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# The ocean response at multiple space and time scales to tidal stream energy extraction by a large-scale turbine array.

Michela De Dominicis (1), Rory O'Hara Murray (2), and Judith Wolf (1)

(1) National Oceanography Centre, Liverpool, United Kingdom, (2) Marine Scotland Science, Aberdeen, United Kingdom

A comprehensive assessment of the tidal energy resource realistically available for electricity generation and the study of the potential environmental impacts associated with its extraction in the Pentland Firth (Scottish Waters, UK) are presented. In order to examine both local (< 100 km) and region-wide (>100 km) spatial scales, the Scottish Shelf Model (SSM), an unstructured grid three-dimensional FVCOM (Finite Volume Community Ocean Model) model implementation has been used, since it covers the entire NW European Shelf, with a high resolution where the tidal stream energy is extracted. A large theoretical array of tidal stream turbines has been designed and implemented in the model using the momentum sink approach, in which a momentum sink term represents the loss of momentum due to tidal energy extraction. The estimate of the maximum available power for electricity generation from the Pentland Firth is 1.64 GW, which requires thousands of turbines to be deployed. This estimate takes into account the tidal stream energy extraction feedbacks on the flow and considers, for the first time, the realistic operation of a generic tidal stream turbine, which is limited to operate in a range of flow velocities due to technological constraints. The ocean response to the extraction of 1.64 GW of energy has been examined by comparing a typical annual cycle of the NW European Shelf hydrodynamics reproduced by the SSM with the same period perturbed by tidal stream energy extraction. The changes were analysed at the temporal scale of a spring-neap tidal cycle and, for the first time, on longer term seasonal timescales. Tidal elevation mainly increases in the vicinity of the tidal farm, while far-field effects show a decrease in the mean spring tidal range of the order of 2 cm along the whole east coast of the UK, possibly counteracting some part of the predicted sea level rise due to climate change. Marine currents, both tidal and residual flows, are also affected. They can slow down due to the turbines action or speed up due to flow diversion processes, on both a local and regional scale. The strongest signal in tidal velocities is an overall reduction, which can in turn decrease the energy of tidal mixing and perturb the seasonal stratification on the NW European Shelf. Although the strength of summer water stratification has been found to slightly increase, the extent of the stratified region does not greatly change, thus suggesting the enhanced biological and pelagic biodiversity hotspots, e.g. tidal mixing front locations, are not displaced. Such large scale tidal stream energy extraction is unlikely to occur in the near future, but such potential changes should be considered when planning future tidal energy exploitation. It is likely that large scale developments around the NW European shelf will interact and could, for example, intensify or weaken the changes predicted here, or even be used as mitigation measures (e.g. coastal defence) for other changes (e.g. climate change).