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IMPROVED DIURNAL VARIABILITY FORECAST OF OCEAN SURFACE TEMPERATURE THROUGH COMMUNITY MODEL DEVELOPMENT

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1. Introduction

During daytime, under low winds and due to solar heating, the skin and sub-skin temperatures, typically measured by satellites can increase by several degrees compared to the foundation temperature. Diurnal variability has been observed in the Mediterranean [5], western North Atlantic [1] and the global ocean [2,3] from in situ and satellite observations. Diurnal heating has been reported at higher latitudes [4] and an extended study to characterise the regional patterns of diurnal SST variability over the Atlantic Ocean and the European Seas [5], showed frequent occurrences of diurnal warming events reaching several degrees, in the Baltic Sea.

Nonetheless, diurnal SST variability it is not fully resolved by ocean and coupled ocean-atmosphere models. Although some of the important diurnal variability and cool skin effects [6] have been shown to be reproducible [7], the vertical grid resolution of the models is of meter-scale. In addition, regional CMEMS ocean forecasting systems only assimilate a single SST field per day, representative of night-time conditions when the water column is well mixed and thus, no diurnal signal is present. Such simplification of the SST has been reported to cause biases in the estimated surface fluxes [8,9]. The implications associated with the lack of a properly resolved SST daily cycle in atmospheric, oceanic and climate models have been quantified in terms of heat budget errors mostly in the Tropics. Heat flux errors associated with the warm layer development were reported in [9] to range between 10 and 50 Wm^{-2}. In regions with diurnal warm layer formation, [10] reported an annual mean surface flux out of the ocean that reached up to 9 Wm^{-2}. In addition, strong SST diurnal signals can complicate the assimilation of SST fields in ocean and atmospheric models, the derivation of atmospheric correction algorithms for satellite radiometers and the merging of satellite SST from different sensors [11]. Not accounting for the daily SST variability can cause biases in the prediction and modelling of algal blooms, especially as cyanobacteria blooms in the Baltic Sea are promoted by high SST values [12] - and the estimated net flux of CO_2, as the outflux of oceanic CO_2 is positively correlated with the increase of SST [13].

Various models exist for the description of the diurnal cycle and their complexity varies from empirical parameterisations, based on various input parameters such as the surface winds and heat fluxes, to turbulent closure models. Parameterisation models are typically developed based on observational evidence at specific locations and depths, thus carry the uncertainty of their parameters and forcing fields, typically from Numerical Weather Prediction (NWP) models not resolving the SST diurnal cycle. Such parameterisations were compared to SEVIRI SST derived signals in the North Sea and the Baltic Sea [14] with moderate results. More sophisticated models such as turbulence closure models can resolve the vertical extend of the diurnal signal but are computationally expensive. The one-dimensional General Ocean Turbulence Model [15] was shown in [16] to perform very well in reproducing the vertical temperature structure as described by satellite SST and buoy measurements. The success of such modelling attempts highly depends on the accuracy of the input fields, typically obtained from atmospheric models. Consequently, there is a need to evaluate the impact of properly resolving the daily variability of SST in atmospheric models as well. When examining very strong diurnal warming cases, it was found that updating the

SST every 6hours in the meso-scale model WRF, as opposed to using one daily value, resulted in average day-time differences of up to 20% for the 10 m winds and up to 40% for the surface heat flux [17].

The "Improved Diurnal Variability Forecast of Ocean Surface Temperature through Community Model development (DIVOST-COM)" project will "improve the representation of diurnal variability and cool skin layer in forced ocean and coupled ocean-atmosphere models" and the aim of this report is to provide an overview of the project. Section 2 describes the project methodology, section 3 describes the background and expected outcomes while the main conclusions are presented in Section 4.

2. Methodology

The project will use the Baltic (BAL) Monitoring & Forecasting Centre (MFC) domain as an example for the implementation and experiments. Relevant input fields for the initialisation of GOTM describing the state of the lower atmosphere will be retrieved from DMI's operational modelling chain (DMI-HARMONIE 54h forecast), thus creating the infrastructure for a future operational application of GOTM. The model vertical grid permits the fine discretization of layers, thus allowing a direct comparison with the operational BAL MFC model, i.e. currently the HIROMB-BOOS Model (HBM), to quantifying the latter's ability to resolve the upper ocean thermal structure (in WP1). In addition, direct comparisons with the SST TAC L4 product for the North Sea and the Baltic Sea will be performed in order to establish the reference depth of the foundation temperature. This will allow the identification of the relevant depths at which the L4 product can be assimilated with optimal results for the HBM system. Furthermore, after the initial impact assessment in WP1, sensitivity tests (in WP2) will aim at i) optimising the bottom boundary conditions in GOTM by using HBM forecasts and ii) optimising the GOTM model in terms of the used light absorption scheme to account for the biological factors, such as chlorophyll [18]. The optimized version of GOTM will be implemented as an add-on model to the HBM system for an updated run over the entire domain for a full year, and the impact for using the GOTM water temperature to improve the L4 SST production, heat flux assessment and Baltic Sea ocean forecast will be assessed in WP3. Finally, recommendations for further use of this research for CMEMS will be provided in WP4.

3. Rationale and expected outcome

A typical diurnal warming event in the region around Denmark was identified from SEVIRI observations (Figure 1), when day-time temperatures increased by as much as 5.5 degrees.

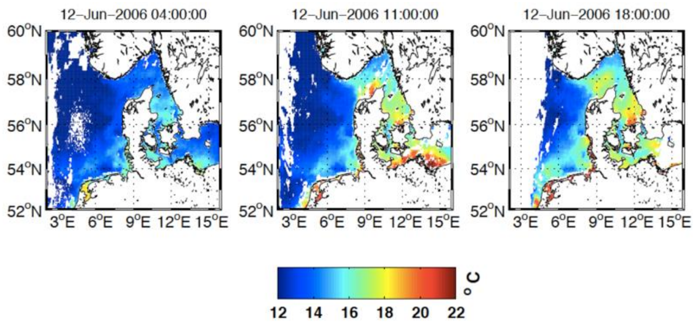

Figure 1: Example of SEVIRI SST changing during the course of a day.

The spatial patterns and characteristics of the diurnal cycle in the North Sea and the Baltic Sea have been characterised in [5]. The monthly averaged daily cycle, computed from hourly averaging grid cells with dSST of 0.5 K or more at least once during a day is shown in the left panel of Figure 2 while the right panel shows the monthly distribution of dSST greater or equal to 1, 2 and 3 K for the period 2006-2011, normalised over the total number of quality 5 SEVIRI retrievals. Modelling of the measured signals using simple parameterisations in [14], showed that the spatial patterns derived by observations are difficult to reproduce, e.g. Figure 3. Using the 1-d GOTM system, in [16] it was found that isolated warming events could be reproduced both at the surface but also along the depth of the water column. Figure 4 (left) shows an example of modelled temperatures at the Arkona Becken station located in the Baltic Sea, for the first GOTM layer at approximately 1.5 cm depth, using different combinations of meteorological forcing and initial temperature profiles along with SEVIRI sub-skin retrievals. The right panel of Figure 4 shows a vertical profile from the insitu measurements (circles) along with GOTM profiles using different forcing combinations. Based on the existing findings, DIVOST-COM aims at producing GOTM model outputs for the entire domain of interest (Figure 3). The final outcome of DIVOST-COM is expected to expand previous findings. Evaluating GOTM at an entire domain will allow direct comparisons to the BAL MFC operational outputs (currently, the HBM model).

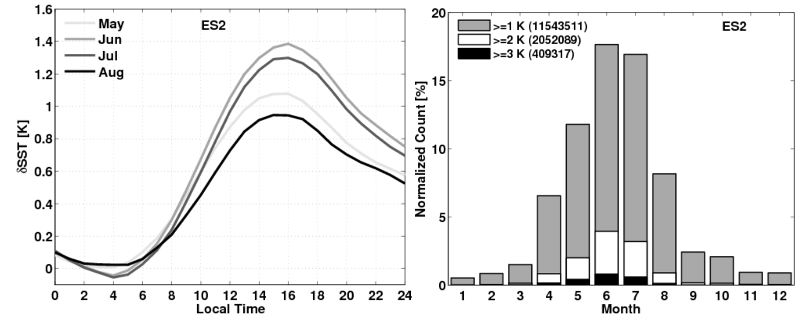

Figure 2: Monthly averaged daily cycle (left) and monthly distribution of anomalies larger than 1, 2 and 3 degrees for the North Sea-Baltic Sea.

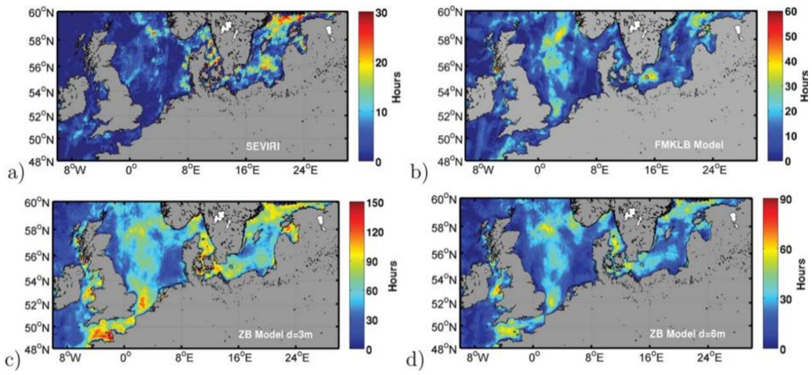

Figure 3: Spatial extent of warming exceeding 2 K from February 2009 to January 2010 from (a) SEVIRI and 3 models (b-d).

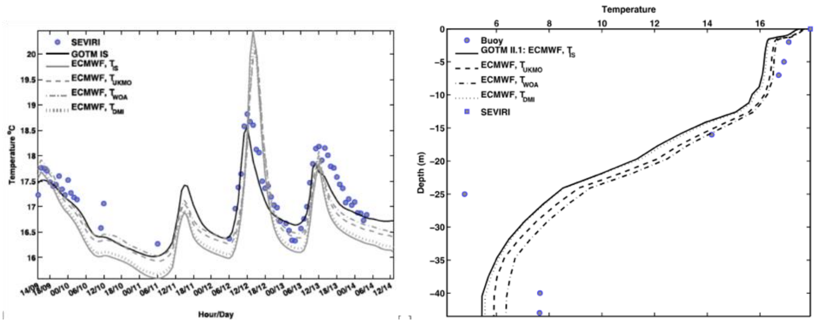

Figure 4: GOTM top layer temperature (solid), with in situ (black) or ECMWF (grey) forcing fields and SEVIRI (circles) sub-skin SST, 9-14 July 2013 (left). Vertical temperature from the measurements (circles), GOTM with ECMWF forcing fields (lines) and SEVIRI on 13 July 2013, 13:00 (right).

4. Conclusion

Diurnal variability in the North Sea and the Baltic Sea has been studied and characterised from SEVIRI SST retrievals. Attempts to model the spatial and statistical patterns of diurnal warming resulted in a candidate model to resolve the temperature profile in the upper few meters of the ocean, where thermal stratification is strong. This will be used within DIVOST-COM and the results are expected to provide insights regarding i) the MFCs' operational system skill to resolve the upper ocean thermal structure and potential weaknesses to be improved, ii) the depth where L4 SST foundation temperature products can be considered representative leading to their optimal assimilation from the MFC model systems and iii) the future ability of SST Thematic Assembly Centre (TAC) to improve the blended L4 products by adding a diurnal variability "layer" to the foundation SST. As demonstrated in [4] and [5], the Baltic Sea is prone to the diurnal variability of the upper ocean, which also has a direct impact on modelling and forecasting the events of algal blooms occurring in this semi-enclosed basin. The proposed project is also expected to support an improved reproduction of biological processes with a diurnal component, in all MFCs.

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