Impacts of sea surface temperature assimilation on heat budget estimates for the North Sea

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Background

To improve the seawater temperature prediction, a data assimilation scheme was often applied to combine data from observations, such as from satellites, in-situ measurements, and that from numerical model simulations. However, the efforts invested in the impacts of DA on physical processes and the secondary effect of DA are insufficient. This study, in contrast, analyzed the influence of DA on heat transport in the North Sea. Specifically, it explored "How does the assimilation of SST observations change the different components of the simulated North Sea heat budget, and what are the secondary effects of temperature assimilation on the remaining prognostic model variables that are relevant for the heat budget?"

Material & Methods

Model and observations

The study applied an ocean circulation (NEMO version 3.6) and wave (WAM) coupled model of the Geesthacht Coupled cOAstal model SysTem. The model domain (Fig.1) has a resolution of 3.5 km. The model was spined up and ran until reach a relatively balanced state (Jan. 1, 2017). Subsequently, the model ran with/without DA for one year (denoted as the DA/Free Run). The modelled seawater temperature was analyzed with OSI SAF SST data.

Assimilation scheme and Analysis

The 3DVAR approach bases on the minimization of a cost function, which was solved using a conjugate gradient method. Moreover, the error covariance matrix in this study is a function of the mixing layer thickness that varies in time and space with the evolution of turbulent mixing.

The advective heat transport was calculated as:

$$q = \int_A \rho c_p u(T - T_r)dA \qquad (1)$$

To gain insight into the mechanisms that induce heat transport, the current velocities and local areas along the five transects were decomposed by applying a tidal harmonic analysis. The heat transport is then attributed to processes of individual mechanisms.

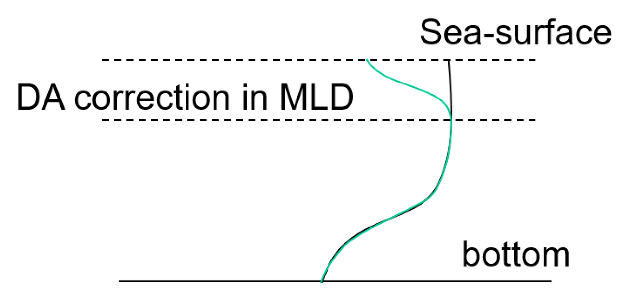

Fig. 2 **Model error covariance matrix as a function of mixing layer depth.**

Results

There are two main processes the North Sea gains/loses heat: (1) air-sea heat exchange through the water surface; (2) advective water exchange through the open boundaries with the adjacent sea. As shown in Fig.3, the North Sea loses heat in 2017 via air-sea heat exchange, with the value changes from 2.5 ×1020 J to 3.3 ×1020 J. Air-sea heat exchange is insensitive to the circulation-wave coupling. The annual variation of the advective transport is much smaller than the air-sea heat exchange. However, contrary to the air-sea heat exchange, the North Sea gains more heat in DA Run than in the Free Run. In total, the North Sea gains 0.27 ×1020 J via advection after DA. A comparison of the Free Run and DA Run shows that the relative amount of net heat loss due to air-sea heat exchange compensated by advective transport remains similar (with the ratio of 25 % in Free Run and 27% in DA Run).

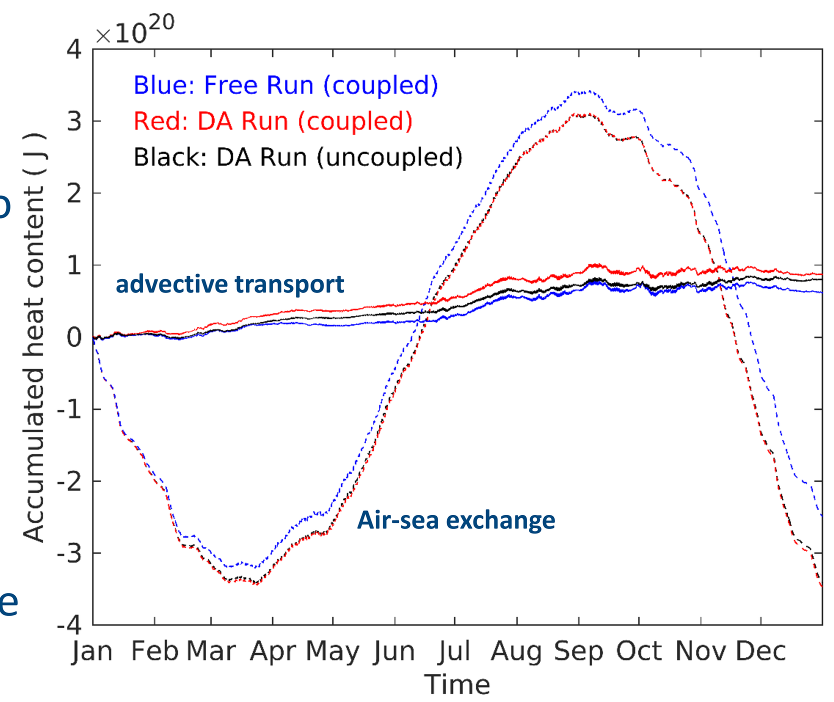

Fig. 3: Temporal accumulateion of net heat transport (in J) into the North Sea.

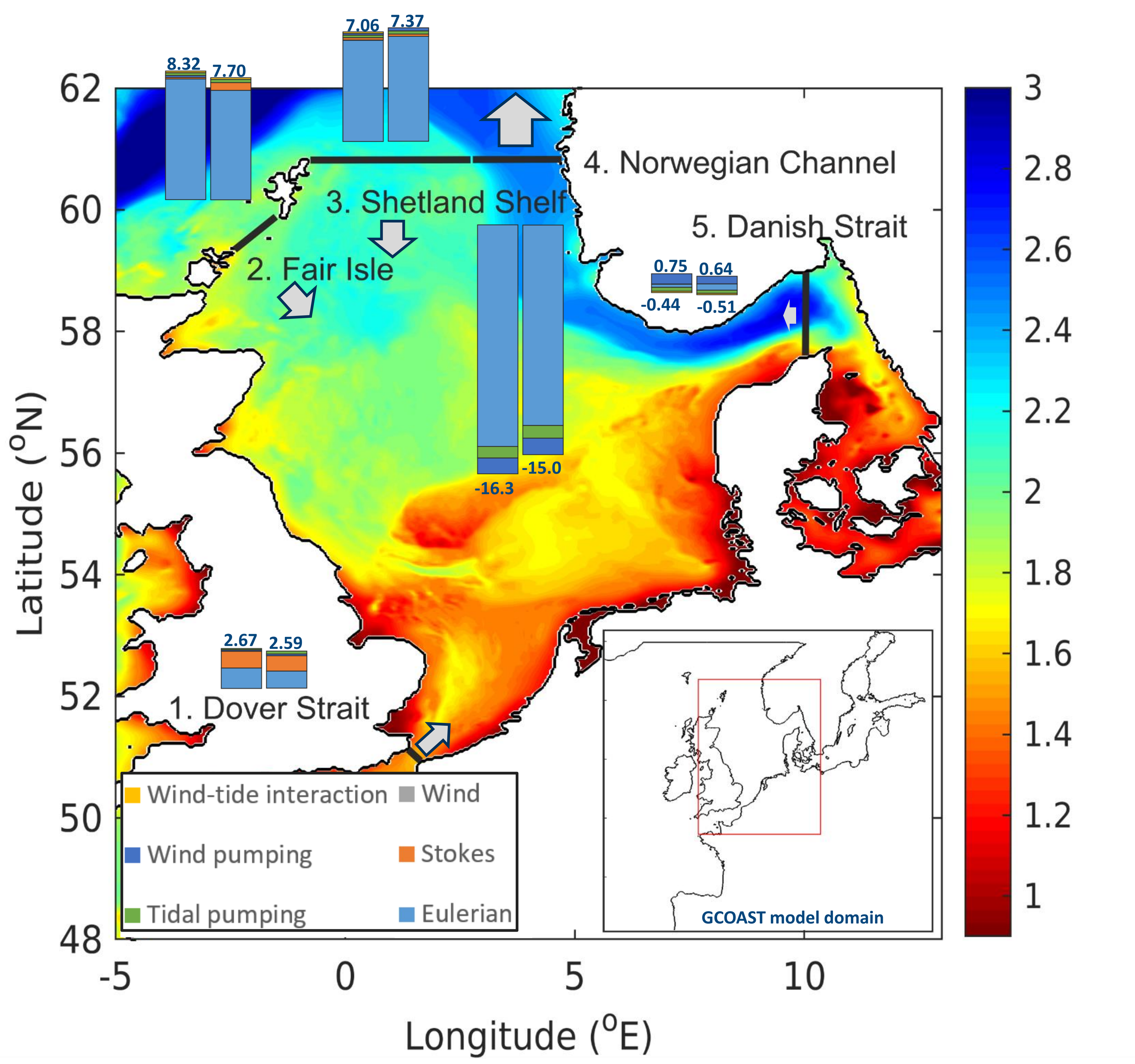

Fig. 1: Model domain with the bathymetry in log10 scale. The locations and names of the transects are shown with the value of advective heat transport through each transect (in 10[12]Watt) for (left column) the Free Run and (right Column) the DA Run. Gray arrow indicate the direction of net heat transport of 2017.

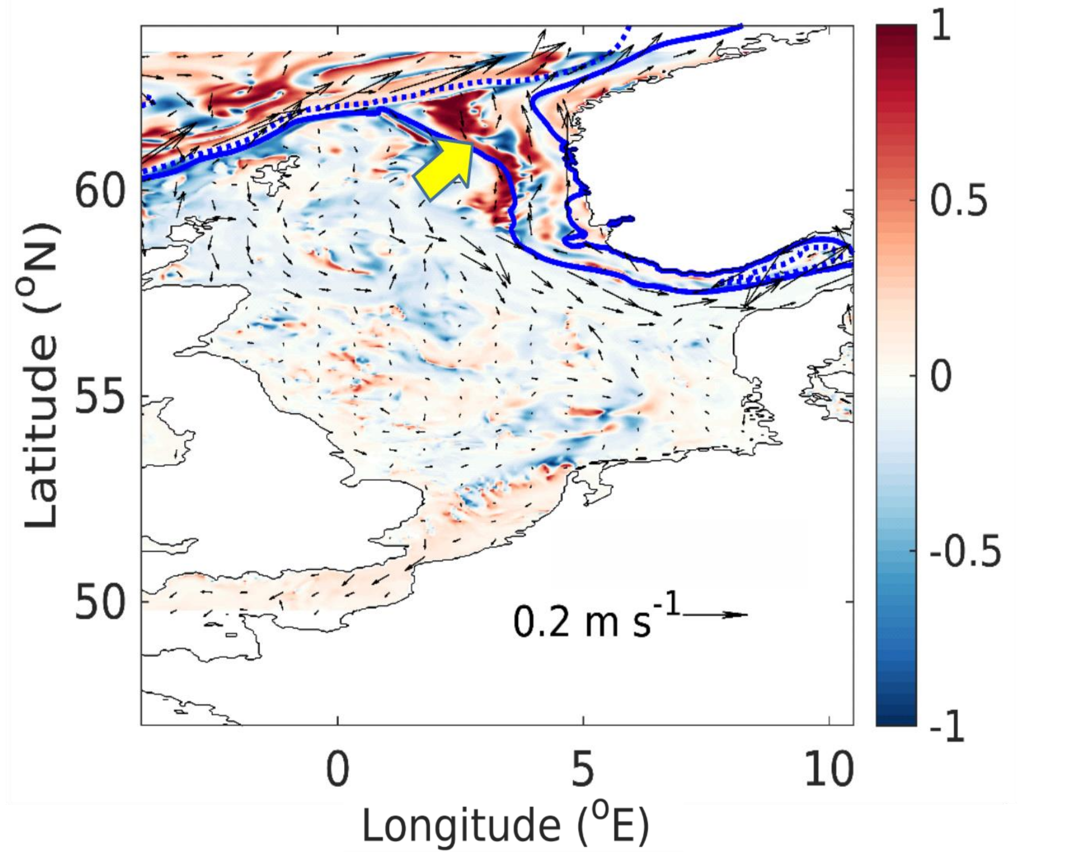

Fig. 4: Vertical mean current averaged over one month. Arrows are velocities of the DA Run and the contours denote the relative changes in dynamic energy between the two model runs. Blue solid lines/dotted lines indicate the sea bottom of 250 m/500 m.

Mechanisms controlling the heat budget are different at west, north, and east boundaries (Fig.1), i.e., West: mean transport + Stokes transport; North: mean transport; East: wind pumping + tidal pumping;Advective heat transport reduction mainly results from decreased mean transport at the Norwegian Channel, which is caused by the enhanced along-shelf current at the west part of the Trench (Fig.4). The latter increases mean volume transport into the North Sea, compensating the mean outward transport of the water from the Norwegian Trench to the Atlantic.

Conclusions

How does the assimilation of SST observations change the simulated North Sea heat budget?

- Direct changes of SST -> air-sea heat exchange;
- Direct changes of temperature below water surface -> advective heat transport;
- Indirect changes of hydrodynamics -> advective heat transport;

How does the assimilation of SST observations change the simulated North Sea heat budget?

The acceleration of the along-shelf current at the northern edge of the North Sea reduces the mean volume transport, thus the advective heat transport, from the North Sea to the Atlantic through the Norwegian Channel.

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