

# Mixable Layers: A Potential Energy-Based Estimate of an Ocean Surface Layer That Is Prone to Easy Mixing

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The upper ocean plays a critical role in the climate system as the interface for the exchange of heat, momentum, and carbon between the atmosphere and the deep ocean. This exchange is mediated through a relatively well-mixed region, which acts as a staging area before properties are moved to the interior or returned to the atmosphere. This well-mixed region has traditionally been quantified in two ways: the mixed layer (a region with uniform density) or mixing layer (a region with high turbulence levels). We propose a new approach for quantifying the properties of the surface ocean. We introduce a new concept of “mixable layers,” a region of the upper ocean that can be mixed easily relative to the water below. A mixable layer is estimated using an approach we call the “energy knee method.” For a given profile, we compute the depth to which the density could be homogenized for a given amount of energy. Repeating this calculation across a range of energy values yields a curve of energy versus mixable depth, and the knee point—the location of sharpest bend—is identified as the mixable layer. This represents the depth where there is a sudden transition to stronger density stratification, where mixing deeper requires much more energy. Our method also introduces a secondary metric for characterizing the upper ocean, called the mixed layer energy (MLE), which is the energy required to completely homogenize a region of the upper ocean. The MLE may also be used with traditional mixed layer or mixing layer depths estimates. Using temperature and salinity profiles from the Argo dataset, we find that our method yields mixable layer depths that closely align with depths of well-mixed water, providing an alternative, potentially more robust approach to estimating the mixed layer depth. In regions with weak pycnoclines, the mixing layer approach generally outperforms the threshold method, conventionally used to estimate mixed layer depths, in identifying the region of homogenous density near the surface. We present global statistics of mixing layer depths and energies, including their regional and temporal mean and variability. Our energy knee method for calculating MLD and MLE provides a more robust and interpretable framework for studying the structure of the upper ocean.