Enhancing projections of sea-level rise with changing seasonality for the Northwest European Shelf

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EGU23-9023

1 Introduction

There are important distinctions between the effect of internal variability on the global rate and regional rates of sea-level rise (SLR) [1]. On short time scales processes of internal variability play an important role in determining sea level. Quantification and projections of sea-level variability could contribute to a better understanding of how sea level is responding to climate change on short timescales.

The objective of this research is to produce projections of seasonal sea-level change for the period of 2023-2053, specifically for the Northwestern European Shelf (NWES) using a statistical approach. The characteristics of seasonal sea-level change (SLC) and the relationship to large-scale atmospheric drivers, such as the North Atlantic Oscillation (NAO) are evaluated. Patterns of sea-level variability quantified from this analysis can then be used to refine existing projections produced from climate models (e.g. CMIP5 and CMIP6) to include seasonal fluctuations of sea level at a fine time scale, to account for SLR resulting from variability.

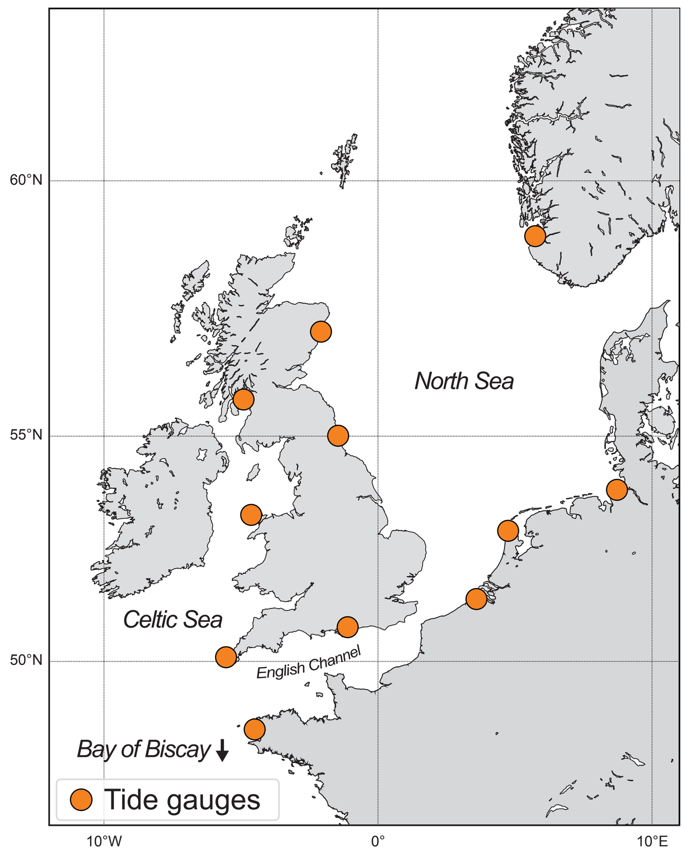

Figure 1: Map of the Northwestern European Shelf with the locations of the analysed tide gauges.

2 Study location

The NWES is a large area of shallow, temperate water consisting of multiple seas and channels. The shelf region is <150 m in depth and meets the North Atlantic via a steep shelf gradient, resulting in oceanographic conditions that are very different between the Atlantic Ocean and the shelf due to the effect of prevailing winds and tidal currents [2].

Large regions of the NWES coastal zone have low topographic gradients and are highly exposed to coastal hazards resulting from SLR. Assessing seasonal SLC across the different zones of the NWES will give a better understanding of how atmospheric drivers, here the NAO, could affect SLR over the next 30 years.

3 Methods

- Monthly tide gauge records [3] detrended using least squares, corrected empirically for the annual cycle and inverted barometer (IB) correction applied [4].
- Monthly altimetry sea surface height (SSH) data [5] detrended to remove linear trend, corrected for the annual cycle and IB correction applied.
- NAO index [6] detrended. Tide gauge RSL and altimetry SSH regressed with the NAO for winter months only (Dec-Jan-Feb). Sensitivity of sea level to the NAO estimated assuming sea level is a linear function of NAO.
- Projections for one tide gauge record made via extrapolating observed seasonal trends on existing CMIP6 sea level projections (cont. in section 5).

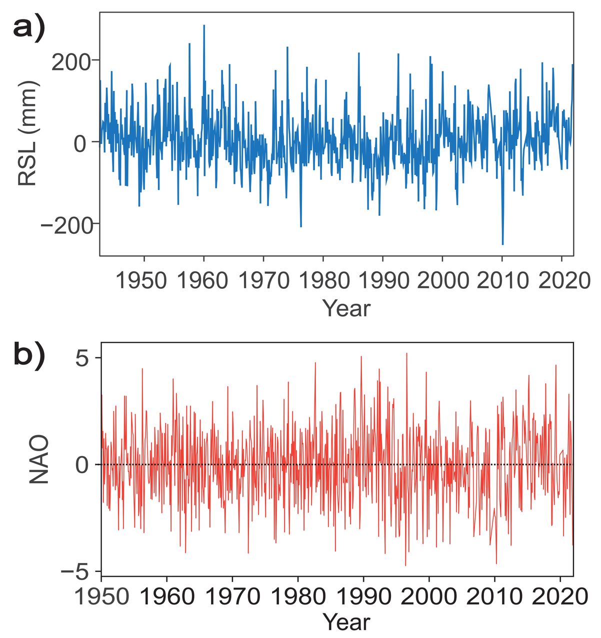

Figure 2: a) MSL from Newlyn tide gauge (detrended, corrected for annual cycle and for the IB-effect); b) monthly NAO values (detrended)

4 Sensitivity analysis

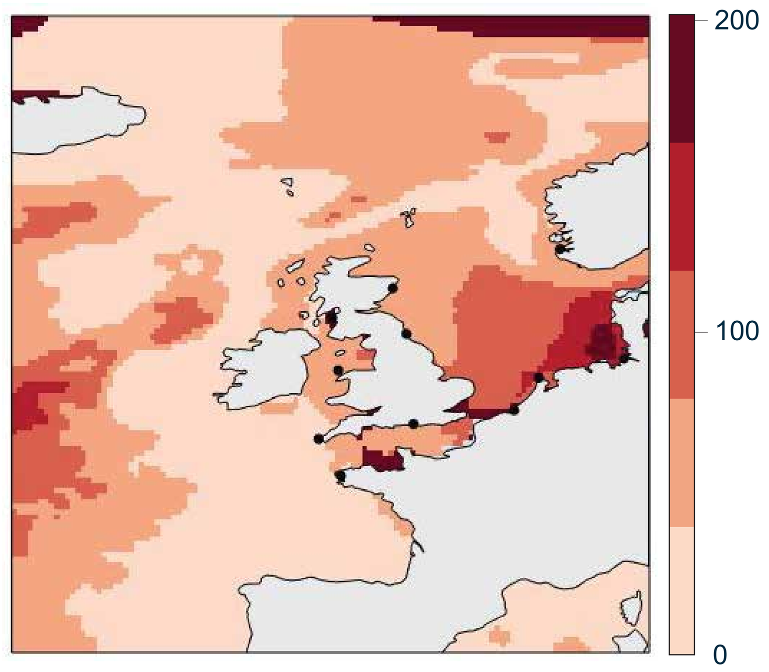

Figure 3: SSH variability (90% range) across the NWES for 1993-2022. SSH is detrended and corrected for the annual cycle from satellite altimetry.

4.1 Sea-level variability

- Sea level over the NWES is characterised by differing levels of variability between regions.
- SSH variability is high in the North Sea, particularly in the SE. Variability is lower on the west UK coast. Sections of the English Channel around Dover and the Channel Islands have a higher variability than the rest of the channel.

4.2 Relationship between sea level and the NAO

- Correlations between winter sea level and the NAO in both tide gauge and satellite altimetry data present similar patterns even with the tide gauge data extending ~40 years previously to the altimetry.
- The NAO fluctuates between periods of dominant positive and negative phases e.g. strong positive phases between 1960-1990 [7], but we show consistency in the NAO/sea level correlation between two time frames.
- This is consistent with the findings of other studies using observational data and model data across regions of the NWES [8-11]
- Sea level pressure (SLP) [12] is weakly correlated to the NAO, indicating the relationship between sea level and the NAO is likely less of a pressure influence and more likely due to wind stress [13].

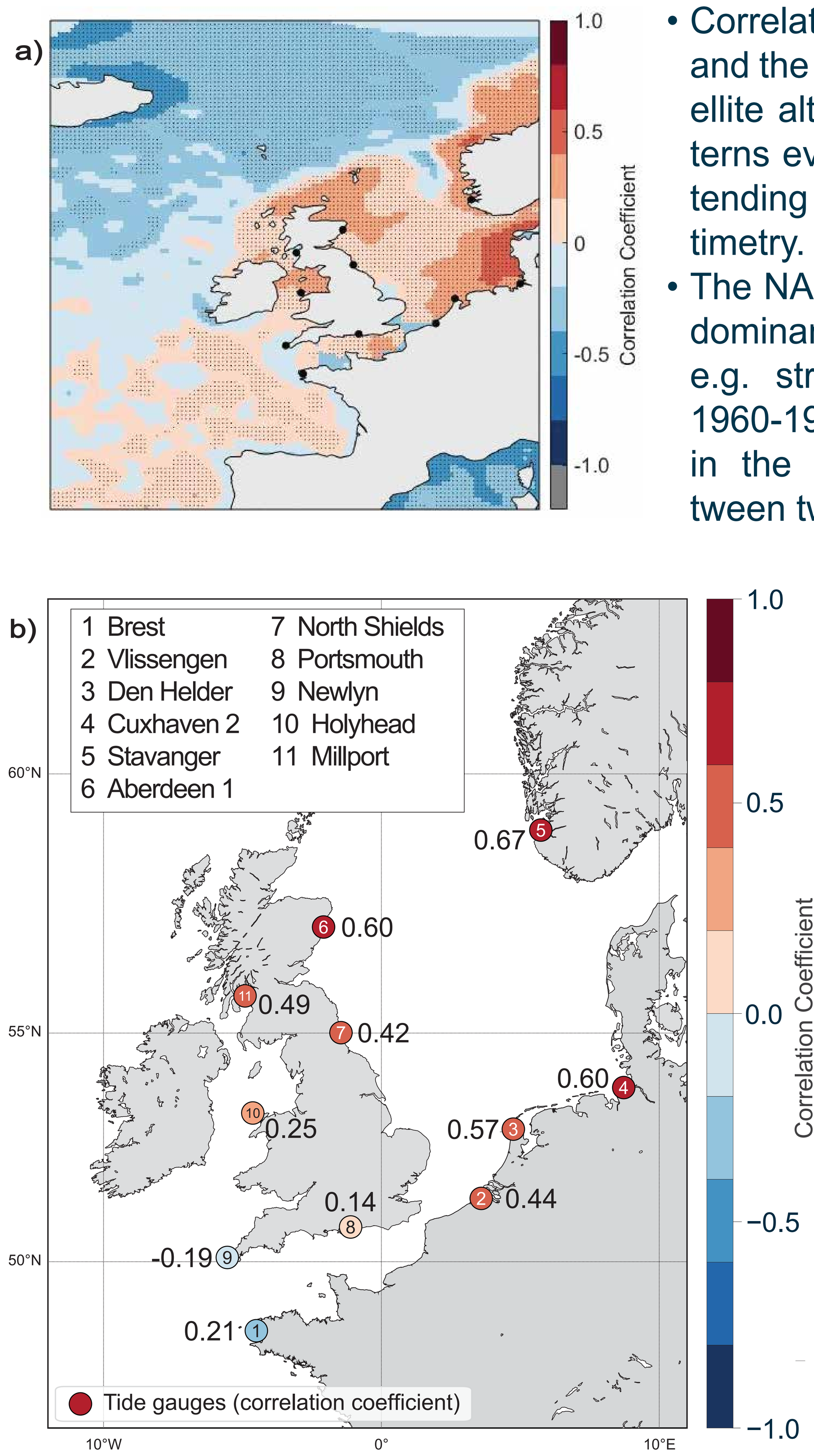

Figure 4: Correlation analysis between sea level and the NAO: a) correlation between NAO and IB-corrected sea surface height for winter months between 1993-2022 from satellite altimetry; b) correlation between NAO and IB-corrected RSL for winter months between 1950-2022 from tide gauge data

5 Projections of seasonal sea-level

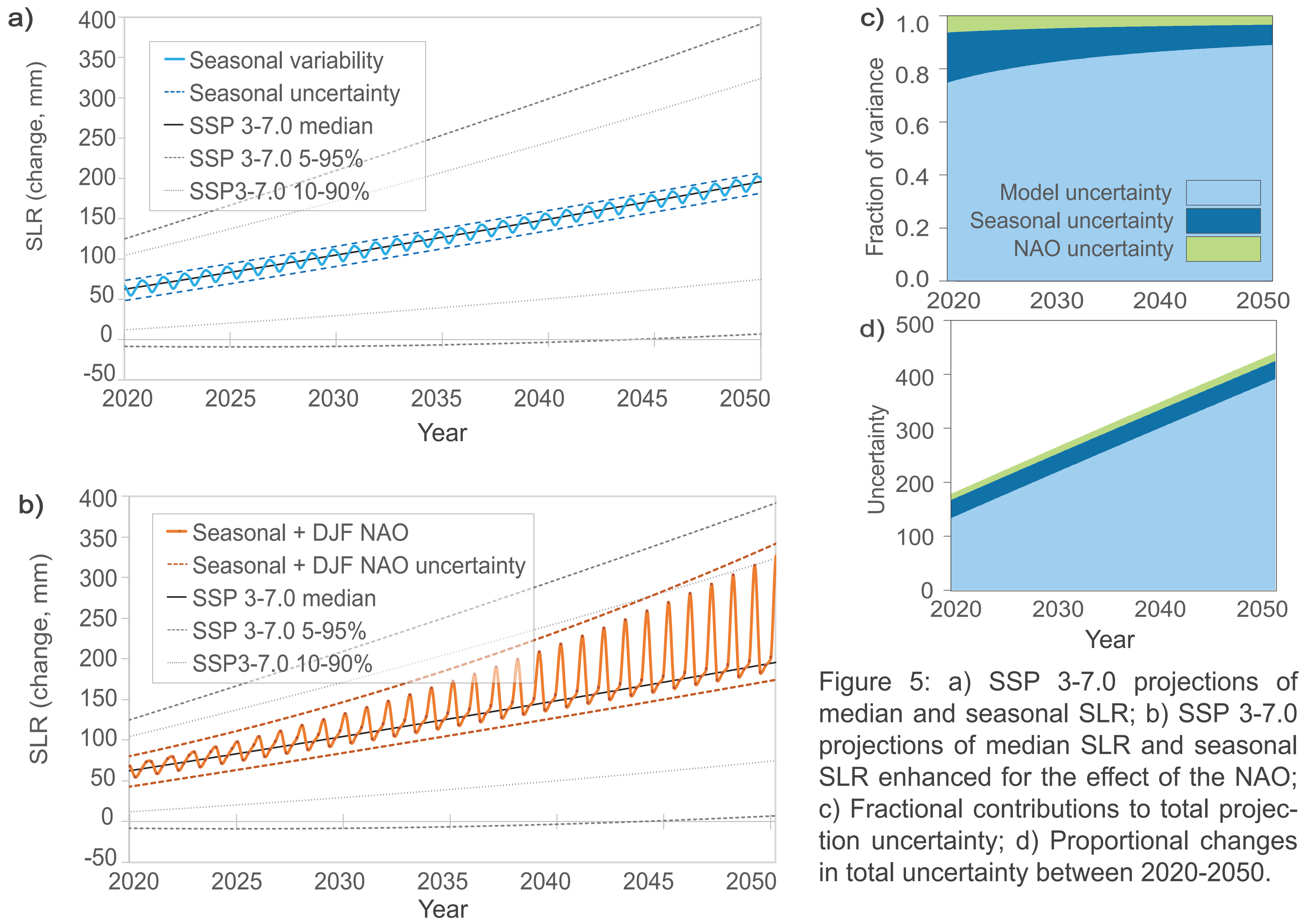

Figure 5: a) SSP 3-7.0 projections of median and seasonal SLR; b) SSP 3-7.0 projections of median SLR and seasonal SLR enhanced for the effect of the NAO; c) Fractional contributions to total projection uncertainty; d) Proportional changes in total uncertainty between 2020-2050.

- Here we produce seasonal mean sea level (MSL) projections for a single tide gauge record (Den Helder) without (Figure 5a) and with NAO enhancement (Figure 5b) by superimposing projections of seasonal variability on annual MSL projections for Shared Socioeconomic Pathway (SSP) 3-7.0 [14].
- Seasonality is projected by extrapolating the observational record of the DNH seasonal residuals. Projections of the NAO index are for DJF under the SSP5-8.5 warming scenario from the Multimodel Large Ensemble Archive (MMLEA) [15]. The observed relationship between NAO and MSL residual is used to project winter seasonal MSL using the NAO projection.
- When projections of seasonal variability are amended to include the projected effect of NAO on SLR winter variability becomes highly amplified (Figure 4). By applying this NAO adjustment, potential winter water levels in 2050 (~315 mm) are comparable to median MSL projections in 2075 highlighting the importance of such variability to adaptation planning [16].
- The fraction of uncertainty in sea-level components changes upon inclusion of sea-level variability into a variance decomposition (Figure 5c and 5d; also [17]).
- Seasonal variability accounts for 18.5% of projected uncertainty in 2020 changing to 7.7% in 2050. This changes to 24.7% (2020) and 11.1% (2050) with the inclusion of NAO driven sea-level change.
- Our findings are consistent with research where dynamic winter-time sea-level change is enhanced across the north-western European Shelf in an analysis of downscaled climate models [18].

6 Conclusions

- This study supports and complements the increasing body of research into sea-level variability and sea level projections. The research will be extended to: increase the number of tide gauge records analysed; assess the relationship between NAO/sea level on multiple time scales across the NWES; enhance existing SLR projections with potential ranges of seasonal SLC and NAO-enhanced SLC.

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