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Quantifying the temporal and spatial sensitivity of forecast storm surge to initial and boundary forcing using the novel technique of adjoint modelling

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Adjoint modelling has only been adopted in atmospheric and large-scale ocean modelling within the last few years. For the first time this study applies it to tide-surge modelling in the coastal region to gain new insight into dynamics and predictability.

In order to improve the skill of storm surge forecasts, one needs to understand how uncertainty propagates through the dynamical system from its boundary conditions, through physical parameterisations and how it is modified by the system dynamics. Uncertainty can come from many sources. Here, we aim to determine the sensitivity of forecast coastal sea level in a tide-surge model to infinitesimal perturbations of two such sources: wind stress and bottom drag. We aim to answer two key questions:

1. What are the relative roles of uncertainties in wind stress and bottom drag in causing changes in forecast coastal sea level?

2. For such changes, what are the temporal and spatial scales over which the sensitivities are largest?

The existing approach to answer these questions is to use forward ensemble experiments to explore the propagation of uncertainty due to small perturbations of each of the parameters at several locations and at several times.

However, to cover all parameters, spatial and temporal scales would require an ensemble with many thousands or millions of members in order to produce sensitivity maps and time-series and may still not capture all the sensitivity due to gaps in the choice of perturbation directions.

We apply a new technique, adjoint modelling, which can produce sensitivity information with a single model integration. The adjoint of a tide-surge model based on MITgcm is used to examine coastal storm surge sensitivities to wind stress and bottom drag for an extreme event on the northwest European continental shelf on 9th November 2007. The forward model is first validated against the UK operational tide-surge model and observations, and then the adjoint is constructed using algorithmic automatic differentiation.

We find that the sensitivity of coastal sea level to wind stress has spatial and temporal characteristics quite distinct to those of bottom drag, and we discuss how these findings might be used to guide our focus on improving the next generation of storm surge forecast models. We also discuss the assumptions required to estimate the amplitude of the impacts of uncertainty in wind stress and bottom drag on coastal sea level.