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AUV observations of mixing in the tidal outflow from a Scottish sea loch

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Improvements in observational capabilities have led to numerous observations of nonlinear internal waves (NIWs) over the past two decades and to increased attention to their role in redistributing energy and mass in the coastal ocean. Most of the observed NIWs have resulted from interaction of the barotropic tide with the continental slope or other bathymetric features and many of the resulting NIW packets were propagating shoreward over the continental shelf when observed. More recently, it has become clear that rivers may act as sources of large amplitude internal waves in the coastal ocean. Off the west coast of North America, the Columbia River plume is a tidally modulated source of fresh water onto the continental shelf, where the leading edge of the fresh water plume regularly evolves into a steep front from which packets of nonlinear internal waves emanate.

The sea lochs of the west coast of Scotland are estuarine systems that can be strongly modulated by the tide. Loch Etive is one such system with a large catchment area and a fresh water outflow that is strongly modulated at semi-diurnal frequency. Here we focus on observations in the outflow from Loch Etive under two considerably different sets of conditions: (1) in early winter following a prolonged period of precipitation during which the surface water was relatively cool (and temperature increased with depth) and brackish, and (2) in mid-spring following a relatively dry period during which the temperature decreased with depth and the surface salinity was relatively high. Freshwater leaves the loch on the ebbing tide in a pulse released into the coastal ocean as a thin layer, the leading edge of which develops into an undular bore or a train of internal solitary waves with strong mixing and associated entrainment. During both periods a Hydroid 600 m depth-rated AUV equipped with a forward-mounted microstructure sensing package was used in conjunction with moored measurements to study the dynamics of the thin freshwater layers. We observed turbulent bores and internal solitary waves. The passage of the bores and internal solitary waves of depression were associated with downward vertical movement of near-surface water and turbulent mixing that was enhanced above background by over 2 orders of magnitude during and after the passage of the waves and bores.