The Loch Linnhe freshwater bore

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Scotland's sea lochs are fjordic systems - glacially-deepened, laterally-constrained salt-water environments which may have considerable fresh water inflow. Classically in such systems, fresh water tends to move seaward near the surface and entrains salt from underlying layers leading to a near-surface export of salt from the system. This export is balanced by a net up-loch flow of more saline water at depth. The details of this circulation are therefore dependent on the dynamics of the buoyancy-driven offshore flow and the entrainment mechanisms on its base.

At a lateral constriction or sill in a sea loch, amplification of the flooding tide may stall the down-loch (seaward) progress of surface water, releasing it as a buoyant gravity current when the tide weakens or turns (Thorpe *et al.*, 1983). Observations from a 4-day mooring near the western shore of Loch Linnhe (Fig 1) show a tidally-pulsed surface fresh layer of 5-10 m in thickness. On at least four consecutive tidal cycles this fresh layer was led by a sharp, bore-like front and a train of internal waves (Fig 2).

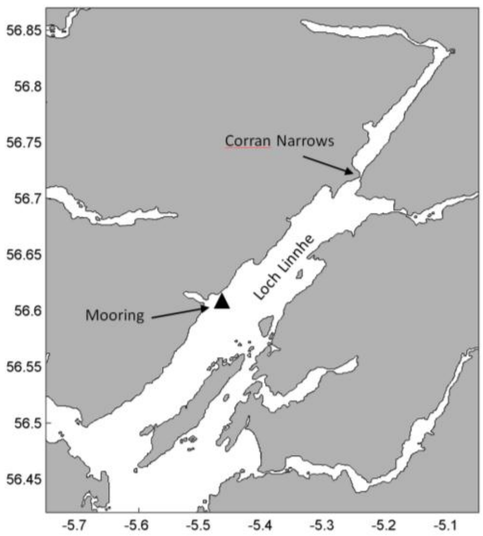

Fig. 1 – The mooring site, near the western shore of Loch Linnhe, 19 km southwest of the Corran Narrows. Open water lies to the southwest via the Firth of Lorn.

The propagation speed of the bore, based on the velocity within the surface layer and the speed of an interfacial wave on its base, is estimated to be 0.2-0.3 ms^{-1}. This considerably exceeds typical barotropic tidal velocities in much of the loch (less than 0.1 ms^{-1}). Underlying the surface layer was a persistent, though tidally-pulsed, up-loch flow, consistent with an estuarine-type circulation resulting from entrainment into the less dense layer above. This up-loch flow was displaced downwards in the water column as it was over-ridden by each fresh pulse, returning gradually towards the surface during the remainder of the tidal cycle.

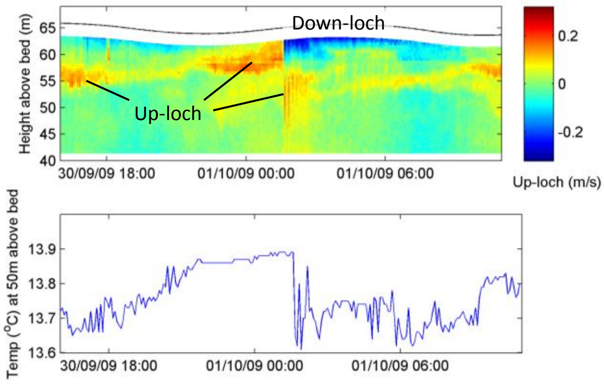

Fig. 2 – The passage of a fresh (and cool) surface bore at the mooring site. Upper panel: up-loch component of velocity in the upper water column (positive to the northeast). Lower panel: temperature 50 m above the bed.

It is presumed that the fresh pulses were released from the constriction and sill at the Corran Narrows, some 19 km up-loch from the mooring. This site is known to arrest the discharge of surface waters from Upper Loch Linnhe (Allen and Simpson, 2002). At a propagation speed of 0.3 m/s, the front would take more than a tidal cycle to reach the mooring site, so a sequence of multiple fronts (3 or more) may be present simultaneously in the loch from successive tidal cycles. Since propagation timescales are comparable to or longer than the inertial period and the internal Rossby radius is shorter than the width of the loch, fresh pulses are expected to hug the western shoreline, propagating with the coast to their right in the manner of an internal Kelvin wave.

References

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