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RTide: A machine learning enabled implementation of Munk and Cartwright's Response method

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ABSTRACT: The prediction of water levels and currents is of importance to the design and operation of all marine renewables. This is particularly true for tidal energy where the resource is dependent on the ocean flows and water levels. It is also important for other offshore infrastructure, including the prediction of currents for scour calculations around monopiles and cables.

The conventional method of predicting currents based on data is Harmonic Analysis (HA). This approach works well for the prediction of astronomically driven water levels in areas where there is not strong interaction with bathymetry. However, in areas such as estuaries where there is non-linearity in the water levels, and even more so for the highly non-linear tidal currents we are interested in extracting energy from, the method struggles. In addition, HA requires relatively long time-series, which for tidal currents, are prohibitively expensive to collect.

The main alternative empirical approach is the Response Method developed by Munk & Cartwright (1966). This approach does not make the same limiting assumptions that limit Harmonic Analysis but it has never been widely used. The main reason for this was the expertise necessary to use the model. We have tackled this problem by embedding machine learning into the method which we have released as the open source package RTide (Monahan et al., 2025). By using a class of neural networks which is equivalent to the Volterra series used in the original formulation we preserve the key mathematical structure of the original approach. Further, a key attraction of the method is that it retains the physics of the original problem in its formulation greatly increasing the reliability of the approach.

Harmonic analysis will remain the "language of the tides" however we foresee the approach used in the RTide code as having significiant advantages for many marine renewable energy applications. These include:

(i) Prediction of strongly non-linear currents. For example, simply running RTide without any special configuration greatly outperforms HA when both are trained on 180 days of measured data at the Meygen site in the Inner Sound of the Pentland Firth.

(ii) Prediction from very short time series. Whilst it is location specific HA generally requires roughly five times as much data as RTide in order to make comparable predictions. This is valuable for field data collection as it greatly reduces the measurements required as well as for computational modelling where the run time is reduced. It is worth noting that HA can then be applied to a longer time series generated by RTide, preserving the interpretability of the harmonic constituents.

(iii) Inclusion of meterological and other inputs. It is straightforward to include other forcing in the Response Method which allows fast prediction of the impact of weather on flows and water levels to be rapidly computed. It is also possible to add other forcing, for instance whether a turbine is on or off.

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