Student Abstracts

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Towards Modelling Hydrological Processes in Boreal Forest Wetlands: Implications from a High-Latitude Site and Multi-Model Analysis

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Abstract

The Canadian boreal zone encompasses one of the world's most water-rich regions, where diverse wetland ecosystems function as critical hydrological regulators. However, the unique characteristics of these cold environments pose substantial challenges for land-surface modelling. To better understand model limitations for boreal forest wetland, this study presents the first comprehensive intercomparison of three leading land surface models (LSMs)—Noah-MP, Community Land Model (CLM), and Canadian Land Surface Scheme (CLASS)—specifically evaluated within boreal forest wetland ecosystems. We assessed model performance using multi-year observational data from a representative site, focusing on key hydrological processes including soil moisture dynamics and soil thermal profiles. All models reproduced consistent seasonal patterns in soil moisture, evapotranspiration, and soil temperature. However, during winter, all models exhibited a cold bias attributed to inadequate representation of snow processes. During dry periods in the growing season, observed soil drying rates at 10 cm were slower than simulated rates, despite models predicting maximum evapotranspiration at this depth. In contrast, observations revealed the fastest drying occurred at 40 cm depth, which we attribute to modelled soil drainage processes at this layer. Our analysis further indicates that soil moisture loss exhibits nonlinear behaviour with extended dry periods. The CLASS model displayed distinctive behaviour, showing soil wetting at 40 cm depth. We attribute this to CLASS's unique peat parameterization, which promotes rapid drainage from surface layers while accumulating water at 40 cm depth. Additionally, the peat configuration provides resistance to soil water loss during dry spells. Our water budget analysis reveals a critical discrepancy: while observations demonstrate the system's capacity to sustain wetland formation throughout the growing season, the models fail to support wetland persistence across several years. This suggests that summer evapotranspiration rates and winter water storage are crucial factors for successful wetland formation during growing seasons. This intercomparison provides essential insights for improving model parameterizations specific to boreal wetlands, thereby enhancing our capacity to predict their responses to climate variabilities and their contributions to regional and global water cycles.

Keywords: Wetland; Multi-Model Analysis, CLM model, Noah-MP model, CLASS model

Future changes in coastal compound flood of storm surge & significant wave height in Pacific Ocean

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Abstract

This study investigates how climate change may intensify compound coastal flooding along the Pacific coast resulting from the co-occurrence of storm surge and high waves. Using projections from four GCM–RCM combinations in the Canadian Coastal Climate Risk Information System (CC-CRIS) under the RCP8.5 scenario, extreme events were identified through the 95th-percentile Peak Over Threshold (POT) method at 500 coastal nodes for four periods: baseline (2006–2025), near-future (2031–2050), mid-future (2061–2080), and far-future (2081–2100). Generalized Pareto Distributions characterized univariate extremes, and copulas were applied to model surge–wave dependence and estimate joint return periods. Results reveal a marked increase in compound flooding potential, with more frequent and severe joint extremes projected in future climates. Over 60% of nodes show a reduction in 100-year joint return periods by 2081–2100, and over 10% experience reductions exceeding 50%, effectively doubling event likelihoods. Although only 10% of projections fall outside the current uncertainty range, these findings underscore the heightened risk of concurrent surge-wave extremes and the need for multivariate flood risk assessment frameworks. The study highlights the importance of incorporating compound hazard interactions into coastal infrastructure design and climate adaptation planning.

Keywords:

Hydrodynamic Modeling of Lake Ontario for Flood Risk Assessment Using TELEMAC-2D

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Abstract

Coastal flooding threatens ecosystems, infrastructure, and communities across the Great Lakes. Lake Ontario is especially vulnerable given its long shoreline, dense population, and sensitivity to climatic and hydrological variability. This study develops and applies a high-resolution hydrodynamic model of Lake Ontario using TELEMAC-2D to predict water-level variability and inform flood-risk management.

Bathymetry from NCEI and topography from USGS were harmonized via datum corrections. Boundary conditions comprise daily Niagara River inflow, St. Lawrence River water levels, and 6-hourly ERA5 winds. The model was calibrated against observations at Kingston, Cobourg, Toronto, Burlington, and Port Weller for 1992–2001. Tests with multiple meshes showed that a medium-resolution grid best balanced computational cost and spatial fidelity, reproducing seasonal cycles and spatial gradients.

TELEMAC-2D solves the depth-averaged Saint-Venant equations on an unstructured finite-element mesh, accounting for gravity, bottom friction, wind stress, atmospheric pressure, and turbulence/diffusion to capture free-surface dynamics and inundation.

For flood-hazard analysis, the calibrated model is extended to a 30-year simulation. Extreme events are extracted using block maxima and fit with the Generalized Extreme Value (GEV) distribution to estimate return levels. In particular, the 60-year return level is derived, indicating the water level expected to be exceeded on average once every sixty years, thereby highlighting shoreline segments with elevated risk.

Overall, the study demonstrates the value of careful data integration, boundary-condition design, and mesh optimization for robust Great Lakes hydrodynamics. The results provide actionable evidence to support long-term mitigation, infrastructure planning and operations, and resilience to future climatic and hydrological change around Lake Ontario.

Keywords: TELEMAC-2D, Lake Ontario, Compound flooding, Storm surge and seiche dynamics

Forecasting the largest expected earthquake in Canadian seismogenic zones

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Abstract

Earthquakes significantly contribute to infrastructure damage, population displacement, and economic losses. To mitigate these impacts, earthquake forecasting models have been developed to predict earthquake occurrences and improve recovery efforts, with the Epidemic-Type Aftershock Sequence (ETAS) model being the most robust statistical framework for characterizing earthquake sequences. In this study, the ETAS model was used to estimate seismic parameters from historical earthquake catalogs, generate synthetic catalogs, and forecast long-term seismicity for seven different regions in Canada. Furthermore, the model was used to compile synthetic earthquake catalogs and generate synthetic parameters to assess its ability to replicate observed aftershock patterns. The study identifies the southwestern region of Canada, associated with the coastal area of British Columbia, to be at the highest seismic risk, with a 66% exceedance probability for M7.5 events or above to occur in the next 30 years. In contrast, Alberta features the least seismic risk, with a 4% exceedance probability for events above 6.5 magnitude. As such, the ETAS model is suitable for real-event practices, but improvements are needed for further synthetic applications.

Keywords: Canadian seismicity, earthquake physics, earthquake simulation, ETAS model, seismicity forecasting

Compound hail-wind-rainfall extremes, convective drivers, and future projections in Alberta's hail alley

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Abstract

Understanding the dependence among multiple extreme events, hail, wind, and rainfall, is essential for quantifying compound risks under a changing climate. This study investigates (1) the projected changes of compound hail–wind–rainfall extremes across Canada under future climate scenarios using the high-resolution CONUS404 dataset, and (2) the relationship between these compound extremes and key convective parameters. Radar-based VIL data are used to evaluate the CONUS404 hail and precipitation fields. A multivariate copula-based framework is developed to quantify the nonlinear dependence structure among hail, wind, and rainfall, and to estimate their joint return periods (JRPs). Convective parameters such as CAPE, CIN, and vertical wind shear are analyzed to interpret the physical drivers of these joint extremes and to assess their projected changes under future warming scenarios. To demonstrate the broader applicability of the framework, the same copula-based methodology is applied to compound temperature–precipitation extremes over Iran using CMIP6 bias-corrected data. The analysis of hot–dry and hot–wet concurrent extremes in summer reveals significant dependence between extremes, providing a comparative case for interpreting compound extreme events behavior in Canada.

Keywords: Compound extreme events, Multivariate copula-based framework, CONUS404 dataset, Convective parameters

Analysis of Hydroclimatic Extremes in the Great Lakes Basin under Climate Change Using WRF-Hydro and Metastatistical Extreme Value Distribution

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Abstract

We assess changing flood risk across the Great Lakes Basin (GLB) using flood-frequency analysis at 160 WSC/USGS gauges driven by observation-based and GCM-driven WRF-Hydro simulations for 1985–2014 and 2071–2100. We compared MEV (gamma/lognormal/Weibull), GEV, GPD, LP3, and ExtGPD models via 1,000 Monte Carlo validations with 10-year calibration windows. MEV distributions were selected at 113 gauges as the best-fitting model. Across the ensemble, 5- and 100-year flood magnitudes generally increase in the southern GLB and decline at many northern sites, particularly in the Lake Superior and St. Lawrence subbasins. Seasonal analyses indicate peak-flow timing advances by one to two months, most notably in the southeast. Additionally, 100-year floods increase strongly in winter, while summer floods decrease across the northern GLB and rise modestly in the south. These contrasts align with earlier snowmelt and intensifying heavy precipitation under climate change. Results demonstrate the utility of MEV for flood quantile extrapolation under short records.

Keywords:

Future Changes in Extreme Winds and Tornado Environments across Canada from Convection-Permitting WRF Simulations

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Abstract

This research examines extreme winds and tornado-supporting environments across southern Canada using 4-km convection-permitting WRF CONUS simulations under present (CTRL) and pseudo-global-warming (PGW) conditions. The high resolution explicitly resolves convective processes and complex terrain, improving the depiction of local wind behavior. The analysis of extreme winds shows strong regional and seasonal contrasts: summer wind extremes intensify notably in the Prairies and southern Ontario, while winter winds strengthen in Ontario, Quebec, and mountainous regions. A conditional probability framework based on CAPE further demonstrates that destructive wind occurrence increases sharply in convectively unstable environments. Meanwhile, this research also focuses on tornado-favorable environments and studies how thermodynamic and kinematic factors such as CAPE, CIN, vertical shear, and storm-relative helicity may evolve under future warming. Together, these efforts aim to provide a unified understanding of convectively driven wind hazards—from broad-scale extremes to localized tornadic potential—and to inform climate-resilient planning and severe-weather risk assessment across Canada.

Keywords:

Drought Signals in Alberta's Hail Dynamics

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Abstract

Drought is a recurring extreme climate event that ranks among the costliest natural disasters worldwide, significantly impacting water resources, agriculture, and the natural environment, leading to substantial economic losses. These impacts are particularly notable in regions such as Alberta, Canada, where drought conditions can also intensify convective weather systems, and potentially affecting hailstorm activity. However, the understanding of the relationship between drought conditions and hailstorm activity remains limited, largely due to the scarcity of long-term ground-based observations. This study performs a comprehensive analysis on how drought periods affect hailstorm activities, using the Vertically Integrated Liquid (VIL) as a proxy for hail size. The Standardized Precipitation Evapotranspiration Index (SPEI) was employed to classify dry and wet conditions across various temporal scales (3, 6, 12 consecutive months, 6 months from April to September, and 12 months from October to September), accounting for inter-annual and sub-annual variations. Extensive timeseries radar and atmospheric reanalysis data covering the period from 1997 to 2020, were utilized for this analysis. Composite analysis was conducted to assess the influence of dry and wet periods on extreme values of maximum VIL (max_VIL) in Alberta for various time scales. The results indicate a significant correlation between drought conditions, as measured by SPEI12, and extreme hail sizes, with both the 90^{th} and 99^{th} quantiles of max_VIL showing statistical significance of less than 5%. This suggests that prolonged drought periods may contribute to the development of more severe hailstorms, likely due to heightened atmospheric instability and stronger updrafts. Although shorter-term drought conditions showed near-significance, they too could influence hailstorm severity to some extent. These findings provide valuable insights into the complex relationship between drought conditions and hailstorm activity, which can inform future predictive models and mitigation strategies.

Keywords: VIL, Composite analysis, Hail dynamics, CAPE

Interpretable Landslide Susceptibility Mapping in Far-Western Nepal Using Ensemble Machine Learning and Rainfall Extremes

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Abstract

Landslides are a frequent and destructive hazard in the hilly and mountainous areas of Nepal. The Far-Western region, in particular, is highly prone to slope failures because of steep topography, active faults, and intense monsoon rainfall, which has become more common in recent years. Despite many studies across central and eastern Nepal, the far western region remains less explored.

This research developed a landslide susceptibility mapping framework using machine learning for the Far-Western part of the country. The work combines topographic, geological, and infrastructure-related factors with rainfall extremes. Four algorithms—CatBoost, XGBoost, Random Forest, and Support Vector Machine—were compared using data balancing (SMOTENC), recursive feature elimination (RFECV), and SHAP values to interpret model behaviour.

CatBoost performed the best (AUC=0.946; accuracy=0.89), followed by Random Forest and XGBoost. The SHAP results showed that proximity to faults and roads, lithology, and 99th-percentile rainfall are the major factors linked to landslide occurrence. The final susceptibility map shows that roughly 11% of the region lies in the "Very High" category, mostly along fault zones and transport corridors, while about 70% is comparatively stable.

These results underline the need for safer road design, proper drainage, and informed land-use planning in sensitive zones. The approach also offers a practical, explainable method for landslide assessment in other mountainous and data-scarce regions.

Keywords:

Hail impact on the clayey soil

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Abstract

I am investigating the effects of hail impact balls (starting with 1 inch balls) on two representative Canadian clay soils — Ottawa and Sombra clays — through a combination of experimental testing and numerical simulation. Controlled drop tests were conducted using 1-inch-diameter spherical projectiles made from various materials to replicate the kinetic energy and deformation behavior associated with natural hailstones. The soil response, including surface deformation, dent depth and kinetic energy dissipation, was recorded and analyzed. Complementary finite element simulations were performed in Abaqus to model the impact process and assess the agreement between experimental and computational results. Comparative analysis highlights the influence of soil type and projectile material on impact-induced stress distribution and surface indentation. The combined experimental–numerical approach enhances understanding of soil–hail interactions, contributing to improved predictions of hail size being fallen in a rural areas in Canada.

Keywords: Hail impact, Soil, Abaqus, Quasi static

Geotechnical Evaluation of Wind Speeds from Windthrow Resistance of Trees

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Abstract

In this presentation, an overview of an innovative mechanistic model developed to predict the wind speed associated with tree failure caused by windthrow is presented. This model enables a more comprehensive investigation of the influence of soil characteristics on tree stability and can serve as a valuable tool for forest management in mitigating the risk of tree uprooting.

Keywords: Windthrow, Failure Envelopes, Soil-Root Plate, Critical Wind Speed

How confident are estimates of extremely low probability rainfall from ensemble pooling and spatial transposition

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Abstract

A central challenge in hydrology is to quantify sampling uncertainty for extremely low annual exceedance probabilities ($AEP \approx 10^{-3}$–10^{-5}), the range most relevant to high-hazard dam design. Multidecadal observations remain too limited to support precise estimation of such return levels. Large climate model ensembles help but do not resolve the problem; for example, a 50 member archive spanning 30 years yields about 1,500 annual maxima per grid cell, which is still inadequate for estimating ten thousand to one hundred thousand year return levels with stability. We introduce a framework that combines ensemble pooling with spatial transposition guided by L moment homogeneity to expand the effective sample size at each location to nearly ten thousand independent annual maxima. The procedure identifies homogeneous neighborhoods using L CV similarity, transposes annual maxima within those neighborhoods, and then fits Generalized Extreme Value models to the expanded samples. Applied at continental scale, the method substantially reduces uncertainty in rare event return levels, with median 95 percent confidence interval widths shrinking by more than 60 percent for the ten thousand year event. The upper tail empirical quantiles also converge more closely to the Generalized Extreme Value fits, indicating improved parameter stability. This data efficient strategy yields defensible extreme tail metrics for multi hazard risk and resilience planning, enabling stronger design checks, stress testing, and risk informed decisions for critical water infrastructure.

Keywords: