The balance of tidal and wind-driven currents in west Scottish coastal waters

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Are you a student? (Delete as appropriate): No

The currents in many exposed west Scottish coastal sites are demonstrably dominated by tidal movement rather than wind.

This tidal view of currents should not colour our view of sites closer to shore, which are shown here to be significantly, and often dominantly, influenced by wind and other effects.

A set of over one hundred current records gathered at fish farm sites for regulatory purposes has been simply analysed in terms of tidal and other components.

The variance attributable to non-tidal motions is roughly constant across all sites. The variance of the tidal components varies considerably between sites.

In consequence, non-tidal variance exceeds tidal variance in about 75% of the sites. This means that in the majority of near-shore west Scottish sites, currents are dominated by non-tidal motion, and owe more to a combination of wind and other effects than to tide.

Reference

Marine Scotland (2015) A Technical Standard for Scottish Finfish Aquaculture, Appendix A6.3 A Note on the Estimation of Extreme Currents in West Scottish Coastal Waters, pp 66-92

Forcing and variability of western inflow routes of Atlantic water into the northern North Sea

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The JONSIS line is a 127 km-long hydrographic section in the northern North Sea at 59.28°N that runs from the eastern coast of Orkney (2.23°W) to the prime meridian. It crosses the paths the main western inflow of Atlantic water into the northern North Sea, the combination of the Fair Isle Current (FIC) and the East Shetland Atlantic Inflow (ESAI). Data from 139 occupations between 1989 and 2015 are examined to determine the annual cycle and long-term trends of temperature, salinity and depth-varying geostrophic flow in the western inflow. On average, the geostrophic flow referenced to the seafloor is at its narrowest (40 km) in spring, during which time it is driven by the strong horizontal salinity gradient; the horizontal temperature gradient is very weak. Velocity exceeds 6 cm/s, but transport is at a minimum (0.10 Sv). In the deeper water in the east of the section, thermal stratification develops throughout summer and persists until October, whereas the west is tidally mixed all year. The bottom temperature gradient becomes the primary driver of the geostrophic flow, which is fastest (9 cm/s) in September and broadest (100 km) in October. Maximum transport (0.34 Sv) occurs in September. Throughout the summer, the horizontal salinity gradient weakens, as does its contribution to the flow. However, it nevertheless acts to broaden the flow west of the location of the strongest horizontal temperature gradient. These results refine our understanding of the density forcing of the western inflow, particularly in relation to the salinity distribution. A glider deployment in autumn 2013 provided ten occupations of the JONSIS line that allow us to quantify the short-term variability of the total transport by referencing the geostrophic shear to the glider dive-average current. This reveals a large (20 cm/s) southward barotropic component of the flow. Understanding the variability of the western inflow is important for understanding the dynamics of the North Sea ecosystem.

Whither the 60 Gigawatt Wave?

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Tides are an essential part of the environment of the seas around Scotland (the northern North Sea and Scottish seas). There is also a reasonable prospect that substantial amounts of tidal stream energy will be extracted (up to the order of 10 gigawatts of power) from these seas in the future. Such developments will need to respect the services naturally performed by the tides in the environment and require projections of the effects of extracting energy. Those projections require models to accurately capture the existing tidal dynamics and especially the flows of energy within and at the boundaries of the Scottish seas.

Tidal models are routinely validated against tide gauges and current measurements and are found generally to perform satisfactorily. This "internal audit" is not routinely supplemented by checks on the regional-scale energy fluxes. In fact, there is an abiding mystery in the balance of energy in the North Sea and Scottish seas that demonstrates weak understanding of tidal friction globally (Cartwright et al., 1980; Munk, 1997).

Cartwright et al. (1980) published a measurement-based analysis of the tides of the northeast Atlantic Ocean, including estimates of lunar semi-diurnal (M2) tidal energy flux across various transects near the edge of the Northwest European Shelf. A M2 flux of 76 GW into the North and Scottish seas was calculated, including 60 GW across the northern boundary, but calculated losses within those seas total only 38 GW. In the same era, the first numerical models of regional tides were emerging including the first M2 tidal model of the shelf (Flather, 1976). The analysis of model output included some estimates of energy flow, both across sections of the open boundary and within the domain. Among the values reported were a sink of 8.8 GW within the Scottish seas and a net flux of 43.7GW across the northern boundary. Cartwright et al. pointed out that the discrepancies were unacceptable. To date, there has been no published resolution of those discrepancies. In order for tides to be understood, tidal models must be able to represent the localized distribution of energy sinks (Munk, 1997). It is unclear whether contemporary models adequately represent the tidal energy fluxes of Scottish seas.

This study represents a new attempt to describe energy fluxes within the Scottish seas. In particular, taking the observed 60 GW flux at the outer boundary as a given, very basic observational data is used to estimate the pathways and sinks within the Scottish seas. The study also includes an initial assessment of the dissipation processes responsible for the sinks.

It is apparent that ~30 GW must be dissipated within the Scottish seas. About 17 GW is likely to be dissipated off the west coast of Scotland, but the locations and processes there are open to debate. The northern isles (Orkney, Fair Isle and Shetland) present a frictional zone to the north of mainland Scotland, and 12-15 GW may be dissipated there, reducing the driving of North Sea tides. The dissipation of ~5 GW within Pentland Firth can be confirmed with significant other contributions from lesser channels.

Further work is required to identify the location and process of energy dissipation within Scottish seas. It is essential that models of the region are confronted by observations of energy flux and where necessary models are developed to improve their representation of tidal friction. Methods are required to represent tidal friction in global or basin-scale models without necessarily resolving the complexity of coastlines and islands in regions such as the west coast of Scotland.

Acknowledgements

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What are the potential consequences of very large-scale tidal arrays on physical processes?

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Marine renewable energy developments such as tidal, offshore wind and wave arrays may occupy large areas and compete with other users of the maritime space. While large scale offshore energy farms have great promise for the UK, their potential environmental impacts should not be underestimated.

An unstructured grid 3D model, FVCOM (Finite Volume Community Ocean Model) has been implemented in an area covering the NW European Shelf, with finer resolution in Scottish Waters (the Scottish Shelf Model, SSM). Scenarios of very large scale tidal stream energy array deployments in Scottish Waters have been implemented in the SSM using the momentum sink approach, in which a momentum sink term represents the loss of momentum due to tidal energy extraction. Near and far-field effects have been evaluated by comparing a set of ocean physical parameters describing the present ocean climate and the future state modified by energy-extraction. The model reproduces baroclinic (density-driven) and barotropic (tidal and wind driven) circulation for a climatological year. This enables the possible effects of large scale tidal stream developments on the tidal circulation, residual currents and ocean stratification during different seasons to be studied.

Acknowledgements

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Freshwater around the Scottish coast: temporal and spatial variability, with a sea loch case study

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Scotland receives large amounts of rainfall, compared to the rest of the UK or Europe, which runs off into coastal regions and sea lochs, showing large variability in both space and time (

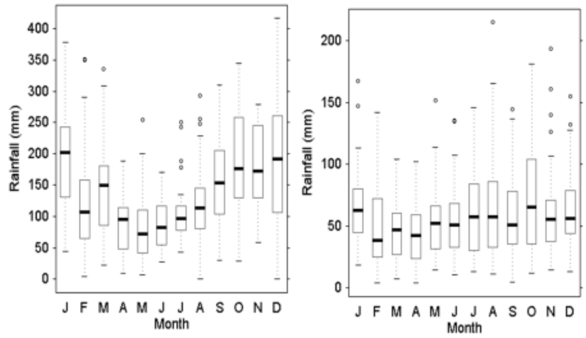

Figure 1).

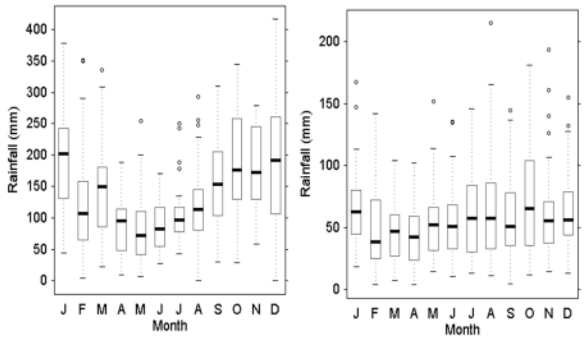

Figure 1. Monthly rainfall variability: a) on the west coast of Scotland, Dunstaffnage b) on the east coast of Scotland, Leuchars. Note the different scales on the y-axis. Source UK Met Office, Historic station data

The largest river in Scotland, the Tay with a mean flow of about 170 m^3s^{-1}, flows directly into the North Sea. However, along the west coast a large network of smaller rivers mainly flow into sea lochs, resulting in estuarine circulation patterns in these fjordic systems.

Here we investigate the spatial and temporal variability in river flow around the coast of Scotland, comparing the run off on the east coast to that on the west coast. We look at seasonal and annual variability, as well as long term trends.

On the east coast the seasonal variability of salinity reflects changes in Atlantic inflow, as well as changes in river run-off. However, river flow on the west coast follows a strong seasonal pattern which is coherent with the salinity patterns; minimum salinities and high river flow in winter and maximum salinities and low river flow in the summer months.

At the scale of a sea loch there is also a close relationship between freshwater input and background salinity. To demonstrate this we describe a case study which will focus on Loch Linnhe – one of the largest sea lochs on the west coast of Scotland. There is considerable freshwater input into the head of the loch, mainly from the rivers Lochy and Nevis. This freshwater leads to an estuarine circulation pattern, with a fresh surface layer flowing out of the loch. Observational and model data has shown that freshwater outflow is enhanced along the north-western coast, implying that Loch Linnhe is dynamically wide and that the Earth's rotation is influencing circulation. Water mass changes due to this freshwater inflow are evaluated for this system on different temporal scales.

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