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MODELLED AND OBSERVED DIURNAL SST SIGNALS: “SSTDV:R.EX.-IM.A.M.” PROJECT PRELIMINARY RESULTS

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Abstract

This study presents some of the preliminary results from the ESA Support To Science Element (STSE) funded project on the Diurnal Variability of the Sea Surface Temperature, regarding its Regional Extend and Implications in Atmospheric Modelling (SSTDV:R.EX.–IM.A.M.). During this phase of the project, the focus is on the regional extend of diurnal variability. Particularly, extensive sensitivity tests regarding the definition of SST$_{found}$ fields show that using only quality 5 SEVIRI data results in warmer foundation fields SST$_{found}$ while there is an added ~0.2 K variability when using multi-day composites. Diurnal warming signals exceeding 1 K are identified in the European Seas but also in the mid-latitudes of the North and South Atlantic as well as in areas with strong currents. In the attempt to connect temperature measurements from satellites and in situ instruments, the 1-dimensional General Ocean Turbulence Model (GOTM) is applied. Preliminary results show that the initial temperature profiles may give a warmer start-up in the model while the light extinction scheme is a controlling factor for the amplitude and vertical extend of the daily signal.

INTRODUCTION

Diurnal variability of the sea surface temperature (SST) has been observed in different areas of the global ocean including the Mediterranean (Merchant et al., 2008), western North Atlantic (Price et al., 1987), and the Gulf of California (Ward, 2006). Large diurnal warming signals compared to drifting buoys were revealed in the inter-tropical Atlantic (Le Borgne et al., 2012) and recently diurnal warming has been reported at higher latitudes (Eastwood et al., 2011; Karagali et al., 2012). Not accounting for the daily SST cycle has been found to cause biases of the modelled total heat budget estimates (Webster et al., 1996; Ward, 2006; Bellenger & Duvel, 2009; Bellenger et al., 2010). Strong diurnal signals may complicate the assimilation of SST fields in atmospheric models, the derivation of atmospheric correction algorithms for satellite radiometers and the merging of satellite SST from different sensors (Donlon et al., 2007).
Thus, understanding and quantifying the diurnal SST variability at different regions and resolving the vertical extend of the diurnal signal is an ongoing scientific task in order to i) relate observations from different instruments, ii) remove trends from climate records and iii) improve atmospheric model accuracies.
In the effort to understand the nature of the diurnal signal and its vertical structure, in situ observations from moored and drifting buoys are required but they most often provide measurements at a minimum depth of 0.2 to 0.5 m from the surface. Models able to resolve the daily SST cycle and its vertical extend can help mitigate the problem of inconsistent depth measurements and serve as a link between satellite and in situ temperatures. The success of such modelling attempts highly depends on the accuracy of the input fields, in particular the wind (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, in terms of momentum and heat fluxes.
The present study is performed within the framework of ESA’s Support To Science Element (STSE) SciNet project “SST Diurnal Variability: Regional Extent – Implications in Atmospheric Modelling” (SSTDV:R.EX.-

IM.A.M.). The 6-year long SEVIRI (MSG) hourly SST fields are used to perform a low, mid and high latitude evaluation of the diurnal cycle and identify regional patterns in order to better understand the conditions under which the diurnal cycle is formed. The General Ocean Circulation Model (GOTM) is implemented in order to establish the correlation patterns between diurnal variability and the upper ocean dynamics. This will serve as the link between the surface signals of the diurnal cycle, available by satellites, and the observational evidence from drifting and moored buoys.

DATA

SEVIRI SST

SEVIRI experimental hourly fields from the Centre Météorologie Spatiale (CMS), Météo France were obtained for the period 2006–2012. The Atlantic domain extends from 73°W–45°E and 60°S-60°N and also includes the European Shelf Seas. MSG/SEVIRI SST retrievals are classified using a quality flag ranging from 0 (unprocessed), 1 (erroneous), 2 (bad), 3(acceptable), 4 (good) to 5 (excellent). A missing reason flag is available, indicating the reason for the unprocessed data quality flagged with 0. The values of the missing reason flag range from 0 (no data), 1 (out of area), 2 (aerosol), 3 (cloud mask), 4 (cloud time variability), 5 (cloud climatology), 6 (ice), 7 (other) to 8 (quality control). SEVIRI SSTs are adjusted to sub-skin temperatures at CMS by adding 0.2 K.

In Situ and Model Data

Temperature measurements from surface drifters are obtained from the Coriolis database (`http://www.coriolis.eu.org/`). These are representative of 20-cm depth temperatures and are available for the entire Atlantic, from 2006 to 2011. In situ temperature measurements at 0.6 m below the surface from buoy 41043 of the National Data Buoy Centre (NDBC), located North-East of Puerto Rico at a depth of 5313 m, are obtained through `http://www.ndbc.noaa.gov/`.
Climatological temperature and salinity profiles are obtained from the World Ocean Atlas 09 (WOA09) through the National Oceanographic Data Centre (`http://www.nodc.noaa.gov/OC5/WOA09/pr_woa09.html`). In addition profiles from the EN3 dataset available from the UK Met Office, are obtained through the Hadley Centre (`http://www.metoffice.gov.uk/hadobs/en3/data/EN3_v2a/download_EN3_v2a.html`).
Atmospheric variables, including the wind speed at 10 m, surface pressure, dry air temperature, dew point temperature and cloud cover are obtained from the European Centre for Medium-range Weather Forecasting (ECMWF) using the global atmospheric model operational archive (experiment version 1), at 0.125° resolution.

METHODS

Night-time Foundation Fields SST$_{found}$

A night-time foundation temperature field, SST$_{found}$, representative of well mixed conditions is required in order to serve as the basis upon which the diurnal signal is developed. Test SST$_{found}$ fields (TFF) are composed from SEVIRI night-time SSTs, for the period 2006–2011 using a moving day and local time window and different ranges of the quality flags (QF). The selection of parameters for each TFF is shown in Table 1.

Name	TFF1	TFF2	TFF3	TFF4	TFF5	TFF6	TFF7
Hours (LT)	00–03	00–04	00–04	22–04	22–06	00–04	00–04
Quality Flags	3–5	3–5	5	3–5	3–5	1–5	3–5
Days	±3	±3	±3	±3	±3	±0	±0

Table 1: **Specifications of the different Test Foundation Fields (TFF) in terms of the night-time window in local time, the type of SEVIRI quality flags and the number of days prior and after the given day. Thus, the ±3-days indicate a 7-day composite while the ±0 days indicate a 1-day composite.**

A validation field (VF) is composed daily from the last pre-dawn SST value with QF 5. The difference TFF−VF is defined and the statistics are computed for each TFF−VF combination. The “successful” TFF should combine minimum bias and standard deviation and maximum TFF–VF and TFF data availability. Karagali et al. (2012) used the TFF1 method but in this project it is sought to investigate the impact of the different moving time windows and quality flags with respect to latitude. In addition, the Coriolis drifter data are used to create similar TFFs from the drifter data (DTFF) in order to compare the SEVIRI TFFs with independent estimates.

GOTM Model

The General Ocean Turbulence Model (GOTM) uses input fields from ECMWF and initial temperature and salinity profiles from WOA09 and UKMO. The vertical layers of GOTM are shown in Figure 1. The model requires atmospheric variables to calculate the surface heat and momentum fluxes using the Fairall scheme (see GOTM version 4.0.0) and it has a 2-band parametrisation for the light extinction method. The time step is 60 seconds and model outputs are saved hourly.

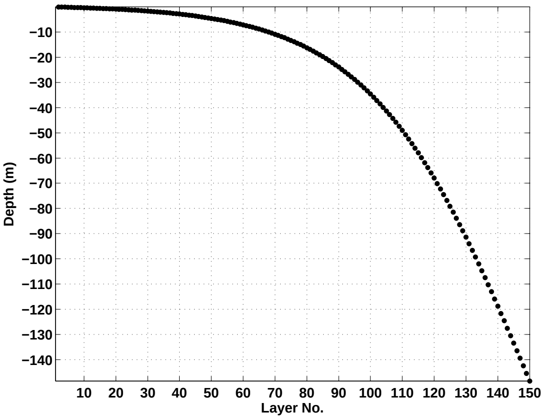


Figure 1: **Distribution of GOTM vertical layers with depth.**

Turbulence parametrisations available in GOTM include the K_ϵ and K_ω models and Kpp. Also, there are different options for the length scale method. Different configurations for the light extinction scheme can be selected from the Jerlov type water classification (I, II, IA, IB, etc.). For this study GOTM has been evaluated at 2 different locations. The first is at the location of the NDBC buoy 41043 while the second is at a location in the North Sea. Different configurations for the Turbulence Scheme (TE), the Length Scale Method (LS) and the Light Extinction (LE) are used and are summarised in Table 2.

For the purpose of comparing GOTM runs with SEVIRI and other existing parametrisation models during a diurnal warming event, the Filipiak et al. (2012) model is used (from now on referred as FMKLB). Extended comparisons between SEVIRI, FMKLB and other simple parametrisation models is available from Karagali & Høyer (2013), along with the FMKLB model description.

Version No.	v1	v2	v3	v4	v5	v7	v8	v9	v10	v11
Profiles	WOA09	WOA09	WOA09	WOA09	UKMO	WOA09	WOA09	WOA09	WOA09	WOA09
TE	2	2	2	2	2	2	2	2	2	T99
LS	10	10	8	8	10	8	8	8	8	–
LE	1	2	1	2	1	3	4	5	6	1

Table 2: **Specifications of the different GOTM versions. The Turbulence Scheme (TE) is either K_ϵ style (2) or Kpp (T99). The Length Scale method (LS) is either the dynamic dissipation rate equation (8) or the generic length scale method (10). Light extinction (LE) schemes are: 1 for Jerlov I, 2 for Jerlov I upper 50 m, 3 for Jerlov IA, 4 for Jerlov IB, 5 for Jerlov II and 6 for Jerlov III.**

RESULTS

Night-Time Foundation Fields

Figure 2 shows the latitude dependent statistics of the SEVIRI TFFs vs the SEVIRI VF for 2006–2011. While δSST for TFF3 (dark grey line) is positive, but without exceeding 0.1 K, the remaining TFFs all show negative δSST. The largest absolute biases are found in the Tropics and this can be associated with the anomalous atmospheric water vapour profiles that cause retrieval errors (Le Borgne et al., 2011). For the 1-day composites (light grey lines) σ is consistently lower, even in areas of higher variability such as the high latitudes of both hemispheres as opposed to the multi-day composite TFFs that have increasing σ for these areas. Data availability does not vary significantly but lowest values are observed for the high latitudes, more for the South compared to the North hemisphere, and for TFFs with either a short night-time window (TFF1) or only QF 5 (TFF3).

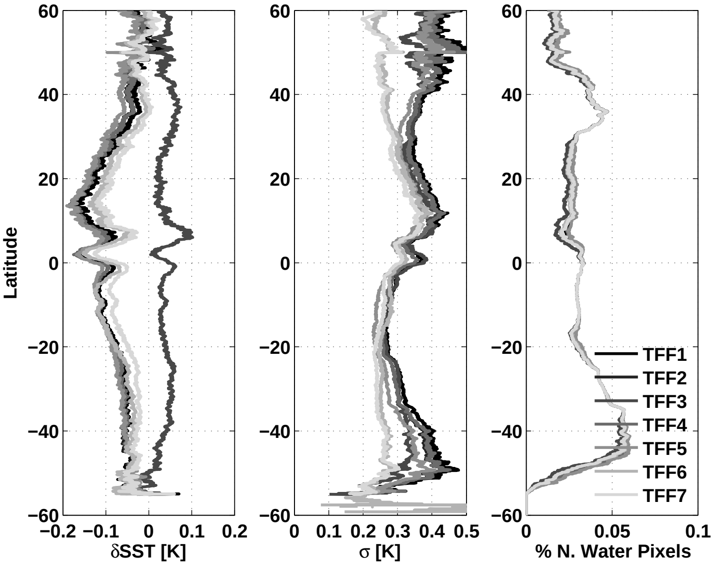


Figure 2: **Latitude dependent statistics of the SEVIRI TFF minus pre-dawn validation match-ups for 2006–2011.**

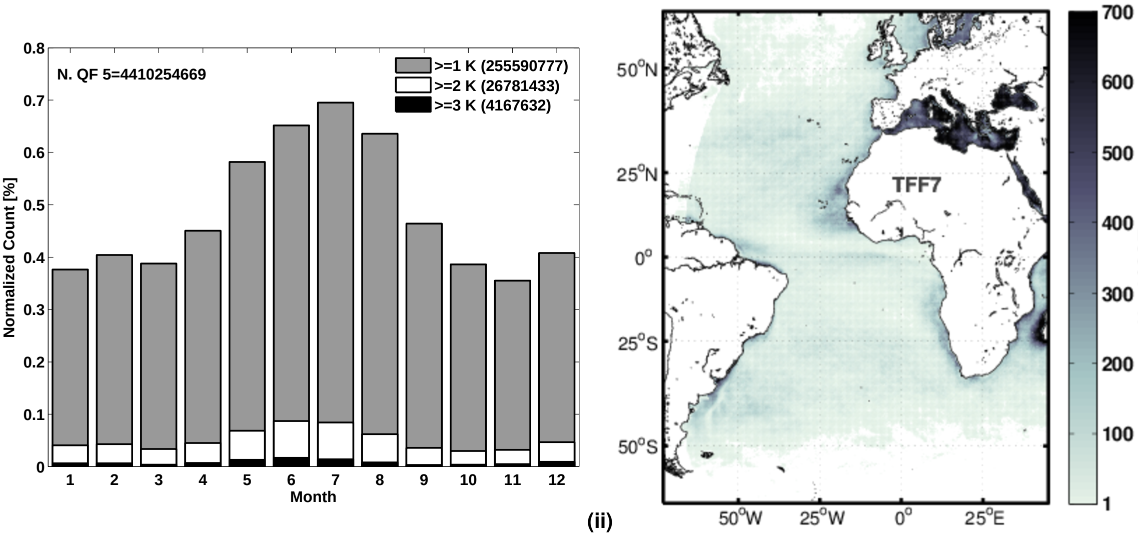
The validation of the test SST$_{found}$ (TFFs) against single-day, pre-dawn SSTs which are assumed to represent the coldest SST during a day, shows absolute δSST not exceeding 0.2 K and σ values ranging between 0.2 and 0.5 K. It is assumed that the night-time fields can represent cold, night-time foundation temperatures and it is shown that only using quality 5 SEVIRI data (TFF3) may introduce a warm bias in the order of 0.1–0.2 K compared to the coldest, pre-dawn value. Using a single-day composite (TFF7) with QF 3–5 may introduce a cold bias of the same order. In both cases, this artefact is mostly identifiable in the Tropics, where SEVIRI SST retrievals are complicated by the anomalous water vapour profiles.
Using the same methodology as for the SEVIRI TFFs, night-time foundation fields are composed from drifter data. The statistics of SEVIRI–Drifter TFFs (DTTF) are shown in Table 3. The bias δSST is mostly negative, not exceeding −0.2 K, indicating that the SEVIRI TFFs are colder than the DTTFs. Only TFF3 has a positive but almost zero δSST of 0.01 K. σ values are between 0.62–0.68 K but are lower for either the best quality TFF (TFF3) or for the single day composite TFF7. Such results are consistent with the previous findings but do indicate higher δSST and σ, which can be attributed to the different reference depth of satellite (sub-skin) and drifting buoy measurements (~20 cm).

	TFF1	TFF2	TFF3	TFF4	TFF5	TFF6	TFF7
δSST	−0.12	−0.12	0.01	−0.13	−0.12	−0.18	−0.17
σ	0.65	0.64	0.63	0.65	0.65	0.68	0.63
r	0.995	0.994	0.996	0.995	0.990	0.992	0.994
N.	3460601	3769122	1665149	4485281	6252432	198424	165553

Table 3: **Statistics of TFF with the Drifting Buoy composites, for the period 2006–2011. Match-ups are filtered for TFF–DTFF within the interval δSST± 4×σ.**

Diurnal Warming

Using as a foundation field SST$_{found}$ the candidate TFF7, i.e. a single day composite showing overall the lowest variability with SEVIRI pre-dawn values, the day-time anomalies δSST are estimated as SST$_{hour}$–SST$_{found}$, where SST$_{hour}$ is of quality 5. Thus, even if the TFF is composed from a range of qualities, a potential discard in estimated anomalies may occur when using only quality 5 to estimate the daily anomalies. Using 3 different thresholds, namely δSST≥1, 2 and 3 K, the monthly distribution of such occurrences is shown in Figure 3i, normalised over the available QF 5 data. Both hemispheres are blended, but nonetheless the shape of the distribution indicates that diurnal warming is more often found in the North Hemisphere as there is a significant peak of the distribution during the boreal summer months. Mostly identifiable are cases where δSST≥1 K but the monthly distribution pattern seems independent of the warming threshold.



(i) (ii)

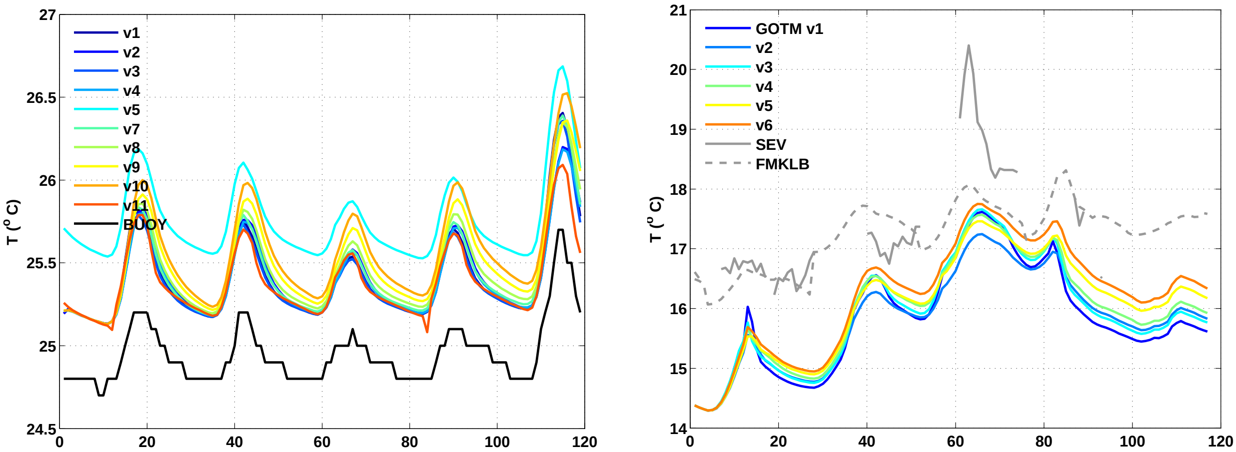
Figure 3: **i) Monthly distribution of cases with δSST≥1, 2 and 3 K and ii) Spatial distribution of cases with δSST≥1 K. Both over the period 2006–2011.**

When examining the spatial distribution of δSST≥1 K, Figure 3ii shows that most frequently such events occur in the European Seas (Mediterranean, Black, Baltic and North Sea) and the Red Sea. Strong signals are also identified in the mid-latitudes of the North and South Atlantic. Areas with strong currents, such as the Agulhas and Benguela in South Africa, the Brazil in South America, the Canaries and the Labrador current in North America also show strong signals of diurnal warming but in those areas it may be associated with the oceanic variability. Thus diurnal warming will further be examined in different regions, including the Mid-Latitudes, the Sub-Tropics and Tropics and the European Seas (Mediterranean, North, Baltic and Black Sea).

GOTM

GOTM evaluated at the location of the NDBC buoy 41043 is shown in Figure 4i against the buoy measurements at 0.6 m (black solid line). The different versions of GOTM are shown as coloured solid lines and the most striking feature is that the model can reproduce the general diurnal signals seen from the buoy measurements but there is a warm “bias” in the model outputs. In terms of the different GOTM versions, V5 (cyan) is shifted towards higher temperatures by ~0.05 K compared to all other versions, and this is assumed to be due to the different initial temperature profiles used in this version. All other versions use the same initial profiles and thus differences amongst them are due to the model configuration. V11 (orange) shows the lowest amplitude and a kink at the time of maximum cooling and this is attributed to the different turbulence scheme (Kpp) used in this version. All other versions use the same TS method but with different LS (Length Scale) and LE (Light Extinction) methods.

GOTM is also run at a location in the North Sea for which a strong diurnal warming event was identified and compared against SEVIRI SST and the results from the FMKLB model (Karagali & Høyer, 2013). Figure 4ii shows the evolution of temperature for 1st–5th July 2009. The grey solid line shows the SEVIRI SST where gaps are due to very low quality retrievals. SEVIRI shows a peak warming on the 3rd of July exceeding 3 K from the coolest part of the cycle. The dashed grey line shows the computed output from the FMKLB model that uses atmospheric variables from the HIRLAM NWP model. The FMKLB model shows a generally well captured diurnal cycle with a maximum amplitude coincident in time with the one from SEVIRI but with reduced magnitude.



(i) (ii)

Figure 4: **i) GOTM at 21.06°N,64.97°W from 01/04/2009 to 05/04/2009, ii) GOTM, SEVIRI and the FMKLB model at 57.3°N,7.7°E from 01/07/2009 to 05/07/2009.**

GOTM runs are represented by the coloured solid lines and show a clear diurnal cycle and a warming trend up until the time of SEVIRI peak warming and then a decrease in SST. The amplitude of the GOTM signal is ~0.5–2.5 K smaller compared to SEVIRI but does match rather well the one of the FMKLB model. The different GOTM versions mostly modulate the peak amplitude rather than the timing of the warming and cooling cycles. It is found that varying Light Extinction methods produce the different curves seen in the figure with more turbid waters giving higher SST amplitudes.

The temperature vs depth plots for the GOTM runs in the location of the NDBC buoy 41043 are shown in Figure 5, for different versions. While the most intense diurnal warming is limited in the upper 4 m of the water column, its signature propagates down to 20 m with intensity that depends on the version. Also, noticeable is the increased temperature in the upper 20 m for the version that uses the UKMO profiles (v5: 2nd row, left) instead of the WOA09.

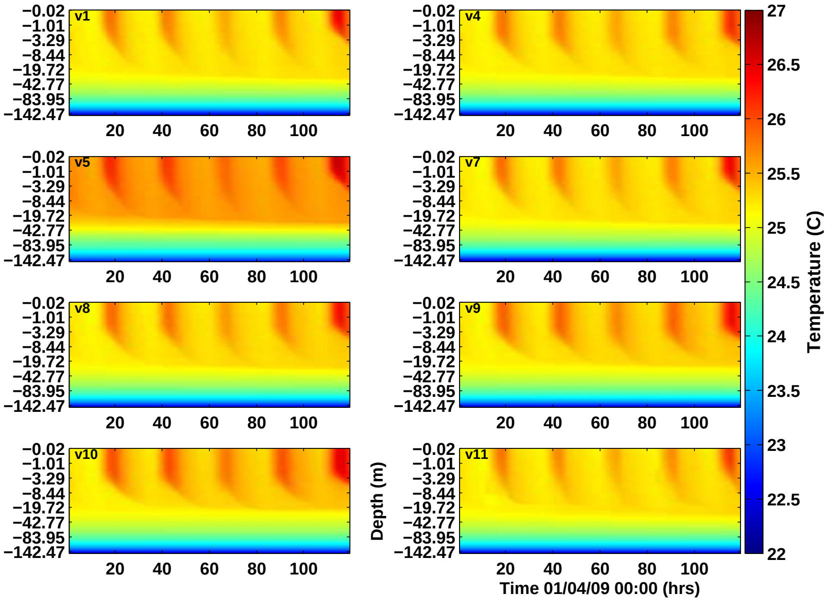


Figure 5: **GOTM at 21.06°N,67.97°W, 01–05/04/2009 for different versions explained in the upper left corner of each plot.**

DISCUSSION

This study describes some preliminary results of the ESA SSTDV:REX-IMAM project focusing on the regional extend of diurnal warming. The validation of SEVIRI night-time composites with pre-dawn SSTs shows almost zero biases and standard deviations of 0.4 K thus providing a good description of night-time, mixed conditions. Using only quality 5 data may introduce a positive bias around 0.1–0.2 K while using quality 3–5 data may introduce a cold bias of the same order, when compared to the last pre-dawn quality 5 value. While the former bias is associated with the tendency of quality 5 data to be warmer it is also related to the averaging night-time window and the potential existence of a residual night-time warm layer, the latter bias is related to the SEVIRI cloud masking scheme where lower quality data have higher percentages of cloud contamination, which lowers the pixel SST. Validated with drifter composites (DTFF), SEVIRI SST_{found} are, on average, colder by approximately 0.2 K. Quality 5 SST provide a warmer TFF that shows better statistics with the DFFs. Thus, the TFF−DTFF biases are partly associated with the potential cloud coverage of SEVIRI pixels for qualities of 4 and lower and the different reference depth of drifting buoys (20 cm) and SEVIRI SSTs (sub-skin estimated as skin+0.2 K).

It is found that σ values decrease for the single-day composite TFFs compared to the ones for the multi-day composite TFF, thus there is variability introduced by multi-day averaging of night-time SSTs and it may contaminate the quantified diurnal warming signals. Nonetheless, using 1-day composite foundation fields reduces this variability without significantly impacting the amount of quantified anomalies. Nonetheless, issues with the SEVIRI SSTs include the cloud masking scheme and the complicated retrievals in the Tropics, due to the anomalous atmosphere. The SEVIRI processing chain has recently been updated to accommodate retrieval biases at some of the problematic areas in the Tropics and Sub-Tropics. The new processing started in 2011 and up to now no re-processing of the SEVIRI archive is being performed, thus this study uses the old dataset. Some of the well documented biases found in this study are compensated for in the new dataset.

Diurnal signals exceeding 1 K have been identified in the entire SEVIRI disk and especially in enclosed seas like the Mediterranean, the Baltic and the Black Sea. The west boundaries of continents also show intense diurnal signals, especially between the Canary Islands and Western Sahara, where the cold Canary current exists and along the west coast of South Africa, Namibia and Angola where the cold Benguela current dominates. The Brazil and Guiana current systems also show increased diurnal warming cases. In areas where strong variability exists due to cold or warm currents, care must be taken when interpreting the diurnal signals as in such cases they may be associated to the existing ocean variability.

Using a one dimensional ocean model to resolve the diurnal SST cycle has shown promising preliminary results. The initial temperature profiles used as boundary conditions may provide a warm (as in the case of the NDBC buoy comparison) or cold (as in the case of the North Sea run) start-up. In addition, the turbulence and light extinction schemes both have an impact on the peak amplitude of the diurnal signal. For the latter, GOTM currently includes a 2-band parametrisation which has already proven insufficient when the diurnal cycle is of interest Hallsworth (2005); Price et al. (1987). Therefore, it is of relevance to include a wider band parametrisation light extinction scheme similar to Hallsworth (2005). This, along with sensitivity tests on the choice of either calculating the heat and momentum fluxes (as in the present study, using the Fairall model) or prescribing them from NWP model outputs are considered for future investigation.

CONCLUSION

This study focuses on some preliminary results on the regional extend of diurnal warming in the SEVIRI disc and on modelling the diurnal cycle. Test night-time SST_{found} fields validated against SEVIRI pre-dawn SSTs, assumed to be the coldest SST of the day, show that a potential warm bias introduced by only using quality 5 data is in the order of 0.2 K. Variability, in terms of σ values, decreases when using 1-day composites against multi-day foundation fields, in particular for areas where strong existing oceanic variability (currents) may contaminate the diurnal signals.

Diurnal warming estimates showed that while $\delta\text{SST}\geq 1$ K occurred to 6% of the total observed SEVIRI SST with quality 5, only 1% was ≥2 K. Despite that, monthly distributions are consistent, independent of the threshold. Nonetheless, as most of the cases are identified from May to August, it is postulated that diurnal variability is more persistent in the Northern Hemisphere, where all the enclosed seas are found. In terms of spatial distribution, δSST≥1 K was routinely identified in the European Seas, the mid-North and mid-South Atlantic and in areas where strong SST gradients exist due to currents (Argentina, Brazil, Benguela, Agulhas, Labrador); there, care must be taken in interpreting these findings as the strong ocean variability rather than diurnal warming may be the reason for such strong signals.

The attempt to model the diurnal cycle in order to connect signals from satellite SSTs (upper few millimetres) with signal from in situ instruments (from 20 cm downwards), is showing promising results. Care must be taken when choosing the model boundary conditions. The model set-up shows sensitivity to the initial temperature profiles and the light extinction scheme used.

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