Sequential Stochastic Optimization of Shipping Routes Under Time-Evolving Metocean Forecasts

Scientific context

Maritime route planning increasingly relies on probabilistic metocean forecasts derived from ensemble prediction systems. These forecasts evolve in time as new observations are assimilated, altering both expected environmental conditions and their associated uncertainty. Classical routing approaches typically assume deterministic and/or static forecasts and therefore do not fully exploit the information contained in evolving probabilistic predictions.

This setting naturally gives rise to a sequential decision-making problem under uncertainty, where routing decisions must be updated as forecasts change. From a mathematical perspective, the problem lies at the intersection of stochastic processes, dynamic optimization, and uncertainty quantification, with strong links to scientific computing and applied probability.

Problem description

The project focuses on the formulation and analysis of a sequential routing problem for marine vessels under time-dependent uncertain metocean conditions. The vessel trajectory is adjusted over time, with decisions taken at successive stages based on the current vessel state and the available probabilistic description of future environmental conditions.

The objective is to understand how evolving uncertainty impacts routing decisions and overall performance metrics such as travel time, energy consumption, or exposure to adverse conditions. A key question is how to account for the fact that future forecasts themselves will change, rather than treating uncertainty as fixed throughout the voyage.

Beyond its mathematical interest, the proposed work is directly connected to challenges arising from the climate transition. Maritime transport plays a central role in global trade and is a significant contributor to greenhouse gas emissions, motivating ongoing efforts to reduce fuel consumption, optimize operations, and increase resilience to climate variability and extremes. As climate change alters wind, wave, and current patterns, and as regulatory pressure encourages more energy-efficient and risk-aware navigation, routing strategies that can explicitly account for uncertainty and its evolution become increasingly important. By developing mathematical frameworks for sequential decision-making under time-evolving metocean uncertainty, this project contributes to the design of navigation strategies that support safer, more energy-efficient, and climate-adaptive maritime operations.

Key mathematical questions

The project raises several open questions of interest to applied mathematics:

- How should time-evolving probabilistic forecasts be represented within a sequential decision framework?
- What is the impact of forecast update frequency and uncertainty structure on routing decisions?
- How does one balance optimality and robustness when decisions must be made under incomplete and evolving information?
- What simplifications or reduced representations are necessary to make such problems computationally tractable?

Expected outcomes and scope

Rather than prescribing a specific solution approach, the project invites participants to explore modeling choices, mathematical formulations, and numerical strategies suitable for this class of problems. Possible outcomes include simplified theoretical models, lower-dimensional or simplified formulations, or proof-of-concept numerical experiments on idealized routing scenarios.