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Variability of shelf sea pH and surface water CO_2 in response to North Atlantic Oscillation forcing

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High biological activity causes a distinct seasonality of surface water pH in the North Sea, which has been identified as a strong sink for atmospheric CO_2 via a particularly effective shelf pump. The intimate connection between the North Sea and the North Atlantic suggests that the variability of the CO_2 system of the North Atlantic Ocean may in part be responsible for the observed, but hitherto poorly understood variability of pH and CO_2 in the North Sea. Here we investigate the role of the North Atlantic Oscillation (NAO), the dominant climate mode for the North Atlantic hemisphere in governing this variability. Based on three extensive observational records covering the relevant levels of the NAO index, we provide evidence that the North Sea pH and CO_2 system strongly responds to external and internal expressions of the NAO. We argue that under NAO+ conditions higher rates of inflow of water from the North Atlantic Ocean limits seasonal shoaling of the summer mixed layer in the northern North Sea, diminishing the biological potential to lower pCO_2 and raise pH. In addition the faster circulation of the North Sea enhances the shelf pump efficiency. These clear patterns are obscured by changing properties of the North Sea waters, masking or enforcing these effects on various time scales. Such controls indicate that inter-annual trends in the North Sea CO_2 system must be carefully examined with consideration to the North Atlantic Oscillation.