All Bent Out of Shape: Buckling Instabilities of Viscous Sheets and Slabs

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The periodic folding of a sheet of viscous fluid falling upon a surface is a common fluid mechanical instability with applications from food processing to geophysics. Using a combination of thin-layer theory and laboratory experiments with silicone oil, we have determined how the amplitude and frequency of the folding depends on the the sheet's initial thickness, the injection speed, the height of fall, and the fluid properties. In the (geophysically most relevant) limit of negligible inertia, folding can occur in two distinct modes: "viscous" folding controlled by the injection rate, and "gravitational" folding in which the viscous forces that resist bending are balanced by gravity. Inertial effects give rise to two additional modes: "inertio-gravitational" folding characterized by frequency multiplicity and hysteresis, and "inertial" folding in which viscous forces are balanced by inertia. Our scaling laws predict a folding amplitude $\approx$ 500 km for the subducted Cocos plate, in good agreement with the tomographically observed apparent widening of the slab below the transition zone. To conclude, we present a new hybrid thin-layer/boundary integral representation for the dynamics of a viscous sheet embedded in a less viscous fluid, a simple model for a subducted slab interacting with the ambient mantle.