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HIDRA 1.0: Deep-Learning-Based Ensemble Sea Level Forecasting in the Northern Adriatic

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Interactions between atmospheric forcing, topographic constraints to air and water flow, and resonant character of the basin make sea level modeling in Adriatic a challenging problem. In this study we present an ensemble deep-neural-network-based sea level forecasting method HIDRA, which outperforms our setup of the general ocean circulation model ensemble (NEMO v3.6) for all forecast lead times and at a minuscule fraction of the numerical cost (order of 2×10^{-6}). HIDRA exhibits larger bias but lower RMSE than our setup of NEMO over most of the residual sea level bins. It introduces a trainable atmospheric spatial encoder and employs fusion of atmospheric and sea level features into a self-contained network which enables discriminative feature learning. HIDRA architecture building blocks are experimentally analyzed in detail and compared to alternative approaches. Results show the importance of sea level input for forecast lead times below 24 h and the importance of atmospheric input for longer lead times. The best performance is achieved by considering the input as the total sea level, split into disjoint sets of tidal and residual signals. This enables HIDRA to optimize the prediction fidelity with respect to atmospheric forcing while compensating for the errors in the tidal model. HIDRA is trained and analysed on a ten-year (2006-2016) timeseries of atmospheric surface fields from a single member of ECMWF atmospheric ensemble. In the testing phase, both HIDRA and NEMO ensemble systems are forced by the ECMWF atmospheric ensemble. Their performance is evaluated on a one-year (2019) hourly time series from tide gauge in Koper (Slovenia). Spectral and continuous wavelet analysis of the forecasts at the semi-diurnal frequency $(12\ h)^{-1}$ and at the ground-state basin seiche frequency $(21.5\ h)^{-1}$ is performed. The energy at the basin seiche in the HIDRA forecast is close to the observed, while our setup of NEMO underestimates it. Analyses of the January 2015 and November 2019 storm surges indicate that HIDRA has learned to mimic the timing and amplitude of basin seiches.