



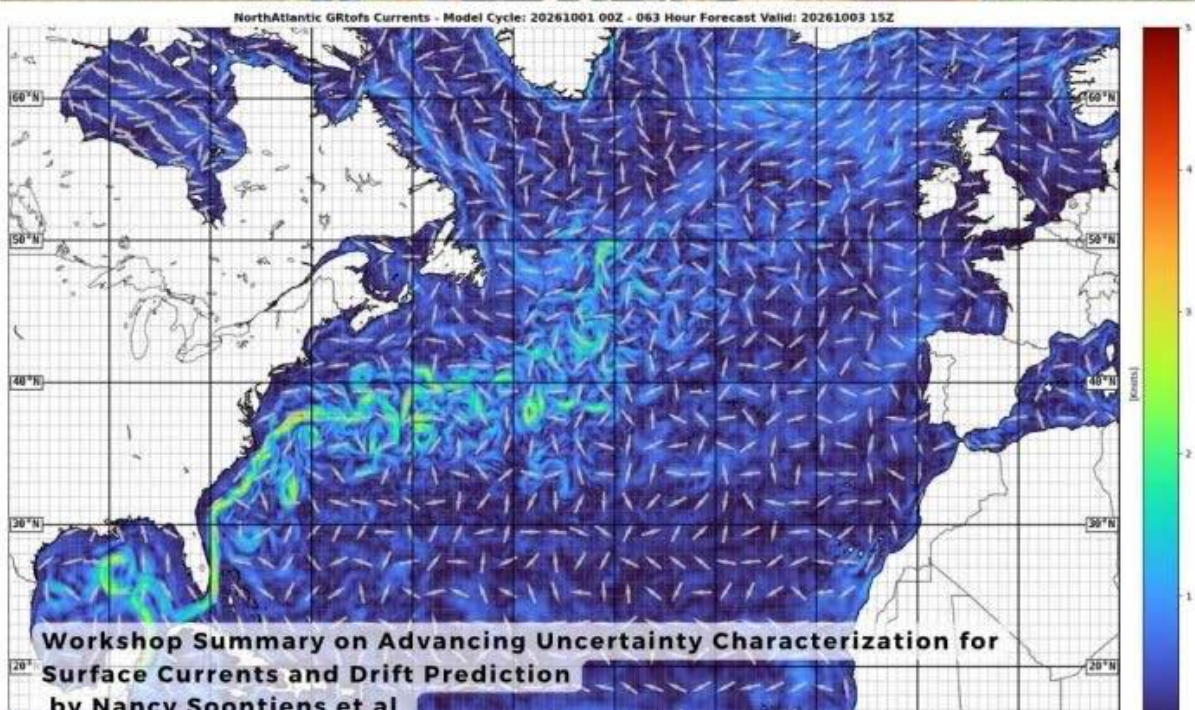
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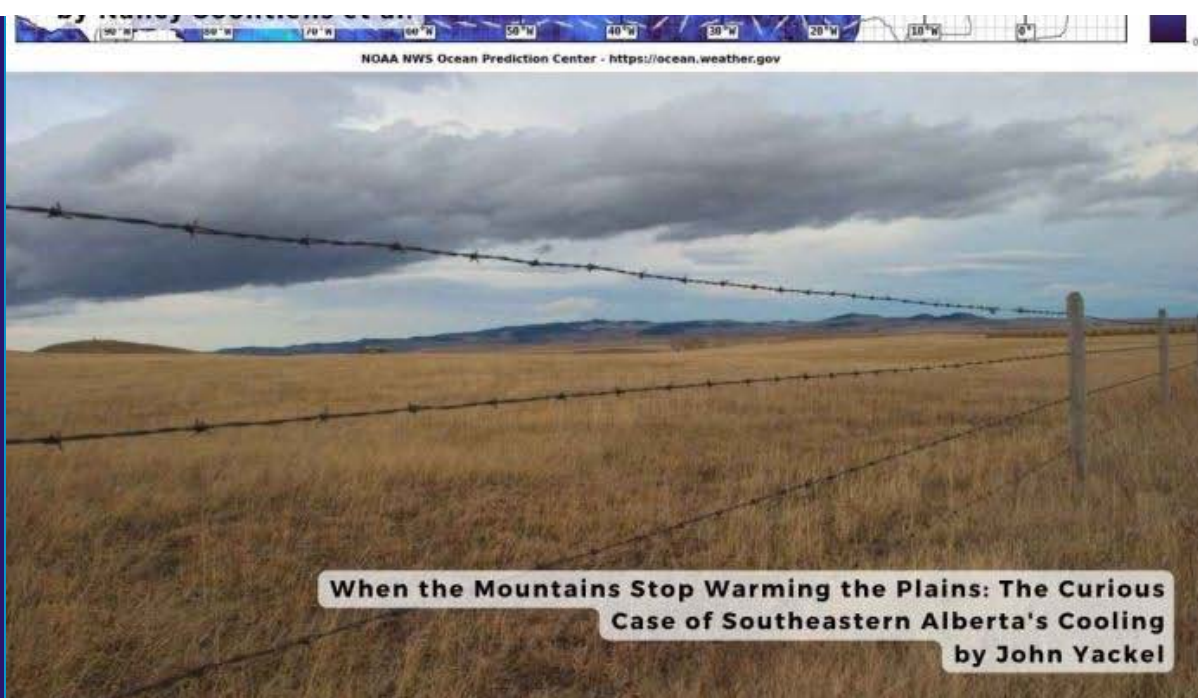
La Société Canadienne
de Météorologie et
d'Océanographie

Bulletin

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... from the Desk of the President

... from the Desk of the President

After a quiet summer, the Executive and our committees have returned to work. The implementation of our 5-year (2025-2030) plan continues to move forward. Improved communication, internally and externally, is one of our priorities.

The Centre chairs held their first meeting in early September. The School and Public Education Committee (SPEC) initiative was discussed. This program highlights the importance of citizen science activities like the *Community Collaborative Rain, Hail and Snow Network* (CoCoRaHS). School talks, science fairs, etc. are ways to showcase our society. We have been collaborating with CoCoRaHS to give our rain gauges as a door prize for the events we participate in. The Centres are also looking to collaborate more often. The Centres are the “front door” to CMOS.

The CMOS Executive meeting on September discussed the Executive Director (Gordon) Succession Plan. If all goes well, we will be hiring a new Executive Director by the beginning of 2027. Gordon will “train” his replacement over the following months. The CMOS Council met recently and covered many of the initiatives above.

Upcoming next month: a CMOS Special General Meeting is scheduled for November 19, 2026. We will be proposing to introduce a new CMOS Science Commission and revise the terms of reference for the Congress and Science Committees. These proposed governance changes were discussed at the June 2026 Annual General Meeting.

Attached is our second CMOS Bulletin in its new format, and contains three interesting articles (including more on CoCoRaHS!). Check them out!

Thanks again to the editorial team, contributors, and volunteers. We really want to hear from you.

Please send all feedback and contributions to bulletin@cmos.ca.

Patrick McCarthy,
CMOS President



... Du bureau du président

Après un été calme, le comité exécutif et nos comités ont repris leurs activités. La mise en œuvre de notre plan stratégique (2025-2030) continue d'avancer. L'amélioration de la communication, tant en interne qu'en externe, figure parmi nos priorités.

Les président.e.s des centres ont tenu leur première réunion début septembre. L'initiative du Comité d'éducation publique et scolaire (CEPS) a été abordée. Cela met en évidence l'importance des activités de science citoyenne telles que le Réseau communautaire collaboratif de surveillance de la pluie, de la grêle et de la neige (CoCoRaHS). Les interventions dans les écoles, les expos STIM, etc. sont autant de moyens de faire connaître notre société. Nous collaborons avec CoCoRaHS afin d'offrir nos pluviomètres comme lots de présence lors des événements auxquels nous participons. Les centres cherchent également à collaborer plus souvent. Ils constituent la « porte d'entrée » de la SCMO.

Lors de la réunion du comité exécutif de la SCMO en septembre, le plan de succession du directeur général (Gordon) a été abordé. Si tout se passe bien, nous recruterons un nouveau directeur général / une nouvelle directrice générale d'ici début 2027. Gordon « formera » son remplaçant au cours des mois à venir. Le Conseil de la SCMO s'est réuni récemment et a abordé bon nombre des initiatives mentionnées ci-dessus.

Au programme du mois prochain : une Assemblée générale extraordinaire de la SCMO est prévue le 19 novembre 2026. Nous proposerons la création d'une nouvelle Commission scientifique de la SCMO et la révision du mandat du Congrès et des comités scientifiques. Ces propositions de changements de gouvernance ont été discutées lors de l'Assemblée générale annuelle de juin 2026.

Vous trouverez ci-joint notre deuxième Bulletin SCMO dans son nouveau format, qui contient trois articles intéressants (dont d'autres informations sur les CoCORaHS !). N'hésitez pas à les consulter !

Merci encore à l'équipe éditoriale, aux contributeurs et aux bénévoles. Nous avons vraiment hâte d'avoir vos retours.

Veuillez envoyer tous vos commentaires et contributions à bulletin@scmo.ca.

Patrick McCarthy,

Président de la SCMO



Articles & Reports

CoCoRaHS Precipitation Network

By: Rick Fleetwood

Are you interested in weather? Does the idea of measuring and reporting daily precipitation which can be used regularly by weather forecasters, the agriculture community and many others, appeal to you? If so, CoCoRaHS (**C**ommunity **C**ollaborative **R**ain **H**ail and **S**now) may be for you!

CoCoRaHS is a citizen-science, volunteer network of individuals and organizations like watershed groups, conservation authorities, agriculture organizations, etc. across Canada that measure and report daily precipitation amounts on the CoCoRaHS Website or Smartphone App.



CoCoRaHS data is used routinely by ECCC meteorologists to help assess the severity and extent of storm systems as well as by AAFC to monitor drought conditions across Canada. Many other organizations and individuals such as flood forecast agencies, emergency responders and others use CoCoRaHS reports to help with their operations.



Figure 1 (left): CoCoRaHS Precipitation gauge set for measuring rain. **Figure 2** (right): CoCoRaHS volunteer measuring snow.

CoCoRaHS is always looking for new volunteers!

Although there are more than 800 CoCoRaHS volunteers across Canada, there are still gaps to fill in the network, especially in more northern areas, and that's important because precipitation can vary significantly even over relatively short distances.

As reports are received, the CoCoRaHS maps and database are continuously updated so you can view your data almost immediately after submitting it. It's interesting to see what others are reporting in your area too... did you have the biggest rainfall or snowfall?... the CoCoRaHS map will let you know!

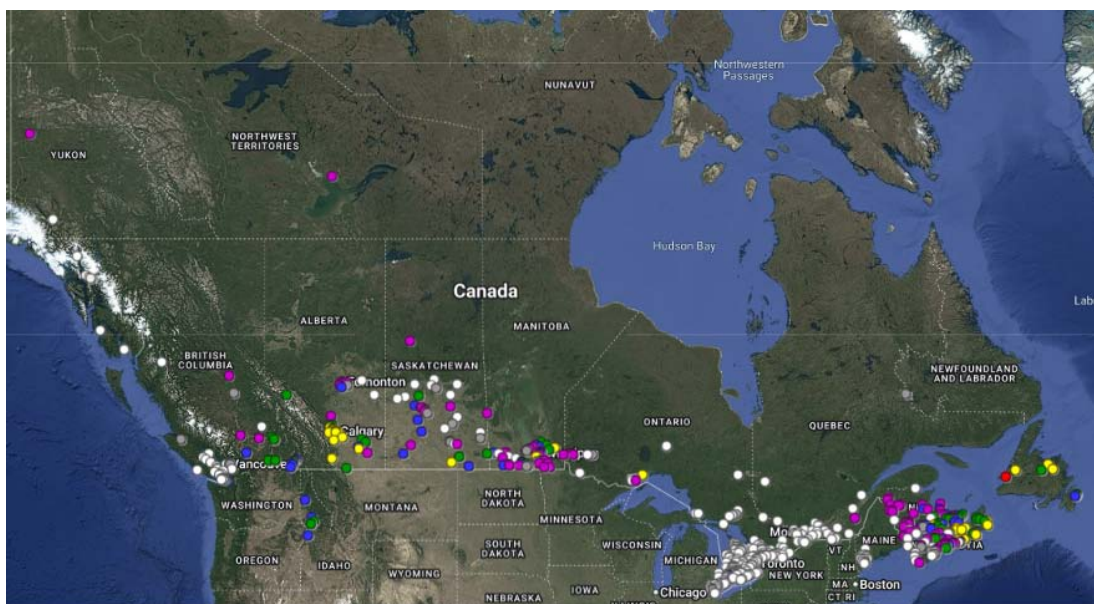


Figure 3: CoCoRaHS map showing colour-coded rainfall reports for July 22, 2025.

And it's easy to get involved! Go to the [CoCoRaHS Canada website](#) to find all the information and [training materials](#) to get you started. You can start reporting as soon as you receive your gauge, which can be purchased at a discounted low cost from the [CoCoRaHS Canada Store](#). Reports can be submitted on the website [CoCoRaHS - Community Collaborative Rain, Hail & Snow Network](#) or Smartphone App (IOS and Android, search for CoCoRaHS).

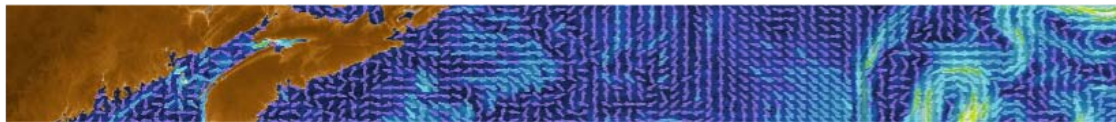
Don't be concerned about reporting every day! If you are away for a few days or longer you can simply submit a multi-day report on the first day you start reporting again.

Are you interested in joining our citizen-science volunteer network or know someone who is? Register [here](#).

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Workshop Summary on Advancing Uncertainty Characterization for Surface Currents and Drift Prediction

By: Nancy Soontiens, Graigory Sutherland, Hauke Blanken, Kuo-Hsien Chang, Patrick Dawson, Michael Dunphy, Andy Lin, Rabab Mashayekhi, Justine McMillan, Patricia Pernica, Andrew Peterson, Jean-Philippe Paquin, Gregory Smith, Simon St-Onge Drouin, Stephanie Taylor, Joshua Turner



Overview

During marine emergencies, such as search and rescue operations or environmental spills, responders rely on ocean circulation models to make high-stakes, time-sensitive decisions. In turn, these operators need accurate drift predictions and a clear understanding of the underlying model's uncertainty. To address this need, the Canadian Operational Network of Coupled Environmental Prediction Systems (CONCEPTS) established the Uncertainty Characterization Task Team. On September 16–17, 2025, the team convened a workshop uniting ocean model developers with end users. The goal was to establish a shared understanding of current research, identify end-user needs, and define a roadmap for defining and communicating model skill and reliability.

To share the outcomes of this workshop with the Canadian ocean circulation modelling community, this report summarizes the main discussion points and areas for future focus and collaboration.

Background

CONCEPTS is an interdepartmental collaboration within the Government of Canada whose aim is to advance the development, deployment, and application of operational coupled atmosphere-ice-ocean-wave prediction systems. These prediction systems support the

Government of Canada's capability to provide reliable and accurate information for planning and decision making in order to ensure safe and sustainable activities in the marine environment. CONCEPTS provides ocean forecasts at various spatial resolutions and on timescales of days to weeks. The prediction systems are supported by a network of field observations via data assimilation and verification. In addition to providing numerical outputs of the prediction systems, CONCEPTS activities translate this data into customized information products distributed to clients, partners, and end users. Examples of Government of Canada activities utilizing CONCEPTS products include environmental and situational awareness for defense and sovereignty needs, response to marine environmental emergencies such as search and rescue and oil spill response, and coupled atmosphere-ocean-ice numerical guidance in weather forecasting.

Workshop Summary

The workshop was organized around six themes which spanned end-user needs, modelling techniques, observational data, and emerging research directions. Discussions revealed a common thread: improving drift prediction requires not just better models, but better ways of knowing when and where to trust them.

The question "When can operators trust the model in front of them?" shaped much of the conversation around end-user needs. Operators need to make rapid decisions under pressure, often without time to interrogate a model's underlying assumptions. What they need is simple, clear guidance on which model is most appropriate for a given region and incident type. Modellers, in turn, were prompted to be more explicit about the decisions worked into their models and how those decisions affect surface current accuracy in different settings.

A review of international literature and ongoing research confirmed that characterizing uncertainty in drift prediction is an active and evolving challenge. Multiple sources of model error were identified in the workshop, from unresolved scales and poorly parametrized processes to numerical error and chaotic variability, none of which have simple fixes. One of the more promising directions is the use of ensemble techniques, both within drift particle tracking and in the underlying ocean forecasts themselves. Running large numbers of particles with small random perturbations, or generating multiple ocean model realizations, allows uncertainty to be represented probabilistically rather than hidden behind a single deterministic output.

One of the more candid discussions concerned how coastline representation affects model performance. Higher-resolution models better capture the narrow channels and complex shorelines where many marine incidents occur, and comparisons of drift predictions across model resolutions using relocatable modelling tools were presented. Notably, the intuitive idea of using discrepancies between the model coastline and a realistic coastline as a proxy for model uncertainty did not hold up well. This metric penalizes the model in areas of relatively simple coastal geometry, where the model in fact may show good skill (Figure 1). Tidal current analysis in near-shore areas emerged as a potential approach for characterizing flow regimes and their associated uncertainty.

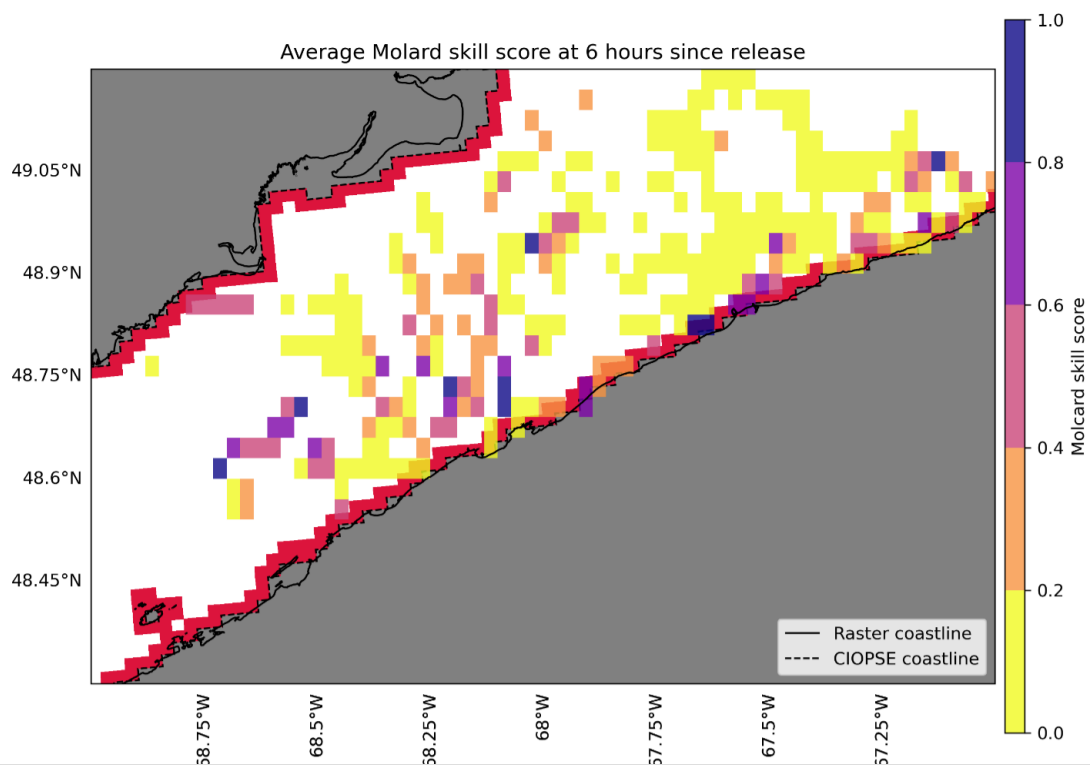


Figure 1: Map of average Molcard skill scores of predicted drift trajectories 6 hours after release. The Molcard skill score is defined as $M = 1 - d/D$ if $d < D$ and 0 if $d \geq D$, where d is the distance between the model and observed trajectory and D is the observed displacement from the point of origin. This score describes how skillful the prediction is when compared to the last known position, where 1 indicates a perfect score and 0 is no skill. The red shading represents a prototype “red zone” which is intended to communicate areas where the model has high uncertainty or error. This redzone definition is based on grid cells containing discrepancies between the model coastline and an observed high-resolution coastline. This prototype “red zone” was deemed problematic because the model is showing skill in areas overlapping with the red zone. Drifters were released in the St. Lawrence Estuary in 2020 as part of the Tracer Release Experiment (TRex; Pawlowicz et al., 2021). The drift predictions were forced by surface currents from the Coastal Ice-Ocean Prediction System for the East Coast of Canada (CIOPS-E; Paquin et al., 2021; Paquin et al. 2024) and winds from the High Resolution Deterministic Prediction System (HRDPS; Milbrandt et al., 2016).

Observational data plays an essential role in grounding these efforts, but comes with its own uncertainties. The workshop examined the strengths and limitations of platforms such as high-frequency radar, free-floating drifters, and acoustic Doppler current profilers for measuring surface currents. Importantly, work was presented showing how uncertainties in the observations themselves can be propagated through a drift trajectory model (Blanken et al., 2021).

Two sessions explored more advanced techniques for identifying where in the ocean uncertainty is likely to be highest. Drawing on dynamical systems theory, the first examined flow-following (Lagrangian) approaches that can flag regions where small differences in initial conditions lead to rapidly diverging trajectories, precisely the situations where a single drift prediction is most likely to mislead. The second revisited ensemble methods, this time focusing on how fine-scale variability in high-resolution models, such as the placement and timing of eddy fields, is often poorly constrained by observations, and how ensemble spreads can make that variability visible and usable for responders.

Areas for Collaboration: Future Projects

While the workshop identified steps to improve communication, it also highlighted gaps such as the lack of high-resolution surface current data in near-shore coastal areas where the majority of marine incidents occur. To address these gaps and advance Canada's environmental prediction capabilities, the group has developed four targeted areas for future projects, described briefly below.

- **Project 1 - Decision-Support Maps and Current Atlas:** A pan-Canadian map would explicitly advise operators on which ocean model is most reliable for a specific region, removing guesswork during rapid-response scenarios.
- **Project 2 – Scotian Shelf High-Frequency Radar (HFR) Process Study:** A targeted field campaign to validate coastal current measurements using HFR would establish a verified baseline for near-shore forecast models, directly addressing current blind spots in coastal monitoring.
- **Project 3 - Coastal Downscaling Initiatives:** High-resolution models are computationally expensive to run nationwide. This project would utilize Artificial Intelligence (AI) and relocatable models to quickly and cost-effectively "zoom in" on complex coastal currents precisely where incidents occur.
- **Project 4 - Dynamic Uncertainty Estimation:** By developing advanced ocean model ensembles, this project would quantify the dynamic "spread" of a drift trajectory, allowing response teams to tighten their search parameters and allocate response assets more efficiently.

Conclusion

Building upon established interdepartmental partnerships, the Uncertainty Characterization Workshop provided a dedicated forum to strengthen the ongoing alignment between ocean model developers and operational end users. The Workshop also outlined a series of collaborative projects that would address key gaps and accelerate the development of capabilities. Ultimately, these collaborative approaches will continuously enhance the accuracy, usability, and user confidence in Canada's environmental prediction systems.

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Author Biography

Nancy Soontiens is a research scientist with Fisheries and Oceans Canada in St. John's, NL. She is co-chair of the CONCEPTS Drift Research Community of Practice and an active contributor to multiple CONCEPTS working groups.

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When the Mountains Stop Warming the Plains: The Curious Case of Southeastern Alberta's Cooling

By: John Yackel, Professor, Department of Geography, University of Calgary

Southeastern Alberta is home to one of the few places in North America where temperatures are not warming. A recent study published in *Atmosphere-Ocean* by John Yackel, Shawn Marshall, and Sunbeam Rahman shows that this region—roughly 220,000 km² of prairie and foothills stretching from Calgary and Lethbridge east toward Medicine Hat—has experienced a persistent spring cooling trend since 1980, in stark contrast to the warming observed across the rest of the continent.

The Chinook Connection

The key to understanding this anomaly lies in the region's famous chinook winds. These warm, dry downslope winds form when moist Pacific air crosses the Rocky Mountains, cooling and releasing precipitation on the western slopes before descending and warming at the dry adiabatic lapse rate on the eastern side. Chinooks can raise winter temperatures by 10–20°C within hours, dramatically reshaping snowpack through melt and sublimation.

The study's authors hypothesized that changes in chinook activity could explain the cooling. Using ERA5-Land reanalysis data and a physically based chinook detection algorithm applied to hourly temperature fields, they found a statistically significant decline in winter chinook frequency of approximately 1.13% per decade, alongside a modest reduction in chinook warming strength. This decline was most pronounced in the "inner core" of the cold anomaly, the area of least warming.

Why are the Chinooks Declining?

The research points to large-scale circulation changes. Upper-air diagnostics at 500 and 700 hPa reveal weakened westerly winds and enhanced northerly flow since 1950, with a significant reduction in the frequency of strong westerly wind events—the very conditions that generate chinooks. This shift is consistent with Arctic amplification reducing the meridional temperature gradient, which in turn weakens the zonal jet stream and increases meridional (north-south) flow. In other words, as the Arctic warms faster than lower latitudes, the atmospheric "engine" that drives chinook-producing westerlies is slowing down.

A Snowy Feedback Loop

Fewer chinooks mean less winter snowmelt and sublimation. Snow water equivalent (SWE) in spring has increased since 1980, even as snowfall has not increased—in fact, snowfall has declined across much of southern Canada. The researchers argue that reduced snowmelt, rather than increased snowfall, is the primary driver of the increased spring snowpack. This sets up a reinforcing feedback: more snow on the ground reflects more sunlight, keeping temperatures cooler, which in turn preserves the snow. The cooling is not just a surface phenomenon—it extends through the lower and middle troposphere, suggesting a genuine atmospheric circulation signal rather than a local surface effect.

Broader Implications

This study highlights the importance of mesoscale processes—phenomena occurring at scales of tens to hundreds of kilometers—in shaping regional climate. While global climate models capture continental-scale warming, they may miss the localized cooling driven by changes in wind regimes and snowpack dynamics. The findings suggest that climate attribution and impact assessments should incorporate evolving wind patterns and land-atmosphere interactions, particularly in regions with complex topography.

The research also raises questions about other lee-slope regions. The authors argue that the specific geometry of the Canadian Rockies—oriented nearly perpendicular to prevailing westerlies—and the historical concentration of chinook activity in southeastern Alberta make this anomaly unique. However, the underlying mechanism of weakened westerlies due to Arctic amplification could have analogues elsewhere.

For residents of southeastern Alberta, the practical implications are significant. Spring cooling and increased snowpack affect agriculture, water resources, and ecosystems. Understanding these regional expressions of climate change is essential for adaptation planning. As the authors note, the story of southeastern Alberta is a reminder that climate change is not uniform—and that some of the most important effects may be hidden in the winds.

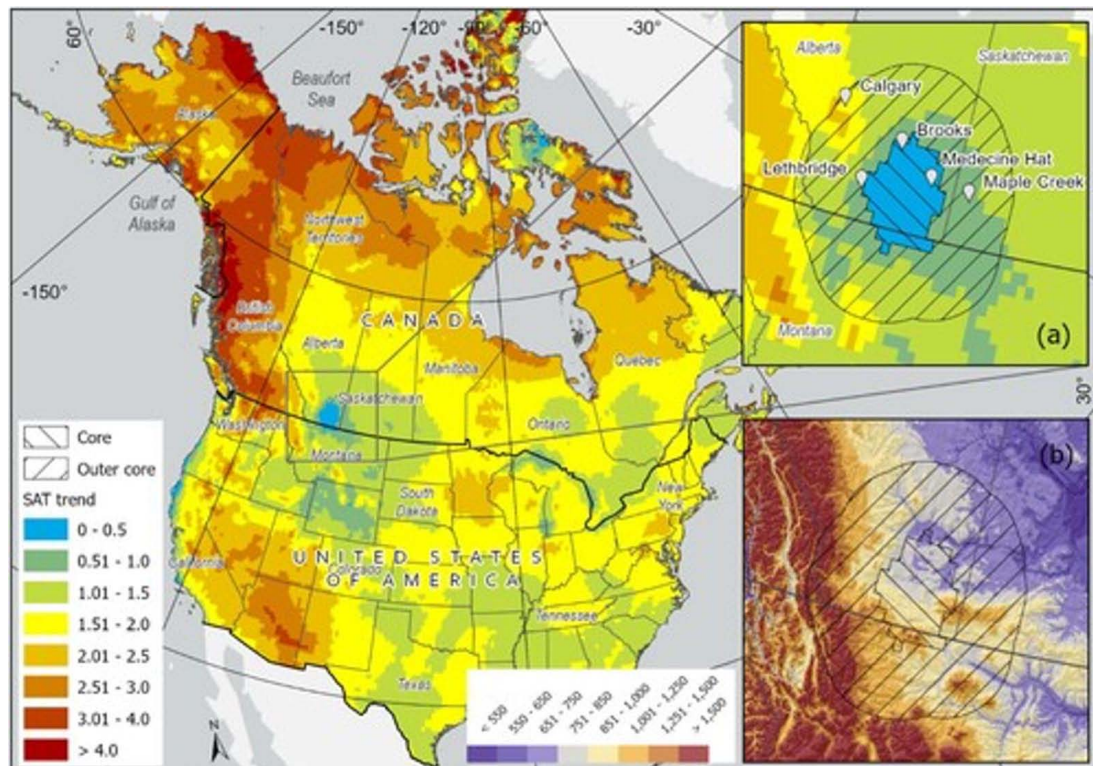


Figure 1: Maps that highlight a localized study area in southeastern Alberta within a broader

North American context. The first map covers most of North America and displays mean annual surface air temperature trend from 1950 to 2025 using a color scale.

Warmer trends appear along the west coast from Alaska through British Columbia and the United States Pacific states, while the least amount of warming appears in southeastern Alberta (Figure1). Provincial and state borders are drawn, namely, Alberta, Saskatchewan and Montana are relevant. A rectangular inset in the upper right focuses on southeastern Alberta and adjacent Saskatchewan and Montana. Within this inset, a cooler trend area is enclosed by the chinook belt of southern Alberta. City locations labeled Calgary, Lethbridge, Brooks, Medicine Hat, Maple Creek, Alberta, Saskatchewan, and Montana are marked with small symbols. The second map in the lower right shows the same Alberta study region using elevation classes measured in meters above sea level. Elevation increases from lower plains in the east toward higher terrain in the west, where the Canadian Rockies appear as a rugged high relief zone. The same inner and outer core outlines are overlaid on the elevation map, centered over the chinook belt region near Calgary, Lethbridge, Brooks, Medicine Hat, and Maple Creek.

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A-O Article Summary Volume 64, Issue 4 (2026)

Weather Research and Forecasting (WRF) Model and Machine Learning Algorithms to Improve Marine Fog Predictions

Piyush Teeloku, Zheqi Chen, Peter Taylor, and Yongsheng Chen - *York University Faculty of Graduate Studies, Earth and Space Science and Engineering, Toronto, Ontario, Canada*

ABSTRACT: In recent years, machine learning (ML) has gained popularity in the field of weather forecasting, particularly in areas where numerical weather prediction (NWP) models face challenges. One such area is fog prediction. Reduced visibility due to fog events poses serious challenges to transportation and public safety. Accurate representation of microphysics processes, radiation, boundary layer turbulence, and air-surface interaction is crucial in fog prediction. Traditional NWP models face limitations in accurately forecasting fog due to those complex processes. In this study, we propose a post-processing approach that combines the Weather Research and Forecasting (WRF) model forecasts with a machine learning classifier to improve fog prediction by distinguishing between fog and no-fog conditions. Using 12 years of data (2012–2023) for St John’s, Newfoundland and Labrador, and Yarmouth, Nova Scotia, Canada, the approach was tested on independent 2024 observations. Compared to forecasts based solely on liquid water content from WRF, the ML model achieved higher skill, with F1-score improvements of 13% at St John’s and 18% at Yarmouth. According to the results obtained, this approach demonstrates the potential of ML techniques to enhance operational fog forecasting capabilities.

An Updated National Tornado Climatology for Canada

D. M. L. Sills, L. Elliott, A. L. Jaffe, J. Kunkel, C. S. Miller - *Northern Tornadoes Project, Canadian Severe Storms Laboratory, Western University, London, Canada*

E. Sutherland - *Western Libraries, Western University, London, Canada*

M. Somers, B. Rousseau - *Meteorological Service of Canada, Environment and Climate Change Canada, Toronto, Canada*

ABSTRACT: The first tornado dataset for Canada covered the years 1950–1979 and allowed a 30-year tornado climatology to be attempted. This was followed by a second 30-year national climatology covering the years 1980–2009. Guided by World Meteorological Organization recommendations, the current study is a 10-year update of the Canadian tornado climatology covering the years 1991–2020. Data conventions and quality control procedures developed by the Northern Tornadoes Project are used to ensure a high-quality, nationally consistent dataset, and are also applied back to 1980 for completeness. The updated 30-year dataset comprises 1948 tornadoes with the vast majority (88%) of these rated F/EF0–1, while 11% had a rating of F/EF2 and only 1% had a rating of F/EF3 or higher. Tornadoes were recorded in nearly every province and territory with the highest annual mean frequency in Ontario (18.5 tornadoes per year). Gridded tornado incidence values were highest in the southern Prairies and southern Ontario with a notable regional maximum in the area west of Toronto, even when only F/EF2 + tornadoes are considered. Tornadoes occurred most frequently from June to August and from 1600 to 1859 LT, inclusive. The median lengths and widths of tornado damage paths are 5615 and 260 m, respectively. F/EF2 + tornadoes were found to peak later in the year and later in the day, with more than double the median path length and path width. A total of 20 tornado outbreaks were identified.

Changes in Oceanic Carbon Storage Due to Anthropogenic Carbon Input Over the Past Three Decades

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Varvara E. Zemskova *Department of Applied Mathematics, University of Waterloo, 200 University Ave W, Waterloo, ON N2L 3G1, Canada*

ABSTRACT: While the ocean is known to be an important sink for anthropogenic CO₂ emissions, assessing trends in the ocean's uptake and storage of atmospheric CO₂ is complicated because changes in the ocean dissolved inorganic carbon (DIC) concentrations due to natural ocean circulation patterns and flux of anthropogenic CO₂ need to be disentangled. In this study, we analyse the interannual and decadal changes in the ocean anthropogenic DIC storage from 1992 to 2022 using data from the physically and biogeochemically consistent ECCO-Darwin ocean state estimate model. We use the quasi-conservative tracer C* to represent the ocean anthropogenic DIC concentrations and offer several key extensions to previous studies: (1) a longer period of analysis (three decades), (2) analysis including the Arctic Ocean, (3) regular spatio-temporal coverage using annually-averaged data to more accurately estimate the rates of change of C*. Over the 1992–2022 period, we estimate a total global ocean C* increase of 60 PgC, corresponding to about 28% of total anthropogenic CO₂ emissions during this time. The general temporal trend shows a nonlinear increase with accelerating rates of anthropogenic DIC accumulation, especially in the last two decades (2002–2022), though a slowdown in the increasing rates is found in some parts of the ocean, in particular in high-nutrient low-chlorophyll regions. Empirical Orthogonal Function analysis of the vertically-integrated rates of change of C* reveals that the top four modes of interannual variability correspond to the Pacific climate modes, such as El Niño Southern Oscillation, Pacific Decadal Oscillation, and North Pacific Gyre Oscillation.

Basin-constrained Hurricane Wave Growth: Simulation of Post-tropical Hurricane Fiona Over the Gulf of St. Lawrence

Laura L. Swatridge, Leon Boegman - *Department of Civil Engineering, Queen's University, Kingston, ON, Canada*

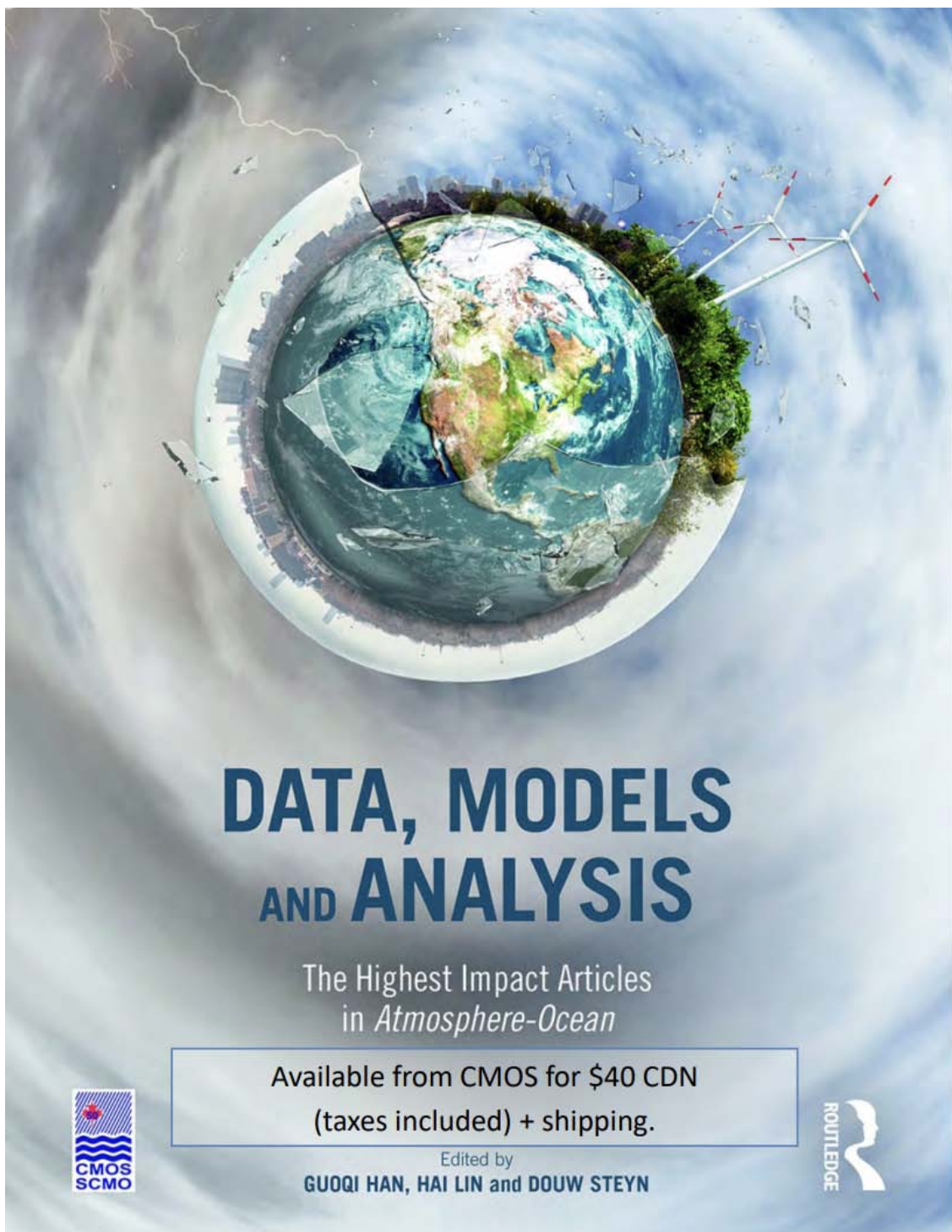
Ryan P. Mulligan, Shiliang Shan - *Department of Physics and Space Science, Royal Military College of Canada, Kingston, ON, Canada*

Julia A. Cantelon, Barret L. Kurylyk - *Department of Civil and Resource Engineering and Centre for Water Resources Studies, Dalhousie University, Halifax, NS, Canada*

ABSTRACT: Post-tropical Hurricane Fiona (2022) crossed the Gulf of St. Lawrence in Atlantic Canada, generating large waves and strong wave-driven currents in this semi-enclosed coastal sea. In this study, surface waves and circulation conditions were simulated using a dynamically coupled wave-circulation model, revealing significant wave heights $H_s \leq 9.4$ m and current speeds >1.0 m s⁻¹. Good agreement was obtained for bulk wave statistics ($r^2 > 0.86$ for H_s), and broad-scale validation was achieved over a large area using observations from seven satellite altimeters. Higher-resolution modelling of wind-generated waves in Malpeque Bay, a back-barrier bay connected to the Gulf, used a nested grid to simulate the waves in sheltered areas with short fetch. Significant wave heights ≤ 2.2 m in back-barrier regions, and current speeds ≤ 1.5 m s⁻¹ in coastal areas around the barrier islands were simulated. Limitations to wind-wave growth were examined through comparison of stationary and nonstationary simulations (time constraints) and analysis of the ratio of storm translational speed to wave celerity (spatial constraints). The results indicate that despite extreme winds, the wave field remained dominated by locally generated young wind sea. Because the storm footprint was comparable to the horizontal basin scale, translating-fetch resonance and sustained swell development were spatially constrained and stationary simulations overpredicted peak wave heights (by up to ~25%) under rapidly evolving wind conditions. These findings demonstrate how basin geometry can fundamentally limit hurricane wave growth in marginal seas, even during extreme events.

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