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Meteorological forcing of long-term temperature variations of the Dutch coastal waters

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ABSTRACT

Time series of observations of the sea surface temperature (SST) at 12 stations in the Dutch coastal zone are analyzed to establish whether an earlier published nearly 150 year long SST time series from the Marsdiep tidal inlet is representative for the whole Dutch coastal zone. The annual cycles (SST range and phase) as well as the long-term SST trends at decadal scales from other estuaries agree with the Marsdiep time series. An increasing SST trend since 1982 is a phenomenon of the whole Dutch coastal zone. In order to increase the understanding of the causes of the observed SST variability, a multiple linear regression model is constructed, which links locally determined seasonal meteorological and oceanographic forcing factors to the seasonal mean SST. The oceanographic forcing factor is the SST value from the preceding season, representing persistence due to thermal inertia of the sea. Season to season changes of the atmospheric circulation, connected with SST variability, are represented by seasonal mean wind components as forcing factors, e.g. the western winds in winter which bring relatively warm air masses to Western Europe. For the seasons where shortwave solar radiation is the dominant term in the local heat budget (spring and summer), the number of bright sun hours is used as forcing factor, roughly representing the effects of changing cloudiness. The annual mean SST, derived from the regression models for the four seasons, applied to 4 locations along the Dutch coast, correlates quite well, not only for the year to year variability ($R = 0.88$) but also for the longer-term SST trends ($R = 0.95$). An explicit local greenhouse effect is not required as separate forcing factor to explain the recent warming trend of Dutch coastal waters starting in the early 1980s; coincident variations in wind statistics and cloudiness are a sufficient explanation.

1. Introduction

The sea surface temperature (SST) is an important parameter describing the climate of the Dutch coastal waters. Water temperature has strong effects on the physiology of marine organisms; e.g. bivalves show a lower metabolism during cold winters, resulting in a higher preservational biomass (Zwarts 1971; Honkoop and Beukema 1997) and consequently in the production of more eggs in early spring (Honkoop and Van der Meer 1997, 1998). Cold winters delay the onset of the crustacean reproduction in the North Sea and subsequent settlement of new-born shrimps onto the tidal flats of the Wadden Sea (Beukema 1992). In the European coastal waters there exists a tendency of increasing water temperature since about 1980, allowing more southern marine species to invade the West European waters. Regime shifts in the ecosystems of the North Sea and Wadden Sea are attributed, by means of principle components analysis, to changes in the climate–ocean interaction in the entire moderate zone of the Northern Hemisphere (Weijerman et al., 2005). The transports of silt and sand in coastal seas depend, among other factors, on the temperature-dependent viscosity of sea water. Climate variability thereby can influence the sediment budgets and coastal morphology (Dyer, 1995).

Stenseth et al. (2004) state, in their monograph on marine ecosystems and climate variations, that the importance of air–sea interaction for marine ecology must be emphasized. In particular the changes in the air–sea exchange due to the long, irregular variations of the North Atlantic Oscillation (NAO), the dominant mode of the North Atlantic atmospheric circulation, exert a strong influence on the surface air temperature and SST across wide regions of the North Atlantic Ocean, North America, Eurasia, and the Arctic. (Hurrell and Dickson, 2004). Therefore the NAO is assumed to play a dominant role in the ecosystem variability of the Atlantic region. However, the mechanism for the relation between the NAO and the ecosystem variability generally remains unclear. The NAO index, a measure for the intensity of the NAO, is a normalized meridional pressure gradient over the northern North Atlantic Ocean, proportional to the zonal geostrophic wind component in that region. Generally, variations of the NAO index from the preceding winter (December to March) are used to present the varying meteorological forcing in ecological studies on phytoplankton, zooplankton, and fish (Smayda et al., 2004; Pershing et al., 2004; Ottersen et al., 2004). Such NAO oscillations also

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may affect the basin-scale variation of populations, on the order of thousands of kilometres, and introduce possible synchronicities or asynchronicities across ocean basins and between ecological parameters (Werner et al., 2004).

In a previous paper (Van Aken, 2008) the nearly 150 year long time series of the (SST) from the Marsdiep, an estuarine tidal inlet in the northwest of the Netherlands connecting the shallow enclosed Wadden Sea with the open North Sea, was analyzed. The seasonal mean SST as well as the annual mean SST showed large variations on a year to year time scale, while at decadal time scales longer-term warming and cooling trends were observed, lasting 20 to 30 years. A period of dominant cooling was found from 1860 to 1890 (~−1.3 °C), while a strong warming was observed from 1982 until 2005 (~+1.5 °C). A similar warming since 1982 of about 1.5 °C was also observed in other parts of the west European coastal waters (e.g. Madsen and Højerslev, 2009). The latter is about 3 times the increase of the global mean air temperature over the same period (+0.5 °C) due to increasing greenhouse gases. Apparently more changes in the SST forcing are occurring than only an increase in the infrared back radiation due to the increase in greenhouse gases. The winter SST variation from year to year correlated well with the winter NAO index, as did the spring SST because of the persistence of the winter variations, probably due to thermal inertia. Since two of these seasons, winter and spring, correlated significantly with the winter NAO index, the annual mean SST also had a significant positive correlation. However, the longer-term SST trends did not correlate with the longer-term trends in the NAO, and also no coherence between the seasonal mean SST and the seasonal mean NAO index could be established for seasons other than the winter season.

In this paper we will analyse time series of the SST variations, observed at 4 stations in the shallow Wadden Sea, 4 stations in estuarine tidal inlets along the Dutch coast, and 4 stations in the deeper offshore southern bight of the North Sea (Fig. 1 and Table 1). First, we want to establish whether the results of SST variations in the Marsdiep on the seasonal to decadal time scales can be generalized to the wider region of the Dutch coastal waters. Secondly, we want to explore a more physically grounded method than using the NAO index to relate the observed inter-annual to decadal variability of the SST in Dutch coastal waters. For this purpose a multiple linear regression model is developed which links the time series of seasonally-dominant meteorological and oceanographic forcing factors to the seasonally mean SST variations. Its capability to simulate the longer-term observed decadal SST trends is analyzed to establish the robustness of the model and explanatory capacity of the seasonal forcing factors.

Table 1
List of SST stations. The italic acronyms agree with the italic lower case acronyms near the station positions (dots) in Fig. 1.

Name	Acronym	Region	Period
Delfzijl	*d*	Wadden Sea	1980–2007
Holwerd	*h*	Wadden Sea	1980–1993
Schiermonnikoog	*s*	Wadden Sea	1980–1993
Harlingen	*ha*	Wadden Sea	1980–1997
West Terschelling	*t*	Vliestroom estuary	1959–1993
Den Helder	*m*	Marsdiep estuary	1906–2007
Hoek van Holland	*hh*	Nieuwe Waterweg estuary	1959–1995
Vlissingen	*v*	Westerschelde estuary	1959–1999
Eierlandse Gat	*eg*	North Sea	1989–2006
Platform K13	*k13*	North Sea	1992–2006
IJmuiden munitions dump	*ij*	North Sea	1990–2006
Euro Platform	*ep*	North Sea	1989–1998

2. Data

Time series of daily observations of the SST were downloaded from the database of the Netherlands Department of Roads and Waterways, Rijkswaterstaat (www.waterbase.nl). We have chosen data from four positions in the shallow Wadden Sea, four estuarine positions near the transition to the North Sea, and four offshore positions in the open North Sea (see Table 1 and Fig. 1). The SST data since 1861 from the Marsdiep estuary were already available (van der Hoeven, 1982; Van Aken, 2008). These data were collected daily at a fixed time, 08:00; from 1861 until 1999 with a bucket thermometer, in later years with an electronic sensor. The time series for the other positions started in 1959 or later. These temperature data were collected once per day at a fixed time, similar to the Marsdiep temperatures. In order to remove the tidal signal from these data collected daily at a fixed time, aliased to a fortnightly period, they were averaged over periods of one month.

Time series of daily meteorological values from the meteorological observatories of Leeuwarden Airport, Den Helder, Rotterdam Airport,

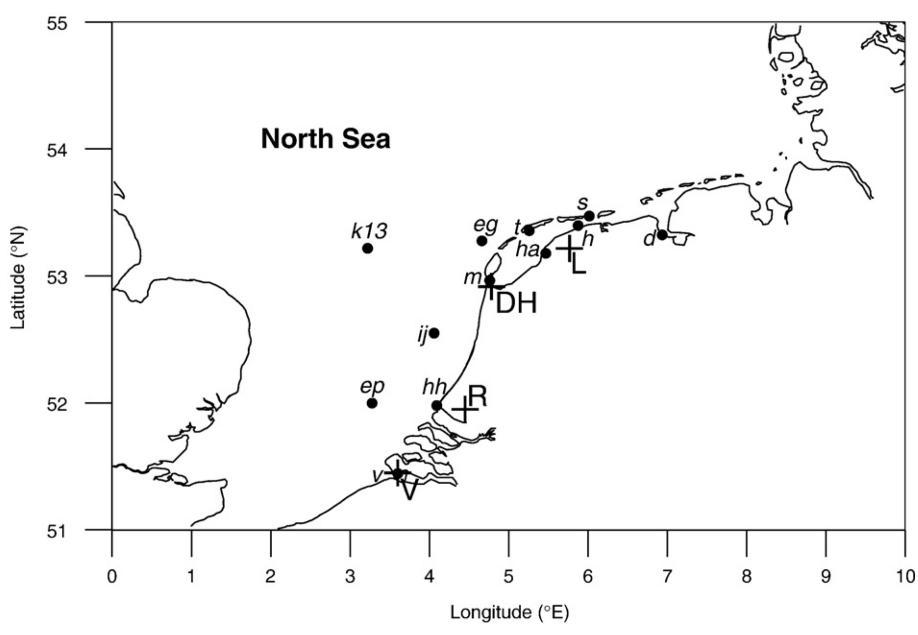

Fig. 1. Position of the stations from where daily time series of the sea surface temperature are available (dots and italic lower case acronyms, sea also Table 1), and the meteorological stations (crosses) Leeuwarden (L), Den Helder (DH), Rotterdam Airport (R) and Vlissingen (V). The shallow enclosed Wadden Sea extends from Den Helder east- and then northwards, behind a barrier of small islands, the Wadden Islands, in the Netherlands, Germany, and Denmark.