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Theoretical results for assessing ice-shelf buttressing and its suppression of marine ice sheet instability

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I present theoretical results describing marine-ice-sheet balances influenced by a buttressing ice shelf. The analysis reveals methods for the efficient assessment of the significance of buttressing, yields simplified models governing the position of grounding lines with buttressing incorporated, and obtains explicit threshold conditions on the length of lateral contact necessary for the Marine Ice Sheet Instability (MISI) to be suppressed. The results are based on asymptotic and numerical analysis of a quasi-one-dimensional marine ice sheet model in which the flow is subject to a lateral-drag parametrization.

The key result is a general equation developed from first principles describing the dynamical balances necessary for a steady grounding line that incorporates buttressing analytically as a function of ice-shelf length. The equation classifies ice shelves onto a spectrum of grounding-line balances spanning unconfined situations, in which extensional stress provides the primary resistance to flow across the grounding line, to those where buttressing provides the dominant resistance. The theory reveals a dimensionless quantity that assesses the relative importance of buttressing for any given ice shelf in terms of well-constrained parameters such as the grounding-line thickness and horizontal dimensions of the ice shelf. For large values of this parameter, the grounding line is controlled primarily by the length and width of the ice shelf and has very little sensitivity to basal-slip and -slope conditions.

Aspects of the theory are tested by comparison with data from a series of fluid-mechanical laboratory experiments involving particle velocimetry of a floating viscous film, showing good agreement.

The theory is applied to assess the significance of buttressing across various ice shelves of Antarctica. The predicted percentage of resistance from buttressing can be as low as 20% for certain inputs to the Ronne and Ross Ice Shelves, but increases to 50% for Filchner and 80% for the smaller eastern component of the Ross.

The theory is extended to develop threshold conditions on physical parameters necessary for lateral stresses to suppress the MISI on a reverse bed slope. The analysis is based on a novel method of effective phase portraits for grounding lines. It is shown that buttressing introduces an independent stabilizing mechanism because a grounding-line retreat increases the length of lateral contact and hence the buttressing force, thus creating a negative-feedback response. Even slight lateral contact of an ice shelf is found to readily suppress the MISI and remove hysteresis effects, indicating that the preservation of floating ice in lateral contact is a vital consideration for assessing future collapse. A critical condition based on the length of lateral contact of the ice shelf is found to set a threshold for when the MISI can be suppressed by lateral stresses.