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Assessment of ocean observing networks based on re-construction errors

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A new method to assess the performance of observational networks is presented. The technique allows to quantify the ability to re-construct the physical state from observations and is based on models for both the measurement error and the background statistics. The method is applied to water levels in the North Sea using the two dimensional (2D) surface elevation field as state vector. The General Estuarine Transport Model (GETM) is used to estimate the second order background statistics of water levels over a period of one month for different seasons. The model was run with 1 km resolution and wind forcing from the European Centre for Medium-Range Weather Forecasts (ECMWF). A general statistical analysis is performed identifying the dominant modes of the water level dynamics. The process is dominated by 3 modes associated with the passage of a tidal Kelvin wave. The remaining modes are mainly associated with the complicated water level dynamics in the very shallow Wadden Sea areas. Tide gauge measurements are simulated from the numerical model assuming a Gaussian distribution of measurement errors. An optimal linear re-construction method is derived and applied to estimate the complete 2-D water elevation field for the North Sea from a set of point measurements. It is shown that the Kalman gain matrix is the key element in the respective operator. It is explained how the re-construction problem is related to the Kalman filter used in assimilation. Furthermore an analytical expression for the spatial distribution of re-construction errors is derived. The corresponding maps give an overview of the information spread of the observational network. The re-construction of certain modes of the dynamical system and the associated signal to noise ratio (SNR) is discussed as well.

Based on the optimal re-construction method the ratio of the global re-construction error and the background variability is introduced as a quality measure for an observational network. The methodology is applied to different scenarios varying the number of tide gauges, the locations, the measurement errors as well as the background statistics. Positions of existing tide gauges are considered in the investigation. The absolute and relative re-construction errors as well as the spatial distribution of the errors is presented and discussed for each scenario. It is shown that the shallow water areas are particularly hard to re-construct. Significant re-construction errors are also observed at the boundaries of the model domain.

Strategies to design an optimal observational network are investigated. An algorithm to extend a network step by step in an optimal way is presented. For example the additional use of altimeter measurements far offshore in combination with existing tide gauges near the coast is considered. Approaches to find the optimal distribution of a given number of measurement instruments are discussed.

It is demonstrated that the method is applicable to networks with different instruments as well. A combination of simulated tide gauge and current measurements is used for this purpose.

It is explained how the technique is related to the scaled re-presenter matrix method proposed in other studies.

The study is performed as part of the German project COSYNA (Coastal Observation System for northern and Arctic seas), which aims at optimising the data exploitation of observational networks in the North Sea and further develop coastal ocean forecasting capabilities.