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Mixed-layer instabilities and turbulence in a submesoscale upwelling filament

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In frontal regions of the ocean, submesoscale motions are frequently observed features in the surface layer. Due to their important role for surface layer restratification, lateral dispersion, and the turbulent energy cascade, this type of motion has been extensively studied over the past decade. Various mixed-layer frontal instabilities, providing potential routes to energy dissipation, have been identified. However, direct turbulence measurements in submesoscale fronts, required to test the relevance of these new theoretical concepts, are so far largely missing. Here, data from a submesoscale upwelling filament (Benguela upwelling system) are presented that combine densely-spaced cross-front turbulence microstructure measurements with simultaneously conducted high-resolution velocity measurements from a towed research catamaran. These data reveal a narrow (width: 2-3 km) submesoscale front associated with an energetic frontal jet reaching speeds up to 1.2 m/s. Our data show a strongly turbulent surface mixing layer down to 30-40 m depth in the frontal region, driven by at least two distinct processes: (i) atmospheric forcing due to down-front winds and surface buoyancy loss on the warm side of the front; (ii) symmetric and inertial instabilities induced mixing in the cyclonic side of the frontal jet, consistent with the strong negative Ekman buoyancy flux in the frontal region. The two fronts bounding the submesoscale upwelling filament exhibited a marked asymmetry in mixing-layer depth and turbulence levels, likely resulting from the stabilizing or destabilizing Ekman transports on the two sides of the filament. Breaking internal waves associated with the collapse of the front were ubiquitous, suggesting an alternative pathway to energy dissipation in frontal regions.