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**July – December / 2023 / juillet – décembre**

# Does anthropogenic noise impact Arctic whales' acoustics?

**WRITTEN BY CMOS BULLETIN SCMO ON JULY 6, 2023. POSTED IN ARCTIC, OCEANS, WHAT'S CURRENT.**

**– By Kimberly Franklin –**

Figure 1. Main research vessel, M/V Kiviuq I, in Baffin Bay.

More opportunities for human activities such as shipping, fishing, and military exercises are arising in Northern Canada as the Arctic warms and sea ice coverage decreases (e.g., Mudryk et al. 2021). These activities contribute to increasing noise levels and changes in the Arctic underwater soundscape (e.g., Stafford 2021, Cook et al. 2022). Marine mammals rely on their specialized auditory system to sense their environment and perform essential life functions like foraging, mating, and navigating (e.g., Hanke et al. 2013). Hearing in whales, dolphins, and porpoises (cetaceans) is vast and diverse. Toothed whales are generally well studied due to research on captive species such as bottlenose dolphins, but considerably less is known about baleen whales (Southall et al. 2019). Thus, cetaceans are quite susceptible to noise from human activities as their vocal repertoire and assumed hearing ranges tend to overlap with the noise ranges of these human activities.

The effects of noise on marine mammals varies greatly in severity. Less severe effects include temporary disruptions to normal life functions and masking (e.g., Shrope 2002, Foote et al. 2004, Southall et al. 2019). Masking is when the environment is so loud it drowns out softer sounds at the same frequencies. More severe effects include temporary and permanent changes in hearing, short- and long-term stress, and even death. Exposed individuals typically exhibit avoidance behaviours such as swimming away, as well as changing their behaviour like ceasing foraging (e.g., Erbe et al. 2019). Acoustic behaviour can also be affected by increasing, decreasing, or ceasing vocalizations and/or echolocation clicks (e.g., Scheifele et al. 2005, Denise et al. 2012, Stainstreet et al. 2022). Echolocation clicks are click like sounds produced by toothed whales to scan their environment and detect prey. Typically, a combination these behaviours are identified, but responses vary by species, environment, the animal's previous experiences, and the original behaviour the animal was engaged in (Miller et al. 2012).

Figure 2. Suction cup hydrophone data logger (DTAG).

Figure 3. Free drifting buoy equipped with hydrophone data logger, SoundTrap (below surface) and the high-flyer with the GPS unit and satellite transmitter (grey octahedron shape above surface).

How Arctic marine mammals react to noise is not well known (Halliday et al. 2020). To fill this knowledge gap, a large project launched by ArcticNet and Defence Research and Development Canada, led by Dr. Sarah Fortune (Dalhousie University), is investigating the behavioural and energetic impacts of anthropogenic disturbance on Arctic whales. One objective of this project is to examine the impacts of military sonar signals and vessel noise on Arctic whales' acoustic behaviour. Specifically, northern bottlenose whales and sperm whales as they are relatively new summer visitors to Baffin Bay and are sensitive to noise, especially sonar signals. We are interested in understanding if these species have an acoustical response to sonar and vessel noise (e.g., changes in echolocation click frequency, changes in click intervals), and if so, what noise factors contributed to the acoustical response (e.g., duration, frequency, sound pressure level) and what behaviours were interrupted (hunting, depredation, etc.).

Figure 4. Underwater speaker used to conduct experiments.

To answer our questions, a series of playback experiments were conducted in Baffin Bay, Canada, around active fishing vessels in the fall of 2022 and scheduled for the fall of 2023. This location was chosen because the whales are known to reliably exploit the Greenland Halibut fishery by foraging on the fishery's discards (Johnson et al. 2021). The playback experiments consisted of deploying various acoustic data loggers to record baseline activity (i.e., undisturbed, natural noises and whale acoustic behaviour) before the experiment as well as capture the playback recordings and any northern bottlenose and sperm whale echolocation clicks produced during the experiment. One type of data logger we used was a digital acoustic recording tag (DTAG) which contains a time-depth recorder, 3D accelerometer, magnetometer, and hydrophone (Figure 2). The DTAGs attach, via suction cup, to the whales' backs for approximately three to four hours. Another acoustic data logger we used was a SoundTrap, which was attached to a free drifting buoy with a high-flyer, GPS unit, and satellite transmitter to ensure recovery (Figure 3). The last acoustic logger was a Slocum glider, which is an autonomous underwater vehicle equipped with a hydrophone, GPS, and other oceanographic sensors. The glider was deployed in the region one to two weeks in advance of the experiments. After the DTAGs and SoundTrap were deployed for a minimum of an hour, an underwater speaker was deployed to play the audio recordings of interest for 20 minutes (Figures 4 and 5). The audio recordings consisted of a control sound (ambient noises previously recorded from the area), vessel noise, or vessel noise with sonar signals. After the playbacks, the whale's responses were monitored and logged for a minimum of 1 hour. Once the experiments were concluded the speaker and the loggers (i.e., DTAGs and SoundTrap) were recovered and the audio recordings were downloaded. The collected audio recordings will be processed for echolocation clicks

using a detector and by manually annotating the data. The clicks will be analyzed for a suite of parameters including, click intervals, frequencies, and amplitudes. The received noise sound levels from the DTAGs will be determined and compared to a sound propagation model of the playback noises to understand how the whales received the noise. To compare the acoustic characteristics of the vessel noise and sonar signals to the parameters of the detected clicks for each playback recording type, statical models such as generalized linear models and/or generalized additive models will be used. These findings will be used to determine specific noise thresholds for acoustical, and ultimately, behavioural responses.

Figure 5. Researchers conducting an experiment while commercial fishing is occurring.

A working understanding of whale behaviour and underwater sound levels in the Arctic can aid in the implementation of well-informed proactive measures. Opposed to employing strong reactive measures later in time, such as those for whales that inhabit urban environments, like the North Atlantic right whale. This work aims to be proactive by determining acoustic behavioural responses and thresholds from military sonar and vessel noise before these noise sources become pervasive. Our research is conducted under a unique circumstance such that the impacts from noise will be investigated in a busy/noisy environment where active fishing is occurring, and the whales are engaged in depredation and fishery discards. This can be interpreted to artificially reflect responses that may occur while the animals are engaged in a natural high rewarding life function activity (e.g., hunting) while human generated noises are present. Thus, the findings

from this work will aid in supporting risk mitigation strategies, legislation, and policy plans for the Department of National Defence Canada (DND) and Fisheries and Oceans Canada (DFO) as these agencies seek to prevent excessive and unnecessary noise for current and future populations of marine mammals in the Arctic. Our research aligns with Indigenous communities' concerns about increased military noise levels on Arctic whale species and provide opportunities to work with them. Overall, this work will support conservation and protection efforts for Arctic whales about the impacts of anthropogenic noise and contribute to understanding these species acoustic ecology.

Figure 6. Sperm whale about to be tagged.

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# The Evolution of Canada's Weather Enterprise: 150 years Anniversary Symposium

**WRITTEN BY CMOS BULLETIN SCMO ON AUGUST 3, 2023. POSTED IN ATMOSPHERE, CLIMATE, MEMBERS, NEWS & EVENTS, WHAT'S CURRENT.**
**– By Stella Melo, Mireille Chaput-Dyer and Paul Joe –**

Abstract

The virtual CMOS-MSC Symposium on 150 Years of Weather Services in Canada, took place during the CMOS Congress in 2021. It provided the opportunity to celebrate the national and international achievements in weather services delivered by the government, CMOS, academic and the private sector partnership. Participants, whose leadership and actions have guided Canada's success, shared their experiences, identified the key transformative moments, and provided their perspectives for the future of Canada's Weather Enterprise. A panel of weather enterprise leaders, many of which are Order of Canada recipients, participated in the first of three sessions. It was conducted as a Round Table discussion and reflected on significant moments. The second session focused on the forecast system with a discussion on a vision of the future and the way forward. The third session discussed the evolution of the user needs and the challenges associated to service provision, particularly in the context of emergency management. We provide here a synthesis of these three workshops,

## Introduction

The Meteorological Service of Canada celebrated its 150th anniversary in 2021. While its mandate remains stable throughout the years: to provide authoritative forecasts, warnings, data, and information services related to weather, hydrological, and environmental conditions using a wide range of dissemination systems to help Canadians, public authorities, and targeted weather sensitive sectors make informed decisions about health, safety, and economic prosperity – the context in which the MSC operates has evolved significantly since the beginning. This eminent milestone provided the occasion to reflect upon the history of the Weather Enterprise in Canada, review the current state, project the view for the future, and discuss the path forward. In collaboration with the Canadian Meteorological and Oceanographic Society (CMOS), a Symposium was held consisting of one Round Table and two online workshops extending over ninety minutes each, with distinguished speakers from the public, private and academic sectors. The sessions were recorded and can be found at Science Catalogue (Canada, 2021).

## The Round Table

The Round Table reflected on the significant moments in the evolution of Canada's weather enterprise. It was structured in a question and answer format. The panelists included three former Assistant Deputy Ministers of the MSC, Jim Bruce, David Grimes, and Gordon McBean; the current Assistant Deputy Minister of the MSC, Diane Campbell; two influential MSC senior meteorologists, Jim Abraham and David Phillips; and a leader from the private sector, Pierre Morrissette. All participants are, have significantly influenced upon the evolution of the Weather Enterprise in Canada and internationally. Most of the participants received prestigious recognition awards, such as the Order of Canada. The speakers were asked questions that were of a reflective nature.

The speakers provided a broad historical perspective with some commonalities. The Weather Enterprise is driven by the demands and needs for the safety, security, and socio-economics needs of Canadians and cooperation at all levels is the key to Canada's success.

## Game Changing Moments

1. Hurricane Hazel (Hazel, 1954) lead to severe floods in Southern Ontario. Although the storm was well forecasted, there was no infrastructure to issue flood warnings. It was the defining event that highlighted the need to link weather, hydrology, and societal impacts. It created the opportunity for collaborative inter-disciplinary approaches which was, and continues to be the hallmark of the success of the Canadian Weather Enterprise that over time extend scientifically, and internationally involving different instances of the public and private sectors. This led to the secondment of an MSC meteorologist into the Ontario government. This marked the importance of the development and integration of scientific partnerships for hydrological emergency management. This led to the first Metropolitan Toronto and Region Conservation Authority (MTRCA) Plan for Flood Control and Water Conservation in 1959 (TRCA, 2023). This model led to the establishment of liaisons in agriculture, conservation, forestry, building, and engineering.
2. The MSC first began with a focus on providing weather information and services to mitigate the impacts of maritime disasters but continued to be driven by weather events in all seasons and in all locations. Throughout its history, focusing events such as Hurricane Hazel (Knox, 1955) , the Saguenay flood of 19 July 1996 (Milbrandt and Yau, 2001), the Ice Storm of 1998 (Henson et. al., 2007), Hurricane Dorian of 2019 (Phillips, 2020) and the $1,2B Calgary hail storm of 13 June 2020 (Phillips, 2021) have been other defining and transformative moments that remind all Canadians of the importance of MSC and the entire Weather Enterprise.

3. As the negative anthropogenic impacts on the atmosphere were recognized, Canada was one of the first, and still one of the only, nations to integrate meteorological (weather, water, and climate) and environmental sciences. In 1972, the MSC evolved from the Department of Transportation to the Department of the Environment.
4. Climate Change: The environmental concerns lead to Canada taking a prominent global role in climate change on the international stage. The MSC established a Canadian Climate Program Board and played a prominent role in the Villach 1985 Conference on Climate Change (ISC, 2018; Agrawala, 1998). This subsequently led to the establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1987 and MSC staff were involved right from the inaugural meeting in Geneva (IPCC, 2023). The Toronto International Conference on Climate Change: Implications for Global Security in 1988 made the first calls for carbon emission reduction where a more coordinated approach to science and political support to address the impacts of climate change began to merge (Hare, 2009). Prime Minister Brian Mulroney and the UN Ambassador Stephen Lewis participated in the discussions. As climate change became a growing concern, the MSC drafted the Emission Control Convention and the International Framework Convention on Climate Change for the RIO summit (UNFCCC, 1992; Rio, 1992).
5. The World Meteorological Organization (WMO): There was a recognition that the only way to understand the weather and its predictability would be rooted in having access to data collected around the world. Common standards and approaches to enable the free exchange of information amongst members led to the establishment of the WMO in 1873. This had a very significant impact on Canada, creating the backbone upon which Canada relies on and contributes toward in order to effectively provide meteorological and hydrological services. The WMO evolved with time and its leadership and coordination functions have been critical to bridging science and political focus at the World Climate Conferences (WCC, 2023).
6. Canada's Place in the World: Canada's reputation, socio-economic financial situation, vast geography, and weather, and relative position on the international stage, provided opportunities to lead internationally. Canada's need for partnerships, the ability to compromise, set priorities, cooperate, and collaborate as well as their capabilities and capacities have been, and continue to be, well-respected on the global stage. Canadians play key roles at the WMO, the International Council for Science, Inter-governmental Oceanographic Commission, UNESCO, UNEP, and in the commercial marketplace. This has led to global successes by rallying the scientific community and programs towards Canadian concerns for the benefit of the global community (e.g., Global Framework for Climate Services (GFCS, 2023), Global Cryospheric Watch (GCW,

2023)). It has also provided the opportunity to share our ethics and values around the world.

Technological advances: Technology and science that made the special moments. The MSC observation and forecasting infrastructure has always been at the forefront with advances in telecommunication, super-computing, and data storage, to name a few. From a private market perspective, it's been a combination of factors involving technology and customer needs, The Weather Network/MeteoMedia became Canada's largest website, and then came mobile services. The challenge is to figure out the next growth opportunities which are based on leveraging market needs, technology, and science.

The second session was conducted in a lecture format and focused on the technical aspects of the forecast system and its future development. The weather knows no boundaries and hence monitoring and the sharing of the data globally is the core mandate of all meteorological services. Canada is geographically vast and sparsely populated. The current and future weather services need broader coverage and higher resolution from the monitoring network to meet the needs of all Canadians. Partnerships with other agencies for surface and near-surface observations; space-based Earth observations to cover land, ocean, and the Arctic; and innovations in the use of non-traditional data sources (e.g., aircraft data, mobile phones, cars) are needed.

For example, with a warming climate, the Arctic is increasingly of interest from the perspective of sovereignty, navigational, socio-economic, and recreation for Canadians. This has great consequences. It challenges the capabilities and capacities to deliver weather services. There are significant gaps in the monitoring system, the scientific understanding, and hence our numerical weather prediction and forecast systems (Jung et. al., 2016; Joe et. al., 2020) on all scales, from weather to a climate that affects the mid-latitudes and vice versa. Also, the atmosphere, the hydrological cycle, the sea ice, the land and the cryosphere are all intertwined and scientifically coupled. The majority of Canadians live in cities that have complex infrastructures that are vital to the safety of the health and socio-economy of Canadians and detailed weather service requirements in complex terrain are evolving (Grimmond, 2020; Schlünzen et. al., 2023; Joe et. al., 2023). Hence, a holistic Earth System Prediction approach at all scales, from months to decades is needed (Brunet et. al., 2015.) that Canada is well positioned to develop.

This will increase the scope of the data gathered, which is the first step, particularly related to the data sparse Arctic cryosphere. The amount of data and model outputs will explode in volume and using this data, the adaptation of the numerical weather predictions systems and interpretations model outputs will require traditional but also multi-disciplinary skills that include 'big data' and artificial intelligence techniques to leverage all the information.

Partnerships with academia will continue to play a significant role in training the next generation of weather enterprise leaders, but also in research and the development of applications. However, the partnerships need to be elevated and coordinated. Academic freedom is a core principle that must be balanced with directed research and training. A high-level weather research board was proposed during the workshop that would allow for strategic guidance but also respect for academic freedom and a competitive research proposal process.

Changing to a multi-disciplinary approach requires building bridges to overcome the gap between the individual disciplines. Articulating and understanding the vision was identified as the biggest challenge and five aspirational goals were provided as unifying themes to unite the community. They are:

1. The transition from the current suites of modeling systems to the Earth System Modelling approach in an exascale computing world.
2. The transition from the current Earth observing infrastructure to the fully integrated one.
3. Addressing the challenge of data, big data discovery, and cloud-based data processing for users to leverage AI technologies, man-machine interface. The role of the human in that is fundamental (Hoffman et. al., 2017). In order to validate the systems, we will need the feedback of people who actually work making decisions with the outputs.
4. The need to work towards and adopt a common goal amongst Canada's Weather Enterprise partners. The convergence, the critical mass working on a common goal is the key to overcoming limited resources.
5. The need to focus on the clients of tomorrow which may also include machine-to-machine interaction with smart electronic navigation system for shipping or aviation travel as two examples.

The third session consisted of presentations looking at the service provision perspective. In the early days, forecasts were disseminated by simplified codes on trains, were posted at public locations and eventually published by reluctant newspaper editors who did not value them while the public clamored for them. A recurring theme, and reiterated in the all the sessions, was that services requirements were ahead of the forecast system capabilities and provided strong motivation for the science and services communities.

Presentations by emergency management services (EMS) at both the provincial and municipal level provided clear testimonials on the benefits of the prediction and warning services for extreme weather for society. This is the primary mandate of weather services for the MSC. Weather was identified as the dominant factor in all phases of emergency response, from preparation, to response and reconstruction as EMS deals

with the cascade of downstream impacts that persist beyond the actual weather event. Provincial level EMS coordinates federal support mechanisms including funding and coordinating the local or municipal EMS agencies. Warnings and their associated uncertainly and interpretation are the first step in preparation, coordination and response. Accurate predictions lead to efficient initial response to a disaster event at the individual and neighborhood levels. Probabilistic products provide uncertainty information. EMS implicitly calibrates the information but embedded forecasters and weather support are needed to interpret the predictions as the complexity of the decision-making include non-scientific but also social-economic and political factors (Golding, 2022; Joe et. al., 2022).

The rise of the private sector and internet technology are critical to getting the warnings heard and understood by the public. Warnings are readily available via its ubiquitous presence on all the media outlets, internet, mobile and alerting notifications apps. Their key skill set is communication and out-reach and can strategically add value to the warnings by responding to specific user needs in innovative ways.

With the evolution and improvements in prediction sciences, the explosion and the availability of data and model products, the use of weather information by downstream users and decision-support systems (e.g. hydrology, health, urban transportation, urban planners, financial markets) is developing and increasing. The weather service providers will need to work in a multi-disciplinary manner from urban to climate scales from mid-latitudes to the Arctic. The current forecast paradigm is in flux and the biggest challenge is to evolve and coordinate the development of the forecast system while it continues to provide weather services for today.

Summary

The three sessions provided a view of the successes of the weather enterprise from a historical, current and future perspectives. The weather enterprise consists of partnerships at three levels of government, academia, the private sector, and increasingly, citizen science/social media.

The Canadian ability to collaborate and compromise has established its place in the world as the “honest and respected broker” to lead, and bridge ideologies to make remarkable and significant contributions internationally. Canadians have been in the leadership of the top meteorological and scientific organizations.

The needs and expectations of Canadians outstrip the operational capabilities and capacities. Advances in technology such as supercomputing, internet, data storage, radars and satellites but also user expectations drive the weather enterprise. Canada is geographically vast and diverse and there are new challenges such as the Arctic, and urban and complex terrain weather services that require an Earth System Prediction

approach from minute to decades in scale that is integrated with downstream decision-support systems. The private sector is critical in the delivery of warnings and weather services.

Canada has always been at the leading edge of designing and implementing weather forecast systems. Canada is one of the few countries in the world where weather, the environment, climate, hydrology, and the cryosphere are within a single government organization and commensurate connections and support from research and academia. Canada's forecast system is highly automated with centralized data archiving and processing, integrated modeling and forecast production. "Big data" and artificial intelligence science and downstream user applications need access to data and data products. The weather enterprise is at a crossroads as new requirements are rapidly emerging. The products and outputs will be complex, including estimates of uncertainty, and generated by chains of processing (e.g. quality control, modeling, post-processing, integrated products, tailored user products) systems. However, producing guidance and answers is not enough. Access to the underlying data and scientific interpretation in a complex decision-making environment will require greater integration and partnership with end users The weather enterprise is rapidly evolving with technology but also with new players entering the landscape. Renewing traditional partnerships, engaging new ones, and clear articulation of a unified vision and a path forward is a grand challenge for all.

Acknowledgements

The workshop was organized by the Meteorological Service of Canada and the Canadian Meteorological and Oceanographic Society. The leadership of Diane Campbell, Assistant Deputy Minister of the MSC and Jim Abraham, President of CMOS are gratefully acknowledged. The participation of The Weather Network/ MétéoMédia, the University of Toronto, the Nova Scotia Emergency Management Office and the Calgary Emergency Management Office are greatly appreciated. We thank all the participants who contributed to the thought provoking discussions and the CMOS technical staff for running the sessions so smoothly.

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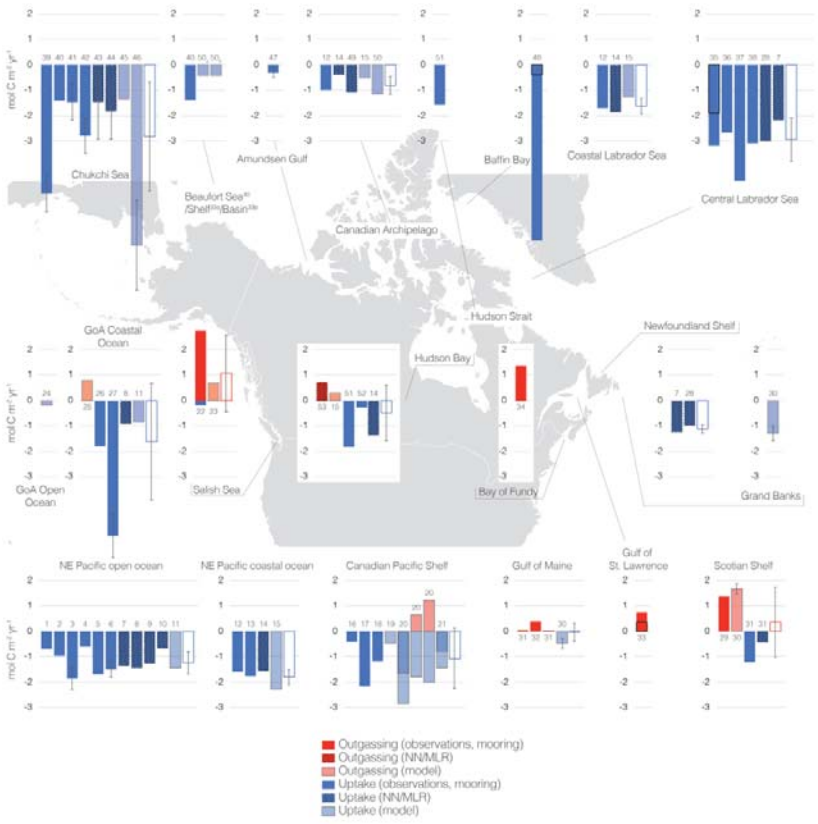
# Uncertainty in Canada’s Marine Carbon Sink

**WRITTEN BY CMOS BULLETIN SCMO ON AUGUST 19, 2023. POSTED IN CLIMATE, OCEANS, WHAT'S CURRENT.**

**– By Patrick Duke –**

Improving our understanding of how the ocean absorbs carbon dioxide is critical to climate change mitigation efforts. Canada’s surrounding waters act as a net sink for atmospheric carbon dioxide. However, given the large heterogeneity and uncertainty attributed to observational and model estimates, challenges exist in informing Canada’s carbon stocktake, establish baselines for marine carbon dioxide removal projects, and supporting efforts to mitigate and adapt to ocean acidification. A new perspectives paper by a group of early career ocean professionals working in Canada, summarizes current research and identifies steps forward to improve understanding of the marine carbon sink in Canadian national and offshore waters. The authors highlight major challenges hindering our ability to quantify a “policymaker relevant” value in terms of grams of carbon dioxide uptake per year, discuss pathways to bridge different ways of knowing in collaborating with First Nations, and present recommendations to improve equity, diversity, and inclusion in ocean carbon science and technology.




Air-sea CO2 flux densities from different estimates in waters around Canada (mol C m-2 yr-1). Negative flux (blue) indicates oceanic sink, positive flux (red) indicates oceanic outgassing. The estimation method is indicated as: direct observations (solid dark bars), observation-based interpolation products such as Neural Network (NN) and Multiple Linear Regression (MLR) (hatched bars), and regional ocean biogeochemical models (solid light
bars).

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Patrick Duke is currently a PhD student studying how the ocean mitigates climate change and is impacted by human emissions. He uses machine learning to create high-resolution regional estimates of air-sea gas exchange of carbon dioxide. Patrick is also a sustainability leader in his community, focused on training people to combat climate change through art, policy, and
innovation.

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# What's in a water sample? Harnessing the power of eDNA analysis for species detections in freshwater ecosystems

**WRITTEN BY CMOS BULLETIN SCMO ON AUGUST 29, 2023. POSTED IN OCEANS, WHAT'S CURRENT.**

**– By Rina Guxholli –**

Long before the world of environmental DNA was introduced to ecologists, forensic biology was already harnessing the power of DNA as a tracer for who, or what, may have been present at a crime scene. Fast forward a few years, and ecologists implemented this strategy in the natural environment (cooler than a crime scene, depending on who you ask).

The use of environmental DNA (or eDNA)-based technology has made enormous strides in the past two decades as a way to detect, quantify, and monitor species living in a variety of environments. Scientists can paint a picture of wildlife that inhabit or inhabited an area based on genetic material left behind from samples like feces, fur, scales, or skin. This monitoring method has been applied to aquatic samples from marine and freshwater environments, soil samples from the land, and even air samples vacuumed through a filter. Through a single environmental sample, a treasure trove of biodiversity data can be captured. But how exactly can we harness the data within an environmental sample?

In the lab, we apply DNA amplification and analysis techniques to pinpoint exactly which species are present in the samples. This process can single out DNA on a species-by-species basis, giving us a robust picture of ecosystem composition. To single out eDNA released from a species, we often use quantitative polymerase chain reaction (qPCR): a powerful technology used for the detection, quantification, and measurement of DNA present in a sample. This tool uses synthetic fragments of DNA nucleotides called assays which are designed to be complementary to the DNA of a species of interest. In the qPCR chemical reaction, assays are combined with the eDNA sample and selectively bind to the DNA of the target species. The qPCR process then amplifies the matching DNA strands millions of times. This amplification is visualized on a computer—if amplification occurs, then the target species was very likely present in the water sample! Assay development requires rigorous analysis of target and non-target genetic sequences: a well-designed assay will exclusively bind to the target species and avoid cross-amplification with co-occurring species.

This is where the work from the Genomic Network for Fish Identification, Stress, and Health (GEN-FISH) comes in. GEN-FISH is a national team of researchers, professionals, and community members working together to determine the location and abundance of Canada’s 200+ freshwater fishes through the power of eDNA. The goal is to develop eDNA assays for all freshwater fish in the country so we can detect any species, from any eDNA water sample, taken from any location in Canada. It’s no easy feat, but incredible steps have been made to develop assays for fishes from multiple regions in Canada.

My work at the University of New Brunswick involved developing eDNA qPCR assays for freshwater and freshwater-dependent fishes in Atlantic Canada, led by Dr. Scott Pavey (UNB). My objective was to develop assays for twenty key freshwater fishes found in the region, so they can be applied widely to eDNA monitoring projects within GENFISH and beyond. To do this, genetic sequences of the twenty target species, as well as hundreds of closely-related and co-occurring fishes were obtained, and the assay development work began. Candidate assays were developed and tested thoroughly—on the computer using specialized genetic sequence analysis software, and in the laboratory using DNA extracted from tissue samples of target and non-target species. After thorough testing, four of the assays were ready to be tested on eDNA water samples taken from Fundy National Park. In partnership with Parks Canada and Dr. Kurt Samways, eDNA sampling was conducted along long stretches of Upper Salmon and Point Wolfe Rivers to monitor and detect Inner Bay of Fundy Atlantic Salmon, Brook Trout, American Eel, and Eastern Blacknose Dace. Our findings were in lockstep with the extensive electrofishing and surveying efforts being done at Fundy National Park—we found strong and clear presence of all four target fishes in both rivers within the Park through qPCR analysis of the eDNA samples.

Our work adds to the rapid and expansive research for eDNA-based technology as a biodiversity monitoring and quantification tool. Further, the twenty target species from our work have broad geographic ranges in North America, spanning outside of Atlantic Canada. The assays we developed and optimized can be used for their detection through eDNA, in many different contexts and applications locally and internationally. qPCR assays are an essential tool used to detect species when conducting eDNA

detection studies. The findings from our study will incentivize continued implementation of eDNA-based monitoring techniques to assess the status of wildlife populations and habitats—empowering scientists and researchers to develop timely and efficient conservation strategies for years to come.

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Rina Guxholli is a Master of Science graduate from the University of New Brunswick. She completed her undergraduate degree at the University of Windsor with an honour's project examining the effects of temperature and abundance on Redside Dace eDNA detection in microcosm settings, which led her to the expansive world of molecular ecology and eDNA research. Presently working as a research assistant with University of Manitoba collaborators, she is expanding her research to focus on conservation of aquatic species all across Canada. Find her at rinaguxholli.ca, @rinaguxholli on Twitter, or rina.guxholli@unb.ca.

# CONCEPTS Science Workshop Report

**WRITTEN BY** CMOS BULLETIN SCMO **ON SEPTEMBER 6, 2023. POSTED IN** CLIMATE, NEWS & EVENTS, OCEANS, WHAT'S CURRENT.

**– By Smith, G.C., P. Pernica, Y. Lu, N. Soontiens, R. Horwitz, F. Dupont, M. Dunphy, Y. LeClainche, I. Gaboury, F. Davidson, C. Bourgault-Brunelle, A. Leroux, A. Holdsworth, D. Lavoie, R. Hourston, D. Schillinger, G. Sutherland, J.-P. Paquin, H. Ritchie –**

## 1. Introduction

The Canadian Operational Network of Coupled Environmental Prediction Systems (CONCEPTS) held a science workshop October 17-27 and November 9-10, 2022. The workshop focused on the following four objectives: 1) the status of CONCEPTS predictions systems and the fit-for-purpose of their products for current CONCEPTS users; 2) the identification of potential areas of improvement in CONCEPTS systems; 3) an assessment of international developments that could be incorporated for use in CONCEPTS systems; and 4) sharing and alignment of research and development plans between CONCEPTS partners. This report provides a brief background on CONCEPTS and a summary of outcomes from the 1.5-day in-person meeting including some areas for potential for future research.

## 2. CONCEPTS Background

Operational oceanography has matured considerably over the last 10 to 15 years. There are now numerous global, regional and coastal prediction systems running operationally across the world’s oceans. These systems are built on sophisticated numerical modelling, data assimilation and production chains to deliver reliable information for a variety of applications.

The potential benefits of an operational ocean forecasting capacity for Government of Canada applications was recognized in the early 2000s and led to the development of a multi-department initiative called CONCEPTS (Smith et al., 2013a). This effort initially involved Fisheries and Oceans Canada (DFO), Environment and Climate Change Canada (ECCC) and the Department of National Defense (DND). It was subsequently expanded to include the Canadian Coast Guard (CCG), the National Research Council (NRC) and the Canadian Space Agency (CSA).

Innovative science has been at the core of CONCEPTS efforts from its onset. The first CONCEPTS system was a ground-breaking effort to develop a two-way coupled atmosphere-ice-ocean forecasting system for the Gulf of St. Lawrence capable of improving operational numerical weather prediction forecasts through interactions across the air-sea interface (Pellerin et al., 2004; Smith et al., 2013b). This initiative was expanded to deliver the first global operational medium-range Numerical Weather Prediction (NWP) system with a 2-way coupled ice-ocean component (Smith et al., 2018).

This was followed by efforts to put in place a high-resolution sea ice forecasting capability to support Canadian responsibilities for METAREAS 17 & 18 as part of the Global Marine Distress and Safety System. This effort led to the development of the Regional Ice Ocean Prediction System (RIOPS; Dupont et al., 2015; Smith et al., 2021) and necessitated several innovations in sea ice analysis (Buehner et al., 2016) and a new parameterisation for landfast ice (Lemieux et al., 2015).

More recently, drift prediction and coastal modelling activities under the first phase of the Oceans Protection Plan (OPP) aimed to address needs for maritime safety and emergency response. This led to the development of ~2-3km grid resolution coastal prediction systems for the east and west Canadian coastlines (Paquin et al., 2023) together with a set of six port models to support needs for ocean prediction in areas of significant navigational risk and high maritime traffic. The development of these port models (Paquin et al., 2020; Dunphy et al., *in prep.*) required applying the Nucleus for European Modelling of the Ocean (NEMO) ocean model (used across other CONCEPTS systems) at extremely high sub-kilometer resolution. This capacity was demonstrated in a comparison with a coastal finite element model (Nudds et al., 2020). The skill of these systems in providing accurate drift estimates (and thus surface currents) was demonstrated by Soontiens et al. (*in prep.*).

Over the past 10 years, CONCEPTS has grown from an initial collaboration between three Canadian government departments interested in the potential benefits of coupled environmental prediction to an important inter-departmental Government of Canada collaboration with four fully-operational coupled atmosphere-ice-ocean prediction systems, global and regional ocean analysis systems, storm-surge and wave systems and port models along with numerous research projects and client systems making use of CONCEPTS innovations. Given the breadth of CONCEPTS applications, both within Government of Canada (e.g. DND, Canadian Hydrographic Service, CCG, Canadian Ice Services) and externally (e.g. Canadian Universities, Industry), there is a need to discuss and align research needs to best make use of available resources and identify gaps to provide the most useful and impactful environmental predictions and products.

3. CONCEPTS Science Workshop

A hybrid science workshop was organized spread over four weeks from Oct. 17 – Nov. 10, 2022. To include the maximum number of participants and minimize costs and environmental impacts, the meeting was split into nine 2-hr virtual sessions followed by a 2-day in-person meeting with a smaller group. The virtual sessions focused on the following topics:

- Overview of current systems with a focus on gaps and user needs
- Enabling service delivery
- Observations
- Biogeochemical prediction systems
- Drift observations and applications
- Future research and development plans
- Air-sea interactions
- Key innovations from beyond CONCEPTS

The virtual sessions included over 60 participants from ECCC, DFO, NRC, and CCG as well as from several Canadian Universities. There were also several international participants from Denmark and France. A number of key priority areas for further discussion were raised during the virtual session presentations and discussions. These areas were elaborated during the in-person meeting as mentioned below.

A final virtual session was held to summarize the previous sessions, identify gaps and areas for research and development coordination, and assist in planning the in-person meeting. It was noted by various participants how extensive and complex the various CONCEPTS research and development activities have become. The need for more active scientific exchanges was clearly highlighted by the fact that most of the virtual sessions had difficulty covering their topic within the 2hr timeslot.

The second part of this session used an online application (mentimeter.com) to get feedback from participants that highlighted the various sessions were well appreciated, in particular the overview, observations, future plans and key innovations sessions. The question “What is the most important topic or area that CONCEPTS needs to focus on?” yielded a number of differing responses (Fig. 1), with product-related aspects showing up most frequently (validation, dissemination and uncertainty). The main objectives for the CONCEPTS products and services were identified as enhancing the documentation of products, facilitating cross-projects coordination in product generation as well as validating data access and format. The main challenges ad gaps for services appeared to be the development of partnerships, improvement of data discoverability, access to data near the coast, accessing archived data and managing the growing volume and diversity of data.


Figure 1: Feedback from CONCEPTS Science Workshop participants using mentimeter.com. Online participants were asked the following question “What is the most important topic or area that CONCEPTS needs to focus on?”.

Following the virtual sessions, more in-depth discussions were held on Nov. 9 and 10 in a smaller in-person meeting at the Canadian Centre for Meteorological and Environmental Prediction (CCMEP) in Dorval. Based on outcomes from the virtual meeting, it was decided to focus on four specific topics: nearshore predictions, coordination on NEMOv4, observations and hindcasts/reanalysis.

4. Summary and CONCEPTS science challenges going forward

It is difficult to summarize a meeting that covered so many different scientific areas, with rich informative discussions in each. That being said, there are several key areas that surfaced on several occasions in different sessions and have a significant potential impact and thus warrant highlighting here. The four key areas are nearshore predictions, small-scale processes at the air-sea interface, uncertainty estimation, and historical variability:

- Nearshore predictions were mentioned frequently in several sessions as a user need for e-navigation (i.e., port model application) but also more broadly for Emergency response and Search and Rescue needs for numerical support.

- Another key area for CONCEPTS future science efforts is improvements in small-scale processes at the air-sea interface. For example, ocean colour and sediment concentrations are found to affect penetration of shortwave radiation thereby affecting surface ocean heat content, stratification and near-surface shear (and thus surface drift).
- A common theme arising throughout the meeting was the use of CONCEPTS products and how to convey error to user groups. While system developers have knowledge regarding strength of different systems, it is not clear how to share this information with users. Development of new quantitative methods to address this has begun. The assessment of intrinsic variability and the use of ensembles to sample uncertainty are seen as two potential first steps. Estimates of systematic errors due to resolution and model physics are also needed. A dedicated effort in this area is required to produce a product to communicate reliability to users.
- In recent years CONCEPTS has been focused on providing near-real time analyses and forecasts of ocean conditions. As these systems and user needs evolve, it is now clear that we need historical simulations (hindcasts and reanalyses) to provide context for current anomalies. This could provide a better understanding of impacts of extreme events and would have lasting long-term benefits for CONCEPTS and the Canadian and international scientific community.

In addition, there are a plethora of important scientific and technical points that were raised and for which ongoing collaboration and coordination activities are being discussed. In particular, a number of areas of CONCEPTS activity were noted that could not be fully explored during the limited time available for the workshop and which would benefit from further discussion, including (but not limited to) sea-ice, data assimilation, biogeochemical modelling applications, management and availability of observational data, and development and dissemination of CONCEPTS products. Regularly occurring, smaller-scale science workshops may be beneficial to continue to advance these and additional science
topics.

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Gregory Smith is a senior research scientist with Environment and Climate Change Canada (ECCC) based in Dorval QC. Greg leads a large research group in ECCC and is co-lead of the CONCEPTS Prediction Systems Working
Group.

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# The Man Who Awoke

**WRITTEN BY** CMOS BULLETIN SCMO **ON SEPTEMBER 14, 2023. POSTED IN** CLIMATE, WHAT'S CURRENT**.**

**– Review by Kevin Hamilton –**

By Laurence Manning, originally published in 1933 in the magazine Wonder Stories; reprinted in 1975 in paperback by Ballentine Books 168 pp. ISBN 345-24367-6-150.

I am taking the occasion of the 90th anniversary of its initial publication to raise awareness of the science fiction novel “The Man Who Awoke” by Canadian author Laurence Manning (1899-1972) at what is now a particularly appropriate cultural moment. (Note that this review considerably expands and adapts an earlier article intended for the general public that I recently published on https://theacademic.com/).

Laurence Manning (1899-1972)

## A Half-Century Lost in the Battle Against Climate Change?

I discovered Manning's novel in the course of my research into a much broader issue, namely why the rather sensational turn-of-the-20th century prediction by Svante Arrehenius of strong climate warming expected from continued burning of fossil fuels had such an extraordinarily muted penetration into the general culture for well over half a century. The lack of interest among the public and among governments in possible anthropogenic climate change occurred despite the fact that Arrhenius was a world renowned scientist and his prediction was included in his book intended for the general public "Worlds in the Making" (an English translation was published by a major international publisher in 1908).

With hindsight we can see that an opportunity was missed for humanity to seriously assess the practical implications of global warming, and then to take some appropriate mitigating actions. As today we face the need for extremely urgent action to avoid looming catastrophes it is reasonable to lament this "lost half-century" in the battle to control global warming.

A possible pathway for initial penetration of scientific ideas into the mainstream is via science fiction. An expert on the history of science fiction, Sherryl Vint, has recently published a survey of stories featuring the modern scientific notion of anthropogenic climate change. Interestingly Vint found no directly relevant examples published until the later decades of the 20th century and she even remarks that "the shift from pollution to climate change as the main engine of dystopian futures [in literature] doesn't firmly take hold until the 21st century".

As I will argue here, Manning's "Man Who Awoke" (which is not mentioned by Vint) represents an interesting datum in documenting the lack of general awareness of anthropogenic greenhouse warming in the early 20th century. Manning's book also has a wider interest for the present day reader as its descriptions of several speculative futures for human society have turned out to be remarkably prescient. With the recent release of chatGPT, artificial intelligence has now joined human genetic modification, virtual reality, climate change and the related challenges of sustainability as potentially disruptive issues currently receiving great public attention. I will show here that Manning's novel quite remarkably anticipated each of these concerns that help define our current anxious cultural moment.

## A Novel of Time Travel

In “The Man Who Awoke” the author adopts a plot involving a “time traveller”, a conceit used as early as 1895 by H.G. Wells in his famous novel “The Time Machine”. As other authors would do, Manning uses this plot device to explore possible future developments in human society. Rather than relying on the utterly fantastical “time machine” dreamt up by Wells, Manning was at pains to describe a more plausible way for a 20th century man to experience life in the distant future. Specifically he imagined his hero, Norman Winters, as a rich man who devises a scheme to lie in a secret underground chamber on his Long Island, New York estate, in a drug-induced hibernation state. Winters succeeds in waking up to experience brief periods of life outside his chamber in the years AD 5000, 10000, 15000, 20000 and 25000, each waking episode presenting an opportunity for the author to explore a different aspect of humankind’s possible future.

## A Completely Sustainable World

At AD 5000 Winters finds a world covered in thick forests from which much of the infrastructure of the 20th century, including New York City, has vanished. Fortunately a stable and reasonably prosperous human society still exists, although Winters learns that civilization had to be rebuilt after a total collapse. At roughly AD 2500 humanity had reached “the height of the false civilization of Waste! Fossil plants were ruthlessly burned in furnaces to provide heat; petroleum was consumed by the billion barrels; cheap metal cars were built and thrown away to rust after a few years’ use..”. The new civilization that had subsequently arisen was keenly focused on sustainability. Most of the population was accommodated in villages of about 1000 people and each depended on the extensive local forests for food (e.g. chestnut flour, mushrooms cultivated on felled logs) and other resources. There were also some factory villages located near a notable renewable energy source – the Niagara Falls hydroelectric dam. Transportation was achieved by “flying wheels” which apparently resemble the kind of vertical takeoff “drone aircraft” that have become familiar in recent years in the real world.

The dominant organizing principle of the civilization was an obsessive commitment to preserving the total amount of the forest, thus maintaining a completely sustainable society. Manning even addresses the issue of how the flying wheels would be powered sustainably with forest resources, anticipating the current real world concern of how commercial aviation could avoid the use of fossil fuel and be carbon neutral. Manning’s solution of using wood alcohol as the fuel even anticipates current proposals to power aircraft with biofuels.

In 1974 the notable writer Isaac Asimov, in his history of early science fiction literature “Before the “Golden Age”, wrote about this aspect of Manning’s novel: “[Now] everyone is aware of […] the energy crisis. Manning was aware of it forty years ago. […] literature had the youngsters who read it concerned about the consequences of the waste of fossil

fuels forty years before the self-styled normal and sensible human beings felt it necessary to become interested."

The society Manning describes at AD 5000 maintains a perfectly sustainable carbon budget. However, Manning does not mention the implications for the atmosphere and climate stability, an omission that will seem amazing to a present day reader. It seems likely that Manning simply was unaware of the issues that had been raised by Arrhenius a quarter century earlier. Interestingly, a later chapter in the book shows that Manning *was* aware of long period global climate change related to natural glacial cycles (see below).

Laurence Manning was born in St. John, New Brunswick and studied at King's College in Halifax where in 1919 he received a Bachelor of Civil Law degree. It seems he may never have worked as a lawyer but began a writing career as a journalist on a local newspaper, later moving to New York City where he found employment in horticulture as a manager of a nursery. In the mid-1920's he wrote some articles for gardening magazines but in 1927 began submitting stories to science fiction magazines. Manning was not a professional scientist but seems to have had exceptionally strong scientific interests. In his own novel he made an effort to propose scientifically plausible descriptions of future technological breakthroughs. He also was a pioneer in amateur rocketry as a founding member of the Interplanetary Society in 1930 (renamed in 1934 as the American Rocket Society) and he later served as the society's president. That a sophisticated person such as Manning was apparently ignorant of the potential threat of anthropogenic global warming in 1933 is a telling (if anecdotal) observation documenting the limited cultural penetration of the global warming issue at the time.

As an aside, Manning also anticipated later developments in Japanese archeology! Specifically Manning's notion that managed chestnut forests could provide the staple food source for a civilization has a striking parallel in an aspect of modern archeological thinking about the Jomon people who lived circa 14000-300 BCE in Stone Age (and preagricultural) Japan. Starting in the 1950's archeologists have speculated that the Jomon supported a surprisingly sophisticated society by supplementing hunting/gathering with food from extensive managed chestnut forests.

A World Ruled by Artificial Intelligence

In the next chapter of "The Man Who Awoke" Winters emerges from his chamber again in AD 10000 and finds a remarkably changed world. The beautifully maintained forest had become an overgrown wilderness. People now lived in a great city run by The Brain, a giant electrically powered computer that apparently had achieved some kind of consciousness and actually had become an object of human worship. Thanks to The

Brain, a technologically sophisticated society had developed that allowed people to live lives mainly devoted to self-indulgence. Winters asks one man about "..the more serious minded men ..scientists, planners…where are they?" and receives a reply "This is the city of The Brain! How should mere men hope to better His work? He is infallible – we are full of human weaknesses and frailties".

It seems this quote could practically be from an account of the promise and perils of today's developments in artificial intelligence. Even the contrast between the hypothetical infallibility of the mechanical brain and the frailty of humans has an echo in the expectation that self-driving cars will be much safer than cars driven by imperfect humans. The recent release of programs such as ChatGPT have fueled fears of increased reliance on the judgements of opaque artificial intelligence algorithms.

Winters, as an outsider, appreciates the danger of the reliance on The Brain and perceives its effective tyranny as a grave threat to humanity. He is able to convince a few people to join him in a scheme that destroys The Brain and liberates society. Winters becomes famous worldwide for his revolution, but decides that he will secretly return to his underground chamber and arrange to emerge again in the year AD 15000.

A World Seduced by Virtual Reality

In this next world Winters finds a much warmer climate compared with the 20th century, a change accompanied by a 30 foot sea level rise and a very disrupted distribution of plants and animals. He attributes this to a continued (presumably natural) retreat from ice age conditions. More dramatically he finds a world with people concentrated in cities and that the vast majority of humans have opted to live their lives in "dream palaces". In a dream palace a person's body becomes nearly inert and his brain is operated on so that nerve endings are connected to a machine that can supply artificial stimulation. The technology has become so evolved that a person opting for the operation can arrange in advance for an entire lifetime of scripted stimulation allowing him to experience the kind of life he prefers: "..as far as the dreamer is concerned he seems to living a complete life. Before he enters he determines what things he wishes to experience. Some […] fight wild beasts in the wilderness; […]; others make trips in rocket ships to Mars or Venus and experience incredible adventures." One young person wished "to dream a life of ease and homely comfort with occasional adventures and dangers that are so arranged as to end happily."

The attraction of the dreaming life is so strong that only a tiny portion of society opts to live real lives and this small minority keep the cities and the dream palaces operating. Winters sees that continuing along this path would mean the extinction of humanity – already 7 months had passed since the last birth in a city of a million people. Again

Winters organizes a kind of revolution and leads a small remnant to escape the city and found a new village that provides hope for the future – while the cities along with all their dreamers must unavoidably die out.

Manning's idea of a dream world fed directly into human brains, bypassing the usual organs of sensation, would later have a clear parallel in the world imagined in Hollywood's 1999 movie "The Matrix". Of course, today we are still far from the technological capacity imagined in Manning's dream palaces or in "The Matrix", but the idea of an immersive world experience directed into our consciousness mediated by sophisticated technology is echoed in today's already extant "virtual reality" technology and the notion of a vast "metaverse" to be "inhabited" by humanity. In just the last few years the notion of a metaverse has had a strong public profile as a large investment has been made by a major company. Manning also anticipated our present day concerns with human brain implants to facilitate a direct machine-brain interface.

## A World of Near-Immortality Via Biotechnology

The novel's final chapter begins with Winters emerging from hibernation in AD 25000 and provides yet another example of Manning's anticipation of current technological developments and related philosophical concerns. Manning imagines that technology then is able to manipulate life on a cellular level to create cultures of what we would today call stem cells for each of a supposed 270 types of cells in a human body. Then scientists could "insert in its proper place in [the body] a small particle of each of the 270 types of cellular tissue. Nature [does] the rest and [the] entire body is [then] made up of new fresh, vigorous cells." By repeating this procedure over and over again an enormous extension of life span can be achieved. The novel concludes with Winters musings on the social and psychological implications of physical near immortality.

Of course in 1933 Manning could not know about the workings of cells on the molecular level and specifically the mechanisms of heredity, but his vision suggested that science would eventually be able to manipulate life at the cellular level with profound consequences for life expectancy. In fact, after only 90 years in the real world we have made remarkable progress in this regard, with tools for genetic manipulation, the discovery and culturing of stem cells and the beginnings of stem cell therapies. A current experimental regenerative medicine procedure to replace a patient's blood vessels with tubes grown from the patients' own cell lines seems like it could have come directly from Manning's novel.

## Manning's Remarkable Foreshadowing of Today's Concerns

The late 1920's and early 1930's marked the beginning of cheap mass-market (or "pulp") magazines devoted entirely to stories about science fiction and fantasy. Hundreds of science fiction stories were published each year by magazines in the US alone. Out of all the stories published in this period, Laurence Manning's "The Man Who Awoke" stands out for its imaginative anticipation of several spectacular real world developments that have played out in subsequent decades. Manning's singular vision presaged our current cultural moment in remarkable fashion and deserves rediscovery and commemoration on this 90th anniversary
year.

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# Verification of Summer 2022 Canadian Temperature Forecasts from Four Different Organizations

**WRITTEN BY** CMOS BULLETIN SCMO **ON SEPTEMBER 17, 2023. POSTED IN** ATMOSPHERE, CLIMATE, WEATHER, WHAT'S CURRENT.

**– By George Isaac –**

Introduction

The Canadian Public has access to weather forecasts from many diverse sources. However, it is difficult for the user to know the accuracy of such forecasts, or which is superior. To illustrate the need and difficulties of such a forecast verification, a study was performed to look at summer daily maximum temperature forecasts produced by Environment and Climate Change Canada (ECCC), MSN Weather (Microsoft), Weather Underground, and the Weather Network. Locations across Canada were selected for the study which included: Halifax, Montreal, Toronto, Barrie, Calgary, and Vancouver. Barrie was selected because it was near the author's residence, and the others were selected because they were major cities near airports with good observation sites. The maximum temperature was selected as the variable because it is forecast and observed. Other variables such as minimum temperature, rainfall, cloud cover, dewpoint, or relative humidity, all have difficulties associated with them in terms of verification. For example, daily rainfall amounts are not forecast by some providers, at least in terms of the availability on public sites.

It is difficult to find papers that compare different forecasts for cities or points in Canada. Stuart et al. (1983) did a study emphasizing the city of Toronto and showed that maximum temperature forecasts did not improve over the period 1960-1979. Isaac et al. (2014a, 2014b) did studies for Vancouver and Toronto International airports, as well as sites for the Vancouver Olympics, but did not compare public forecasts. These studies showed how statistical significance tests can be used in forecast verification, but such robust tests were not used here, as will be briefly explained later.

All the observations were from the ECCC corresponding sites on their Webpages. For the summer period being analyzed, there being very few unusual temperature trends, the maximum temperatures occurred during the daytime. An attempt was made to verify

the mimimum temperature, but forecast providers forecast the “tonight” temperature and it is not clear this means the minimum temperature.

For the forecasts between 22 June to 23 September 2022, the morning forecasts of that day were copied into a spreadsheet. ECCC only produces on their public site, forecasts for 7 days, while the others tend to emphasize 10 days or more. For Microsoft, Weather Underground, and the Weather Network, only forecasts to Day 10 were used.

For the ECCC public forecasts, their in-house numerical weather prediction models are used. Microsoft, Weather Underground, and the Weather Network use a variety of weather models and proprietary software. Weather forecasting is becoming “big business.” For example, Weather Underground is owned by IBM. However, how forecasts are produced, and how they are quality controlled is unknown to the normal user. Considering the importance of accurate forecasts, this increases the need for independent verification of their products.

## Does the Forecast Site Represent the Observation Site

Often forecasts are produced for locations like Toronto and Vancouver where there are substantial variations in terrain, with nearby large bodies of water. The forecast providers do not indicate the exact location for which they are forecasting. One way to check if the airports are suitable sites for verification is to determine the forecast bias, or in this case the median difference between the forecast and observed maximum temperatures. Ideally this value should be 0oC at least for Day 1 and Day 2. Table 1 shows the median differences between observed and forecast temperatures for the Day 1 to Day 10 forecast. Day 1 indicates the morning of that same day. For Day 1 and Day 2, the differences are below 1oC for Montreal, Barrie, and Calgary. For the ECCC forecasts, the differences are less than 1oC for all locations in Day 1 and Day 2. However, for the Microsoft, Weather Underground and Weather Network, there are indications that the observation site at some locations (Halifax, Toronto, and Vancouver) may not correspond to the forecast site. This will be discussed further. Table 1 also shows that the maximum temperature median difference values are generally within 1oC for all forecast providers for Montreal, Barrie, and Calgary for Day 1 to Day 10.

| | | Halifax | Montreal | Toronto | Barrie | Calgary | Vancouver |
|---|---|---|---|---|---|---|---|
| | Median Temperature | 24.0 | 25.1 | 26.7 | 23.7 | 24.5 | 21.7 |
| Day 1 | Median Difference ECCC Forecast | 0.3 | 0.1 | -0.5 | 0.1 | -0.3 | 0.2 |
| | Median Difference Microsoft Forecast | -1.5 | -0.6 | -1.6 | -0.5 | -0.6 | 0.5 |
| | Median Difference Weather Underground Forecast | -0.5 | -0.3 | -2.6 | 0.6 | 0.2 | 1.5 |
| | Median Difference Weather Network Forecast | – | – | – | – | – | – |
| Day 2 | Median Difference ECCC Forecast | 0.2 | 0.0 | -0.3 | 0.1 | -0.4 | 0.4 |
| | Median Difference Microsoft Forecast | -1.4 | -0.3 | -1.7 | -0.4 | -0.8 | 0.6 |
| | Median Difference Weather Underground Forecast | -0.1 | -0.4 | -2.7 | 0.4 | 0.3 | 1.7 |
| | Median Difference Weather Network Forecast | -0.8 | -0.3 | -0.9 | 0.4 | -0.5 | 0.4 |
| Day 3 | Median Difference ECCC Forecast | 0.1 | 0.1 | -0.7 | -0.1 | -0.8 | 0.1 |
| | Median Difference Microsoft Forecast | -1.6 | -0.3 | -1.4 | -0.4 | -0.9 | 0.6 |
| | Median Difference Weather Underground Forecast | -0.1 | -0.6 | -2.7 | 0.5 | 0.1 | 1.6 |
| | Median Difference Weather Network Forecast | -0.6 | -0.3 | -0.9 | 0.6 | -0.8 | 0.5 |
| Day 4 | Median Difference ECCC Forecast | -0.2 | -0.2 | -1.0 | 0.0 | -0.7 | 0.2 |
| | Median Difference Microsoft Forecast | -1.4 | -0.8 | -1.2 | -0.8 | -0.8 | 0.6 |
| | Median Difference Weather Underground Forecast | -0.4 | -0.6 | -2.4 | 0.3 | -0.1 | 1.5 |
| | Median Difference Weather Network Forecast | -0.7 | -0.4 | -1.3 | 0.3 | -0.8 | 0.4 |
| Day 5 | Median Difference ECCC Forecast | -0.7 | -0.1 | -0.9 | 0.4 | -1.0 | 0.3 |
| | Median Difference Microsoft Forecast | -1.0 | -0.3 | -1.6 | -0.8 | -0.1 | 0.3 |
| | Median Difference Weather Underground Forecast | -0.3 | -0.4 | -2.3 | 0.4 | 0.0 | 1.4 |
| | Median Difference Weather Network Forecast | -0.6 | -0.2 | -1.0 | 0.4 | -0.5 | 0.5 |
| Day 6 | Median Difference ECCC Forecast | -1.0 | 0.6 | -1.0 | 0.7 | -0.7 | -0.2 |
| | Median Difference Microsoft Forecast | -1.3 | -0.3 | -1.5 | -0.5 | -0.8 | 0.2 |
| | Median Difference Weather Underground Forecast | 0.2 | -0.6 | -1.2 | 0.8 | -0.4 | 1.2 |
| | Median Difference Weather Network Forecast | -0.4 | -0.5 | -0.8 | 0.7 | -0.7 | 0.1 |
| Day 7 | Median Difference ECCC Forecast | -1.1 | 0.6 | -0.8 | 0.4 | -0.7 | -0.2 |
| | Median Difference Microsoft Forecast | -1.3 | -0.3 | -1.6 | -0.6 | -0.8 | 0.3 |
| | Median Difference Weather Underground Forecast | -0.3 | -0.6 | -2.2 | 0.4 | -0.7 | 1.2 |
| | Median Difference Weather Network Forecast | -1.3 | -0.6 | -1.2 | 0.5 | -0.8 | -0.3 |
| Day 8 | Median Difference ECCC Forecast | – | – | – | – | – | – |
| | Median Difference Microsoft Forecast | -1.4 | -0.6 | -2.6 | 0.3 | -0.1 | 0.3 |
| | Median Difference Weather Underground Forecast | -0.7 | -0.8 | -3.5 | 0.7 | -0.1 | 1.2 |
| | Median Difference Weather Network Forecast | -1.7 | -0.8 | -2.8 | 0.7 | -0.5 | 0.0 |
| Day 9 | Median Difference ECCC Forecast | – | – | – | – | – | – |
| | Median Difference Microsoft Forecast | -1.2 | -0.5 | -0.9 | -0.1 | -0.6 | 0.4 |
| | Median Difference Weather Underground Forecast | -0.7 | -0.8 | -2.0 | 0.3 | -0.9 | 1.2 |
| | Median Difference Weather Network Forecast | -2.1 | -1.0 | -1.0 | 0.3 | -1.1 | -0.6 |
| Day 10 | Median Difference ECCC Forecast | – | – | – | – | – | – |
| | Median Difference Microsoft Forecast | -1.6 | 0.1 | 0.2 | 0.5 | -0.8 | -0.5 |
| | Median Difference Weather Underground Forecast | -0.3 | -0.6 | -1.5 | 1.0 | -0.8 | 1.1 |
| | Median Difference Weather Network Forecast | -1.7 | -0.7 | -1.2 | 0.4 | -1.5 | -1.2 |

Table 1: Median Difference in Temperature (Forecast-Actual) for Day 1 to Day 10.

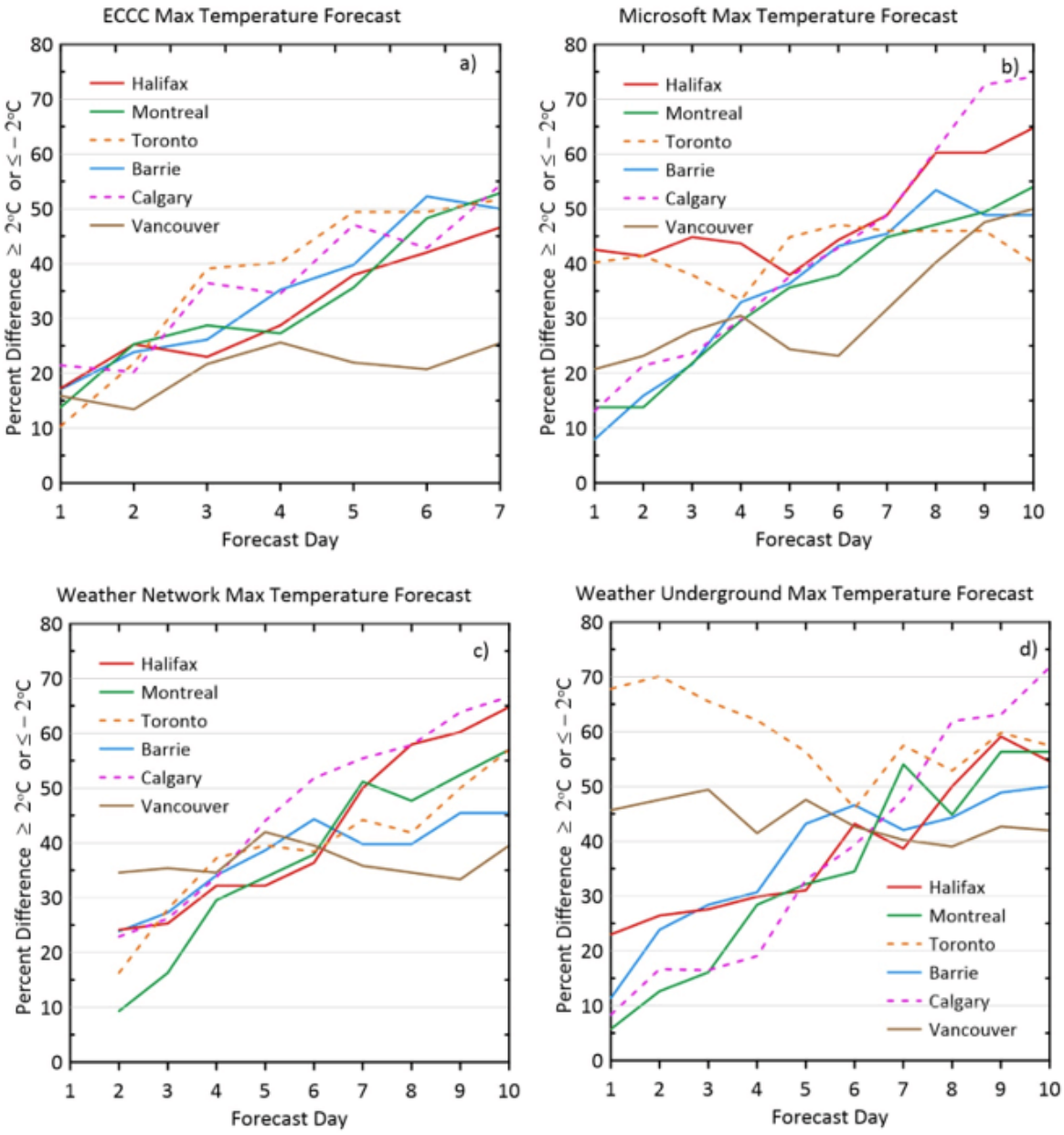


Figure 1: The percentage of forecasts with maximum daily temperature differences between forecast and observed values falling outside of +2oC or -2oC. Weather information providers include a) Environment and Climate Change Canada (ECCC), b) Microsoft, c) Weather Network, and d) Weather Underground.

“Accuracy” of the Maximum Temperature Forecast

For this discussion, the accuracy of the forecast is described as the percentage of forecasts with differences between forecast and observations greater than plus or minus a specified number. This is an easy-to-understand parameter. For this analysis,

forecasts with errors greater than 3oC are considered poor while those within 2oC are quite acceptable. Figure 1 shows the percentage of ECCC, Microsoft, Weather Network and Weather Underground forecasts greater than 2oC of the observations at the corresponding airport observation site. Figure 3 shows the same but for forecasts beyond 3oC of the observations.

Generally, the percentage of forecasts outside of a difference of 2oC or 3oC increases with forecast lead time. For the four forecast providers, at Forecast Day 7, the percentage with errors greater than 2oC, is about 40-50%. However, for ECCC for Vancouver, that error is closer to 25% at Day 7. Some locations and providers have unusually high errors for Day 1 to Day 3 forecasts, for example Halifax and Toronto (2oC only) for Microsoft, and Vancouver and Toronto for Weather Underground. This suggests that the models for those locations may not be forecasting for the airport observation site. If temperature forecasts with errors less than 2oC are acceptable, then the forecast providers are providing useful forecasts even at Day 10 where most forecasts are within that range (Figure 2).

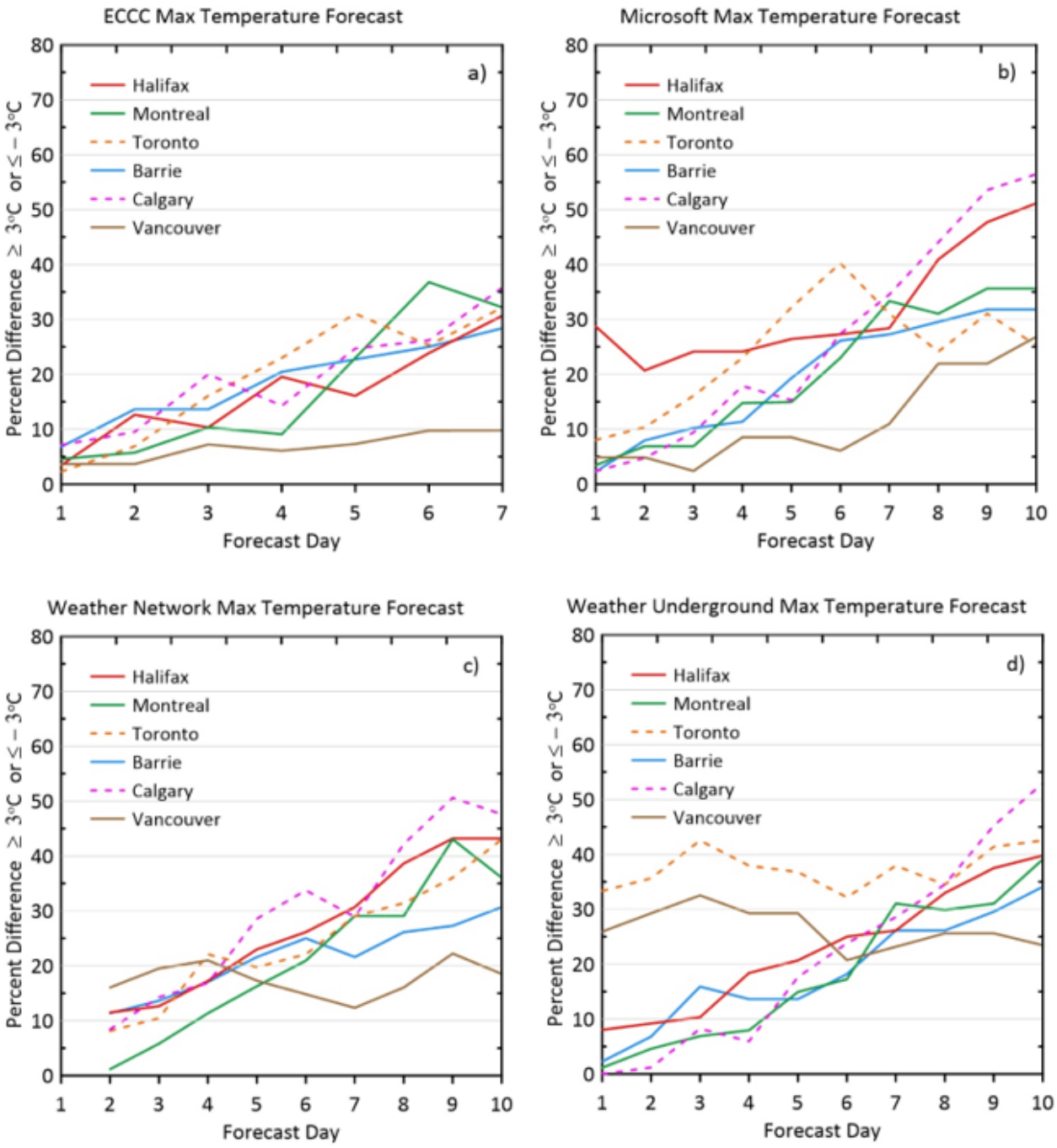


Figure 2: The percentage of forecasts with maximum daily temperature differences between forecast and observed values falling outside of +3oC or -3oC. Weather information providers include a) Environment and Climate Change Canada (ECCC), b) Microsoft, c) Weather Network, and d) Weather Underground.

Summary

It should be stated that this study represents only one summer season for one year. As such it is a limited sample. It would be difficult to indicate that one forecast provider is better than another. This is especially true since only temperature is being considered, not relative humidity, precipitation, and winds which can be considered the other primary forecast variables. Another caution is that forecast providers are constantly improving their products, so what happened in 2022 cannot be easily transferred to future years. However, the study is relatively unique in that it examines four different public forecast providers in the same manner. As mentioned previously, differences were not statistically evaluated for their significance. This is a small data set and hopefully any differences will be interpreted with that in mind. Despite the above reservations, the following conclusions can be stated.

1. The forecasts from the four providers are reasonably similar and provide useful information out to 7-10 days. This is best illustrated in Fig. 3 which looks at Montreal and Calgary which seem to be forecasting for the airport location. Shown are the differences between forecast and observations greater than plus or minus 2oC and 4o It would have been interesting to examine forecasts made out to longer periods, such as 14 days, but that is left for future studies.
2. The maximum temperature forecast errors generally increase with forecast lead time, which is logical.
3. The forecast providers do not explain how they produce the forecasts or indicate levels of expected accuracy. Although, there is obviously a need to keep intellectual property secure, the user would benefit by some explanations, such as the resolution of the models used.
4. The exact location for the forecast is not given. Numerical weather prediction models are now running at resolutions of several kilometers, so simply indicating one value for a large city like Toronto is potentially giving misleading information.
5. Users will have their own favourite forecast providers. Indeed, there is a wide range of presentations of the information which will appeal to different users. However, given the differences between forecast providers, users should probably get information from several sources rather than rely specifically on one.
6. The ECCC weather warnings are copied by the other providers such as Microsoft, Weather Network, and Weather Underground. Although not stated, this could be to avoid possible legal actions for poor forecasts, or to make sure that users are aware of existing government alerts. However, there are times when the other forecast providers will not agree with the ECCC forecasts. It is not known how, or indeed if, this is managed when alerts or warnings are involved.

Studies such as this could benefit developers of improved forecasting techniques. It is assumed all of the forecast providers do their own verification studies, but they are generally hard to find, and are not done by independent groups. Independent reviews are available for almost all products including cars, food, insurance, medications,

appliances, computers, software, etc. Given the importance of weather information, more independent intercomparison studies should be done. Hopefully, this article will provide motivation for future work. Finally, this study shows that forecasts of maximum temperatures are not exact, and any user must evaluate what that means to them.

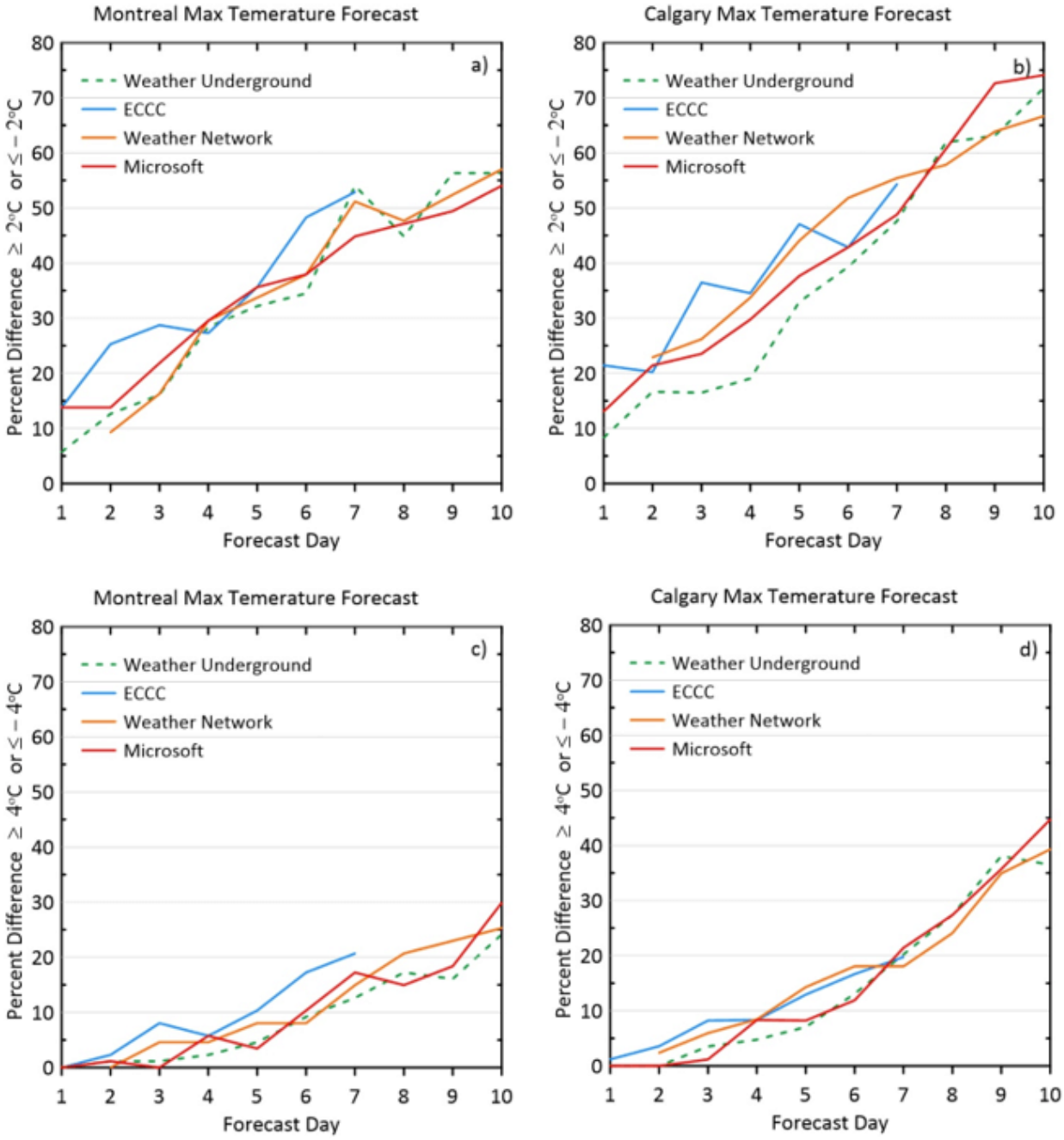


Figure 3: A comparison of the weather information providers for maximum temperature forecasts for Montreal and Calgary using the differences falling outside the range +2oC or -2oC (a and b) and +4oC or -4oC (c and d).

Acknowledgements

Environment and Climate Change Canada (ECCC), MSN Weather (Microsoft), Weather Underground, and the Weather Network, who provided public weather information for this study, are gratefully acknowledged. They provide a community service which is invaluable. Weather Impacts Consulting funded this study out of their resources. No financial or other types of assistance was provided by any of the four weather information providers. The data used in this study can be obtained, without restrictions, by corresponding with the
author.

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George Isaac retired in 2013 as a Senior Scientist from ECCC after 40+ years of service. He formed a small company, Weather Impacts Consulting, and has continued doing research. He is also active as an Adjunct Professor at York University and Dalhousie University with their Atmospheric Science groups. Current projects include studying aircraft in-flight icing, better methods for using weather radar data, fog/visibility forecasting, impacts of clouds on climate, and methods to improve weather forecasting in general.

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# The Great Smoke Pall of 1950 and Other "Dark Days" that have Blanketed Eastern North America

**WRITTEN BY** CMOS BULLETIN SCMO **ON SEPTEMBER 24, 2023. POSTED IN** AIR QUALITY, ATMOSPHERE, CLIMATE, NEWS & EVENTS, WEATHER, WHAT'S CURRENT.

**– By Kevin Hamilton –**

The extraordinary 2023 Canadian wildfire season has been in the public eye for much of this spring, but during June 7-8 the event entered a new phase of global media attention as extremely smoky conditions were experienced in the major population centers in the eastern US. On June 7 a headline in the *Washington Post* read "It looks like Mars outside: Smoke engulfs East Coast, upending daily life." Then on June 8 among the many smoke-related headlines in the *Washington Post* were: "The East Coast can't breathe – and more wildfires are coming" and "On the East Coast, residents don masks, cancel outdoor activities", and in the *New York Times*: "Wildfires spread smoke, and anxiety, across Canada to the US".

The weather in the month of May in western Canada was dominated by a persistent heat dome leading to favorable conditions for the initiation and spread of wildfires. According to Dave Phillips of Environment Canada "in western Canada, this May was the warmest and driest on record" (see also this summary of May 2023 mean conditions). Then, according to Owens (2023), the proximate cause of extreme smoke conditions on June 7-8 in the eastern US was "a large low-pressure system […] sitting over Maine for several days. The system […] block[ed] transport of the smoke to the east, while the system's counter-clockwise winds […] act like a conveyor belt, dragging the smoke south to the eastern seaboard".

An Unprecedented event?

There have been claims in the media and by government officials, including New York City Mayor Eric Adams, that the effects in the eastern US were "unprecedented". The word unprecedented indeed was used in the headlines of several media stories at the time.

A relevant new scientific result was quickly produced to characterize the health effects of the wildfire pollution in the June 7-8 period. The Environmental Change and Human Outcomes group at Stanford University computes a 10 km resolution daily gridded

analysis of a standard measure of air quality due to particulates (specifically PM2.5) from wildfire smoke over the contiguous US. Convoluting this analysis for individual times with a high resolution map of population density in the US produces an estimate of the integrated effect of wildfire smoke on human health in the US. By the morning of June 10, the Stanford group published their results on Twitter showing that June 7th (8th) was the worst day (second worst day) on record. This detailed result supports the notion that the June event in the US was unprecedented, but their analysis was limited to after 2005 because it relies on a NOAA smoke plume product which is only available starting in 2006.

While the degree of widespread smokey conditions over eastern North America seen now in early June 2023 is unprecedented in most people's memory, without longer records of detailed observations across the country it is difficult to know precisely how the extraordinary conditions in June 2023 compare with past events.

## Famous "Dark Days" in Eastern North America

History actually records very occasional eastern North American "dark days" in the 18th, 19th and 20th centuries that clearly made great impressions on the populace at the time. Two memorable 19th century events notable for their widespread extent in Ontario and Quebec, as well as throughout New England, occurred on November 8, 1819 and September 5, 1881. Contemporary reports suggest that the daytime darkness in some locations was severe enough to be compared to night and led to candles being lit. These events have been described in articles published long ago in the now-defunct CMOS magazine *Chinook* by Scott Somerville and by the present author. A feature of the reports of these events that appeared in the newspapers of the time is the degree of anxiety that much of the populace felt, with concerns that the sky conditions were a prelude to "the end of the world". In these cases the source of the sky-filling smoke was presumably wild fires in some remote western regions of North America, but there was a lack of actual knowledge of the fires. The mysterious nature and unexpected arrival of the sky phenomena likely fed the anxious concerns of the populace during these "dark days".

## The Great Smoke Pall of 1950

In the 20th century it seems the closest analogue of the recent wildfire smoke pall event occurred in late September 1950 when nearly the entirety of eastern North America experienced "dark days" resulting from wildfires in western Canada. A review of that event, referred to as "the great smoke pall of 1950", provides some context for the remarkable conditions observed in early June 2023.

In the *New York Times* the first reference to the 1950 smoke pall was in a front page story on September 25 headlined “Forest fires cast pall on Northeast: Canadian drift 600 miles long darkens wide areas and arouses ‘atom’ fears”. According to the story a:

“… blanket of smoke from smoldering Canadian fires cast an awesome pall over parts of the Northeastern United States yesterday, causing consternation in countess communities as day turned into night. The smoke blanket, which plunged New York City into an eerie twilight in the early afternoon, swept across the Canadian border like a great shroud. It blotted out the sun in many places; in others, it turned the sun’s rays into a patchwork of brilliant purple, pink and yellow colors. Residents of Detroit, Cleveland, Pittsburgh, Buffalo and other cities and towns in the path of the smoke blanket deluged police and newspaper telephone exchanges with calls for explanations of the phenomenon. Some worried folk thought there had been an atomic explosion. Some saw in the pall a sign of the world’s end.”

It is interesting that even as late as 1950 an intense popular anxiety from the appearance of the dark sky was widely felt, although it had a new contemporary feature in the concern about possible atomic explosions – the first Soviet atomic bomb test had taken place in August 1949. Of course, there was no satellite surveillance of the earth in 1950, but, compared to the 19th century, there was more capacity for information about remote fires to propagate quickly. In fact by the end of the day on the 24th the explanation for the dark skies in the eastern US was known; quoting again from the *New York Times* story:

“An official explanation came late in the day from the Weather Bureau in Washington. It said the smoke originated from a series of smoldering fires in the forests of Northern Alberta and the District of Mackenzie In Canada. […] A Canadian Press dispatch said the smoke drifted over the Province of Ontario in the morning, rising as high as 17,000 feet. The dispatch reported that the Alberta fires were burning through hundreds of acres of scrub timber 340 miles northwest of Edmonton.”

The New York Daily News published a story on the 25th reporting on some details of the previous day’s events when smoke

“spread across the Midwest and caused a heavy overcast, which occasionally amounted almost to darkness through the metropolitan area […] At Laguardia Field it was disclosed that many planes in the affected area had to fly by instrument…”

The United Press wire service had a story on the 25th including more description:

“The weird pall of smoke spread alarm across thousands of square miles in the US and Canada during the day. In Ohio chickens and birds roosted in the afternoon. In

southern Ontario some persons […] believed an atom bomb had fallen and a Third World War had started. In Pittsburgh and Cleveland day baseball games were played under lights.[…]In Pennsylvania it was so dark street lights were turned on in many towns."

Fig. 1. Helen Sawyer Hogg (1905-1993). Pioneering Canadian astronomer and popularizer of astronomy. A long time University of Toronto faculty member, she was the first president of the Canadian Astronomical Society. Shown here in the Dunlap Observatory in Richmond Hill, Ontario.

Extraordinary Eyewitnesses

We are fortunate in having personal records of the impression made by the 1950 smoke pall in the writings of two sophisticated scientists of the time. The prominent Canadian

astronomer Helen Sawyer Hogg (Fig. 1) and the prominent American meteorologist Harry Wexler were witnesses of the effects in Toronto and Washington, D.C. respectively.

Hogg wrote a monthly column in the *Journal of the Royal Astronomical Society of Canada* and her December 1950 column referred to people in Ontario being "startled on September 25 at a brief glimpse of the sun as a pale, bluish-mauve disc. At the same time the western sky became a dark, terrifying mass of cloud and haze […] The darkness was so marked at 3:30 in the afternoon that the writer observed a group of six wild ducks going to sleep quietly in the middle of the pond." Hogg returned to this subject in her column 15 years later writing that "Anyone who witnessed, as I did, the great smoke pall of September 1950 can never forget the eeriness of the occurrence and the extraordinary gloom."

Wexler (1911-1962), who was then head of research at the US Weather Bureau, wrote an article about the smoke pall that appeared in the December 1950 issue of the magazine Weatherwise. He noted the event was exceptional in featuring a "high concentration of smoke that so obscured the sun that it was visible to the naked eye without discomfort". He also noted the extraordinary "violet and lavender color of the sun, and to a less extent, of the moon..".

## The Synoptic Situation

Wexler's 1950 article reports on his investigation of the extent of the smoke coverage. He queried the experiences at 384 weather stations in the US and combined these with "synoptic reports" from the Canadian weather authorities and concluded that the "smoke covered the north central states, the Great Lakes region, New England, and the Atlantic coastal states as far south as Florida and inland as far west as northeastern Illinois, Kentucky, eastern Tennessee and Alabama. [although] the exact boundaries are uncertain". Wexler also noted that on subsequent days there were reports of the smoke pall in Europe. In Fig. 2 I have denoted with colored shading Wexler's estimated maximum smoke coverage area.

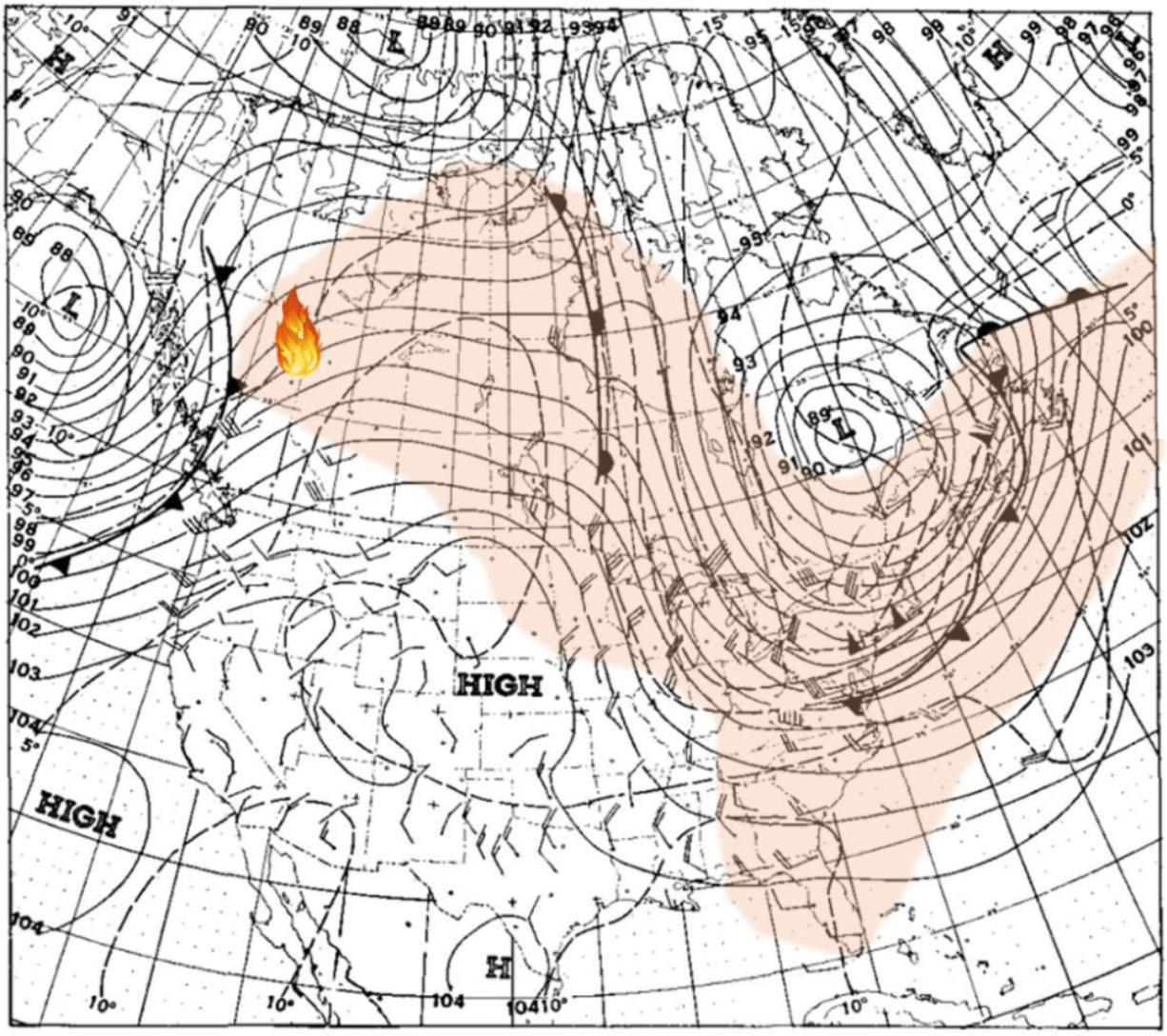


Fig. 2. 700 hPa map for 0300 UTC 24 September 1950. Shading shows the area affected by the smoke pall in late September as estimated by Wexler (1950). The flame symbol marks the approximate location of the bulk of the western Canada forest fires burning in late September. Adapted from Smith (1950) .

Of course, 1950 was before the deployment of artificial satellites and before the invention of lidar, so the capacity to monitor smoke plumes then was much inferior to that available today. However, simple ground based measurements of solar flux can provide some information on the aerosol column. While the Canadian historian of science W.E.K. Middleton remarked in his 1953 edition of his book “Meteorological Instruments” that equipment measuring the solar illumination at the surface was “not very commonly used in meteorological service”, in 1950 such measurements were apparently being taken regularly at about 50 US Weather Bureau stations. Wexler notes that at Buffalo, New York, “because of the presence of both smoke and clouds, the illumination from 1400 to 1600 EST on the 24th was comparable to pre-dawn or twilight.”

At Sault Ste. Marie, Michigan, “also with clouds and smoke on the 24th, the insolation dropped to […] less than one percent of the normal clear weather value.”

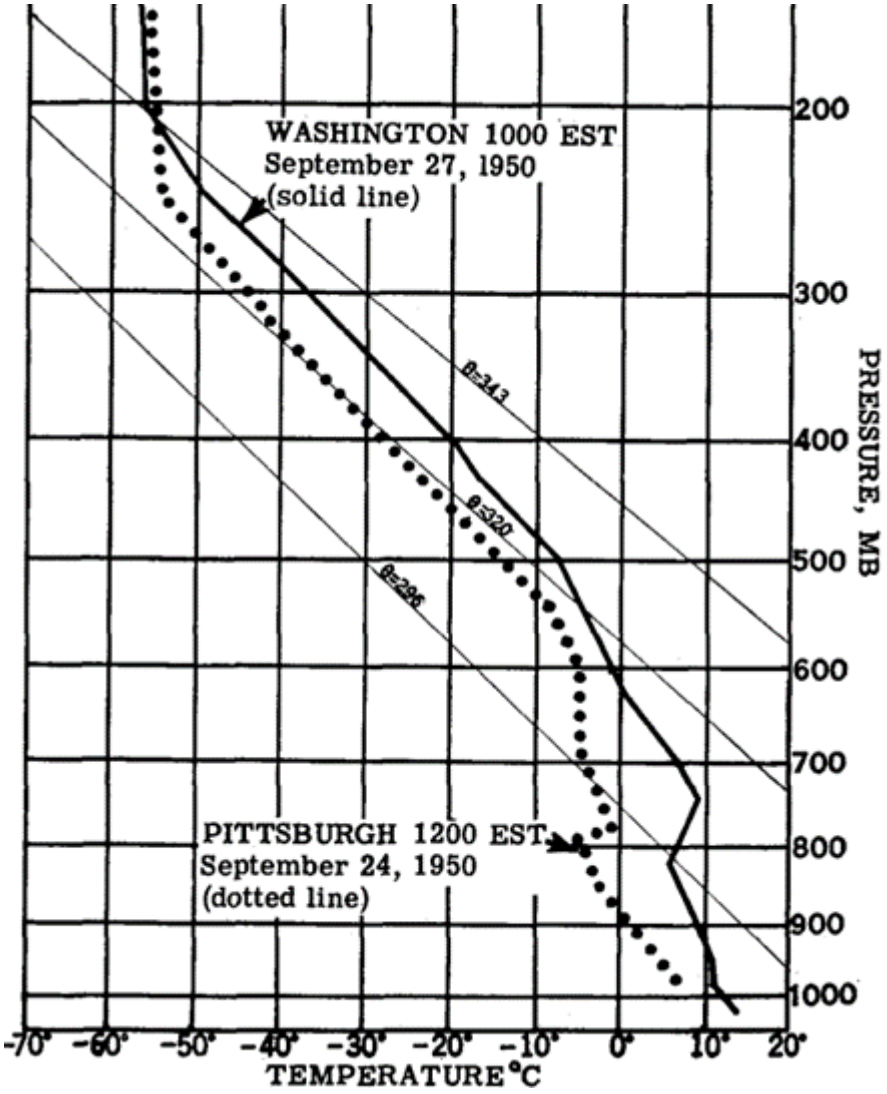


Fig. 3. Soundings near midday on September 24, 1950 at Washington, D.C. and Pittsburg, Pennsylvania. From Smith (1950).

One notable feature of the smoke pall, at least as it initially spread over the eastern US, was its confinement in a layer well above the ground. Wexler notes that “many reports by airline pilots of the heights of the bottom and top of the smoke were received. Although these values varied to some extent, it seems likely that the smoke observed in the eastern US was largely confined to a layer whose base was at 8,000 feet and whose top was at or above 15,000 feet. No smoke was observed at the ground in this area; in fact the horizontal visibility was generally unlimited throughout the entire period.”

Clarence  Smith, a US Weather Bureau meteorologist, also quickly wrote a more detailed examination of the synoptic situation associated with the 1950 smoke pall and published it in *Monthly Weather Review*.  Smith notes that “The weather in British Columbia and Alberta was unseasonably warm and dry during the first half of September, contributing materially to the onset of extensive forest fires.” Later in the month the smoke from the fires streamed into the eastern US as a developing cyclone brought strong southward winds (Fig. 2).  The Arctic air advected into the US displayed a strong inversion near 800 hPa on the 24th (Fig. 3) which helps explain why the thick smoke in the midtroposphere did not mix down to the ground.

With what must have been a large effort using hand calculation, the meteorologists in the US Weather Bureau calculated some isentropic back trajectories for a level within the smoke plume (potential temperature 312K) and were able to directly connect the smoke that arrived over Washington D.C. on September 24th with the region of the intense fires in Alberta more than 50 hours earlier.  This presumably represents one of the earliest applications of this sophisticated technique to investigate long range atmospheric transport.

## Conclusion

The heavy smoke pall overlying much of the eastern US on June 7-8, 2023 was an extraordinary event and almost certainly unmatched in this region by other events within most people’s memory today.  However, this very recent event can be considered in a larger context and, in fact, widespread reports of intense “dark days” in the region appear occasionally in the historical record.  The “dark days” of the 18th and 19th centuries are recorded purely as anecdotal reports of the sky appearance and other subjective measures of air quality. The “great smoke pall” of September 1950 is more fully documented through systematic meteorological measurements than the earlier dark days, but there are still not enough data for a direct quantitative comparison of the intensity of the 1950 event with that in June
2023.

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Kevin Hamilton is Emeritus Professor of Atmospheric Sciences and retired Director of the International Pacific Research Center (IPRC) at the University of Hawaii. He has had a long career in academia and government including stints at McGill and the University of British Columbia in the 1980’s. His main research interests have been in stratospheric dynamics and climate modeling, but he has also investigated aspects of the history of meteorology. He currently serves as an Editor of the journal History of Geo- and Space Sciences.

# Tackling planetary threats through innovative technology

**WRITTEN BY CMOS BULLETIN SCMO ON OCTOBER 22, 2023. POSTED IN OCEANS, WHAT'S CURRENT.**

**– By Karly McMullen –**

On the ocean, sailors know to expect the unexpected. In fleeting moments, puffs of air hint at humongous animals below, dolphins come to dance on the bow and dynamic weather can change in an instant, ensuring a constant state of unease. Dean Wenham, an avid sailor and scuba diver, was drawn to the allure and unpredictable nature of the ocean but became increasingly concerned with the presence of plastics interrupting his time at sea. He sought to advance plastics science by collecting microplastics on his sailing expeditions, but quickly realized the technology was not fit for purpose. Simultaneously, marine scientist and engineer, Ethan Edson, was innovating new tools specifically for microplastics research at Northeastern University. Fuelled by the pressing need for suitable methodologies, Wenham and Edson joined forces, giving rise to Ocean Diagnostics—an organization now boasting a suite of cutting-edge technologies to collect the actionable data needed to mitigate microplastic pollution and biodiversity loss.

From portable depth sampling instruments and automated imaging tools to state-of-the-art spectroscopy capabilities, Ocean Diagnostics empowers global researchers, marine managers and community scientists to easily capture the reliable microplastics data needed to influence informed decision making.

“Making data more accessible through innovative technologies and tools is now critical to navigating our way out of the plastic pollution crisis that unfortunately not only affects our oceans, but us, who depend on clean and healthy seas for sustaining life on Earth”, said ODI Founder and CEO, Ethan Edson.

## Navigating microplastic research challenges

Microplastics discourse surged in environmental and ecotoxicological science after the term debuted in literature in 2004 (Akdogan & Guven, 2019; Thompson et al., 2004), Every year, microplastics, plastics 5 mm or less in size, are uncovered in new environments, spanning deep sea beds (Bergmann et al., 2017; Chiba et al., 2018; Hamilton et al., 2021; Kane et al., 2020) to Arctic sea ice (Kanhai et al., 2020; Lusher et al., 2015; Peeken et al., 2018). They have been found in human blood (Leslie et al., 2022), human breastmilk (Ragusa et al. 2022), liver (Horvatits et al., 2022), and lung tissues (Amato-Lourenço et al., 2021), and just recently the human heart (Yang et al., 2023).

Given the quick rise in microplastics research, scientists have had to adapt by using traditional contaminant sampling techniques to study microplastics, which has led to inevitable issues not only in quality and control, but in data accessibility and comparability.

Microplastics are often ubiquitous in the environment but inherently difficult to sample due to their increasingly complex and diverse set of physical and chemical properties. Even after decades of microplastics research, sample contamination remains a major concern. Any sample exposed to air risks being contaminated with microplastics from clothing fibers, long range transport through air or virtually any piece of plastic in the vicinity. Contamination is a constant concern because it can sway our understanding of the major sources of microplastic pollution. Recognizing this concern, Ocean Diagnostics set out to develop instruments to significantly reduce contamination potential

by filtering for microplastics directly in environmental compartments, like at depth in the ocean. 

Distinct environments call for different microplastics retrieval and analysis techniques. Nets (e.g., Manta trawls, neuston nets) or bottles (e.g., Niskin bottles) are used to collect microplastics in water, sand is often sieved, animals are typically dissected, and biological material is digested using different methods to isolate microplastics. Unlike legacy contaminants that have been studied for generations, proper harmonized methods for microplastics are lacking and are a critical block to addressing the issue (Provencher et al., 2020; Rochman et al., 2019). Different research questions require different techniques and necessitate expertise to ensure quality samples are retrieved. The growing team at Ocean Diagnostics is equipped with technology, consultation and laboratory services that ensures high quality microplastics research for any group undertaking a project.

In many cases, conventional tools and methodologies tailored for legacy contaminants fall short of ensuring robust quality control and quality assurance (QA/QC) for microplastics analysis. QA/QC are particularly challenging in the field of microplastics science, and standards are not yet well established, however, Ocean Diagnostics is working to improve the current state of research through expert consultation and

technologies that anyone can use to elevate the quality of microplastics data that is being collected.

After particle isolation, microplastics analysis is laborious and expensive, which has resulted in varying specificity levels and inconsistent data collection and reporting. Many microplastics cannot been seen with the naked eye, so they require careful microscopy and chemical identification procedures, best completed by experts within specialized laboratory environments and with state-of-the-art spectroscopy techniques including Raman and FTIR. Since these instruments are extremely expensive for an individual or research group to obtain, Ocean Diagnostics has set out to offer affordable and enabling scientific services to process samples on behalf of its partners.

## Consistent and regular microplastic monitoring is needed to effectively tackle the problem

As microplastics research limitations persist, these contaminants still enter the environment at alarming rates every day. Current estimates suggest 170 trillion plastic particles persist in our global Ocean (Erikson et al., 2023). To make matters more complex, the ocean is highly dynamic and microplastic point sources change greatly from location to location. Therefore, reliable and locally grounded data is needed to drive solutions, from policy to management and industry action, to restrict microplastics from entering the environment. Ocean Diagnostics notes that the public can play a key role in generating local data and the team has made it easy for anyone to contribute scientifically sound data through a Community Science Toolkit.

While many organizations and government-funded initiatives are at work to study microplastics, regular testing of the environment using consistent approaches has been a challenge. Further, much of this effort has concentrated on easier-to-sample large microplastics (over 300 microns in size), thus leaving us with poor knowledge of the small particles that are thought to be most abundant and bioavailable. This has largely been caused by lack of efficient tools to sample and analyse microplastics in the lab. Consistent ongoing data, both in terms of coverage, time and resolution, is needed to establish a baseline on microplastic exposure in the environment. This is especially important to local and regional management and environmental organizations as they are at the forefront of creating and implementing strategies that affect the environment directly. Furthermore, locally sourced data is fundamental for evaluating the effectiveness of emerging policies and measures, such as the recent bans on single-use plastics and microbeads in Canada (Government of Canada, 2018) and mandatory filtration in washing machines in France (Sánchez, 2021). Ocean Diagnostics laboratory is equipped with the latest technology to provide governments and industry organizations tools to generate baselines and evaluate future states of contamination. Its

critical to collect local data on what types microplastics enter the environment, where they come from and if mitigation efforts are working, to effectively address microplastic pollution.

Innovative solutions to a complex problem

Recognizing the pressing issue of microplastic pollution and research limitations, Ocean Diagnostics has developed tools and technology to empower governments, researchers, the public, educators and more to collect data to better detect and diagnose our planet from plastic pollution. This data-driven approach enables informed decisions and actions to protect our marine ecosystems. Today, the team of problem solvers and explorers is

pushing boundaries, empowering scientists and citizens alike to study microplastics and drive meaningful global change.

Ocean Diagnostics has a suite of commercially available technologies specifically designed for improving microplastic sampling and analysis. The company's Ascension Depth Profiler is a an easily deployable sampling device that allows for microplastic filtration directly in the water down to 400m of depth, eliminating the need to transfer large volumes of water and in turn reducing potential contamination risks. The Saturna Imaging Device is a standardized computer vision camera system that quickly counts and physically characterizes visible plastics (> 400µm) collected in Manta trawls, neuston nets, beach quadrat samples and community studies. This device provides a standardized set of size, colour and categorical metrics to harmonize reporting methods across different environments. It is also included in the Community Science Toolkit, which pairs Saturna with an educational and field sampling protocol and empowers community scientists to collect data and expand scientific knowledge on microplastic pollution in their local areas.

The team of microplastic experts at Ocean Diagnostics offers scientific services, including laboratory analysis of microplastics in an ISO 5 Clean Lab with state-of-the-art Fourier Transform Infrared Spectroscopy with ultrafast FPA system. This technology coupled with our advanced methodologies is suitable for analysis of water, air, wastewater/sludge, sediments and biota, to chemically identify plastics, enhancing the ability to determine the sources of microplastics and monitor baseline levels. Further, Ocean Diagnostics laboratory offers flexible microplastic polymer identification services to support the scientific community in addressing various research questions. The team's technology is being used by partners in government and academia in Canada, Europe and Australia. To highlight a few, Ocean Diagnostics recently partnered with Environment and Climate Change Canada to pilot a community science microplastic study on Vancouver Island, which identified polystyrene as the most prominent microplastics on beaches around Victoria, B.C. The team has also recently provided laboratory services to British Antarctic Survey researchers studying microplastics at depth in the Southern Ocean. These collaborative partnerships and services are inspired by the team's mission to make microplastics data more reliable, accessible and accurate. This, in turn, enables government entities and passionate organizations to adeptly monitor microplastics within their respective regions.

Recently, Ocean Diagnostics has further expanded its technology applications into environmental DNA sampling to aid in biodiversity assessments and contribute to species-at-risk management. The team takes pride in their active engagement in addressing two facets of the triple planetary threat—pollution, biodiversity loss, and climate change—through empowering scientific understanding and robust data collection.

Towards a brighter future

The tap of plastics has yet to be shut off and microplastics are continuing to accumulate at unprecedented levels in our oceans. As the challenges posed by microplastic pollution and biodiversity loss cast long shadows over our efforts in sustainable development, jeopardizing the future generation's opportunity to revel in the wonders of our oceans, Ocean Diagnostics is on a mission to provide solutions to solve these complex global problems. This data-driven approach, delivered through deployment of technological, scientific, and community-based solutions, provides the best possible path to return our oceans back to a healthy and flourishing state, and the team at Ocean Diagnostics is more optimistic than ever to be a part of this change.

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Karly McMullen (she/her), Ocean Diagnostics' Science Communicator, helps to advance the team's mission to diagnose and protect the planet from plastic pollution and biodiversity loss. Leveraging her background in microplastics research, Karly communicates Ocean Diagnostics' innovative tools and technology to researchers, organizations and the public.

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# Is global warming causing Atlantification of the Barents Sea, a collapse of the North Atlantic currents, or neither?

**WRITTEN BY CMOS BULLETIN SCMO ON OCTOBER 22, 2023. POSTED IN CLIMATE, OCEANS, WHAT'S CURRENT.**

**– By Knut L. Seip and Hui Wang –**

This study is about the Barents Sea and two North Atlantic currents, the Atlantic meridional overturning circulation (AMOC) and the Atlantic multidecadal oscillation (AMO) and what happens when the North Atlantic currents reach the Barents Sea.

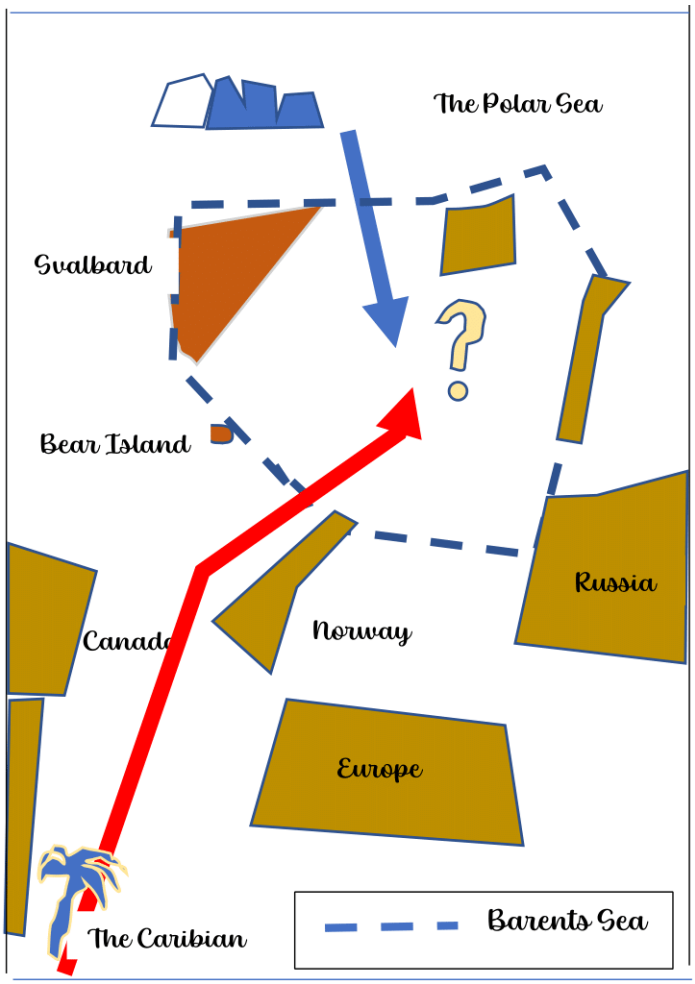


Figure 1. The warm surface water that comes from the Caribbean turns away from Canada and reaches Europe before it meets the Barents Sea North of Norway. The Barents Sea is cold and is feed by ice breaking off from the North Pole ice cover.

Why are the AMO and the AMOC important?

The AMO and the AMOC are two currents that are shown to strongly impact the climate on the Northern Hemisphere. The trajectory for the AMOC is sketched in Figure 1. Warm currents, like the Gulf Stream, which are part of the AMOC, are coming from the Caribbean and meet cold water in the Barents Sea. Three major effects from AMO and AMOC on the Barents Sea are suggested because of global warming. *First*, the Barents Sea will be Atlantificatied (Barton et al. 2018) and the ecosystem of the Barents Sea will be similar to that of the North Atlantic (Ingvaldsen et al. 2021). *Second*, the cold and ice fed water in the Barents Sea moves into the North Atlantic and changes the Atlantic currents dramatically. In an extreme scenario, the AMOC will collapse (Ditlevsen and

Ditlevsen 2023) and a sudden and severe decrease in temperature across northern Europe and the United States can occur. The *third* scenario is that there is no effect from the Barents Sea on the AMOC and AMO (Li et al. 2021) or vice versa.

## How to get closer to the answer

Since ocean currents show variability (most probably with pseudo cycles), we can assume that a peak in the causal variable would occur before a peak in the effect variable. Therefore, if AMOC peaks before cycles peak in the Barents Sea, we interpret this as meaning that the temperatures in the Atlantic waters impact the temperature in the waters of the Barents Sea. If AMOC peaks after the current peaks in the Barents Sea, then it is the Barents Sea that affects the North Atlantic waters and the AMOC.

The real story is a little bit more complicated. The AMOC is measured in cubic meters per second (Sv), the AMO in oC, and salinity also plays a role. However, here we focus on the temperature part and on AMOC.

To use the information on lead and lag (LL) relations between ocean currents, you need a method that quantifies LL relations over very short time spans. The trick to do that is explained in the method section below. To test if the result is significant, we do as one always does. We compare the persistence of an LL relation to that of two stochastic series. The more persistent a leading relation is, the more confident we are in its causal effect. And it is even better if the cycle periods change in duration (the series are non-stationary), and the two series still show persistent LL relations. To show the resulting LL relations between two time series, we use a graph with bars that are either positive (the first series leads the second) or negative (the second series leads the first) in Figure 2.

## We got two results

We examine two inlets for the AMOC to the Barents Sea. The peaks in the AMOC series came before the peaks in the currents that was observed in the Bear Island trough (BIT, one of the inlets) from the year 1991 to 2014, that is 23 years, Figure 2a. However, in the inlet at the Barents Sea northeast (BSNE), there is first a short period of 6 years where the Barents Sea currents lead the AMOC, but then a second short period of 8 years where the AMOC leads the Barents Sea currents, Figure 2b.

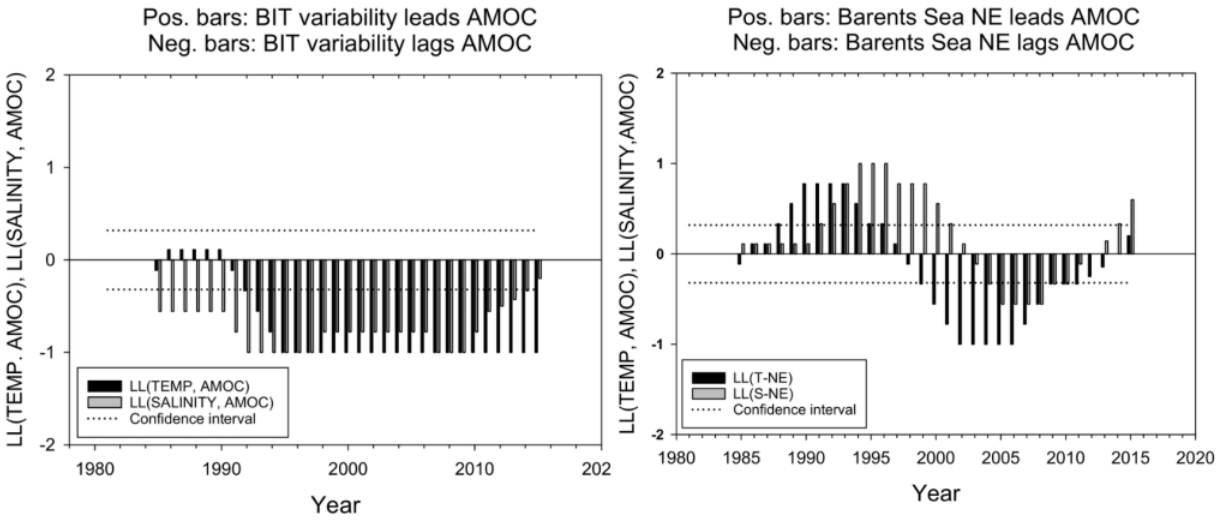


Figure 2. The AMOC and the currents in the Barents Sea outlets meet each other. a) In the Bear Island trough (BIT) at about 400-m depth. The negative bars mean that for the period 19912014, the AMOC was significantly leading currents in the Bear Island trough and salinity was doing the same. b) In the Barents Sea northeast the lead-lag patterns are more complex, and salinity and temperature do not follow each other as closely as at the BIT (Yashayaev (2015) observed that temperatures lead salinity as in the first half of the time in Figure b.) The dashed lines denote approximate confidence limits.

Time series for heat and salinity transport between the North Atlantic waters and the Barents Sea are based on observations. Our results and interpretation of the data suggest that heat and salt are transported both ways, and with different timing at the two regions where the AMOC meets the Barents Sea.

If we assume that the water flows through the two inlets are similar in size, then it is the inflow at the BIT, that is, the water carried with the AMOC and the AMO that dominates the waters in the Barents Sea during the period 1971 to 2014. The inlet through the BIT may have a larger cross section than the inlet at the BSNE (Barton et al. 2018).

We also obtained a second result. We found that temperature variations in the surface water of the Barents Sea always lead the temperature variations in the intermediate water, suggesting that heat variations in the atmosphere are transported to the Barents Sea waters (graphs not shown).

Our conclusion is that temperatures in the Barents Sea are influenced by temperature variations in the atmosphere and by temperature variations in the North Atlantic waters (the AMOC and the AMO) until about 2000. In addition, temperature variations within the Barents Sea are caused by ice melting and accompanying changes in albedo. After about 2018 global warming may play an increasingly important role in the Barents Sea-North Atlantic Ocean system.

There are four caveats in our results. i) The assumption that the flow through the BIT is larger or of about equal size to the flow through the BSNE may not be correct, and there are more gateways to the Barents Sea than those two studied here. ii) The study period was only 48 years, and ocean currents may change directions after that time (Seip et al. 2023). iii) Global warming may alter ocean flow patterns in the Barents Sea and in the North Atlantic. In particular, the return flow of cold-water at large depths may change characteristics. iv) Last, the atmosphere-ocean exchange of heat may change with global warming and global cooling (Li et al. 2023).

## The method trick

The trick to distinguish lead-lag patterns is to depict the potential causal and effect series in a phase plot. In such a plot, we can determine the lead-lag pattern based on three paired consecutive observations (and not only for the peaks or troughs). Figure 3 shows that if one time series peaks before another (blue and black in Figure 3, black on the x-axis), then the trajectories rotate clockwise. If one time series peaks after another (black and red, black on the x-axis), then the trajectories rotate counterclockwise.

Although it may be easy to see the relation between series in a phase diagram, the equation that calculates rotational directions in the phase diagram could be difficult to write out. For readers that are interested we would be glad to provide a one-page spread sheet (Excel book) with the appropriate calculations. Then, to use the method, just paste the time series into two columns in the spread sheet.

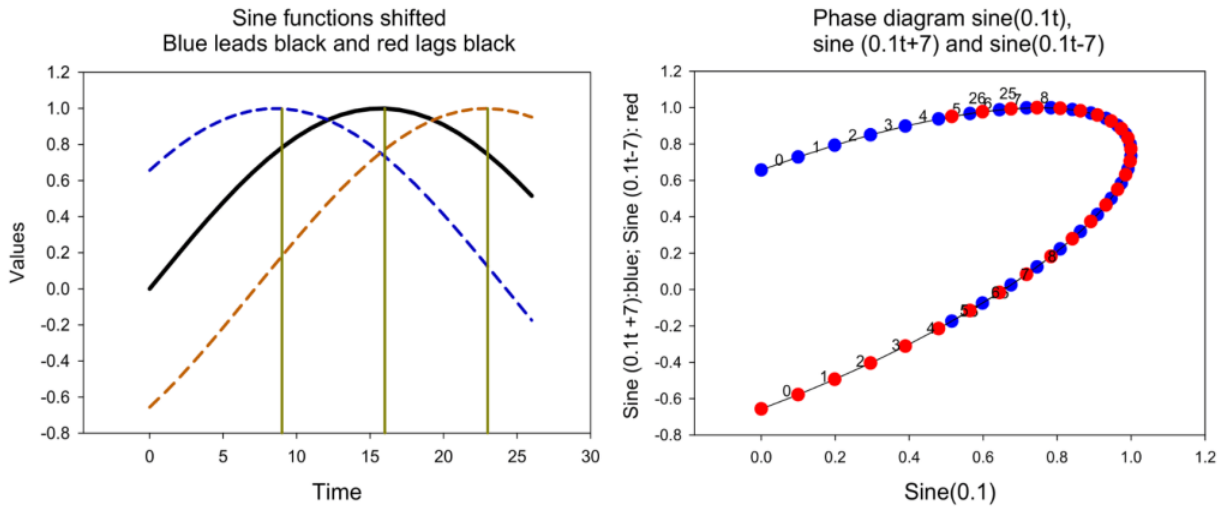


Figure 3. The trick: How to know which series is leading which. a) Three series, the blue series leads the black series because it peaks before the black series, the red series

trails the black series because it peaks after the black series. b) Phase plot with sine (0.1t) on the x-axis and sine(0.1t+7): blue and sine (0.1t-7): red on the y-axis.

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Knut L. Seip is professor emeritus at Oslo Metropolitan University. He has recently been working on aquatic and economic problems using a high-resolution lead-lag (cause before effect) methodology to disentangle causal variable in observed time series.

Hui Wang is a meteorologist from the Climate Prediction Center of the U.S. National Oceanic and Atmospheric Administration. His research interests are climate variability, climate modelling and prediction.

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# Yes, there is selenium in our atmosphere: a quick look into recent discoveries about its biogeochemical cycle

**WRITTEN BY CMOS BULLETIN SCMO ON NOVEMBER 28, 2023. POSTED IN ATMOSPHERE, WHAT'S CURRENT.**

**– By Paul Heine –**

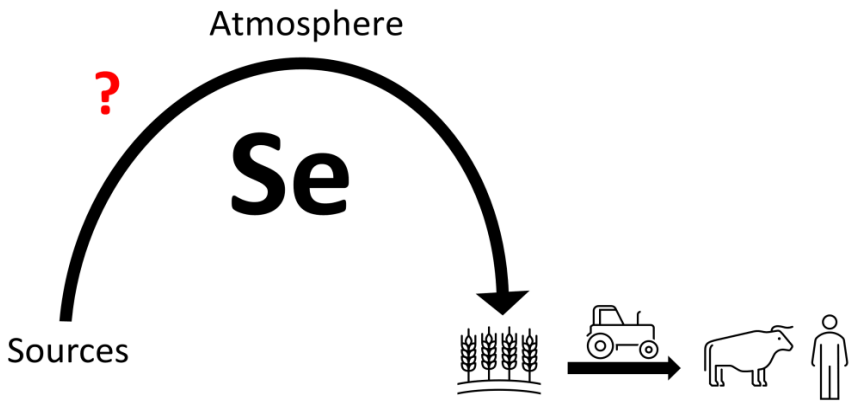


Figure 1. Schematic flux of atmospheric Se to soils.

Selenium (Se) is an element with similar chemical properties compared to elements like sulfur. Just like sulfur, Se can be found naturally in bedrock, soils, the atmosphere, and marine systems, but also in plants. As part of their metabolism, plants take up Se from soils, to incorporate into amino acids and build proteins. These Se containing proteins serve vital functions for both animals and humans, thus making Se an essential micronutrient. Contrarily, exposure to slightly higher amounts of Se can result in adverse health effects or even death. Therefore, it is important to ensure that food for both animals and humans contains just the right amount of Se. Unfortunately, there are estimations that up to 1 billion people globally do not have an adequate amount of Se in their diet. The dominant cause of this is low levels of Se in soils, which limits plants' ability to metabolize Se and consequently leads to deficient levels of Se in food stuff. But

how exactly does Se get transported through the environment to soils to ultimately end up in people's food (Figure 1)?

To answer this question, Paul Heine, a graduate student in the research group of Nadine Borduas-Dedekind at the University of British Columbia, conducts laboratory experiments (Figure 2). Heine and Borduas-Dedekind are interested in how Se changes chemically as part of its atmospheric transport through the environment. The researchers use a Vocus proton-transfer-reaction time-of-flight mass spectrometer, a state-of-the-art analytical instrument that detects volatile organic molecules, that are constituents of the atmosphere in relatively small amounts. Interestingly, phytoplankton in marine systems form these volatile organic molecules containing Se, as part of Se's biogeochemical cycling. Due to their high volatility, these molecules then evaporate into the atmosphere. Here, various physical and chemical transformations driven by light, temperature, humidity, and atmospheric oxidants can occur. In the lab, the researchers use a pillow bag, a reaction vessel for atmospheric chemistry to study these transformations in a controlled environment. Connecting the Vocus to the pillow bag allows the researchers to then monitor the atmospheric oxidation of Se-containing gas-phase molecules in real time.

Figure 2. Experimental setup used to study the atmospheric oxidation of volatile organic Se. The Vocus proton-transfer-reaction time-of-flight mass spectrometer can be seen in the center left of this picture.

A recent study, published by Heine and Borduas-Dedekind, identified atmospheric lifetimes and new products of Se containing molecules with respect to their reaction with ozone, a ubiquitous atmospheric oxidant (Figure 3). Moreover, the authors found that the newly identified Se containing reaction products are less volatile, and subsequently condensate onto already existing particles, or directly form new particles. When applying these findings to the atmosphere, Heine and Borduas-Dedekind can then draw conclusions on the atmospheric fate of these Se containing molecules. Oxidation by ozone drives volatile organic compounds containing Se to the particle phase, where they can then be washed out of the atmosphere by rainfall to subsequently be deposited onto soils. The chemical information on reaction times and products of the atmospheric oxidation of volatile Se obtained in this study can be used in computer models estimating the atmospheric flux of Se. With this work, the authors ultimately contribute to improving

our predictive capabilities of how Se is distributed globally, and which regions may be at risk of being Se deficient in soils.

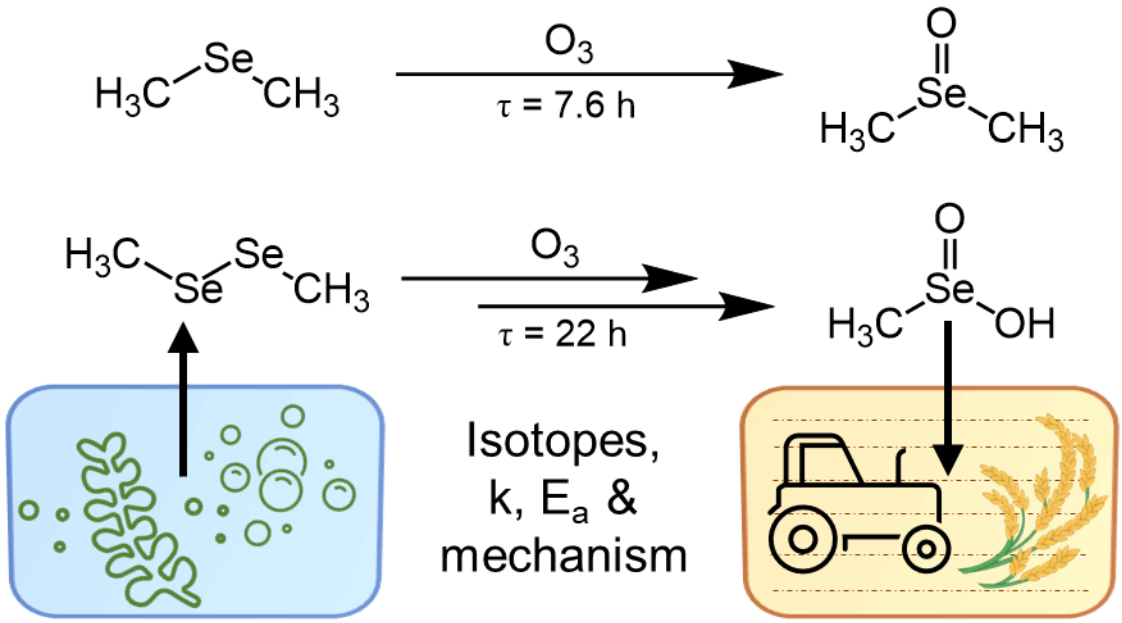


Figure 3. Summary of the atmospheric lifetimes and products formed during the reaction of volatile organic Se with ozone.

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Paul Heine is a PhD candidate at the University of British Columbia (UBC) under the supervision of Nadine Borduas-Dedekind (NBD). With a background in organic and inorganic synthesis, Paul has joined the NBD reserach group in 2021 to use the Vocus proton-transfer-reaction time-of-flight mass spectrometer and other analytical tools to study the oxidative fate of volatile organic selenium in the atmosphere. Outside of the lab, Paul enjoys cycling and ski touring. You can find Paul on Twitter (now X) @paul_a_heine, and to learn more about the NBD research group please visit atmoschemgroup.org

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