EXECUTIVE SUMMARY

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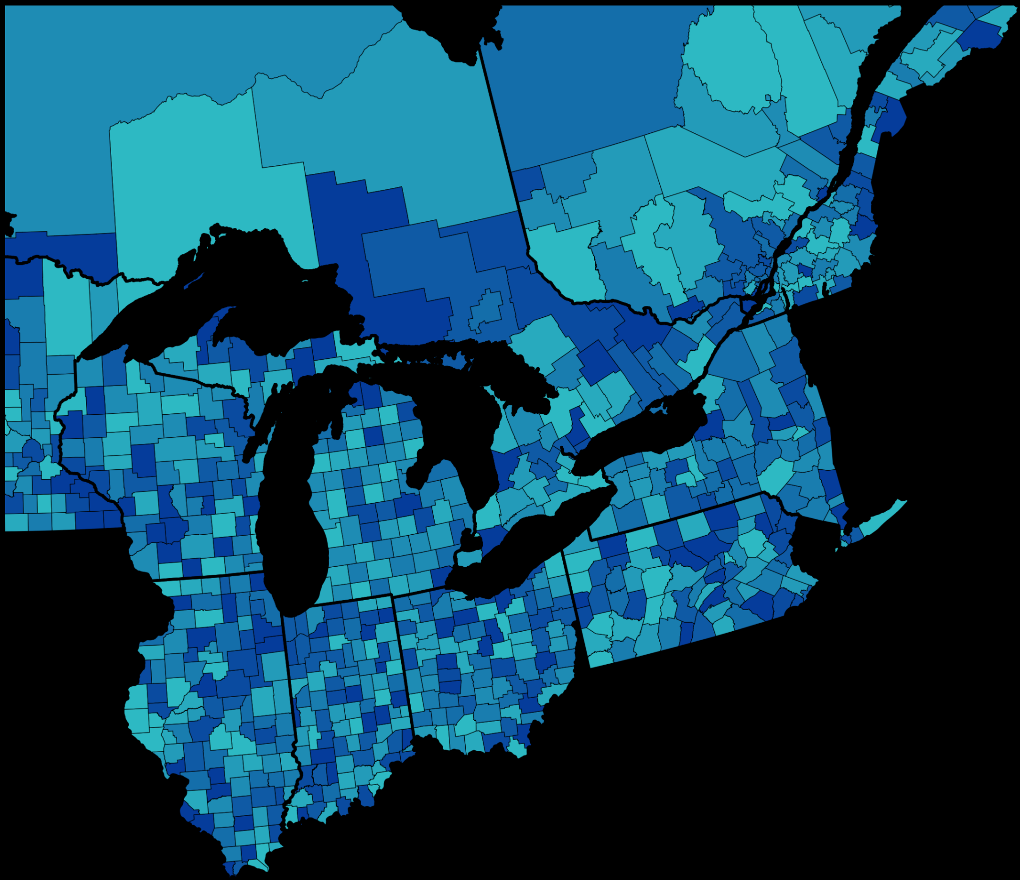

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AI for Climate-Resilient Trade Governance in the Great Lakes-Saint Lawrence Corridor

Authors: Igor Sadoune, Nathalie de Marcellis-Warin, Martin Trepanier, Thierry Warin

The Great Lakes-Saint Lawrence corridor (GLSL), the world's third-largest economy with $8.8 trillion USD gross domestic product and 31% of the combined Canadian and American workforce, faces existential risks from intensifying hydrological extremes. Rising temperatures, volatile precipitation, and water-level fluctuations threaten to disrupt maritime trade, critical to North America. The importance of the GLSL maritime corridor stems from the irreplaceable role maritime transportation plays in moving essential commodities such as steel, grains, gas, and oil, which underpin the region's heavy industries, including automotive, machinery production, and mining.

Furthermore, the recent U.S.-Canada trade war may place additional stress on maritime infrastructure, as economic entities could be compelled to seek alternative routes to circumvent U.S. border tariffs. Indeed, if a significant portion of interstate trade is redirected towards international partners (e.g., Europe) by both U.S. and Canadian stakeholders, the navigability of the St. Lawrence River will become increasingly critical, further amplifying the strategic importance of the GLSL system.

To address this challenge, we propose an AI-driven governance framework integrating synergistic capabilities: predictive analytics combining machine learning (ML) with the National Oceanic and Atmospheric Administration (NOAA) hydro-climatic data, Automatic Identification System (AIS) navigation patterns, and economic data to forecast climate-economic cascades; deep generative modeling (DGM) to synthesize high-dimensional maritime scenarios while amplifying rare events; and multiagent reinforcement learning (MARL) that trains decentralized port, vessel, and regulator agents to coordinate climate adaptation.

1 Framework

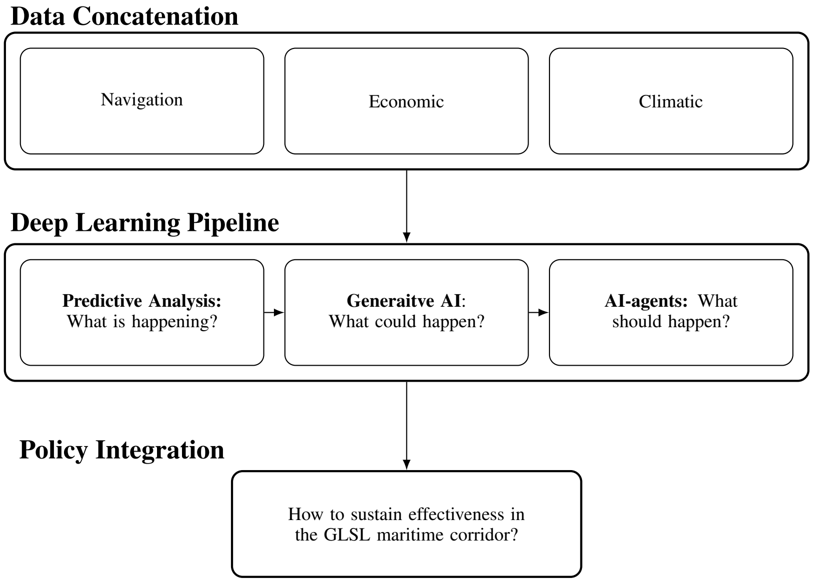
As climate volatility intensifies in the GLSL region, AI-driven methodologies offer novel pathways to enhance systemic resilience and policy coordination. This section delineates a tripartite framework depicted in Figure 1—spanning predictive modeling, synthetic environment generation, and adaptive multiagent systems—that synergistically addresses the region's governance challenges. This framework's efficacy stems from its iterative synthesis of predictive, generative, and adaptive components. First, supervised ML models distill causal relationships from observational data, identifying latent variables that mediate climate-economic interactions. Second, DGM instantiates these relationships within synthetic maritime-climatic environments, enabling counterfactual stress-testing of policy interventions. Third, MARL agents train extensively in these environments, developing robust decision protocols that transfer to real-world governance.

Predictive analytics. By integrating navigation patterns from the AIS with hydro-climatic observations from NOAA, predictive models can forecast water-level fluctuations and their cascading impacts on maritime logistics.

Deep generative modeling for synthetic policy environments. While traditional ML excels at pattern recognition, DGM offers paradigm-shifting potential for synthetic environment creation and transcend traditional forecasting by constructing synthetic policy environments where stakeholders can safely test interventions. These architectures address two persistent challenges in policy design: data scarcity and counterfactual uncertainty. By amplifying weak signals through categorical data balancing and enabling privacy-preserving synthetic data generation, DGM facilitates robust policy testing without compromising sensitive information.

Multiagent reinforcement learning for adaptive governance. The stochastic nature of climate impacts demands governance systems capable of decentralized coordination among heterogeneous stakeholders. MARL provides a computational framework for modeling this complexity, wherein autonomous agents—representing governments, shipping firms, and environmental agencies—coevolve adaptive policies through iterative interactions. Unlike conventional optimization approaches, MARL agents learn hierarchical decision rules that balance local objectives (e.g., port efficiency) with global constraints (e.g., carbon budgets).

Figure 1: Operational pipeline.



2 Expected Outcome

The proposed AI-driven governance framework is expected to yield two primary outcomes: high-impact research contributions and an operational decision-support tool for the GLSL corridor. First, the integration of predictive analytics, generative AI, and MARL will generate multiple peer-reviewed publications addressing critical gaps in climate adaptation, maritime logistics, and decentralized governance systems. These interdisciplinary studies will advance both theoretical understanding and applied methodologies in AI for environmental resilience.

Second, the framework will culminate in a dynamic decision-making tool embedded within the GVCdtLab's digital-twin dashboard. This tool will provide real-time insights into climate-economic risks, enabling stakeholders to simulate policy interventions, optimize vessel routing under volatile conditions, and coordinate cross-border responses to hydrological extremes. By unifying climatic, navigation, and economic metrics, the tool will empower ports, regulators, and shipping entities to proactively mitigate disruptions while balancing efficiency, safety, and sustainability goals.

Table 1: GLSL MARL Agent Specifications

Agent Type	Observation Space	Action Space	Objective
Ship Owners	Draft limits, fuel prices, cargo urgency	Speed adjustment, load allocation	Minimize delay + fuel costs
Port Agents	Berth availability, vessel queues	Docking priority, tariff adjustments	Balance congestion vs. revenue
Regulator	System-wide emissions, water levels	Emission caps, toll pricing	Enforce sustainability + equity

Table 1 provides a glimpse of the coordinated decision-making dynamics enabled by the MARL architecture. Each agent type—ship operators, port authorities, and regulators—employs distinct observation spaces, action sets, and optimization goals to model real-world trade-offs. Ultimately, this work will enhance the GLSL corridor's adaptive capacity, ensuring its continued role as a linchpin of North American trade amid escalating climate and geopolitical uncertainties.

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