: Nicole Renaud
Director of Publications / Directeur des publications: Douw Steyn

Canadian Meteorological and Oceanographic Society / Société canadienne de météorologie et d'océanographie
E-mail: bulletin@cmos.ca
Courriel: bulletin@scmo.ca

CMOS Office / Bureau de la SCMO

P.O. Box 3211, Station D
Ottawa, Ontario, Canada, K1P 6H7
Homepage: http://www.cmos.ca
Page d'accueil: http://www.scmo.ca

Gordon Griffith, Ing., P. Eng., FEC
Executive Director - Directeur général
Tel/Tél.: 613-990-0300
E-mail/Courriel: cmos@cmos.ca

Ms. Qing Liao
Office Manager - Chef de bureau
Tel/Tél.: 613-990-0077
E-mail/Courriel: accounts@cmos.ca

CMOS exists for the advancement of meteorology and oceanography in Canada.

Le but de la SCMO est de promouvoir l'avancement de la météorologie et l'océanographie au Canada.

Message from the Incoming Editor

Hello from Edmonton and Treaty 6 territory, traditional lands of First Nations and Métis people.

I am thrilled to be joining the CMOS team as the new Bulletin Editor! My passion for the environment has been a life long build up, with my interest in water security emerging while I lived in Mexico's Sonoran desert, in the Baja peninsula. While there, I saw locals unable to afford water contrasted against empty golf courses outside of tourist season being draped in water. My interest truly became crystallized during my Master's field work, when I found myself in the middle of the Andean mountains, chatting in very shaky Spanish with Quechua peasant farmers about the aridification they were seeing affecting their fields as we sipped on corn beer (an acquired taste!), and the shrinking glaciers that crowned their lands and long populated their oral histories. While the terrain was different, my work with algae harvesters along the Peruvian coast highlighted a similar intensity in concern for ocean contamination and the impact it had on their lives. My passion deepened in rural Malawi during my PhD field work, as I listened to Tumbuka farmers who were keen to plant more drought-resistant local varieties to meet the struggles they faced with growing water scarcity. I had the pleasure of speaking with fishers about the changes they observed along Newfoundland's ocean shores, along with declining predictability in weather patterns. Seeing the pictures of the enormous amount of snow dumped on St. John's recently, I can't help but recall collaborating on a Newfoundland climate adaptation guide a decade ago, and specifically drafting the "winter hazards" section. I must admit, I personally did not envision winter hazards of this magnitude at the time.

I have gained invaluable experience working with a variety of environmental NGOs, universities, and government on water and climate-focused work, and more recently have worked as a Climate Policy Analyst with Indigenous electricity technicians to increase Indigenous participation and preference in the energy field. I have a long history of volunteering with environmental NGOs, and currently sit on the Executive Committee for Sierra Club Canada Foundation's Prairie Regional Chapter and provide advice on our Wild Child Program. More recently, I attended Climate Leadership training in Minneapolis as part of Al Gore's Climate Reality Project, and have been dedicated to delivering climate presentations and increasing climate literacy to many types of audiences. I am proud to say my six-year-old can talk at length about the Earth's "blanket" being too hot, and has firmly stated that us adults need to do better to make the planet healthier. We're working on it, little buddy. In my spare time, I enjoy making eco-themed paintings and am hoping to connect with local artists to hold a joint climate-themed exhibit to continue to build public interest, thought, and conversation on these important matters.

This job as editor, and working with all of you, is one I consider to be an incredible privilege. While it can be hard to see more and more extreme events and ecological degradation unfold, I am encouraged by the increasing momentum we are experiencing as topics surrounding the health of our oceans, erratic weather patterns, and climate change rise to the forefront of people's minds and conversation. The important work you are doing helps make this rising awareness possible, and I look forward to being a part of it all.

Sincerely,

Nicole Renaud

CMOS Bulletin Editor / Rédactrice en chef du bulletin de la SCMO
bulletin@cmos.ca

Mot de la nouvelle rédactrice

Bonjour d'Edmonton et du territoire du traité no 6, territoires ancestrales des premières nations et des Métis.

Je suis ravi de joindre l'équipe SMOC comme nouvelle rédactrice de bulletin! Ma passion croissante pour l'environnement et en particulier la sécurité d'eau s'est culminé durant le temps que j'habitais au Mexique, dans le désert de Sonora dans la péninsule Basse-Californie. Lors là, j'ai vu des citoyens sans moyens de payer pour l'eau, contrastés contre les terrains de golf vide (hors de la saison touristique) couverts de systèmes d'arrosage. Mon intérêt s'est vraiment cristallisé durant mon travail de terrain pour ma maitrise, lorsque je me suis trouvée au milieu des montagnes andines, parlant avec mon espagnol pas mal faible, avec les agriculteurs paysans qui me contaient de l'aridification de leurs champs et du recul des glaciers qui peuplait leur montagnes et histoires orales lorsqu'on buvait la bière de maïs (un gout acquiert!). Mon travail avec les pêcheurs des algues sur la côte péruvienne a démontré une préoccupation comparable pour la contamination des océans et l'impact sur leur vie. Ma passion s'est intensifier durant mon travail de terrain de doctorat au Malawi, où que j'ai écouté les agriculteurs Tumbuka me conter comment qu'ils voulaient planter des variétés plus résistantes pour lutter contre la sécheresse. J'avais aussi le plaisir de jaser avec les pêcheurs qui me contaient des changes qu'ils observaient le long des côtes de l'océan en Terre-Neuve, incluant une prévisibilité abaissante des régimes climatiques. Voyant les portraits de toute la neige tombée sur Terre-Neuve récemment, je ne peux pas arrêter de penser au guide d'adaptation au changements climatiques en Terre-Neuve que j'ai collaboré dessus il y a une décennie. Quand j'écrivais la section sur les dangers d'hiver, il faut que j'admets que je n'imaginais rien comme la tombée de neige de cette magnitude.

J'ai gagnée beaucoup d'expérience incroyable travaillant avec une variété de ONG environnementales, des universités, et gouvernements sur les sujets d'eau et climat, et plus récemment j'ai travaillée comme analyste des politiques climatiques avec des techniciens Indigènes d'électricité pour promouvoir la participation et préférence des personnes Indigènes dans le domaine d'énergie renouvelable. J'ai aussi fait beaucoup de bénévolat avec des ONGs, et couramment je fais partie du comité exécutif pour le chapitre régional des prairies de Sierra Club et j'offre des conseils à notre programme « Wild Child ». Plus récemment, j'ai pris la formation avec Al Gore pour le Projet de la Réalité Climatique, et je suis dédiée à délivrer des présentations et ateliers visant à améliorer la connaissance sur les changements climatiques avec de nombreux publics. Je suis fière de partager que mon fils de six ans peut parler beaucoup à propos de la 'couverte' de la terre seyant trop chaude, et que nous les adultes doivent faire mieux pour aider la planète à être en meilleure santé. Nous y travaillons, mon p'tit bonhomme. Dans mon temps libre, j'adore faire des peintures sur des thèmes environnementaux, et j'espère de connecter avec d'autres artistes locale pour arranger une exhibition sur le climat pour continuer à promouvoir l'intérêt, la réflexion, et la conversation sur ces matières importantes.

Ce travail comme rédactrice, et travailler avec vous tous, c'est qu'est-ce que je considère un privilège incroyable. Lorsque je sais que ça peut être difficile de voir des évènements extrêmes et la dégradation écologique augmenter, je suis encouragée par la sensibilisation que l'on expérience avec les thèmes liés à la santé de nos océans, les situations météorologiques changeantes, et les changements climatiques préoccupant nos esprits de plus en plus. Le travail important que vous faisiez permet cette sensibilisation à continuer, et j'ai hâte d'en faire partie.

Sincèrement,

Nicole Renaud

Rédactrice en chef du bulletin de la SCMO / CMOS Bulletin Editor
bulletin@scmo.ca

Words from the President

Resilience and Possibility in Challenging Times

Dear CMOS Friends and Colleagues,

As we go 'to press' with this issue of the CMOS Bulletin, Canada and the world are in the midst of major disruptions due to the COVID-19 pandemic. The resilience that we saw Canadians exhibit this winter will be needed more than ever as we face this new challenge. I'm thinking particularly of the Newfoundlanders who had to cope with multiple snowstorms, including the massive mid-January blizzard that dropped more than 90 cm of snow on the St. John's area, and who did so with humour and community spirit. We will need a lot of that in the months ahead as we all take preventive action to reduce the spread of COVID-19, and later deal with the aftermath.

We watch the impact of COVID-19 on other countries with concern and sympathy, and hope that the actions being taken by all levels of government and by individuals will 'flatten or plank the curve' in Canada. Some of these steps were unthinkable just a few short weeks, or even days, ago. On the positive side, these actions demonstrate that we can change and respond radically in the face of a major threat. Canada's policy response to COVID-19 has been strong and has included international coordination and recognition of the central role of scientific research to develop, test and implement measures to deal with the outbreak. It is interesting to contemplate why the speed of this response has been so much faster than effective action on climate change, as discussed, for example, in a recent article in The Conversation.

As we move ahead, we might keep in mind these words from the UN Secretary General: "… in managing this crisis, we also have a unique opportunity. Done right, we can steer the recovery toward a more sustainable and inclusive path. But poorly coordinated policies risk locking in — or even worsening — already unsustainable inequalities, reversing hard-won development gains and poverty reduction. … We have a responsibility to 'recover better'. … We have a framework for action – the 2030 Agenda for Sustainable Development and the Paris Agreement on Climate Change. We must keep our promises for people and planet."

The effect of the coronavirus quarantine on the atmosphere over China can be clearly seen in NASA Earth Observatory maps of nitrogen dioxide (NO2) concentrations measured by the Tropospheric Monitoring Instrument (TROPOMI) on ESA's Sentinel-5 satellite. NO2 is an air pollutant emitted by motor vehicles and industrial activities; as these emissions were reduced during the Chinese quarantine, a dramatic reduction in NO2 was seen between January and February, and in 2020 relative to 2019. As air travel and other activities are now being scaled back globally, scientists will be watching the consequences for air quality and greenhouse gas emissions.

Closer to home, we are evaluating options for the CMOS Congress in Ottawa, which is scheduled for May 24-28, 2020. The Local Arrangements Committee and the Scientific Program Committee, along with the CMOS Executive, continue to monitor the rapidly evolving COVID-19 situation on a daily basis. We will inform CMOS membership and Congress participants of any changes, and updates will be posted on the CMOS Congress website.

I would like to note that this issue of the CMOS Bulletin marks the first with our new Editor, Nicole Renaud. She brings a decade of experience in working on water, climate, and Indigenous issues, some of which you can read about in this Bulletin article. I'm delighted to welcome Nicole to the CMOS community.

Finally, as we all adjust to the new reality of social distancing, self-isolation, travel restrictions, working at home, closure of schools, university courses moving online, businesses closing or restructuring, and the explosion of virtual communications, please stay connected and look after yourself and others, especially those more vulnerable.

Keep well.

Kim

Kimberly Strong, CMOS President and Professor & Chair, Department of Physics, University of Toronto

president@cmos.ca

Mot de la présidente

Résilience et possibilité en ces temps troublés

Amis et collègues de la SCMO,

Tandis que nous préparons ce numéro du Bulletin de la SCMO, le Canada tout comme le monde entier est aux prises avec les perturbations majeures que cause la pandémie de la COVID-19. La résilience dont les Canadiens ont fait preuve tout l'hiver sera plus que jamais nécessaire pour contrer ce fléau. Je pense notamment aux Terre-Neuviens qui ont affronté, avec humour et esprit de communauté, de multiples tempêtes de neige, notamment l'énorme blizzard de la mi-janvier, qui a laissé plus de 90 cm de neige sur la région de St. John's. Nous devrons rester dans cet esprit au cours des mois à venir, tout en prenant des mesures préventives pour réduire la propagation de la COVID-19 et pour faire face aux conséquences qui suivront.

Nous observons l'impact de la COVID-19 sur d'autres pays avec inquiétude et empathie, et nous espérons que les mesures que prennent tous les ordres de gouvernement et les particuliers « aplatiront la courbe » au Canada. Certaines de ces mesures semblaient impensables il y a quelques semaines, voire quelques jours, à peine. Sur une note positive, ces actions démontrent que nous pouvons changer et réagir radicalement face à une menace majeure. La réaction stratégique du Canada à la COVID-19 a été forte. Elle s'appuie sur une coordination internationale et la reconnaissance du rôle central de la recherche scientifique pour élaborer, tester et mettre en œuvre des mesures pour gérer l'épidémie. Nous pourrions nous demander pourquoi la réaction est dans ce cas tellement plus rapide que la lutte contre les changements climatiques, comme l'explique, par exemple, un article récent de « The Conversation ».

Tandis que nous progressons, n'oublions pas les paroles du secrétaire général de l'ONU (en anglais, traduction libre) : « dans la gestion de cette crise, se trouve aussi une occasion unique. Une bonne gestion nous permettra d'orienter la reprise vers une voie durable et inclusive. Mais des stratégies mal coordonnées risquent de cimenter, voire d'aggraver, des inégalités déjà insoutenables, d'annuler des gains durement acquis en matière de développement et de réduction de la pauvreté. […].. Nous avons la responsabilité de "mieux nous rétablir". […] Nous disposons d'un cadre d'action, le Programme de développement durable à l'horizon 2030 et l'Accord de Paris sur le climat. Nous devons tenir nos promesses, pour les gens et la planète. »

L'effet du confinement lié au coronavirus sur l'atmosphère au-dessus de la Chine est nettement visible selon les cartes de concentrations de dioxyde d'azote (NO_2) que diffuse le NASA Earth Observatory et les mesures de l'instrument de surveillance de la troposphère (TROPOMI) embarqué sur le satellite Sentinel-5 de l'Agence spatiale européenne. Le NO_2 est un polluant atmosphérique qui émane des véhicules motorisés et des activités industrielles. Comme ces émissions ont diminué en Chine pendant la quarantaine, une réduction spectaculaire du NO_2 a été observée entre janvier et février, et en 2020 par rapport à 2019. Maintenant que les voyages en avion et autres activités tournent au ralenti sur toute la planète, les scientifiques en observeront l'incidence sur la qualité de l'air et les émissions de gaz à effet de serre.

Quant à nous, nous évaluons les options pour la tenue du Congrès de la SCMO à Ottawa, qui doit avoir lieu du 24 au 28 mai 2020. Le comité local d'organisation et le comité du programme scientifique, ainsi que le comité exécutif de la SCMO suivent quotidiennement l'évolution rapide de la situation qu'entraîne la COVID-19. Nous informerons les membres de la SCMO et les participants du congrès de tout changement. Les mises à jour paraîtront sur le site Web du Congrès de la SCMO.

Je tiens à souligner que ce numéro du Bulletin de la SCMO est le premier à paraître sous la direction de notre nouvelle rédactrice en chef, Nicole Renaud. Elle nous arrive avec une dizaine d'années d'expérience dans les domaines de l'eau, du climat et des enjeux touchant les Autochtones. Son expérience est détaillée dans cet article de notre bulletin. Je suis ravie d'accueillir Nicole au sein de la SCMO. Pour finir, tandis que nous nous adaptons tous à la nouvelle réalité de la distanciation sociale, du confinement, des restrictions de voyage, du travail à domicile, de la fermeture d'écoles, des cours universitaires en ligne, de la fermeture ou de la restructuration d'entreprises et de l'explosion des communications virtuelles, ne négligez pas votre « connexion » au monde, prenez soin de vous et des autres, particulièrement des gens vulnérables.

Portez-vous bien!

Kim

Kimberly Strong, Présidente de la SCMO et directrice du département de physique de l'Université de Toronto
president@scmo.ca

Toward Quantifying Area-fugitive Greenhouse Gas (GHG) Emissions from Open-Pit Mines

by Amir Nazem, Md. Rafsan Nahian, Ryan Byerlay, Manoj K. Nambiar, and Amir A. Aliabadi, University of Guelph

Conventional techniques to quantify area-fugitive Greenhouse Gas (GHG) emissions from an open-pit mine have serious drawbacks. The bottom-up approach is based on inventory estimates, in which the emissions from different stationary sources across a mining facility are combined. This approach does not include the atmospheric measurements of GHGs or meteorology and relies on assumptions of the strength of each GHG source within a facility that may not be up-to-date.

The top-down approach, however, makes use of an aircraft to directly measure the atmospheric meteorological conditions and mixing ratios of GHGs. The downsides of this methodology are high cost as well as limitations of flying around a facility all-year-round, at nights, and at low altitudes. Other techniques such as Inverse Dispersion Modelling (IDM) also suffer in lack of accuracy because they assume horizontal homogeneity in meteorological conditions, a condition that is seldom met for complex topographies (Liggio, 2016) (Gordon, 2015).

Objective:

A new methodology incorporates high resolution numerical modelling to forecast the fluxes of GHG emissions as a function of time and space given accurate initial and boundary conditions for meteorology and GHG mixing ratios near the source. This article summarizes the first step toward this goal, which is meteorological predictions over a complex open-pit mine. Details of adaptation of a numerical weather model with topographical and land use changes over an open-pit mining facility are discussed. Also, brief results are provided revealing near-surface meteorological processes.

Methodology:

Open pit mining activity creates a significant land surface modification through changes in surface elevation and land use in the scale of tens of kilometers. These modifications affect the local meteorology by affecting the near-surface wind field, and temperature. Such processes are investigated using a distribution of the Weather Research and Forecasting (WRF) model titled the Unified Environmental Modelling System (UEMS).

The weather model builds the computational atmospheric domains on top of a static land surface domain (including topography and land use). The static domain parameters are retrieved from the global datasets. Often the terrestrial data are not updated with the latest land use or topographical changes made to a fast-pace industrial site (e.g. a rapidly changing open-pit mine). Studying the local meteorology over such modified regions based on old terrestrial data is highly questionable. In addition, the local meteorology is highly dependent on local microscale phenomena, while the default global datasets are provided at relatively low resolution.

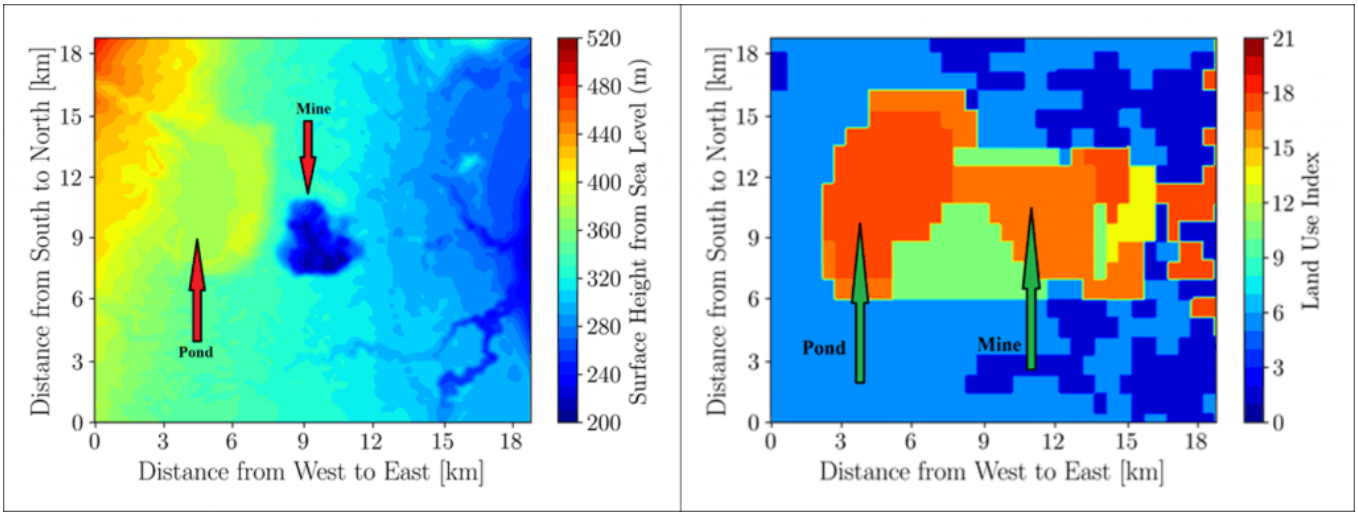

Figure 1: left) the facility showing a tailings pond on the left and an open-pit mine at the center; right) land use configuration showing the 21 classes of land use.

A procedure to acquire and incorporate high resolution static information including topography and land use changes and incorporating them into the global terrestrial data was needed and was implemented to ensure accurate simulation of meteorology for a rapidly-changing open-pit mine environment in northern Canada for May 2018. The default topography of the site was the Global 30 Arc-second (GTOPO 30s) dataset, but it was modified using the Shuttle Radar Topography Mission 1 Arc-Second (SRTM 1s) dataset and a local LIDAR dataset with a resolution of 1m. The default land use dataset was the MODerate Resolution Imaging Spectroradiometer (MODIS) 30s 20-category IGBP data product but, it was modified using a MODIS 30s 21-category IGBP data product observing the recent land use changes at the site and incorporating a lake model (Friedl et al. 2010, Subin et al. 2012 and Gu et al. 2015). Fig. 1 shows the modifications of topography and land use for the open-pit mining facility.

Results:

To visualize the sensitivity of the model results to the change in topography and land use, contours of near-surface wind velocity magnitude and direction are plotted in Fig. 2 for both the default topography and the case with high resolution topography and land use updated. The results demonstrate a notable difference in flow patterns because of changing topography and land use classification. Particularly, lower wind speeds and a local circulation is are predicted inside the mine-pit during night time (thermally stable condition). On the other hand, lower wind speeds and meandering of wind direction are predicted over the tailings pond during day time (thermally unstable condition).

Fig. 3 shows the contours of near-surface potential temperature corresponding to the thermally stable and unstable atmospheres. The contours show that the model's predictions in both the thermally stable and unstable atmospheres are sensitive to the changes in topography and land use. Adding a body of water (tailings pond) tends to reduce the near-surface potential temperature compared to the surroundings during daytime, while it tends to increase the near-surface potential temperature compared to the surroundings during nighttime.

These phenomena are likely due to the difference between heat capacity of water and surrounding land surfaces as well as the modified aerodynamic roughness of the land surface due to the presence of the mine pit.

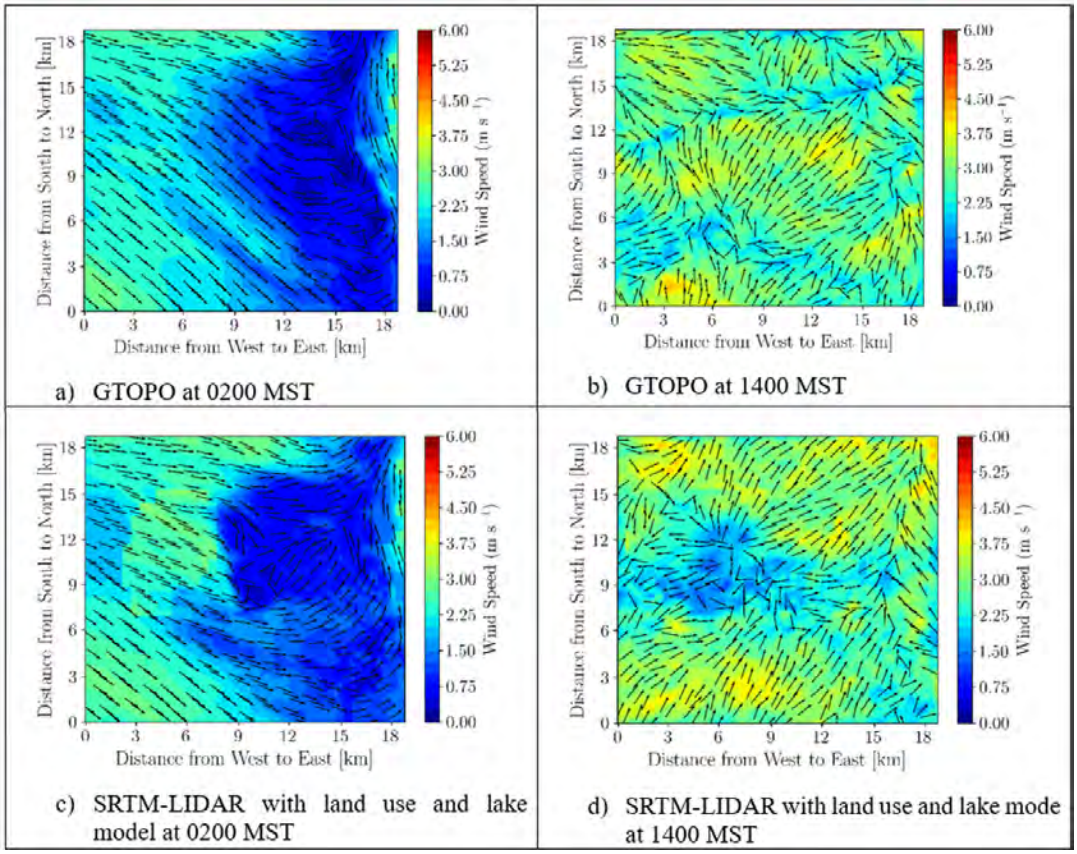

Figure 2: Effects of topography and land use changes on 10-m wind speed magnitude and direction at 0200 and 1400 MST on May 18, 2018; times in Mountain Standard Time (MST).

Conclusion:

This study demonstrates the effectiveness of the Weather Research Forecasting (WRF) model in predicting the meteorological conditions over an open-pit mine under fair weather conditions in northern Canada. The recent changes in the topography and land use of the mine indicates notable changes in meteorological conditions as predicted by WRF. This is the first step toward quantifying area-fugitive Greenhouse Gas (GHG) emissions, while future effort requires detailed plume dispersion and flux integration of GHGs inserted in the WRF model as boundary conditions.

High-resolution meteorological modelling shows promise toward more accurate quantification of area-fugitive GHG emission fluxes from open-pit mining facilities. This technique overcomes the current limitations of operational approaches such as bottom-up, top-down, and Inverse Dispersion Modelling (IDM) methods of quantifying area-fugitive GHG emissions.

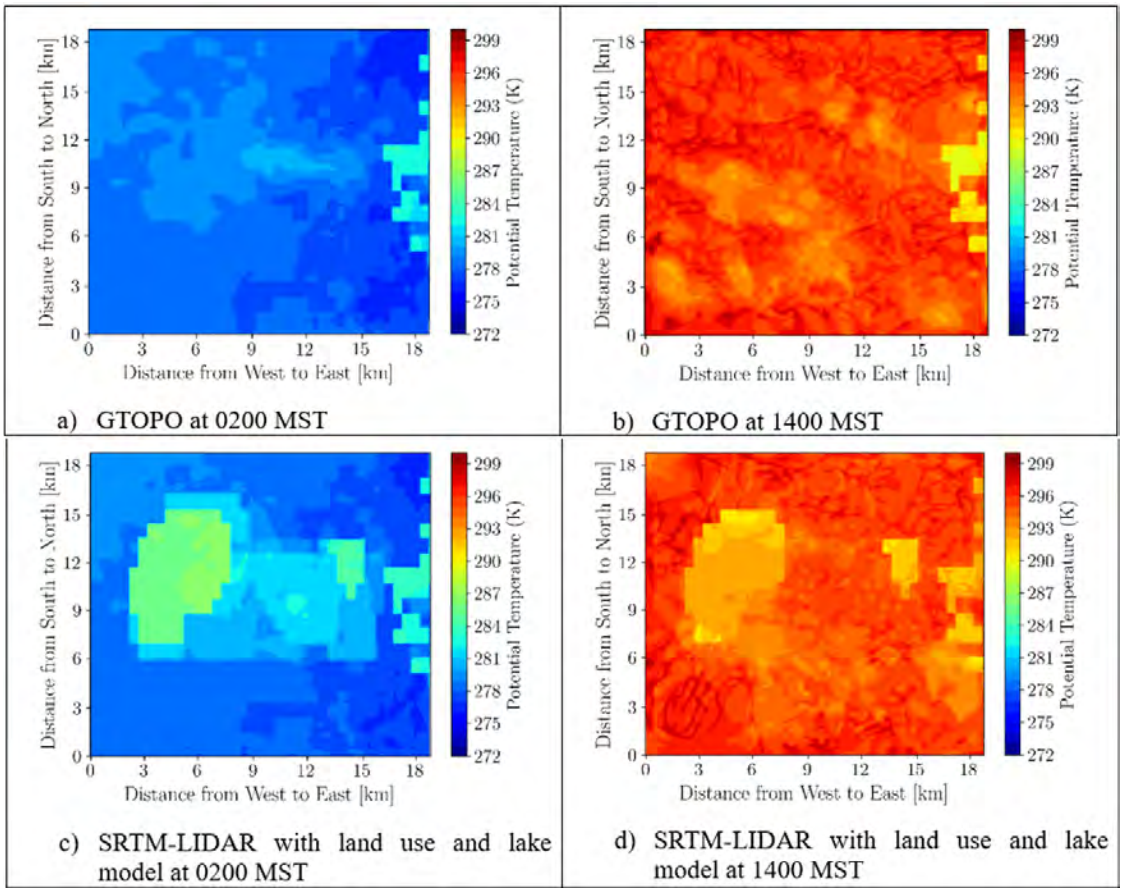

Figure 3: Effects of topography and land use changes on 2-m potential temperature at 0200 and 1400 MST on May 18, 2018; times in Mountain Standard Time (MST).

About the Author

Amir Nazem is a Research Assistant at the Environmental Research Lab at the University of Guelph. Having started his education in aerospace engineering, he is interested in applications of environmental fluid mechanics from engineering scales to meso scale problems. He did his Master's of Applied Science in Environmental Engineering at the University of Guelph. During his Master's program, Amir had the opportunity to participate in an important project to develop a new methodology to estimate the emissions of greenhouse gases from an open pit mining facility in Northern Canada. They incorporate both the experimental and numerical fluid mechanics and coupled the micro and meso scales to forecast the pollution independent of time and space, which is the topic of this article.

Note: A full version of this study is under review in the Journal of Applied Meteorology and Climatology.

Article: Modular Ocean Research Infrastructure (MORI)

Modular Ocean Research Infrastructure (MORI): A Flexible, Scalable and Affordable Approach to Ocean-going Research in Canada and Worldwide

By Doug Wallace, Scientific Director, MEOPAR; and Doug Bancroft, President and CEO, Canadian Scientific Submersible Facility

Research vessels (RVs) remain critical infrastructure for many classes of ocean-related research. Robots and autonomous vehicles are used increasingly for monitoring and some process-oriented research when appropriate sensors are available. However, there are also a growing number of questions related to ocean and seafloor resources, as well as complex physical, chemical, biological and atmospheric processes critical to climate change and biodiversity, which require that multidisciplinary teams of researchers can access the ocean with highly sophisticated instrumentation, from vessels.

Modern RVs are complex, custom-designed ships that are built and operated exclusively for science. They tend to have highly specialised capability for navigation, seakeeping, noise reduction, equipment-handling, sensor and sampling systems and are equipped with sophisticated laboratories. Consequently, RVs are expensive to build and are operated exclusively by developed countries. A corollary is that although developing countries face pressing ocean research questions, independent access to modern RVs is usually out of their reach.

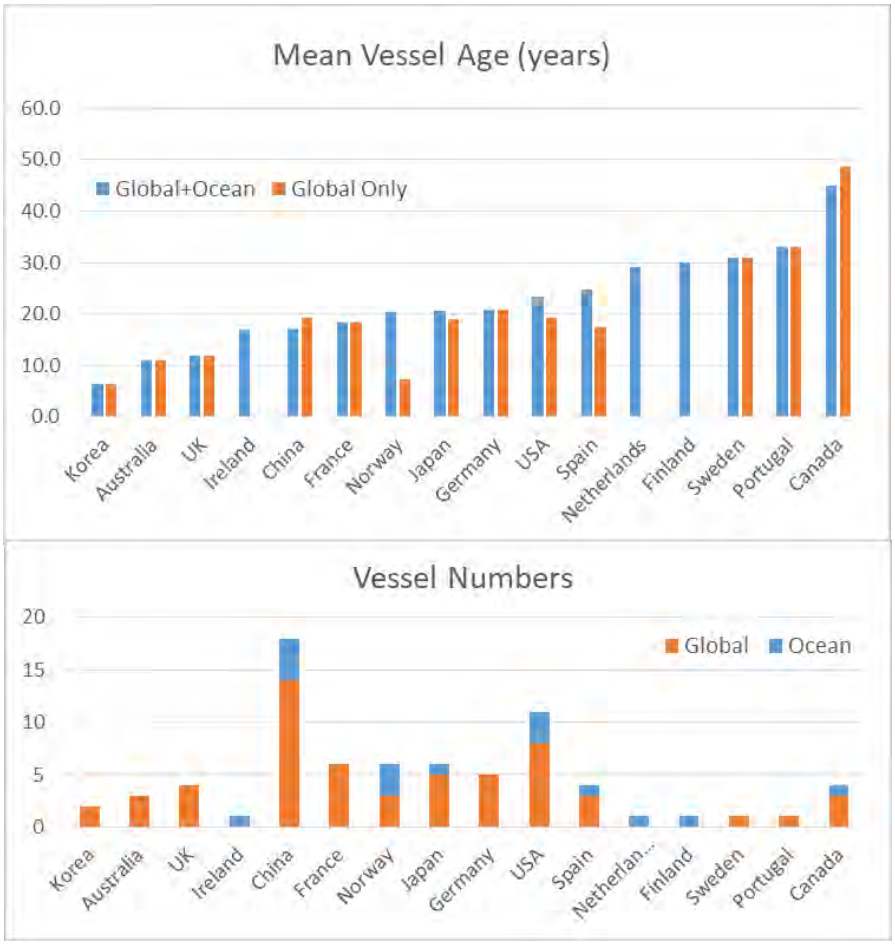

Figure 1. Distribution of average age (as of 2020) of ocean-going research vessels, worldwide. Only vessels capable of supporting modern, multidisciplinary ocean research in an open ocean environment are considered. Classification of "Ocean" and "Global" vessels is based on criteria of the European Marine Board (Nieuwejaar et al., 2019) and the US-based University-National Oceanographic Laboratory System (https://www.unols.org/ocean-class-research-vessel-update-project). Both classes require accommodation for teams of at least 20 researchers and capability to support diverse ocean research activities. "Ocean" and "Global" class vessels are categorised as 55-70m and >70m in length, respectively. These classifications exclude vessels designed for highly specialized tasks (e.g. fishery management; oil spill response), irrespective of their size.

Canada is not a developing country but faces major challenges with respect to RV capacity. With the world's longest coastline and one of the larger Economic Exclusion Zones spanning highly diverse ecosystems, Canada has major requirements for RVs. Yet Canada's RV capacity, which is owned and operated primarily by the Canadian Coast Guard (CCG), is in a state of crisis, especially on the Atlantic coast (Hughes et al., 2019), so that even the Government of Canada is unable to meet its mission requirements there (CBC News report, Dec. 2019). Growing needs of other sectors (e.g. academia, Provincial governments, industry and NGOs) for vessel time across Canada are not being met. There are now serious limitations in terms of geographical/ temporal availability of vessels, flexibility of use, and multi-sectoral access to available capacity. Further, the available vessels are not necessarily state-of-the-art.

The situation is particularly acute for the larger vessels that are required for expeditions to remote locations and regions subject to challenging weather or ice conditions. This is also the vessel type required to accommodate the larger, multidisciplinary teams of researchers and students required to address complex questions of today's ocean. Figure 1a shows that Canadian vessels of this type, including research-capable icebreakers essential for Arctic research, are the oldest in the world by far.

The RV situation is likely to deteriorate further over the near term as the oldest vessels undergo refits and repair, or are taken out of service permanently. Recent and planned new builds under the National Shipbuilding Strategy (NSS) are sufficient only to replace retiring CCG vessels required by the Department of Fisheries and Oceans (DFO) for its fishery and ecosystem management mandate. The three replacement "offshore fishery and science vessels" have berths for only 13 researchers, which precludes their use for multidisciplinary research, even if vessel time were available.

The situation on Canada's Atlantic coast is particularly acute. Ocean research in this region depends on the CCGS Hudson, which was commissioned in 1962, has undergone multiple refits, and is now far beyond its life expectancy and no longer meets requirements of modern ocean research. Although a replacement for CCGS Hudson is part of the NSS, construction has been deferred (CBC News report, Feb. 2019), and it will not be ready for use for many years. On a more positive note, additional naval and CCG Arctic and Offshore Patrol Ships (AOPS) are under construction or planned, and may be made available for research. However, these vessels were not designed for science so that their utility is unknown. They will also not be available for several years, and will have other important, competing uses. Overall, currently planned capacity of ocean-going research vessels is unlikely to meet existing and projected demand.

To help better define and address this problem, MEOPAR (www.meopar.ca) has established a National Research Vessel Task Team with representation from end-users and other interested parties across Canada. The Task Team will develop a vision for the medium to long-term (5-20 years) future of Canada's vessel needs for both coastal and offshore research, while proposing practical solutions to address the immediate capacity crisis. It will focus especially on the larger vessels required for offshore research, and include consideration of the needs of users in academia and the private sector as well as different levels of government. This document is intended as an input into discussions by the Task Team.

What are possible solutions to Canada's RV capacity crisis?

a) Build and operate more dedicated, specialised RVs;
b) Rely on cooperation with foreign nations/ institutions and their vessels via shared cruises and/or charters;
c) Develop modular ocean research infrastructure (MORI) for use with available, "workhorse" industry vessels as well as future CCG and naval AOPS, in order to convert them into sophisticated RVs on a temporary, "as-needed basis".

Option a) may be unrealistic given the scale of the need across Canada. Further, it would take years to realize, and involve massive cost as well as a major, long-term commitments to support that might outstrip the ocean research community's capacity. It also would be inconsistent with the National Shipbuilding Strategy, which as noted above is now just delivering new ships to the CCG and RCN.

Option b) is used increasingly, by default, by academic, private-sector and government users. It has some advantages in mitigating near-term deficits, but has several disadvantages over the medium-to-longer term. The disadvantages include dependence on foreign countries, which in turn risks restricting Canada's sovereign ability to access its own waters for research and pursuit of Canadian priorities. The ability to charter or share a foreign vessel may involve legal and financial arrangements beyond the reach of many Canadian institutions and could risk legal challenge from Canadian ship operators. Use of foreign vessels typically involves long transits for repositioning, which limits flexibility and raises costs. Sharing of vessels could involve legal restrictions on Canadians (e.g. involving intellectual property or publication rights). Access to foreign vessels will, typically, be restricted by the priorities of the foreign owners, which might limit Canadians' vessel access to times of year with less interest/demand.

Option c) MORI is original and would require fundamentally new approaches, but represents a scalable, flexible solution to RV availability that might work well for Canada. It is compatible with flexible scientific use of Arctic and Offshore Patrol Ships (AOPS) and offers options for Canadian private sector involvement. Significantly, the MORI concept could alleviate Canada's ocean-going RV capacity crisis in the near future, through use of existing and planned, capable vessels that are Canadian owned and operated. This option would require a national approach for accessing and coordinating vessel time and MORI infrastructure, however such a system is probably required whatever solutions are implemented.

What is the MORI concept?

The MORI concept is to deploy “modular, portable infrastructure,” temporarily, on industry “workhorse” vessels, and other “non-specialised vessels” (e.g. AOPS), in order to convert them for use as sophisticated, capable RVs. The modular infrastructure could include:

- sea-going containerized laboratories;
- accommodation “pods” and meeting rooms for scientists/ technicians;
- ROVs and AUVs;
- Launch and recovery systems (LARS) for ROV and AUVs;
- Specialized sampling gear (e.g. rosette samplers; coring devices; nets; meteorological stations);
- winches and A-frames;
- cranes; and
- capstans for deployment and operation of scientific gear.

The infrastructure should be designed for mobility, and flexible deployment on diverse vessel types. In a departure from existing use of containerized systems (e.g. container labs), modules would be designed to work together as an interoperable system in terms of data transfer, services, communications, logistics, etc. The current Technology Readiness Level (TRL) of MORI components varies from 6 to 9, with the former being sea-going labs, the latter being ROV and AUV operations conducted using “plug-and-play” sea-going containers.

The vessels used with MORI should ideally have space for mounting of over-the-side sampling gear including A-frames, winches, cranes, etc. as well as for 10-foot, 20-foot and/or 40-foot standard containers. For offshore research, vessels should be able to accommodate teams of at least 24 researchers: either within on-board accommodation or in accommodation modules. In order to support many modern scientific operations, the vessels should have dynamic positioning (DP).

Industry-owned platform supply vessels (PSVs) and government-owned AOPS both have potential for temporary conversion to RVs using MORI. PSVs are workhorse vessels, widely used in the offshore industry, and are often designed to be multipurpose with open deck space suitable for container installation. With a general lack of superstructure it should normally be possible to install gear for over-the-side operations. Most such vessels have DP, and many have “hotel” accommodation for transportation of crews to/from offshore platforms. Some have specialized cranes and, even, their own ROVs. Ideally such vessels would allow for underway sampling of clean surface water (via a sea-chest) as well as installation of hull-mounted sensors.

Figure 2. The Akademik Tryoshnikov in the Antarctic in January 2017

Figure 3. The CCGS Hudson is Canada’s most capable ocean science ship. She is also 58 years old, and in a refit that is not going well. (Photo Robert Short/CBC)

The AOPS have space for containers and berth space is available for use by teams of researchers. While not designed for science-use, and presently without DP capability, the potential of these new vessels should be maximized, and the MORI concept is fully compatible with their flexible use.

Commercial Opportunities

By extension, MORI offers a means of supporting modern ocean research by many countries worldwide that do not currently have access to specialized RVs, including developing countries. Successful demonstration in Canada of a fully developed MORI concept could open commercial possibilities for deployment of the concept in other markets worldwide.

Projected Use

Assuming required MORI components were maintained and made available via a common pool, diverse users (e.g. government agencies and/or Universities), could enter into charter agreements with vessel owners and/or other operators for the periods of time required for their research. As noted, a national system for accessing vessel time and sharing of MORI would be required. Sea time on commercial vessels could be made available through long- or short-term charters and sea time on CCG and RCN AOPS would require a mechanism to allow for coordinated access, including by non-government users.

The innovation required to implement MORI should not be underestimated: modern RVs are equipped permanently with highly sophisticated laboratories and state-of-the-art equipment. Conversion of these shipboard installations to a modular, interoperable, portable and safe system will require originality and innovation as well as extensive testing. However, if Canada can demonstrate the concept and use it to address its national crisis of RV capacity, the system will be attractive for use elsewhere, especially by countries that do not have their own RVs (which is the situation of most countries in the world).

Fig. 4 depicts a typical PSV configured with MORI for multidisciplinary ocean-going research. We envision this type of vessel being capable of supporting highly-advanced research, involving teams of 20 to 40 scientists and technicians working on-board (depending on vessel size), as is common on the custom, ocean-going, global- and ocean-class RVs operated by France, Germany, China, UK, USA, Japan, etc.

Next Steps

The most important next step is to convene a Canada-wide discussion about RV capacity needs and potential solutions. The MORI concept can be one item for discussion by the National Research Vessel Task Team, but the authors are aware that a mix of solutions will likely be required. Involvement of the Canadian private sector in the development of efficient and effective solutions, including MORI, should be considered and encouraged.

Figure 4. Sketches of a 95m platform supply vessel (PSV) configured with Modular Ocean Research Infrastructure (MORI) including 5 custom laboratories, launch and recovery systems (for CTDs and towed vehicles), extra accommodation “pods”, meeting space and a data processing room. The vessel, as shown, would fall within the “Global” vessel category of Figure 1.

Acknowledgements

Thanks to Dan Kehoe for the PSV drawings and Rodrigo Menafra, Bridget Graham and the MEOPAR staff for support.

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About the Authors

Dr. Douglas Wallace

Dr. Wallace is Canada Excellence Research Chair (CERC) Laureate in Ocean Science and Technology as well as Canada Research Chair (Tier 1) in Ocean Science and Technology in the Oceanography Department at Dalhousie University in Halifax, NS, Canada. Dr. Wallace also serves as Scientific Director of the Marine Environmental Observation Prediction and Response Network (MEOPAR; www.meopar.ca), a ca. $5 million/year national research network focussed on marine risk. Prior to his appointment at Dalhousie, Dr. Wallace was professor of marine chemistry at the Helmholtz Centre for Ocean Research Kiel (GEOMAR). There, he also served as deputy director and head of the Marine Biogeochemistry Research Division. He holds a Ph.D in chemical oceanography from Dalhousie University and a bachelor's degree in environmental science from the University of East Anglia, United Kingdom. Dr. Wallace spent more than a decade working as a scientist at the Brookhaven National Laboratory in the United States. He has made significant scientific contributions to his field through the Intergovernmental Panel on Climate Change, and the US Department of Energy, where he developed the first survey to measure the global distribution of fossil-fuel carbon in the oceans. Dr. Wallace has contributed to building a number of multidisciplinary research teams and programs in the USA, Germany, Europe, West Africa and Canada. His research interests focus on carbon cycle and air-sea exchange of gases.

Douglas Bancroft, OMM CD MSc

Douglas Bancroft joined the Meteorological Service of Canada, Environment Canada in 1981, and then served progressively in several weather centres. Highlights included Officer-in-Charge of the west coast Meteorology and Oceanography Centre; and later Director of the Canadian Ice Service, and Co-Director of the Canada-United States North American Ice Service. Doug also served in Fisheries and Oceans Canada in 2000 as a Senior Science Advisor, and then national Director of Oceanography and Climate Science. Doug was promoted to Director General of the Canada Center for Remote Sensing with Natural Resources Canada in 2010. In 2013 Doug retired from the Public Service and transitioned to the Private Sector and academia. Today he is President and CEO of the Canadian Scientific Submersible Facility; and serves on three Board of Directors. He is also a Visiting Scientist/Sessional Instructor at the School of Earth and Ocean Science, University of Victoria. In parallel to his civil career, Doug served of the Royal Canadian Navy (reserve) for thirty-eight years. He has commanded six HMC Ships for various periods at sea, Port Security Unit Four and HMCS CARLETON (Canada's largest naval reserve division). Doug holds a BSc in Physics, a specialized undergraduate diploma in meteorology, and an MSc in Physical Oceanography.

Article: Mapping Tundra Snow with Drones

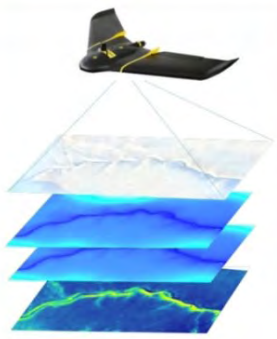
Observing Snow from the Sky: Breakthroughs in mapping tundra snow with drones

By Branden Walker and Philip Marsh
Cold Regions Research Centre, Wilfred Laurier University, Waterloo, ON

Snow is not evenly distributed across Arctic tundra landscapes. Strong winter winds and low-lying vegetation allow snow to easily be eroded, transported and deposited across the open landscape resulting in a heterogenous distribution of snow depth, snow density, and snow water equivalent (SWE). Understanding the distribution of snow in these environments is of upmost importance as the winter snow accumulation in these northern regions often covers the ground for 8 to 9 months, accounts for over half of the annual precipitation, and is the dominant driver of the hydrological system. Snowcover also greatly influences surface albedo with feedbacks to the weather and climate. With the onset of the spring melt (an event that lasts only a few short weeks) we observe a rapid release of accumulated precipitation, often resulting in spring freshet events that account for 60-80 percent of the annual stream discharge. To better understand how the hydrology of these environments will respond to a further warming climate it is necessary to accurately and efficiently measure the water stored as snow.

At present our ability to accurately measure snow at hillslope to watershed scales using standard snow survey methods, point sensors at weather stations or remote sensing techniques has proven difficult, whereby these methods often fail to accurately represent small-scale spatial and temporal variations in snow accumulation and melt. In tundra environments this raises issues as a significant portion of the SWE is found in relatively small drifts features located on leeward hillslopes and within tall shrub patches. These drift and vegetation features may only account for 20 percent of the watershed area, but they often contain 2-4 times more water storage when compared to open tundra regions and release meltwater later into the spring snowmelt period. Developing methods that accurately measure snow at the across this snowdrift scale is of critical importance in order to both document snow across the watershed, and for developing appropriate hydrologic and earth system models.

The Arctic Hydrology Research Group (AHRG) has been working to address these issues through testing and application of multiple novel snow observing sensors in the tundra dominated Trail Valley Creek Research Basin located north of Inuvik, NWT. One such example is the application of Remotely Piloted Aircraft Systems (RPAS, commonly referred to as “drones”) for measuring snow. For the past few years we have been developing and testing methodologies for using RPAS to map high-resolution tundra snow cover at watershed scales. To do this we apply Structure-from-Motion (SfM) photogrammetry to aerial imagery collected using a fixed-wing RPAS (Sensefly EBEE+). This enables the production of high-resolution maps of the snowpack surface elevation, which when subtracted from a snow-free elevation provides maps snow depth. In addition, we can calculate Snow Covered Area (SCA) and using estimates of snow density we can also map SWE at spatial and temporal resolutions unobtainable using traditional methods. This is very important over the brief spring snowmelt period, where heterogenous snowmelt patterns result in localized snowmelt runoff to the stream channels affecting the timing and magnitude of the spring freshet event.



Left: Branden Walker Launching the EBEE RPAS to map snow depth at the Trail Valley Creek Research Basin, NWT. Photo Credit to Arvids Silis.
Centre: Mapping snow depths using RPAS and Structure-from-Motion photogrammetry. A conceptual overview.
Right: Hetergenity in snow depths and landcover type within Trial Valley Creek. Note the large drift features where blowing snow

The flexibility to capture daily- or sub daily- changes to the snow enables us to document changes to the watershed snowcover at unprecedented temporal and spatial scales with decimeter vertical accuracy. For several years our research has focused on using RPAS to map end-of-winter snow cover for multiple headwater watersheds and documenting changes over the spring snowmelt period. Results from 5 years of extensive field campaigns resulting in thousands of ground validation survey points conclude we can accurately measure snow depth in these environments with error estimates ranging from 8 to 30cm, with a consistent positive bias.

This past winter (2018-19) we had the opportunity to collect snow depth using RPAS through a collaboration with Environment and Climate Change Canada's (ECCC) TVCSnow airborne radar campaign (Follow along on Twitter #TVCSnow). We successfully collected SfM snow depth data for five winter dates for a small headwater watershed, Siksik Creek, located within the Trail Valley Creek Research Basin, north of Inuvik, NWT. Continued flights were conducted over the 2019 spring melt period beginning at the end of April. To ensure accuracy and precision of the RPAS snow-surface elevation models we incorporated manual Ground Control Points (GCPS) surveyed across the study area with a high-precision Real-Time Kinematic (RTK) GNSS. This increases our snow -surface elevation model accuracy to ±2-5cm when directly compared to RTK measurements of snow surface elevation.

Preliminary analysis of the data provides valuable insights into the spatial and temporal accumulation patterns across the watershed, whereby we can directly measure changes in snow depth and SCA across the basin. Here we observe heterogeneity in snow accumulation by land cover type following snow precipitation and blowing snow events with great accuracy across a 1 km^2 watershed. Over the 2018-19 winter snow accumulation period we measured little change across most tundra and short shrub sites as that the snow carrying capacity of these regions was filled very early in the winter and did not increase for the remainder of the winter. With all additional snow removed by blowing snow and accumulated in drifts. In contrast, we observe stark increases in drift and tall shrub regions snow depths, specifically on steep (slope >10˚) north-NE facing slopes resulting from sporadic mid-winter blowing snow events. These results agree with present literature of snow distribution patterns across the Arctic; however, we now possess the ability to quantify these changes at fine resolutions which will serve as important useful datasets to balance our measurements of snowfall and snow on the ground and validate high-resolution spatially distributed snow models.

Measurement of snowpack conditions continued across the 2019 spring melt period for the Siksik Creek basin to provide a detailed documentation of snow ablation patterns during the melt period. Specifically, we assessed changes to snow covered area (SCA) and snow depth across the four dominant landcover types. When combined with spatially distributed snow density estimates we were able to map changes in SWE, and hence snowmelt contribution to runoff. To our knowledge, this ability has not been demonstrated in any other studies in the Arctic. Not surprisingly, we observed distinct snowmelt patterns based on landcover type throughout the melt period. Notably we found a rapid decline in SCA for areas dominated by short shrubs (height <0.5m) such as dwarf birch, followed closely by the shallow snowpacks across open tundra regions. Short shrub dominated regions melt out completely days before the remainder of the snowpack, a result of their shallow snowpacks, favorable slope and aspect to incoming radiation, and localized melting caused by radiative transfer through the shrubs woody material into the snowpack. In contrast, the SCA for deep snowpacks found in the tall shrub and drift sites decreases slowly over a period of a few weeks. Previous research has demonstrated these areas contain a high SCA late into the melt period, lasting days or even weeks after the majority of the basin becomes snow-free. This is important as they contain a relatively large proportion of snow-water storage and provide meltwater runoff to the stream systems late after the initial freshet discharge event. Furthermore, the timing of snow removal was recently found as one of the most influential factors affecting the seasonal development of the active-layer in the Siksik Creek basin (Wilcox et al. 2019), highlighting the need for ongoing research to better understand how a changing snowcover may influence future permafrost.

Further analysis of the dataset will provide valuable insights into the effects of blowing snow events on the timing and magnitude of drift development, spatial patterns in snow water storage, and spatial snowmelt patterns. This becomes important with the onset of the snowmelt as we quantify the spatial heterogeneity of snowpack ablation and snow-free onset spatially across the watershed which is important for controlling the release of meltwater to the spring freshet and controls the development of the seasonal active-layer. In previous years, we coupled the high-resolution snow conditions collected using RPAS with in-situ observations of stream discharge,

evapotranspiration, and precipitation to create a daily snowmelt water budget for the Siksik Creek watershed (Walker 2018). In this study we were able to quantify the relative importance of snowcover across four dominant landcover types to understand how they control the availability of meltwater to the system. With further changes to the climate in this region including; changing precipitation, warmer temperatures and earlier spring melt dates, understanding the distribution of snowcover will be important to understand how the streamflow regime will shift. Using this combination of RPAS remote sensing and hydrological measurements we will be able to advance our understanding of the complex interaction between climate-vegetation-snow in attempts to improve our ability to model future conditions.

Left: Aerial perspective of the Trail Valley Creek stream network. Situated just above the treeline, isolated patches of spruce trees do exist and act as a sheltered area in contrast to windswept tundra regions.
Right: The TVCSnow radar system aboard a small manned aircraft flies off into the winter sunset. Our RPAS surveying provides valuable snowcover data to help improve current and future earth observing systems.

RPAS application for snow: Challenges

Conducting RPAS flights during the harsh Arctic winter is not without its challenges. Availability of daylight, or lack thereof, during the polar winter presents a significant issue for optical remote sensing that cannot easily be overcome using survey-grade RPAS systems. Variable lighting results in unusable images or poor stitching by the SfM software. In the future, these issues may be overcome through integration of multispectral sensors. However, for most flight dates across the 2018-19 winter period lighting conditions were sufficient to successfully map the snow surface elevation from above. Over-exposure of images resulting from the high albedo of snowcover during the spring period presents challenges, but this is easily overcome by manually adjusting the camera internal settings.

Poor lighting was not the only environmental limitation to this study. Strong arctic winds periodically reached an excess of 40km/hr and daytime high temperatures were well below the manufacturer recommended operating temperature. For future airborne campaigns we recommended flight operations be suspended when winds speeds exceed 30km/hr as the quality of the imagery often degrades, and battery life is greatly diminished in the cold, with the latter overcome through applying creative heating strategies for the RPAS, batteries, Laptop and radio.

About the Author

Branden Walker is a Research Associate in the AHRG, located in the Cold Regions Research Centre at Wilfrid Laurier University, Waterloo, Ontario. His research addresses how Arctic hydrological systems are changing under a rapidly warming climate. His research combines traditional cold regions hydrological techniques with remote sensing to better understand snow and stream hydrological regimes. Beyond research, Branden is also the Operations Manager for the Trail Valley Creek Research Station located in the Western Arctic. When not in the field he enjoys the outdoors and is an avid supporter of science communication. Follow closely with his ongoing research in the Canadian Western Arctic @Branden0Walker

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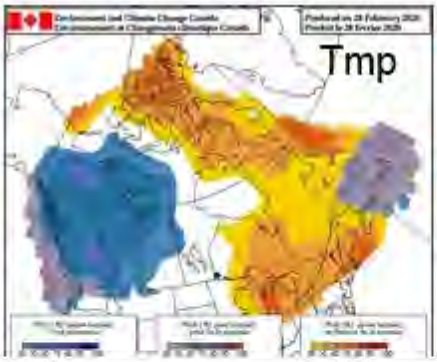
Canada

Seasonal Outlook for the spring 2020 (MAM) based on the official CanSIPS forecast issued on the 28th Feb. 2020

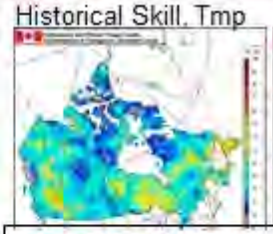
By Marko Markovic, Bill Merryfield and Marielle Alarie

Temperature: odds favour above normal spring in the east, below normal spring in the west. The highest probabilities (>50%) for a warm spring are in southern parts of ON, QC and the Maritimes, and over the Canadian Archipelago. Below normal spring (40% or more) is expected across the central and northern Prairies stretching to BC. The highest below normal probabilities (>60%) are in central BC and parts of YT and NT. Southern coastal BC will most likely experience near normal spring.

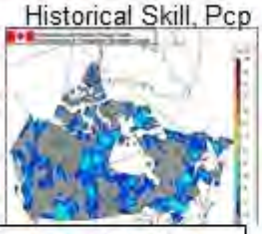
Equal chances for precipitation forecast across most of Canada. There is a probability of >40% for above normal precipitation over central QC, Great Lakes region, central SK and MB. Above normal probabilities of at least 40% are expected over the central BC/AB Rockies region and central YT. Southern coastal BC is forecast to be below normal with at least 40% chance.



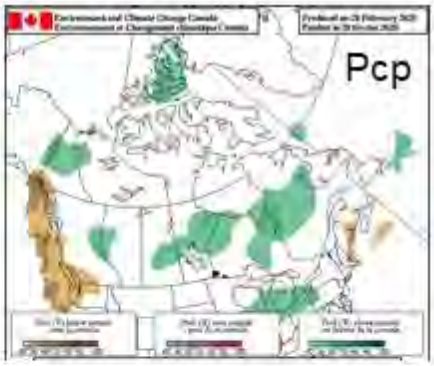
Historical Skill, Tmp



Historical Skill, Pcp



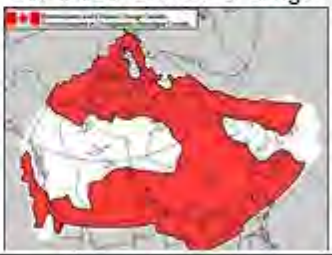
CanSIPS MAM20 forecasted Indices:
Nino3.4 = 0.1 (Neutral conditions)
PDO = -1.8 (strong negative phase)



What will influence the next season? It is highly likely that neutral ENSO conditions will occur in the equatorial Pacific this spring. ECCC predicts this neutral condition to persist into the following summer. According to the longer lead seasonal forecast issued by International Research Institute (IRI), there is a probability of ~70% that a neutral ENSO will prevail this spring and of ~60% to continue in summer. **PDO** index is expected to stay negative throughout the spring and summer. Its strong negative phase may bring cooling effect to the western coastal BC. Positive but weak **NAO** index (according to the NOAA/ CPC prediction) is forecasted at least until mid-March after which the forecasting skill is low. Positive NAO is historically linked with above average temperatures across northeastern Canada. PNA index will likely remain negative but weak by mid March according to the CPC, providing a cold influence across western Canada. Spring is the season with the highest historical skill for temperature forecasts over Canada.

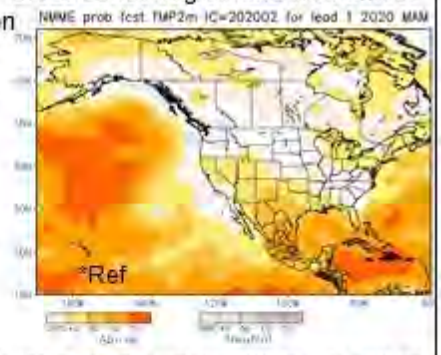
DJF19/20 Obs. Categories

DJF19/20 CanSIPS Catgs.

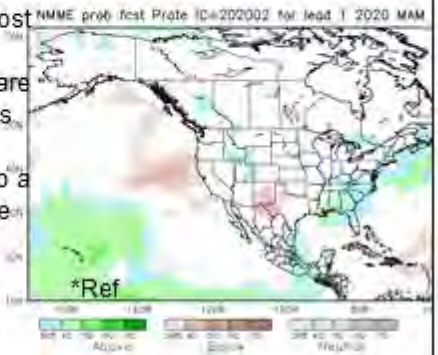


Verification DJF: Temperature, 44%. The CanSIPS forecast did not predict near normal conditions over the southern central prairies and BC as well as below normal DJF over northwestern Canada.

Seasonal forecast by other centers: Temperature: There is a significant difference between CanSIPS and the longer lead forecast from NMME (upper figure) mostly above western Canada. NMME is forecasting equal chances for temperature probability in the central and south eastern Canada. According to the NMME there is slightly elevated probability for above normal temperatures over northern Canada, Canadian Archipelago, over the Great Lakes region and Maritimes. Both systems agree on forecasted probabilities of >40% for an above normal Spring over eastern Canada.



Precipitation: Like CanSIPS, the longer lead forecast from NMME (lower fig.) predicts equal precip. chances for across most Canadian regions. However differences are seen in some locations (e.g. coastal BC, QC, ON, SK). There is also a difference between the two systems over the Maritimes where the NMME is showing above normal precip.



*Ref: http://www.cpc.ncep.noaa.gov/products/NMME/

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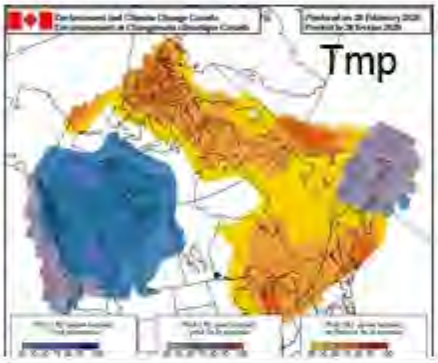
Canada

Prévision saisonnière pour le printemps 2020 (MAM) basée sur la prévision officielle de SPISCan, émise le 28 fév. 2020

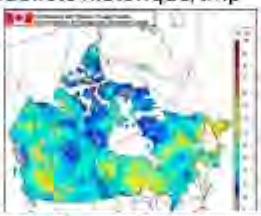
par Marko Markovic, Bill Merryfield et Marielle Alarie

Températures: Les probabilités sont supérieures à la normale ce printemps sur l'est, et inférieures à la normale sur l'ouest. Les probabilités les plus élevées (>50%) pour un printemps doux sont sur le centre et le sud de l'ON, le QC, les Maritimes, et l'Archipel Arctique. Le printemps devrait être sous les normales (> 40%) est attendu dans le centre et l'ouest des Prairies, jusqu'en C.-B.. Les probabilités les plus élevées (>60%) sont sur le centre de la C.-B. du Yukon et du T.N.-O. Des conditions plus près des normales sont prévues sur le sud-ouest de la C.-B.

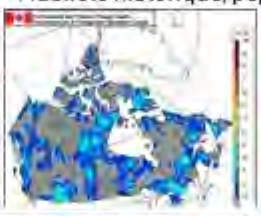
Précipitations: Des chances égales sur la plupart des régions du Canada. Cependant la probabilité d'observer des précipitations plus élevées que la normale est >40% sur le nord du QC, la région des Grands-Lacs, le centre de la SK et du MB. Cette probabilité est plus près de 40% sur les Rocheuses de la C.-B. et l'AB, et le centre du Yukon. Par ailleurs, du temps sec est prévu à au moins 40% sur le sud de la C.-B. et le long la côte-ouest ce printemps



Habileté historique, tmp



Habileté historique, pcp



Indices climatiques prévus par SPISCan pour MAM20
Nino3.4 = 0.1 (conditions neutres)
PDO = -1.8 (phase négative forte)

Qu'est-ce qui influencera notre saison?
Il y a de fortes chances que des conditions ENSO neutres se produisent dans les eaux équatoriales du Pacifique ce printemps. ECCC prévoit que ces conditions devraient persister jusqu'à l'été prochain. Selon les prévisions saisonnières à long terme publiées par l'International Research Institute (IRI), il y a une probabilité ~70% que ces conditions neutres d'ENSO prévaudront ce printemps, et ~60% qu'elles persisteront cet été. L'indice **PDO** est prévu demeurer négatif tout au long du printemps et de l'été. Cette forte phase négative pourrait entraîner un effet de refroidissement sur la Côte-Ouest de la C.-B. Un indice faible mais positif de **l'ONA** (selon la NOAA/CPC) est prévu au moins jusqu'à la mi-mars; par la suite l'habileté à prévoir est faible. L'ONA positif est historiquement lié à des températures supérieures à la normale sur le nord-est du Canada. L'indice PNA restera probablement négatif mais faible d'ici la mi-mars selon le CPC, ce qui aura une influence froide sur tout l'Ouest canadien. Le printemps est la saison où les prévisions de température au Canada sont les plus fiables.

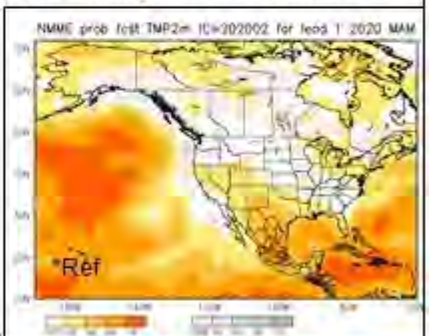
DJF19/20 Catégories observées

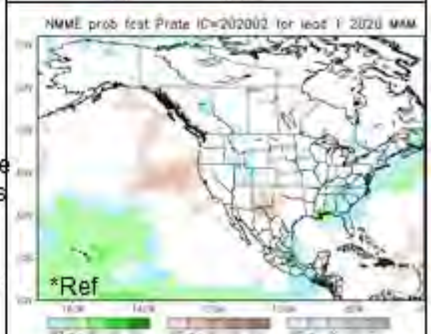
DJF1920 Catgs. prévues SPISCan

Vérification DJF: Températures, 44%. La prévision SPISCan ne prévoyait pas de conditions proches de la normale sur le sud-ouest des Prairies et la C.-B., ni de conditions inférieures à la normale en DJF sur le nord-ouest du Canada.

Prévisions saisonnières des autres centres. Températures: Il y a une différence significative entre SIPSCan et la prévision à long terme du NMME (première figure ci-bas) spécialement sur l'ouest du Canada. Sur le centre et le sud-est du pays, le NMME prévoit des chances égales de probabilité de température. Par ailleurs, le NMME suggère une probabilité légèrement élevée d'observer des températures au-dessus des normales sur le nord du Canada, l'Archipel Arctique, la région des Grands-Lacs et les Maritimes.
Les deux systèmes prévoient des probabilités >40% pour un printemps au-dessus des normales sur l'est du Canada.

Précipitations: La prévision à long terme du NMME (figure inférieure) prévoit des chances égales à travers la majorité des régions canadienns. Cependant des différences sont observées localement (i.e. C.-B., SK, ON,QC). Il y a aussi une différence entre les deux systèmes sur les Maritimes où le NMME prévoit des précipitations au-dessus des normales pour ce printemps.

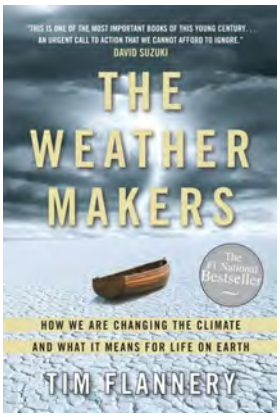




*Ref: http://www.cpc.ncep.noaa.gov/products/NMME/

In My Opinion: On Greed, Power and Making the Weather

By Phil Chadwick, Meteorologist and EcoArtist



I figure if one is going to have an opinion about climate change, it had better be an informed opinion. I thought I was well informed but there is always something to learn too. *The Weather Makers* by Tim Flannery was published in 2005 just after Hurricane Katrina. Fifteen years later not much has changed – the politicians continue to dither.

The book delivers as advertised. The 356 pages detail exactly how we are changing the climate and what it means for life on the only planet we know. It is thorough and accurate. The earth and atmosphere system is indeed complicated with many feedback mechanisms that swing both ways. The research and science devoted to how humans are interfering with this delicate balance have been peer reviewed and closely examined for weaknesses. Simply, there are none. Any unknowns are clearly stated. We have reached the "Act of God" tipping point.

A.P. Herbert defined in *Uncommon Law* in 1935 that an Act of God was "something which no reasonable man could have expected". The impacts of climate change are no longer Acts of God. Science can prove it and "the judiciary will be faced with apportioning guilt and responsibility for human actions resulting from the new climate".

The rich and powerful have been polluting the atmosphere and oceans for profit. Simple greed. You might also read *Dark Money* described as "The Hidden History of the Billionaires Behind the Rise of the Radical Right" (2016). *Dark Money* is a non-fiction book written by the American investigative journalist Jane Mayer about a network of extremely wealthy conservative Republicans, foremost among them Charles and David Koch who have together funded an array of organizations that work in tandem to influence academic institutions, think tanks, the courts, statehouses, Congress, and the American presidency for their own benefit.

Their game plan is simple and has been played without variation on many occasions when their self-centred profits where threatened: (from *The Optimistic Environmentalist* by David R. Boyd):

- Deny the existence of any problems
- Pay charlatan scientists to lie and say their products or emissions are safe
- Finance scientific journals with official-sounding titles to publish bogus articles based on junk science
- Buy the support or acquiescence of politicians and bureaucrats

Far worse has been done as well but few have been held responsible which is concerning about the independence of the judiciary.

There are many other books that cover similar material. In 2000 Jack Doyle published *Taken for a Ride: Detroit's Big Three and the Politics of Pollution* in which he exposed the fight and miss-information campaign resisting the creation of clean transportation. This was in response to the London air pollution disaster of 1952 and the public outcry about air pollution in general. Ford argued in 1953 that automobile exhausts "are dissipated in the atmosphere quickly and do not present an air pollution problem". President Reagan declared in 1981 that "Trees cause more pollution than automobiles". Corporations clearly have enough money to buy democracy.

Flannery also investigates "the corrupt relationship between government and industry. And it is into this cesspit that we must now leap.", as he described in chapter twenty-six entitled "People in Greenhouses Shouldn't Tell Lies". The campaign of deceit and spreading misconceptions has been very successful though, as employed by the transportation, tobacco, DDT, CFC's, asbestos and GMO industries to name just a few. The result has been decades of indecision when the viable solutions are readily available. The net results being that those funding the bogus science and confusion continue to profit.

The issue returns to one of greed and power. As Flannery says the Act of God Defence will no longer work. The science and knowledge explaining climate change are established just as it was for the other harmful industries. Those profiting from promoting fossil fuels can be held accountable by law.

Real change though apparently needs to come from the people. Elected followers closely study the polls to ensure they remain in power. Power is paramount and it can control you like greed. When the polls tip toward green innovations, as they surely must, the politicians will eventually follow. The transition to a green economy will not be politically supported until the polls reflect that the public want green.

The impacts of a changing climate could sway public opinion. Hurricanes, floods, droughts, wildfires and heat waves can be very persuasive. I always thought that becoming informed and prepared would be better than waiting for the catastrophes. Being proactive is much more affordable than simply being uninformed and reactive. Meanwhile species are going extinct as the result of our inability to act.

The Weather Makers is an important read if you want to have an informed opinion regarding climate change. Time for real, pre-emptive action is long past but better late than never. This needs to get done even if only to tell your children and grandchildren that you tried to make a difference. The school presentations, letters to the Editor, MP, MPP and PM have yet to bear any fruit. But it is important to remain optimistic for the sake of the generations yet to come.

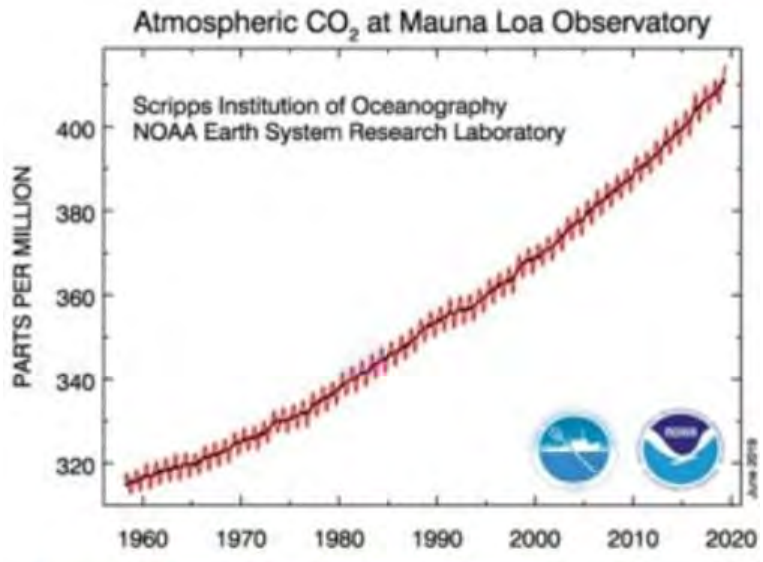
Canada has a very long way to catch-up on the Scandinavian countries that are leading the way forward into a greener future. Meanwhile our politicians are still debating the pros and cons of dumping billions of litres of raw sewage into the nation's waterways. Shame.

You might consider reading *The Optimistic Environmentalist* by David R. Boyd published in 2016. Portions of the world are actually proving that the circular, green economy is the way forward. Indeed people and the planet can profit while preserving the environment and the habitats of the creatures that also share the globe.

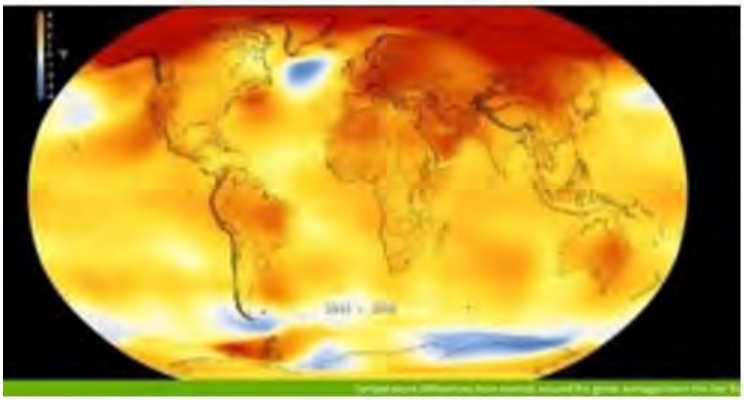
How have things changed in the fifteen years since the release of *The Weather Makers*?

Pictures are worth a thousand words – maybe a lot more. Here they are.

Greenhouse gas emissions climbed by 70 percent in the 34 years between 1970 and 2004. Atmospheric carbon dioxide concentrations rose by 1.8 percent between 2017 and 2018. The burning of fossil fuels for electricity, heat, and transportation has only increased since 2005 although the rate of increase is about steady near 2 percent a year.



Global temperatures have responded to the continuing increases in greenhouse gas concentrations. The temperature deviations from normal during the period from 2014 to 2018 are displayed in the depiction from NASA on the right. The Arctic is warming much faster than the rest of the globe.



The impacts on the jet stream because of the weakening of the temperature gradient between the equator and the poles are now being felt in the weather patterns.

The resultant rise in global average temperature has been well predicted by complex computer simulations of the earth-atmosphere system that are increasingly inclusive of the physical processes at work. The science of climate change has improved dramatically.

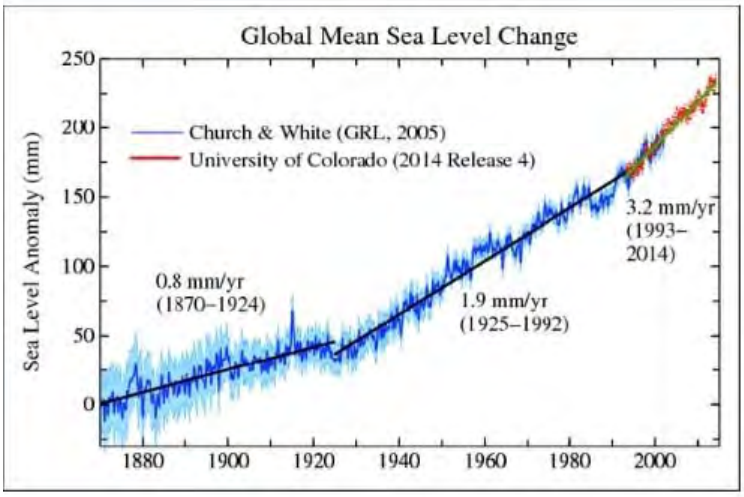
The thawing of the permafrost is a runaway feedback mechanism that will release methane into the atmosphere. CH4 has 30 times more impact that CO2 but is not as persistent in the atmosphere.

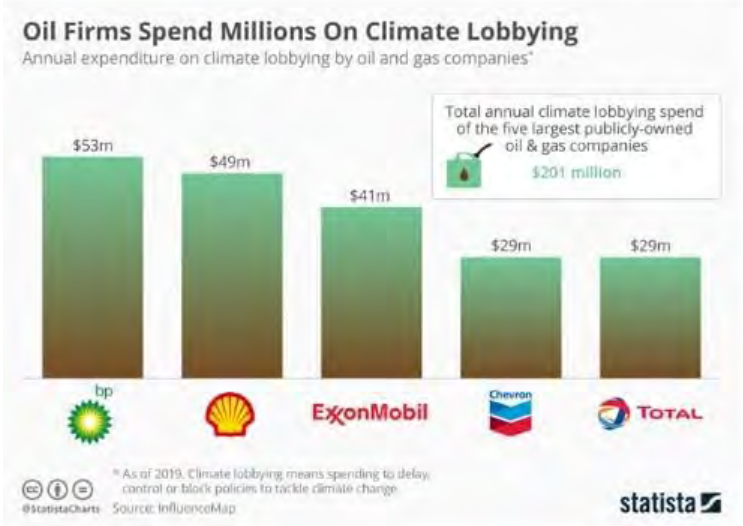
The global ice packs are melting at an accelerated rate as the globe warms. The melting of the Greenland ice sheet has finally caught the attention of the world. Greenland is losing ice seven times faster than it was in the 1990s. The Antarctic as a whole contains about 90 percent of the planet's ice and is showing signs of an increased melt as well Antarctic ice shelves that float on the Southern Ocean are eroding. The vast glaciers behind these shelves could accelerate their slide into the sea as happened in 2002 when the Larsen B ice shelf collapsed off the Antarctic Peninsula.

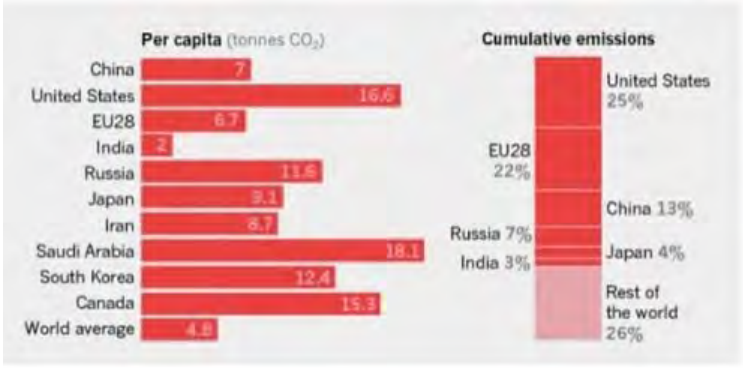
The mean sea level must rise on a warmer globe due to thermal expansion and the melting of the planet's ice. The rate of mean sea level rise is increasing.

The melting on the Greenland ice will contribute 10 to 20 mm to the global mean sea level. About 10 per cent of the world's population live in coastal areas that are less than 10 meters above sea level. Approximately 40 per cent of the world's population (2.4 billion people) live within 100 km of the coast. Rising sea levels, tides and storm surges from stronger tropical storms will have considerable impact.

The effects of climate change as described in "The Weather Makers" are being observed. The surprise is the speed at which these changes and their impacts are occurring – way faster than it was ever believed to be possible. Incremental influences of climate change can be heard in the daily news. Record breaking weather gradually accumulates to become the new climate.

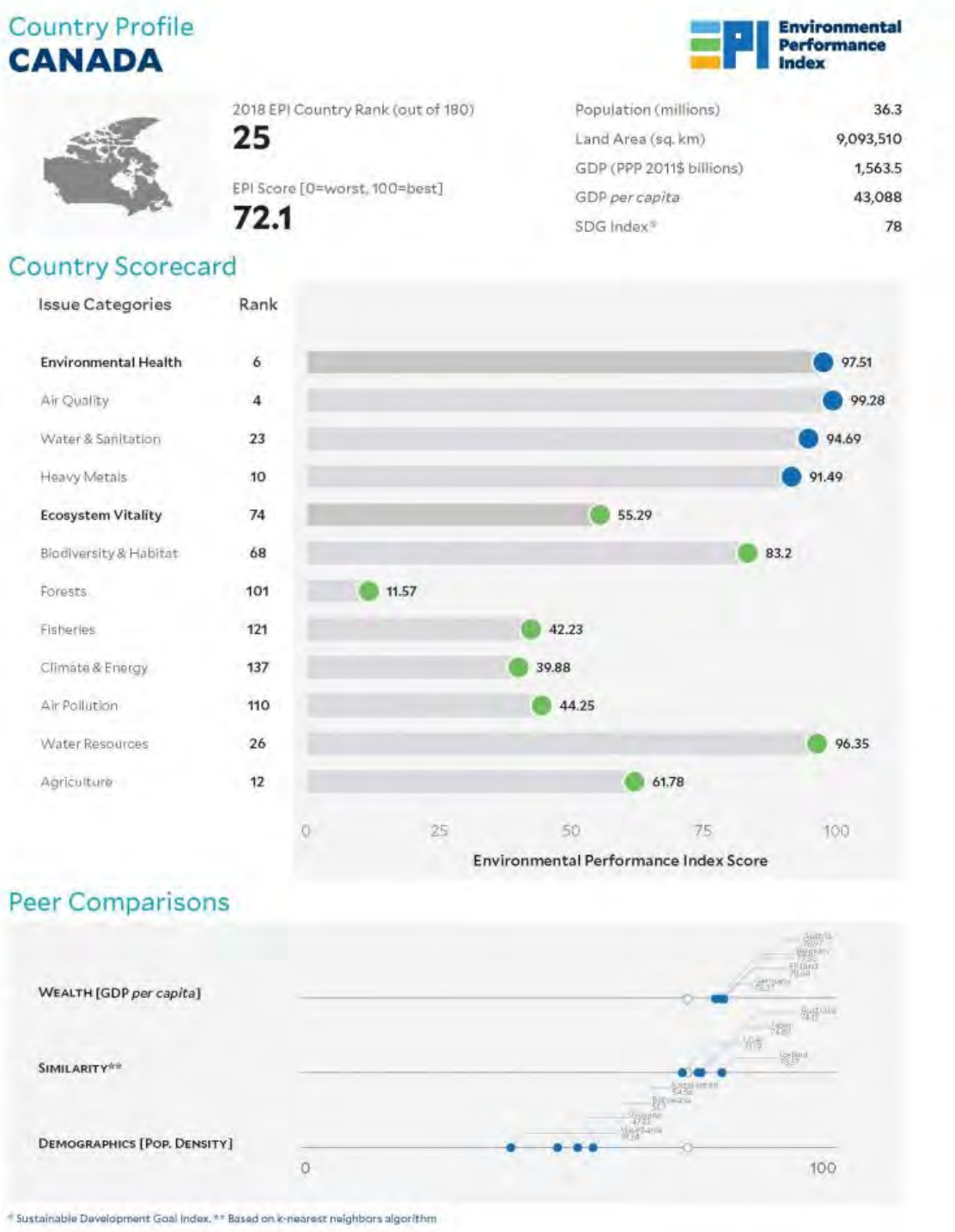






Although the science of climate change continues to improve, there are powerful and influential organizations that refute this knowledge. They are well-funded by corporations that profit from the burning of fossil fuels. These actions have escalated since 2005 and the publication of The Weather Makers.

Climate lobbying has been very effective as demonstrated by the inactions of most of the countries of the world. Canada still relies heavily on the extraction of fossil fuels and is the third highest per capita emitter of CO2 – three times the world average.



The Environmental Performance Index (EPI) offers an independent assessment at a national scale of how close countries are to established environmental policy goals. The EPI is a joint project of the Yale Center for Environmental Law & Policy and The Center for International Earth Science Information Network (CIESIN) at Columbia University's Earth Institute. The EPI is produced in collaboration with the World Economic Forum (WEF). The EPI ranks 180 countries on 24 performance indicators across ten issue categories covering environmental health and ecosystem vitality. These metrics provide a scorecard that highlights leaders and laggards in environmental performance, gives insight on best practices, and provides guidance for countries that aspire to be leaders in sustainability. Canada ranks 25th in this list.(A good reference, worth a read.)

Not enough has changed since 2005. Canada needs to do much more. Political decisions in recent years have turned Canada in more of a laggard.

CMOS SCMO

54th CONGRESS / 54e CONGRÈS

Canadian Meteorological and Oceanographic Society (CMOS) Annual Congress

Congrès annuel de la Société canadienne de météorologie et d'océanographie (SCMO)

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to Changing Weather, Climate, Oceans and Environment

BÂTIR UNE RÉSILIENCE SOCIÉTALE

face à l'évolution du temps, du climat, des océans et de l'environnement

Sunday May 24, 2020 to Thursday May 28, 2020 at the Delta Hotel, 101 Lyon St., Ottawa

Dimanche le 24 mai 2020 au jeudi le 28 mai 2020 à l'hôtel Delta, 101, rue Lyon, Ottawa

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In case you missed it...

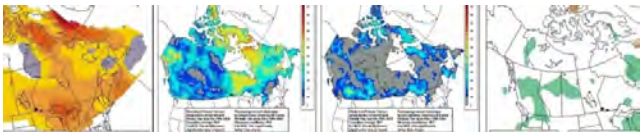
From CMOS Bulletin Volume 48, Number 6:

Message from the CMOS President for the New Year / Mot de la présidente Kimberly Strong : l'occasion de revenir

Message from the Outgoing Bulletin Editor, Sarah Knight / Mot de la rédactrice : un adieu chaleureux

Canada's Top Ten Weather Stories of 2019 / Les dix événements météorologiques les plus marquants au Canada en 2019
by David Phillips

Searching towards creating a sustainable integrated mesonet for the Canadian Prairie Provinces / Création d'un mésonet intégré et durable pour les provinces des Prairies
by Jeannine-Marie St-Jacques et al.



Seasonal Forecast for Winter 2019/20 / Prévision saisonnière pour l'hiver 2019-2020
by Marko Markovic

Arctic Regional Climate Centre Consensus Statement: Temperature / Déclaration de consensus du Centre climatologique régional de l'Arctique : Température
by Gabrielle Gascon, Katherine Wilson, Marko Markoic, et al.

MOPITT: Measuring Pollution in the Troposphere for 20 Years / MOPITT mesure la pollution dans la troposphère depuis 20 ans
by James Drummond

Members Updates
Meeting Notifications, Books for Review, and more

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La Société Canadienne de Météorologie et d'Océanographie

CMOS BULLETIN
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Weather - Climate - Ocean - Atmosphere
Météo - Climat - Océan - Atmosphère

After 45 years in print, the Bulletin of the Canadian Meteorological and Oceanographic Society (CMOS) has gone virtual. See bulletin.cmos.ca for articles, news, events and updates from Canada's top meteorologists, climatologists and oceanographers.

Après 45 années de publication papier, le Bulletin de la Société canadienne de météorologie et d'océanographie (SCMO) passe en mode virtuel. Consultez le site bulletin.scmo.ca pour lire des articles, des nouvelles, des annonces d'événements et des faits nouveaux que partagent les éminents météorologues, climatologues et océanographes du Canada.

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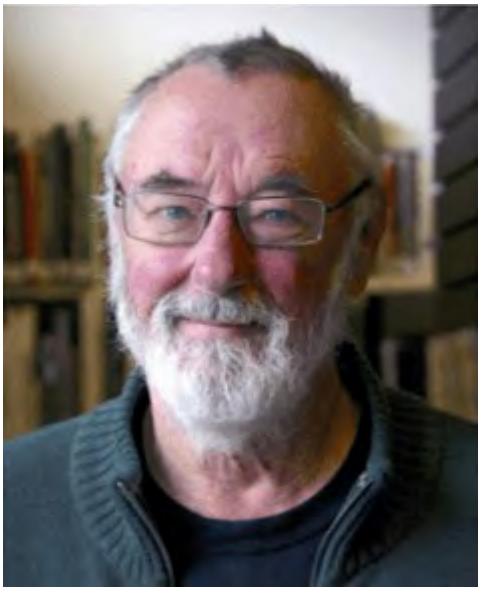
In Memoriam

Remembering Paul LeBlond 1938-2020



Paul Henri LeBlond

December 30, 1938 – February 8, 2020

Surrounded by his family, Paul passed away peacefully at home at the age of 81, after a lengthy illness. Paul was born in Quebec City and grew up in Chicoutimi.

His innate curiosity and love of learning led him naturally into science, earning his undergraduate degrees at Laval and McGill Universities. In 1963 he married Josee Michaud and together they moved to British Columbia, where they raised three children. Paul LeBlond gained his doctoral degree at the University of British Columbia, and was a distinguished scientist and one of Canada's leading physical oceanographers, most notably in his joint appointments in both the Physics and Oceanography Departments at the University of British Columbia (UBC) from 1965 -1996 and since 1996 as a Professor Emeritus. His research interests were primarily in ocean waves ranging from surface waves, to tides, internal waves and tsunamis generated by underwater landslides, but also extending to beach processes and gas bubble dynamics.

Beyond his scientific research, he was actively involved in the oceanographic community, both in Canada and internationally. In the 1970s, he was instrumental in bringing oceanography into the Canadian Meteorological Society to form CMOS. He became a well-known and much-consulted expert in ocean dynamics specializing in waves, tides, tsunamis and beach formations. In 1978 he coauthored an important textbook Waves in the Ocean with Lawrence Mysak. During the 1990s, Paul took on key leadership roles for physical oceanography within the North Pacific Marine Science Organization (PICES), an intergovernmental science organization, and received its prestigious Wooster Award in 2004, one of many he was honoured with during his career. Other awards he received include: President's Prize, Canadian Meteorological & Oceanographic Society (CMOS); Tully Medal, CMOS; Fellow of CMOS; Honorary Doctorate in Science, Memorial University; Fellow of the Royal Society of Canada; and Foreign Member of the Russian Academy of Natural Science. Paul made major contributions to many other scientific organizations as well, including:

- World Ocean Circulation Experiment (WOCE);
- Pacific Fisheries Resource Conservation Council (PFRCC), founding Chair;
- Canadian Ocean Frontiers Research Initiative (COFRI);
- the Ocean Production Enhancement Network (OPEN); and
- the Natural Sciences and Engineering Research Council (NSERC).

Paul traveled extensively for his work, and learned languages as he went. He was fully fluent in French and English, and spoke German, Russian and Spanish. As a dynamic teacher and researcher, he was an inspiration to his students for over 30 years. His friendly, easy going but authoritative style of teaching was admired by all. He loved his students and treated them with much respect, often saying that he learned as much from them as they did from him. Paul's love of science and discovery led him to investigate sightings of unidentified marine mammals such as Cadborosaurus seen many times in the local waters of the Salish Sea. This passion led him to co-found the International Society of Cryptozoology and the British Columbia Scientific Cryptozoology Club (BCSCC). He co-authored and published two books, Cadborosaurus: Survivor of the Deep (with Ed Bousfield) and Discovering Cadborosaurus (with John Kirk and Jason Walton). He also translated

several books on the subject. A few years after his first marriage ended, he met and fell in love with artist Annette Shaw. They spent a sabbatical year in France, enjoyed traveling and exploring the world. In 1990 they moved to Galiano Island where Paul became an active member of the community and local organizations including the Museum Society, Trails Society, Parks and Recreation, Galiano Island Recycling Resources, Tour des Iles, the CRD, the Economic Development Committee and Transportation Committee, to name a few. Galiano Island was the perfect place for Paul to retire and continue enjoying his love of the ocean and the outdoors, camping, swimming, hiking, trail building, chopping wood, reading and always learning something new. Throughout his life, he exemplified generosity, kindness and a love of learning. He expressed his zest for life in all he did, and inspired those who met and worked with him.

Paul's former students stated that to them, he was much more than a great researcher. He was also a wonderful educator and teacher, and those who were his graduate students were privileged to benefit from the depth and breadth of his scientific insight and excellent teaching skills. As a professor, he was very approachable – friendly, good-natured and easy going. He treated his students with respect and the relationship he had with them is captured in his own words: "The greatest enjoyment of a research career for me has been the interaction with graduate students. In some cases, they worked on my ideas. In many others, they brought their own ideas and I learned as much from them as they from me." Paul was the opposite of a remote, ivory tower academic. He was attracted to quirky and original ideas. He had a long-time interest in cryptozoology, as a founding member of the international society. He wrote many books and articles on the subject and would speak on it whenever he got the chance. He frequently attended the Friday afternoon beer garden at the Graduate Student Centre, and was the centre of many vigorous discussions there, usually but not always scientific in nature. He was also a good athlete, skating circles around many of us at the weekly early morning hockey games before classes and joining in the summer soccer games.

Paul loved a party and could always be counted on to enliven a conference banquet or reception, even to the extent of rolling empty wine bottles along the floor during one particularly tedious speech. Students were always welcome at his home and could often find an excellent dinner with Paul and his family in a friendly atmosphere. He was a great person to have as a supervisor, a colleague or as a friend. Those of us who were fortunate enough to be his students and go on to careers in oceanography and other fields will always remember him with admiration, respect and deep affection.

Paul was predeceased by his parents: Sylvio and Jeanne, and will be lovingly remembered by his wife Annette; his children: Michel, Philippe and Anne (Fred Delgiglio); step-daughter: Jenny Breukelman; grandchildren: Mikayla, Nina, Cody and Tia; his brother: Pierre (Michele); his nephew and nieces; and his former wife Josee (Boyd). The family is profoundly grateful to Dr. Erin Carlson and her medical team for their great care and compassion. Memorial donations can be made in Paul name to the Galiano Health Care Society, 908 Burrill Rd, Galiano Island, V0N 1P0, by cheque, or online at www.galianohealth.org.

The following former students of Paul's have contributed to this obituary:
(Signed)
Richard Thomson, North Saanich BC
David Lemon, Victoria BC
David Fissel, Brentwood Bay BC
Brad deYoung, St. John's NL
Alex Hay, Halifax NS
Bill Crawford, Brentwood Bay BC
Greg Crawford, Oshawa ON
Richard Dewey, Victoria BC
Charles Hannah, Brentwood Bay BC
Ken Denman, North Saanich BC
Yves Gratton, Quebec City PQ
Ana Carrasco, Oslo Norway
Ann Gargett, Victoria BC
Steven Bograd, Monterey, CA

CMOS and the COVID-19

As concern about the COVID-19 virus is increasing and some international scientific conferences are being cancelled, you may be wondering about the status of the CMOS Congress in Ottawa, which is scheduled for May 24-28, 2020.

At this time, the CMOS Congress is still scheduled to proceed as planned. The Chairs of the Local Arrangements Committee (LAC) and the Scientific Program Committee (SPC), along with the CMOS Executive, will continue to monitor the situation.

If anything changes, we will inform CMOS membership and Congress participants. We will also post updates on the CMOS Congress website: https://www.cmos.ca/site/congress_home

For further information see:
Ontario Ministry of Health
Public Health Ontario
Public Health Agency of Canada
World Health Organization
Government of Canada Travel Advice (COVID-19)
Immigration, Refugees and Citizenship Canada

Kimberly Strong, CMOS President
Bruce Angle, 2020 CMOS Congress LAC Chair
Leonard Barrie and Gordon McBean, 2020 CMOS Congress SPC Co-Chairs
Gordon Griffith, CMOS Executive Director

SCMO et le COVID-19

Tandis que l'inquiétude au sujet du COVID-19 augmente et que certains congrès scientifiques internationaux sont annulés, vous vous demandez peut-être ce qu'il en est du Congrès de la SCMO d'Ottawa, qui doit se tenir du 24 au 28 mai 2020.

Pour l'instant, le Congrès de la SCMO se déroulera comme prévu. Les présidents du comité local d'organisation et du comité du programme scientifique, ainsi que les dirigeants de la SCMO suivent la situation de près.

S'il survient un changement, nous en informerons les membres de la SCMO et les participants au Congrès. Nous publierons également des mises à jour sur le site Web du Congrès de la SCMO : https://www.cmos.ca/site/congress_home?language=fr_FR&.

Informations supplémentaires :
Ministère de la Santé de l'Ontario
Santé publique Ontario
Agence de la santé publique du Canada
Organisation mondiale de la santé
Conseils aux voyageurs du gouvernement du Canada (COVID-19)
Immigration, Réfugiés et Citoyenneté Canada

Kimberly Strong, présidente de la SCMO
Bruce Angle, président du comité local d'organisation du Congrès 2020 de la SCMO
Leonard Barrie et Gordon McBean, coprésidents du comité du programme scientifique du Congrès 2020 de la SCMO
Gordon Griffith, directeur général de la SCMO

CMOS at the ArcticNet Annual Scientific Meeting, Dec. 2019, Halifax NS

CMOS participated in the recent ArcticNet Annual Scientific Meeting (ASM), Dec. 2-5 2019, Halifax NS. The CMOS Arctic Special Interest Group (Arctic SIG), organised and conducted an exhibit which was well attended by ArcticNet ASM delegates. At the exhibit were Arctic SIG executive members, David Fissel, Chair, and Helen Joseph, Past-Chair as well as Matthew Asplin, Chair, CMOS Vancouver Island Chapter.

The ArcticNet Annual Scientific Meeting (ASM) has been the largest Arctic and Northern research gathering held in Canada for many years now. The 2019 meeting, held in Halifax NS in December, attracted more than one thousand Arctic scientists and others. This is the first ArcticNet ASM held since the April 2019 announcement that the ArcticNet Network of Centre of Excellence (NCE) was renewed for another five years of funding. The renewal of the ArcticNet NCE was unprecedented for an NCE after the full original funding cycle, spanning 14 years from 2004 – 2018, had run its course. A more complete report on the renewal of ArcticNet and the 2019 ArcticNet ASM can be found in the CNC-SCOR January 2020 newsletter.

More information on the CMOS Arctic SIG, created in 2012, is available at https://cmos.in1touch.org/site/arctic_sig.

Left to Right: Helen Joseph, David Fissel and Matthew Asplin.
Photo Credit: Ed Ross, Trailmark Systems

CMOS News

CMOS Membership Renewal Time!

Every year at this time, we send you reminders to renew your membership. Please help the Society save money on postage and renew online. Outstanding invoices will be mailed out if required.

I trust you will continue to be part of the CMOS community. Take the time to renew online at **http://www.cmos.ca/**. When doing so please consider making a voluntary donation to one of the CMOS funds – your generosity will greatly enrich our CMOS activities. In addition, please continue to use our web-site as a useful resource of our events, publications, news and announcements.

Thank you for being a member of our Canadian Meteorological and Oceanographic Society. I hope to see you at our 2020 Congress in Ottawa, ON. I speak on behalf of our Society to thank you and express my appreciation of your active participation in our community!

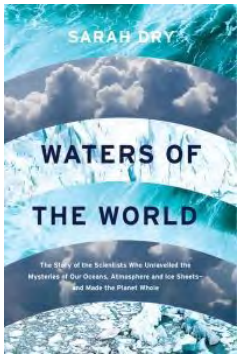
Renouveler votre adhesion!

Chaque année, à cette époque, nous vous invitons à renouveler votre adhésion. S'il vous plaît, aidez la Société à économiser sur les frais des timbres et à renouveler en ligne. Les factures en suspens seront expédiées si nécessaire.

J'espère que vous continuerez à faire partie de la communauté de la SCMO. Prenez le temps de renouveler votre adhésion en ligne à : http://www.scmo.ca/. Merci de considérer de faire un don à l'un des fonds de la SCMO — votre générosité enrichira considérablement les activités de la SCMO. De plus, merci de continuer à utiliser notre site Web en tant que ressource utile pour en savoir plus sur nos événements, publications, nouvelles et annonces.

Merci d'être membre de la Société canadienne de météorologie et d'océanographie. J'espère vous voir à notre congrès de 2020 à Ottawa. Au nom de notre société, je vous remercie de votre participation active au sein de notre communauté !

NEW Books Available for Review



Winds, Waves and Warriors: Battling the Surf at Normandy, Tarawa, Inchon, 2019. By Thomas M. Mitchell, Lousiana State University Press. ISBN 978-0-8-71-7223-0 (Cloth), 168 pages, $39.95 USD (2020-1)

Waters of the World: The Story of the Scientists Who Unraveled the Mysteries of Our Oceans, Atmosphere, and Ice Sheets and Made the Planet Whole, 2019. By Sarah Dry, University of Chicago Press. ISBN 978-0-226-50770-5 (Cloth), 368 pages, $30.00 USD (2019-4)

Other recent titles still available for review by a CMOS member:

- **An Introduction to Tides**, 2019. By Theo Gerkema, Cambridge University Press, ISBN 978-1-108-46405-5 (Paperback), 211 pages, $51.95 USD (2019-3)
- **A Bright Future: How Some Countries Have Solved Climate Change and the Rest Can Follow**, 2019. By Joshua S. Goldstein and Staffan A. Qvist, Hachette Book Group, ISBNs 978-I-5417-241O-5 (hardcover), 978-1-5417-2409-9 (e-book), 288 pages, $34.00. (2018-9)
- **Tropical Extremes: Natural Variabilities and Trends**, 2019. Edited by V. Venugopal, Jai Sukhatme, Raghu Murtugudde, Remy Roca, Elsevier Inc. ISBN 978-0-12.809248-4, 333 pages, US$110 (2018-11)
- **World Seas, An Environmental Evaluation. VOLUME III: Ecological Issues and Environmental Impacts**, Second Edition, 2019. Edited by Charles Sheppard, Elsevier Inc. ISBN 978-0-12-805052-1, 633 pages, US$250. (2018-12)
- **Rainbows: Nature and Culture**, 2018. By Daniel MacCannell, The University of Chicago Press and Reaktion Books Ltd, ISBN 9781780239200, 208 pages, US$24.95 (2018-4)
- **The Deep Pull: A Major Advance in the Science of Ocean Tides**, 2018. By Walter Hayduk, FriesenPress, ISBN 9781525518706 (hardcover) $35.49, 9781525518713 (softcover) $27.49, 9781525517820 (eBook) $11.99, 251 pages. (2018-7)

Never reviewed a book before? No problem! Check out some of these past reviews for ideas: Ice: Nature and Culture; Weather in the Courtroom; Convenient Mistruths: A Novel of Intrigue, Danger and Global Warming; Weather, A Very Short Introduction; Nonlinear and Stochastic Climate Dynamics.

If you a review a book it is yours to keep! Contact the Editor to get involved.

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Thank you to Bob Jones for his continued editorial assistance and guidance.

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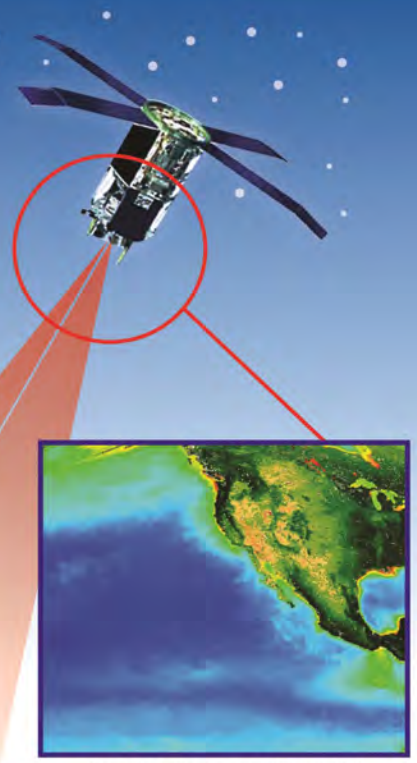
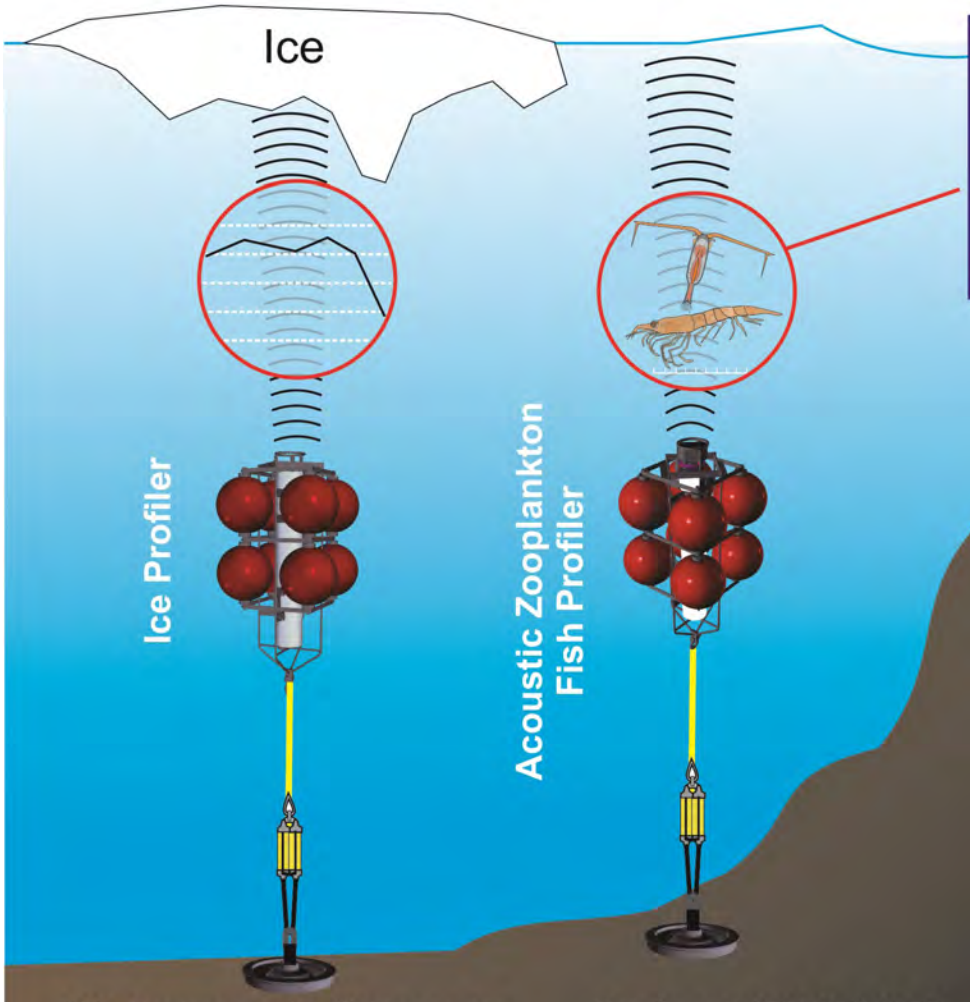
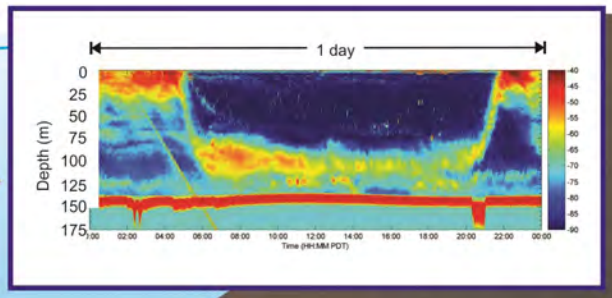


Ocean colours are chlorophyll concentrations and land colours are NDVI





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