Advancing bathymetric reconstruction and forecasting using deep learning

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Motivation

- Bathymetric evolution in coastal environments is driven by complex interactions between hydrodynamics, sediment transport, and morphodynamics.
- Traditional morphodynamic models often face challenges in capturing these dynamics, particularly in regions like the Wadden Sea, where the feedback mechanisms between physical processes and seabed changes are highly intricate.
- Using 30 years of high-resolution Wadden Sea data, we explore two main objectives:
  (1) whether ML can accurately reconstruct the spatial patterns of the seabed,
  (2) whether it can forecast future bathymetric changes.

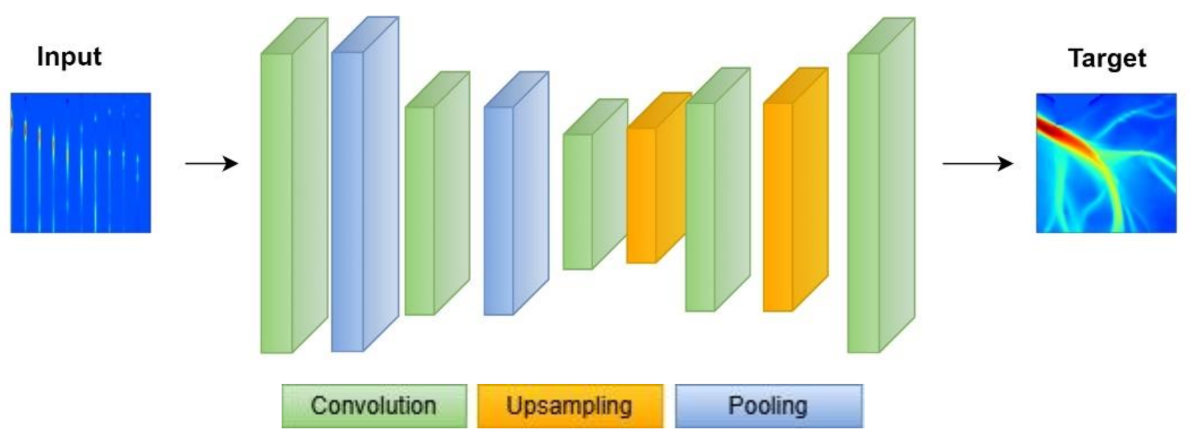

Figure 1 : The proposed architecture for reconstruction

Reconstruction

The maps for each year were divided into tiles of one hundred by one hundred pixels. Tiles containing less than 10% of the maximum amount of data per tile were not analysed. A total of 425 tiles were analysed for each year.
Each tile was designated as an output, as shown in the target and the inputs corresponding to each output tile, as shown in Fig. 1, consist of pixel lines taken along the y-axis (meridional sections) every 10th pixel. All other pixels were assigned the value zero.
To reconstruct the data over the entire area covered by the tiles, we used only the spatial characteristics of the data, so the tiles are included in the analysis without taking time into account.
The model architecture in Fig. 1 is proposed for the reconstruct phase.

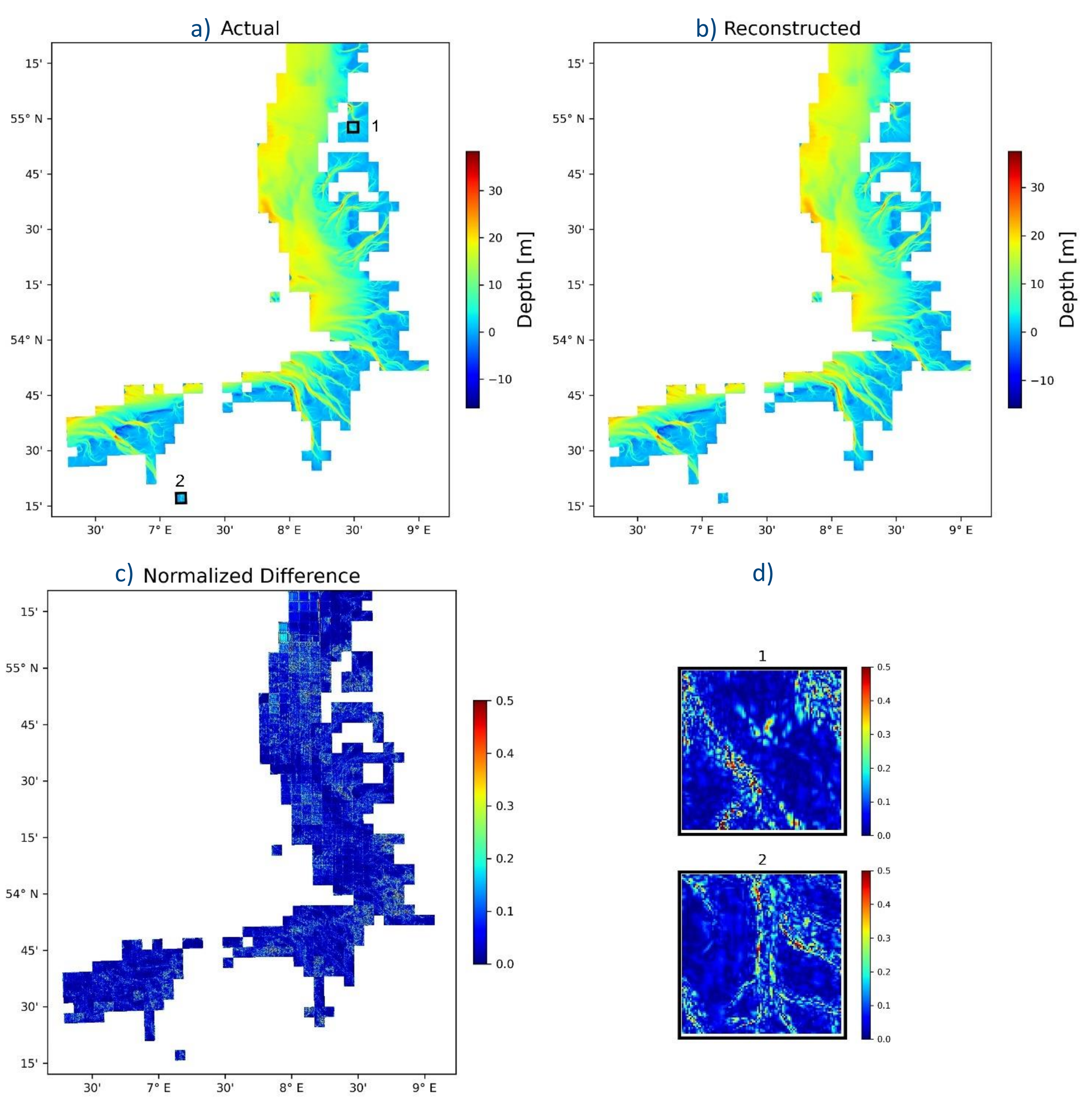

Figure 2: Bathymetry in 2012. (a) observations, (b) model reconstructions, (c) normalized absolute difference between data and reconstructions over the entire area, (d), the same as (c), but for two individual tiles (1 and 2, see (a) for their positions)

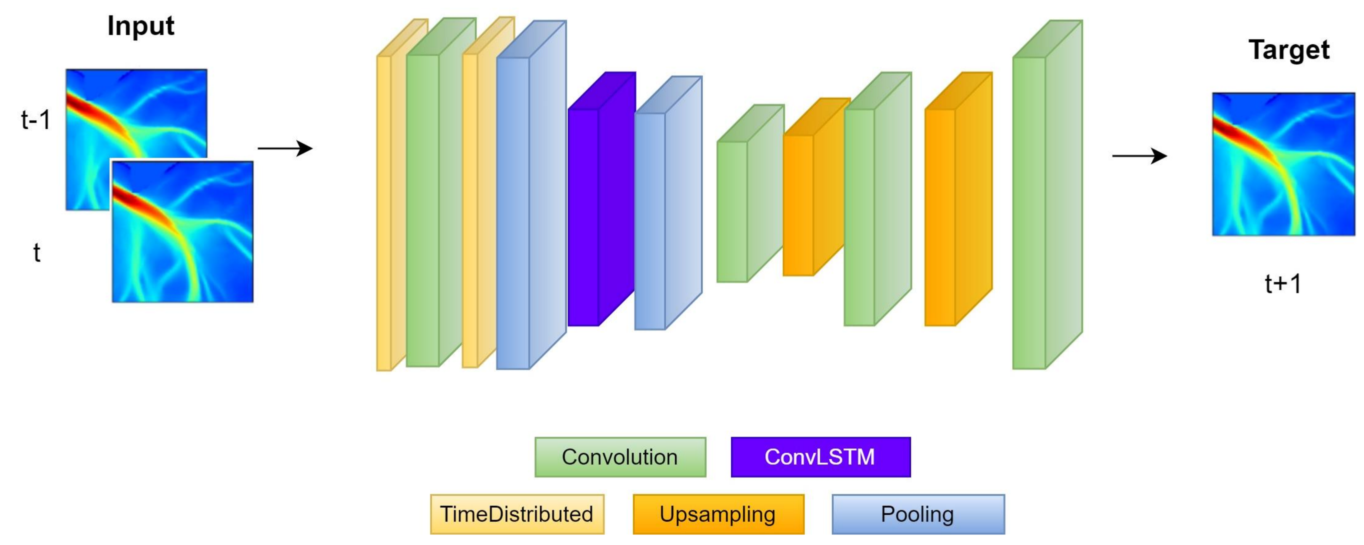

Figure 3 : The proposed architecture for forecasting

Forecasting

One-step-ahead forecasting is the process of predicting the next value in a time series based on the analysis of previous observations.
The process of converting the data into tiles is the same in the forecast phase as in the reconstruct phase.

The model architecture in Fig. 3 is proposed for the forecast phase. This architecture is based on CNN-LSTM architecture, which combine models using both spatial feature extraction and temporal sequence learning.

The data are prepared with $X_{t-n+1}, \ldots, X_t$ as model input and X_{t+1} as model output. Each X represents a single observation, i.e. one year for this study, and n denotes the number of time steps used as predictors. This process is repeated for each tile.

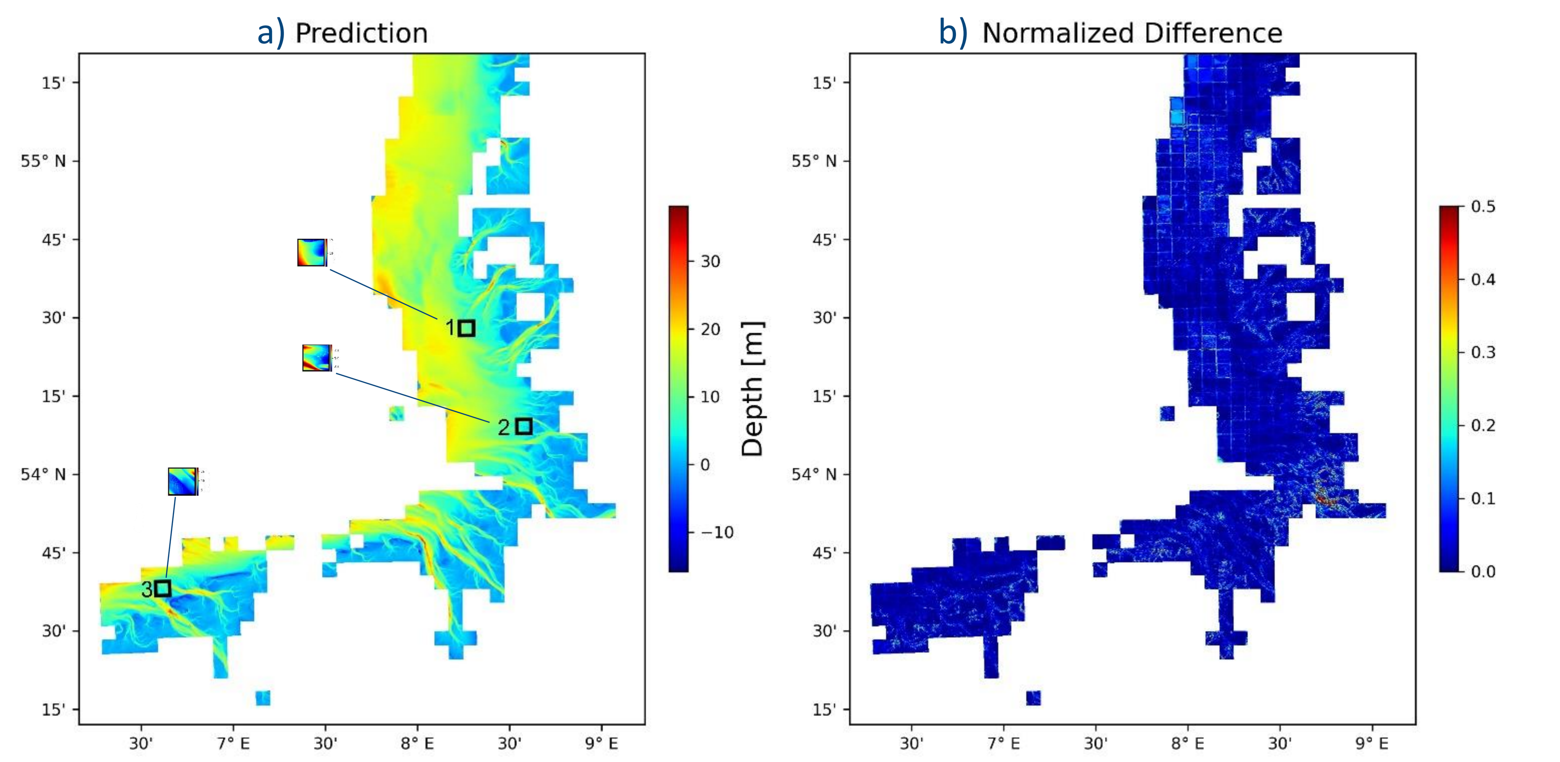

Figure 4 : Forecasting bathymetry for 2012. (a) model predictions, (b) normalized absolute difference between the observations and predictions

Highlights

Results

- The reconstructed bathymetry of the tiles for 2012 is shown in Fig. 2. The rms error for the entire area is 0.19 m.
- The prediction for the year 2012 using the years 2010, 2011 as predictors is shown in Fig. 4. The mean RMSE of all tiles is 0.139 m.

Summary

- This study demonstrates the potential of deep learning models in analyzing and predicting bathymetric changes in the German Bight, a region characterized by complex morphodynamics and significant spatial and temporal variability.
- The CNN network was able to successfully reconstruct spatial patterns using limited input data.
- The ConvLSTM network demonstrated strong performance in forecasting future bathymetric changes based on past observations.
- The models employed provide novel insights into the reconstruction and forecasting of bathymetric features, contributing to the advancement of coastal management and seabed monitoring practices.

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