

Local and Global Controls on AMOC Stability

1. Context

The possibility of a shutdown of the Atlantic Meridional Overturning Circulation (AMOC) has attracted growing public attention because of its potentially far-reaching consequences for climate and human societies. Beyond assessing the likelihood or timing of such an event, a fundamental scientific challenge is to identify the physical factors that govern the stability of the circulation and how they evolve with climate. Climate proxies and numerical simulations show that the AMOC can undergo major reorganizations, sometimes accompanied by rapid climatic changes (Lynch-Stieglitz 2017; Menviel et al. 2020). Identifying the mechanisms driving these changes is therefore essential for anticipating the evolution of the AMOC in a warming climate.

A fundamental insight into AMOC dynamics dates back to Stommel (1961), who showed that the circulation can sustain itself through a feedback involving the northward transport of salt. This feedback can allow two stable circulation states to coexist under identical forcing conditions, a phenomenon known as bistability. Subsequent studies have identified additional mechanisms involving deep convection, sea ice, and ocean variability that can generate oscillations or modify the conditions under which multiple equilibrium states exist (Welander 1982; Winton 1993; Loving and Vallis 2005; Cessi 1996). Together, these processes help explain the range of possible AMOC dynamical behaviors, from oscillations to abrupt transitions between distinct circulation states.

The processes governing the AMOC, however, extend well beyond the Atlantic basin. In particular, the Southern Ocean connects deep waters to the surface and helps regulate the global ocean density distribution (Gnanadesikan 1999; Nikurashin and Vallis 2012; Rogers et al. 2023). By influencing global stratification, these processes can modify the conditions under which the AMOC operates, without necessarily directly affecting its regional feedback mechanisms. Recent studies also indicate that the different possible AMOC behaviours, including oscillations, bistability, and abrupt transitions, depend on the background climate state (Vettoretti et al. 2022; Nadeau et al. 2025). Yet, how these regional and global processes interact to shape AMOC dynamics under different climate conditions remains an open scientific question.

2. Objective

Determine how climate change influences AMOC stability and transitions between its different dynamical regimes.

3. Methodology

We will begin by investigating the mathematical origin underlying the emergence of multiple equilibrium states and oscillatory behavior using simplified low-dimensional models of the AMOC. We will then develop a sequence of increasingly complex models, progressively incorporating different physical processes to identify the conditions under which distinct dynamical regimes emerge and the parameter ranges over which they occur.

We will then incorporate the influence of Southern Ocean overturning on the Atlantic circulation into this conceptual framework (Johnson et al. 2007). This approach will allow us to quantify how changes in the global ocean density structure affect the existence and stability of different AMOC states. Our previous work has shown that high-frequency intrinsic variability in North Atlantic general circulation model (GCM) simulations depends on the background climate and can substantially modify the bifurcation structure. We will investigate this further by examining how this variability affects the stability of different dynamical regimes. We will first isolate the effects of Southern Ocean-related density changes and intrinsic variability before assessing their combined influence on the system's bifurcation structure.

A possible extension of the project will be to investigate how variability in overturning circulation and sea ice affects ocean carbon storage by coupling a biogeochemical model to the GCM, following the approach of Gregorio et al. (2026).

Candidate profile: Master's degree in physics, mathematics, engineering, or a related field, with a strong mathematical background.

For further information or to discuss the project before submitting a formal application, please contact Louis-Philippe_Nadeau@uqar.ca.