

CSSL- CMRR - WindEEE Multi-Hazard Risk and Resilience Workshop

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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

Resilience has gained prominence in academic research as key approaches to climate and environmental risk reduction. However, dominant interpretations are shaped by experts, practitioners, and scholarly opinions, with limited attention to how local communities perceive and experience these concepts. This study addresses that gap by drawing on in-depth interviews with residents of Old Fadama and Nima informal settlements in Accra, Ghana—areas highly vulnerable to climate-related hazards. Three key findings emerge: (1) practitioner frameworks do not fully capture the multiple local perspectives of resilience; (2) resilience is an interconnected concepts embedded in everyday experiences; and (3) institutional responses remain poor and undermine efforts to transition resilience into long-term sustainability. Based on the findings, the study recommends rethinking resilience and recognizing informal community structures as important actors in local climate adaptation and urban planning processes.

Keywords: climate change; resilience; informal settlements; local perspectives; Ghana

Designing Sustainable Systems with Immersive Climate Analytics

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Abstract

Climate change and unsustainable energy use are contributing to growing environmental challenges, disrupting communities, infrastructure, and interconnected socio-technical systems. Although climate and disaster risk models provide valuable insights, their complex analytical outputs often remain difficult to translate into practical action.

This research explores the integration of disaster-risk modelling, generative artificial intelligence (AI), and immersive analytics to better understand, communicate, and reduce the impacts of extreme weather events. The proposed framework connects multi-scale climate impact modelling with realistic, location-specific visualizations to create immersive experiences of potential future climate scenarios. As an initial step, the research involves developing image-based datasets of real-world storm damage and exploring AI-generated disaster visualizations.

By making climate risks more tangible, accessible, and locally meaningful, this research aims to bridge the gap between complex analytical outputs and real-world decision-making, supporting climate adaptation, risk reduction, and the design of resilient and sustainable systems.

Keywords: immersive analytics; climate resilience; sustainable systems design; generative AI; climate risk communication; disaster risk management

Simplified Assessment of Compound Flooding under Tropical Cyclones and Future Mean Sea-Level Rise

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Abstract

Coastal inundation during tropical cyclones results from the combined effects of storm-driven water levels, wave processes, and rainfall, while future mean sea-level rise (MSLR) can increase flood extent. However, explicitly resolving these processes across multiple storm and climate scenarios can be computationally demanding. As part of the Community and Infrastructure Resilience to Climate-geological Long-term Effects (CIRCLE) project, this study develops an efficient framework for coastal inundation assessment along the southern coast of Cuba, in the Gulf of Batabanó. Five historical tropical cyclones were simulated with Delft3D-FLOW and Delft3D-WAVE, while XBeach-NH was used to assess in-fragravity waves during Charley (2004). A representative 0.20 m wave-induced water-level contribution was derived from 25 peak values, and future water levels were approximated by vertically translating present-day series by +0.29 m and +0.95 m for 2050 and 2100, respectively. The static adjustment closely reproduced future Delft3D-FLOW simulations, while the infragravity contribution at peak total water level was limited. SFINCS was used for inundation modeling and validation with observed maximum depths during Rafael (2024). Including the wave contribution reduced MAE and MRE, while adding rainfall further improved performance and increased Pearson correlation to 0.982, highlighting the relevance of compound coastal-pluvial flooding.

Keywords: coastal flooding; compound flooding; tropical cyclones; mean sea-level rise; SFINCS

EVAMIC: A Multivariate Probabilistic Framework for Compound Coastal Flooding Hazard Assessment in Havana

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Abstract

Coastal structures like the Havana Malecón face severe compound flooding risks that traditional univariate analyses often underestimate. This presentation introduces EVAMIC, a Methodology for the Multivariate Statistical Assessment of Compound Flooding. The framework consists of three main phases designed to overcome the limitations of historical records. First, synthetic hurricanes representing current climate conditions are generated using the TCWISE tool, providing a robust dataset of extreme events. Second, a hazard-based screening applies K-Means clustering and a novel Multiparametric Hazard Index (IP) to reduce scenarios. This index penalizes inversely proportional risks like low central pressure and slow movement, selecting the most critical storm families for high-fidelity hydrodynamic simulation (SICOM). Finally, a multivariate statistical analysis is performed using C-Vine Copulas. By adopting a “forensic engineering” approach that prioritizes the worst-case physical scenario maximizing overtopping discharge, the model constructs joint return period maps. Application to the Havana Malecón demonstrates that this multivariate approach captures strong tail dependencies. The results reveal that ignoring simultaneous wave and surge action leads to critical risk underestimations of up to 60%, highlighting EVAMIC as an essential tool for updating coastal defense design standards.

Keywords: compound flooding; multivariate analysis; vine copulas; hazard index; coastal resilience

Shade Deserts: Mapping Shade Supply-Demand Gaps Using Hyperlocal Microclimate Simulations

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Abstract

As climate change increases the frequency, duration, and intensity of extreme heat events, inequitable access to thermally comfortable outdoor environments has become a pressing urban planning and public health challenge. In dense cities, limited shade can amplify heat exposure and compound existing social and health inequities. This study develops a spatio-temporal framework to identify gaps between shade supply and demand. We introduce the concept of shade deserts, defined as areas where shade availability (supply) fails to meet the need for shade (demand). Shade supply is quantified using hyperlocal, 1-metre resolution microclimate simulations that capture temporal variations in shadow patterns throughout the day. Shade demand is estimated by integrating the Universal Thermal Climate Index (UTCI), a physiological indicator of heat stress, with measures of physical vulnerability. We further identify persistent shade deserts and shade oases, referring to locations that consistently remain underserved or well-served. Applying this framework to Vancouver, BC, Canada, we identify a clear east-west divide, with persistent shade deserts concentrated in the eastern neighbourhoods and shade oases more prevalent in the west. Statistical analyses reveal that the presence of shade deserts is significantly associated with socioeconomically disadvantaged populations. The proposed approach and findings from this study provide a practical tool for planners and public health practitioners seeking to prioritize interventions, enhance climate resilience, and promote more equitable urban environments in the face of intensifying climate change.

Keywords: shade desert; microclimate simulation; heat mitigation; thermal equity; climate change

Flood frequency under climate change in the Great Lakes Basin: reliability of non-asymptotic extreme value inference with short records and GCM-driven WRF-Hydro projections

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Abstract

Floods are among the most frequent and damaging natural hazards, and their characteristics are evolving under climate change. However, flood assessments under climate change still rely largely on asymptotic EVT methods that can be unstable for short records, and few studies have combined non-asymptotic flood frequency models with future, GCM-driven streamflow projections while evaluating the reliability of estimated return levels, particularly in snow–rain transition basins. This study investigates projected changes in flood magnitude and flood-peak timing across the Great Lakes Basin (GLB), an important freshwater resource of North America. We integrate streamflow simulations from the WRF-Hydro model, driven by an ensemble of eight CMIP6 climate models under the SSP5-8.5 scenario, with non-asymptotic and flexible-tail flood frequency models. We compare classical flood frequency models with MEV and ExtGPD formulations fitted to ordinary flood events using short calibration windows. MEV distributions were selected as the best performing models at a majority of gauges and provided comparatively stable return-level estimates across calibration samples, although their comparatively narrow calibration-sampling intervals showed below-nominal coverage of observed tail events, particularly for larger return periods. Future projections indicate that flood magnitudes increase most strongly in the southern and eastern GLB, while northern subbasins show smaller increases or localized decreases. GCM-driven simulations project earlier annual flood peaks at most gauges. These findings suggest a reorganization of flood regimes driven by effects of intensified precipitation and altered snowmelt dynamics. Overall, the results demonstrate the value of MEV for short-record flood extrapolation while emphasizing the need to evaluate interval reliability separately.

Keywords: flood frequency analysis; metastatistical extreme value; WRF-Hydro; return-level uncertainty; Great Lakes Basin; climate change projections

Modelling Vertical Wind Angle Effects by Varying Building Roof Slopes

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Abstract

The effects of the vertical wind angle on building surface pressures is investigated in this study. Specifically, the behavior of the linear correction term, $B(\theta)$, which accounts for the vertical wind angle effects following the Wu & Kopp (2016) QS model was studied using the synchronous pressure and velocity data from the experiments conducted by Acosta (2024). Four different roof slopes (0° , 14° , 27° and 45°) were considered in the analysis. The term, $B(\theta)$, was determined by plotting the change in the conditionally averaged pressure coefficients with respect to the variation in the vertical wind angle. The linear plot of $B(\theta)$ showed similarity for flows governed by strong flow separation and decreases in slope as the effects of flow separation is reduced and becomes negligible for flow cases where there is no flow separation such as the windward panel for 45° roof slope with wind direction perpendicular to the ridge. It was also found that changes in pressure is more sensitive to upward wind cases as compared to downward winds which can be attributed to the enhanced flow separation associated with upward winds.

Keywords: vertical angle effects; quasi-steady theory; low-rise buildings

Evaluation of SWOT Lake Levels and their Uncertainties in the Mackenzie River Basin

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The Surface Water and Ocean Topography Mission (SWOT) provides a suite of remotely sensed products to assess terrestrial hydrology. In this study, we evaluate the SWOT L2B Lake Level product at lakes across the Mackenzie River Basin (MRB) in Northern Canada. As Canada's largest river basin, the MRB is home to abundant freshwater and natural resources. The MRB and its subwatersheds are of tremendous economic, agricultural and cultural significance, and the region is threatened by water security challenges and climate change. This research seeks to quantify the potential to use SWOT L2B data to constrain hydrologic simulations for the MRB. Using data from 2023 to present, we compare SWOT lake levels against in situ gauge stations and hydrologic model output for fifteen MRB lakes with areas ranging between 1 km² and 30,000 km². Preliminary results show SWOT measurements exhibit useful fidelity for medium-large lakes, with challenges at smaller scales and in lakes with unique geomorphology and/or outlet orientation.

Keywords: remote sensing; radar; water surface elevation; Mackenzie River Basin; lakes

Towards Automated National-Scale Regional Flood Modelling in Canada: A Modular Geospatial Preprocessing Workflow

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Abstract

Flood hazard maps provide essential information for assessing flood exposure, guiding land-use planning, informing risk assessment, and supporting emergency management. Producing these maps consistently at a national scale requires high-resolution hydraulic models supported by extensive hydrographic and terrain datasets. However, preparing hydraulic-model inputs for thousands of river reaches across diverse watersheds is a time-consuming task, particularly when performed manually. Additional challenges include ensuring hydrographic connectivity, preprocessing high-resolution digital elevation models (DEMs), and delineating computational tiles that respect subbasin boundaries and river-network connectivity. Automated and scalable workflows are therefore needed to minimize manual intervention while maintaining hydrologic and hydraulic consistency. This study presents a modular, automated geospatial preprocessing framework developed as an initial step toward high-resolution 2-D and 1.5D flood modelling across Canada using nationally available datasets. The framework integrates three complementary workflows: river and lake preprocessing, computational tile generation, and river bathymetry burn-in. Together, these workflows provide an integrated approach to automating the preparation of high-resolution hydraulic-model inputs across large river networks.

The framework is demonstrated on a selected area in southern Ontario to generate continuous hydrographic rasters, computational tiles, modified DEMs, and supporting inputs for hydraulic simulations. This work lays the foundation for developing a fully automated and scalable hydraulic modelling framework for Canada-wide high-resolution flood-hazard mapping as part of the multi-University Open-FRANC project supported by Public Safety Canada.

Keywords: flood modelling; automation; geospatial processing; hydraulic modelling; flood hazard mapping

Multi-Hazard Coastal Flooding in Tofino: Sea-Level Rise, Cascadia Deformation, Storm Surge, and Extreme Rainfall

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Abstract

Coastal communities along the Cascadia margin are exposed to several hazards that can occur together and amplify future flood risk. In Tofino, British Columbia, these include sea-level rise, earthquake-induced land deformation, storm surge, and intense rainfall. This study uses LISFLOOD-FP hydrodynamic modelling to explore how these drivers interact and how their relative importance changes across different future conditions. The first part of the study examines the combined effects of Cascadia coseismic deformation and relative sea-level rise using 100 simulations covering multiple deformation percentiles, sea-level scenarios, and earthquake-magnitude ranges. Sea-level rise explains most of the variation in simulated inundation area, while coseismic deformation changes the spatial pattern and magnitude of flooding and can lead to non-monotonic responses across scenarios.

The second part extends the analysis to compound coastal-pluvial flooding using 240 rainfall-on-grid simulations. Joint flooding is compared with coastal-only and pluvial-only cases across historical and future sea-level conditions. At a 0.15 m depth threshold, pluvial-only simulations reproduce most of the joint flood footprint, while the coastal contribution becomes more important as sea level rises. Rainfall timing also matters: concentrating the same 24-hour rainfall depth near the coastal peak increases the maximum flooded area by 13.5-18.7%.

Keywords: compound flooding; sea-level rise; coseismic deformation; extreme rainfall; multi-hazard resilience

A Data-Driven Machine Learning Framework for Predicting the Undrained Shear Strength of Bio-Treated Soils for Infrastructure Resilience

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Abstract

Soil is the literal foundation of infrastructure. When soil is subjected to rapid, sudden loading, water trapped within the soil cannot drain away fast enough. This creates high pore-water pressure, reducing effective stress and potentially causing severe loss of soil strength. In loose, saturated soils, this behavior can lead to strain softening and flow liquefaction, creating significant challenges for infrastructure resilience during seismic and other rapid-loading hazards.

Traditional soil stabilization often relies on cement and lime, which involve high energy consumption, pollution, and significant greenhouse-gas emissions. Microbially induced calcite precipitation (MICP) and enzyme-induced calcite precipitation (EICP) offer promising, sustainable alternatives for improving soil strength while reducing reliance on conventional stabilizers.

However, evaluating the mechanical response of bio-treated soils currently relies heavily on laboratory testing, which can be time-consuming and requires destructive testing of treated specimens. This study develops a data-driven machine learning framework to predict the monotonic undrained shear strength of MICP/EICP-treated soils using fundamental soil properties, initial state conditions, treatment protocols, and shearing conditions. By learning complex, nonlinear relationships within an experimental database, the framework aims to provide rapid estimates of undrained strength without requiring every potential treatment condition to be physically tested.

The proposed framework will support the identification of treatment conditions associated with improved strength and reduced susceptibility to strain-softening behavior. Ultimately, this research aims to support more efficient and sustainable bio-mediated ground improvement and contribute to the development of resilient infrastructure.

Keywords: machine learning; undrained shear strength; bio-mediated soil improvement; infrastructure resilience

Extreme Wind-Driven Rain Across Canada Under Global Warming: Projected Changes and Drivers

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Abstract

The co-occurrence of wind and rainfall can yield larger impacts than when either hazard occurs in isolation. In Canada, extreme precipitation events commonly co-occur with strong winds during extratropical cyclones, frontal systems, and convective storms. Wind-driven rain (WDR) occurs when wind drives rainfall against building façades, increasing the potential for water penetration, moisture deterioration, and damage to building envelopes. As Canada's climate warms, changes in heavy precipitation and wind may intensify WDR and increase risks to buildings and infrastructure. Understanding where and why these changes occur is therefore important for climate-resilient communities.

This study examines historical and future WDR events across Canada using high-resolution regional climate simulations (CRCM5–CMIP6). Hourly precipitation and wind data are used to estimate WDR exposure and identify extreme events. Statistical analysis is then used to estimate the severity of rare WDR events under different levels of global warming. To understand what drives future changes, the roles of precipitation, wind, and their dependence are also separated and evaluated seasonally. Finally, projected changes in WDR hazard are translated into building-envelope risk across Canadian communities.

Under 3°C global warming, extreme WDR increases by up to 22.6% across Canada. Precipitation is the main driver of these changes, while changes in the dependency between precipitation and wind also play an important role. The projected increase in WDR translates into a 12–26% increase in building-envelope risk.

These results identify where and why WDR risk may increase. This information can support climate-resilient infrastructure planning and adaptation across Canada.

Keywords: wind-driven rain; compound extremes; climate change; building-envelope risk

Addressing the validation paradox in large-scale vulnerability assessment: subdistrict-level tropical cyclone vulnerability in India

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Abstract

Quantifying societal vulnerability to climate hazards is essential for risk reduction, yet the lack of observable ground truth creates a "validation paradox" where methodologically sound frameworks yield contradictory rankings. This study provides a comprehensive robustness evaluation of eight objective aggregation frameworks applied to 50 relevant vulnerability indicators across 6,300 subdistricts in India to assess tropical cyclone vulnerability. We show that widely used methods like Principal Component Analysis (PCA) and TOPSIS exhibit important limitations, including extreme high-score bias, high sensitivity to indicator selection, and "sign indeterminacy", where arbitrary eigenvector orientation can invert vulnerability rankings. Specifically, the widely adopted variance-based Cutter and Finch (2008) additive framework can produce risk signals diametrically opposed to known socio-economic realities. To address these limitations, we propose the application of Non-negative Matrix Factorization (NNMF) as an objective dimensionality reduction and aggregation technique in disaster science, and introduce the novel Pareto Ranking-based Method for Aggregate Relative scoring (PARMAR). NNMF provides a dimensionally efficient, non-negativity-constrained decomposition ensuring reproducible and physically interpretable latent components. PARMAR extends Pareto dominance to resolve "tied ranks" among decision-making units, transforming discrete ordinal hierarchies into a continuous vulnerability gradient necessary for targeted prioritization. Through a comprehensive Monte-Carlo simulation, we show that NNMF achieves superior stability under data perturbation and indicator sampling. The combined NNMF-PARMAR approach emerges as the most robust and interpretable framework, demonstrating minimal sensitivity to indicator selection and data noise. This benchmarking study offers a mathematically rigorous, scalable and transparent foundation for prioritizing climate adaptation and disaster risk reduction under intensifying hydroclimatic extremes.

Keywords: climate adaptation and resilience; disaster risk reduction; non-negative matrix factorization; PARMAR; tropical cyclone risk; vulnerability assessment

Implementation of the Performance-Based Hurricane Engineering framework for concurrent multi-hazard analysis in Cuban coastal communities

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Abstract

Cuba, located in a region of high cyclonic activity, faces significant economic losses in its housing sector. Although Hazard, Vulnerability, and Risk (HVR) studies are fundamental for territorial management, these studies have, to date, analyzed hazards in an isolated manner. Performance-Based Hurricane Engineering (PBHE) is presented as an advanced alternative that integrates multiple hazards concurrently. This investigation proposes a multi-risk assessment of two case studies located in the coastal community of Playa Cajío, associated with the hazards of strong winds and intense rainfall, through the implementation of the PBHE framework in Cuba. The six phases of PBHE were applied, from the probabilistic characterization of the hazards, performed by means of a joint distribution model based on Copula theory, to the analysis of losses. Risk is evaluated in economic terms on the basis of the repair costs of the damage, expressed as percentages of the dwelling value. The thesis concludes that, for the two dwellings analyzed, the expected annual losses under the combined hazard scenario (wind + rainfall) exceed those under single-hazard scenarios by more than 20%. The results of this work will serve to enrich the range of tools upon which risk managers in Cuba will be able to rely.

Keywords: Performance-Based Hurricane Engineering (PBHE); multi-hazard risk assessment; copula theory; expected annual losses; coastal housing vulnerability; strong winds and intense rainfall

Escaping Gases: How Global Warming contributes to gases escaping Earth's Atmosphere

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Abstract

In the 1990s, greenhouse gases were becoming a major concern due to the increase in global average temperatures. Consequently, in 1997, the Kyoto Protocol was implemented to reduce the use of greenhouse gases in daily-use products. But this was only a short-term goal. As the century turned, researchers began realizing that another major substance that contributed to global warming was CO_2 in particular. To mitigate this, as well as establish a long-term goal of climate improvement, the Paris Agreement was signed by many signatory nations in 2016. But on Jan. 27, 2026, Donald Trump withdrew from the Paris Agreement in hopes of increasing the industrialization of the USA. While this threatens to increase the global average temperature again, there is another angle that needs to be considered. The atmospheric escape of gases has been a process that occurs for every planetary body since the creation of an atmosphere, and Earth is no different. Since its creation, Earth has been leaking gas to maintain a temperature, as the gases that escape carry excess heat with them. But the escaping gases are pushed away from Earth by solar wind, which means that the Earth cannot recover them. CO_2 is heavier than O_2 or H_2 ; therefore, the escaping gas is more often than not the one needed to cool the planet. This presentation aims to discuss the three most impactful types of atmospheric escape and how they are influenced by global warming. Global Warming affects Thermal escape through the excess heating of particles, ejecting gases that don't usually have enough thermo-kinetic energy. Warming also affects atmospheric gases by hastening the hydrodynamic rise of the atmosphere. As gas heats up, it rises; if it rises into the ionosphere or higher, the gases are able to escape. Finally, greenhouse gases change the rate of UV radiation entering the atmosphere, allowing for the breakdown of molecules in gases, which now have the energy to escape.

Keywords: global warming; atmospheric escape; greenhouse gases

Thank you

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