Abstract

Polynyas are large areas of open water within sea ice. Along the Antarctic coast, they are primarily formed by strong katabatic winds blowing from the continent, which drive sea ice away from the coast and allow new ice to form continuously. During ice formation, salt is rejected from the ice crystal lattice and released into the underlying ocean, a process known as brine rejection. This mechanism increases the salinity and density of the shelf waters. When polynyas form above the continental shelf, the densified water can cascade down the continental slope, ultimately reaching abyssal depths and contributing to the formation of Antarctic Bottom Water. This process plays a central role in driving the global thermohaline circulation, a key regulator of Earth's climate system.

In this thesis, the complexity of this phenomenon is addressed by separating it into two complementary parts. The first part focuses on the densification of water through brine rejection and its ability to generate buoyancy-driven flows. To this end, we developed a novel experimental apparatus capable of producing gravity currents driven exclusively by brine rejection. The experiments demonstrated that brine rejection alone is sufficient to generate gravity currents. Moreover, the results revealed that both flow rate and current thickness were greater without a slope than with one, and that the polynya size exerts a direct control on the current's discharge.

The second part of the thesis investigates the dynamics of cascading currents as they descend along a continental slope in a stratified environment. In such conditions, the current may arrest when it reaches a layer of equal density, with the maximum depth reached referred to as the penetration depth. The key parameters controlling this depth are the initial buoyancy of the current, the background stratification, and the slope angle. The slope angle controls the mixing of the current with the ambient fluid, which reduces its density. Using large-eddy simulations (LES), we examined the influence of slope angle on the penetration depth of turbulent gravity currents. The simulations successfully reproduced the results of previous laminar experiments, while also highlighting significant differences between laminar and turbulent regimes. Whereas slope angle had little effect in the laminar case, turbulent currents exhibited a strong dependence: penetration depth was maximized at intermediate slope angles (40–60°) and reduced at both small and steep slopes.