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Karagali, Ioanna; Hasager, Charlotte Bay; Høyer, Jacob L.

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PRELIMINARY RESULTS FROM THE ESA STSE PROJECT ON SST DIURNAL VARIABILITY, ITS REGIONAL EXTENT AND IMPLICATIONS IN ATMOSPHERIC MODELLING (SSTDV:REX–IMAM)

Ioanna Karagali[1], **Charlotte B. Hasager**[1], **and Jacob L. Høyer**[2]

[1]*DTU Wind Energy, Risø Campus, Frederiksborgvej 399, Roskilde, 4000, Denmark*
[2]*Centre for Ocean and Ice, DMI, Lyngbyvej 100, Copenhagen-Ø, 2100, Denmark*

ABSTRACT

This study presents some preliminary results of 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.). Comparisons of SEVIRI SST with AATSR show zero biases and standard deviations around 0.5 K mostly in the Tropics where SEVIRI is found colder. Sensitivity tests on the methodology to derive foundation temperature fields show that using only quality 5 SEVIRI data results in warmer foundation fields while there is an added 0.2 K variability when using multi-day composites. Diurnal warming signals exceeding 2 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 and salinity 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.

Key words: SST; diurnal variability; GOTM.

1. INTRODUCTION

During day time and under favourable conditions of low winds and solar heating, the upper few meters of the oceanic layer may experience an increase of temperature that can reach up to several degrees. This is most intense in the first few millimetres of the water column; the part observable from microwave and infra-red sensors on space-borne platforms. Diurnal SST variability has been observed in different areas of the global ocean including the Mediterranean [12], western North Atlantic [13], and the Gulf of California [16] using combinations of in situ and satellite observations. Recently, a preliminary study has revealed large diurnal warming signals when compared to drifting buoys in the inter-tropical Atlantic, when in other regions of the SEVIRI disc the agreement between drifters and the satellite diurnal signal was found to be around 0.5 K [11]. Most of the studies mentioned above were limited in the Tropics and mid-latitude regions but recently diurnal warming has been reported at higher latitudes [4, 8].

The diurnal variability of SST is currently not properly understood. Atmospheric, oceanic and climate models are currently not adequately resolving the daily SST cycle, resulting in biases of the total heat budget estimates [15, 16, 2, 1] and therefore, demised model accuracies. 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 [3]. Not accounting for the daily SST signal can cause biases in the scatterometer derived ocean wind fields and biases in the estimated net flux of CO_2, as the out flux of oceanic CO_2 is positively correlated with the increase of SST.

Thus, there is an increased need to understand and quantify the diurnal SST variability at different regions and resolve the vertical extend of the diurnal signal, in order to relate observations from different instruments and to remove trends from climate records. Part of the effort to create a long time series of stable SST fields consists of successfully modelling the diurnal cycle at a given location in order to correct for the inconsistent satellite overpass times. This can be achieved using either observational evidence from in situ and satellite-derived SSTs or, models able to resolve the daily SST cycle and its vertical extend. 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 ESA STSE funded project SSTDV:R.EX.-IM.A.M. aims at characterizing the regional extend of diurnal SST signals and their impact in atmospheric modelling. The 6-year long SEVIRI (MSG) hourly SST fields will be used to perform a low, mid and high latitude evaluation of the diurnal cycle and identify regional patterns. Identifying areas where common diurnal warming patterns occur is important to better understand the conditions under which the diurnal cycle is formed. ENVISAT AATSR SSTs hold a key role for comparisons with the SEVIRI SSTs, especially in areas where drifting buoys are not available.

In addition, the General Ocean Circulation Model (GOTM) will be 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. The second part of the project aims at characterizing how the diurnal SST signals impact atmospheric modelling. Hourly SST fields, when available, will be used to initialize the high resolution Weather Research & Forecasting (WRF) model, currently operational in DTU. Modelled 10-m wind fields will be compared with ENVISAT ASAR 10-m winds and in situ measurements at various atmospheric levels, from meteorological masts located offshore. Heat flux error estimates will be assessed and compared with the SEVIRI SSI & SLI products.

2. DATA

2.1. Satellite Data

The AATSR Reprocessing for Climate (ARC) dataset v1.1 is used, for the period 01/2006-03/2010 and the v1.1.1 from 04/2010-2012. Data are obtained through the NERC Earth Observation Data Centre (`http://www.neodc.rl.ac.uk/browse/neodc/arc`). The selected file types are i) Day-time dual-view 2-channel and ii) Night-time dual-view 3-channel SST retrievals. The ENVISAT platform had the Local Equatorial Crossing Time (LECT) at 10:00. The nominal orbit had a repeat cycle of 35 days and the satellite crossed from North to South during the descending orbit in day-time and from South to North during the ascending orbit in night-time. The daily files contain three different temperature measurements and in this study SST_{skin} is used.

SEVIRI experimental hourly fields from the Centre Météorologie Spatiale (CMS), Météo France have been obtained for the period 2006–2012 in order to analyse the regional diurnal warming in the SEVIRI disk. The selected domain extends from 73°W–45°E and 60°S-60°N. MSG/SEVIRI SST retrievals are classified using a quality flag index that ranges from 0 (unprocessed), 1 (erroneous), 2 (bad), 3(acceptable), 4 (good) to 5 (excellent). In addition, a missing reason flag is available, which indicates the reason for the unprocessed data that are 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 corrected for the cool skin bias by an addition of 0.2 K at CMS, before they are released.

2.2. In Situ and Model Data

Temperature measurements from surface drifters are obtained from the Coriolis database (`http://www.coriolis.eu.org/`). The data 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.

3. METHODS

3.1. SEVIRI–AATSR Match-Ups

The spatial and temporal matching of the SEVIRI−AATSR SSTs is performed based on i) a maximum 30 minute difference between local times, ii) SEVIRI SST with quality flags$\geq$3 and AATSR SST with uncertainty $\leq$0.8 are selected, iii) SEVIRI−AATSR latitude and longitude difference $\leq$ 0.049°. To correct for the different reference level of the AATSR and SEVIRI SSTs, 0.2 K are subtracted from each SEVIRI retrieval, so both datasets are representative of SST_{skin}.

3.2. Test Foundation Fields

In order to study the diurnal SST variability, a foundation SST field representative of well mixed conditions in the upper oceanic surface layer, is necessary. Test foundation fields (TFF) are composed from SEVIRI night-time SSTs, for the period 2006–2011 using a moving local time window and different ranges of the MSG quality flags (qf). The selection of parameters or each TFF is shown in Table 1.

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 ±3days indicate a 7-day composite while the ±0 days indicate a 1-day composite.

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

In addition, two types of validation fields (VF) are composed daily from the last pre-dawn value flagged with i) VF1: QF 3-5 and ii) VF2: QF 5. The difference TFF-VF is defined and the statistics are computed for each TFF-VF combination. The "successful" TFF must combine minimum standard deviation and maximum TFF–VF and TFF data availability. Karagali et al [8] 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 drifter foundation fields as the TFFs for the test year 2010. The SEVIRI TFFs are also compared against the drifter TFFs.

3.3. Modelling

The General Ocean Turbulence Model (GOTM) is using input fields from ECMWF and profiles from the 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.

Different turbulence schemes are available, including TKE K_ϵ and K_ω styles and Kpp, while for the length scale different options are also available. In addition, 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 summarized in Table 2.

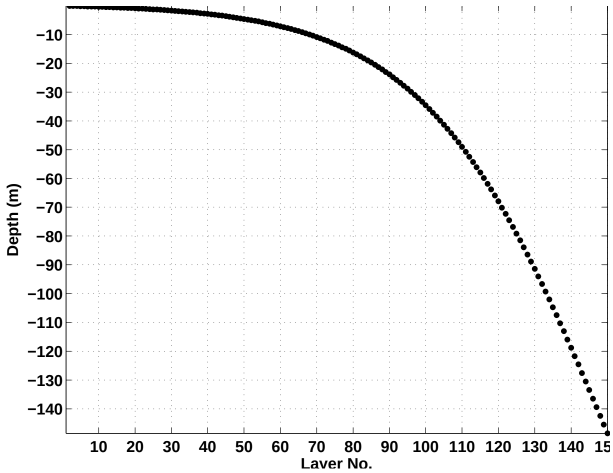

Figure 1. Distribution of GOTM vertical layers with depth.

For the purpose of comparing GOTM runs with SEVIRI and other existing parametrisations during a diurnal warming event, the Filipiak et al. [6] model is used. Extended comparisons between SEVIRI, this model and other simple parametrisations is available from Karagali & Høyer [9], along with the model description.

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 range 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.

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

4. RESULTS

4.1. SEVIRI–AATSR

The SEVIRI-AATSR match-ups have a mean bias (δSST) of −0.06 K, standard deviation (σ) 0.56 K, correlation coefficient (r) 0.996, estimated using 53393988 match-ups. To avoid the contamination of spurious SST values, a filter is further applied, defined as δSST$\pm 4\times\sigma$. Match-ups within this range are slightly reduced to 53127984 and have δSST=-0.07 K, σ= 0.51 K and r=0.997. When match-ups are binned every 1° of latitude (Figure 2), biases are mostly zero for the mid-latitudes of both hemispheres and become negative in the Tropics, indicating that SEVIRI SSTs are colder compared to AATSR. Le Borgne et al.[10] have shown such negative SEVIRI biases in the Tropics and relate them with the anomalous vertical distribution of water vapour that complicates the SST retrieval. The standard deviation is generally between 0.4 and 0.6 K and only slightly exceeds this upper threshold around the Equator. Correlation coefficients are relatively stable around 0.996 and only decrease between the Equator and 10°N. Most match-ups are between 30° and 40°N while the lowest match-up availability is found in the high latitudes of both hemispheres and between 5° and 10°N.

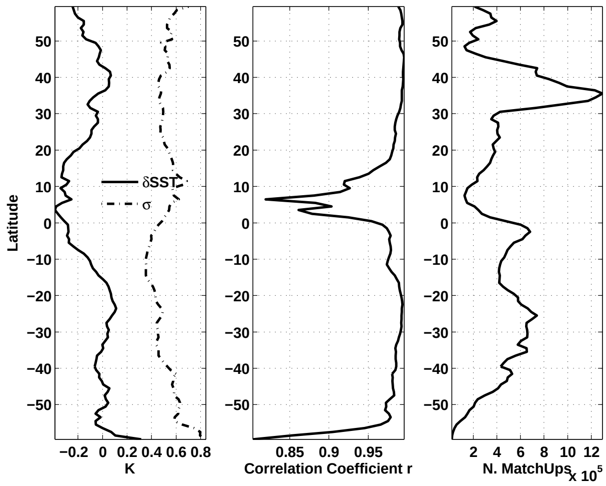

Figure 2. SEVIRI–AATSR match-ups binned every 1° of latitude, 2006–2011.

4.2. Test Foundation Fields

Figure 3 shows the latitude dependent statistics of the SEVIRI TFFs vs the SEVIRI VF1 for 2006–2011. All the TFFs have a similar behaviour with latitude. Biases are generally around zero, except for TFF3 which uses only quality 5 SEVIRI SST and shows an overall positive bias of 0.2 K. A fluctuating trend for all TFFs is observed around the Equator and in the high latitudes of both hemispheres. The σ values show the same latitudinal behaviour for all TFFs, but for the 1-day composites σ is lower in areas of higher variability, i.e. 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.

On average, the validation of the test SST_{found}

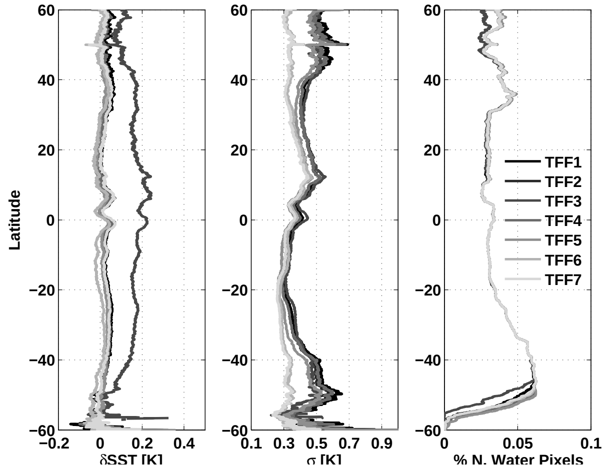

Figure 3. Latitude dependent statistics of the SEVIRI TFF minus pre-dawn validation match-ups for 2006–2011.

(TFFs) against single-day, pre-dawn SSTs which are assumed to represent the coldest SST during a day, shows almost zero biases and σ values between 0.3 and 0.5 K. Thus, the night-time fields can accurately represent cold, night-time foundation temperatures. Only using quality 5 SEVIRI data (TFF3) or just single-day composites (TFF6, TFF7) slightly decreases the data availability in the foundation field. In addition, a warm bias may be introduced using only quality 5 data (see grey line in Figure 3) for the night-time foundation field compared to the coldest, pre-dawn value, but current findings show this bias to be in the order of 0.1-0.2 K.

Using the same methodology as for the SEVIRI TFFs, night-time foundation fields are composed from drifter data. The latitude dependent statistics of SEVIRI−Drifter TFFs are shown in Figure 4, binned every 10°. The mean δSST is mostly negative indicating that the SEVIRI TFFs are colder than the drifters. σ values are between 0.8–0.9 K for most latitude bands, except around 0–10°N where they exceed 1 K and where correlation also decreases. TFF3 (dark grey line), which only has quality 5 SEVIRI SSTs, compares best with the drifters as it shows the lowest δSST and σ values.

4.3. Regional 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$\geq$1, 2 and 3 K, the monthly distribution of such occurrences is shown in Figure 5.

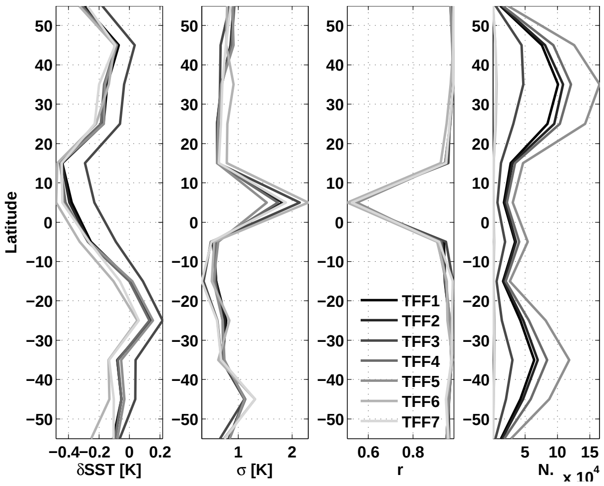

Figure 4. Latitude dependent statistics of the SEVIRI−Drifter TFF.

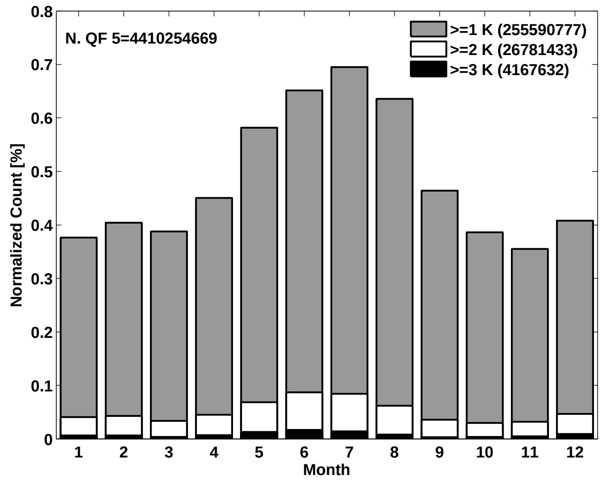

Figure 5. Monthly distribution of cases with δSST$\geq$1, 2 and 3 K over the period 2006–2011.

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. A dramatic difference between the different thresholds is identified, as δSST$\geq$1 K is the dominant pattern and the amount of identified anomalies is greater by an order of magnitude compared to the δSST$\geq$2 K case. Nonetheless, the monthly distribution pattern seems independent of the warming threshold.

When examining the spatial distribution of δSST$\geq$2 K, Figure 6 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 Angulhas and Benguela in South Africa, the Brazil in South

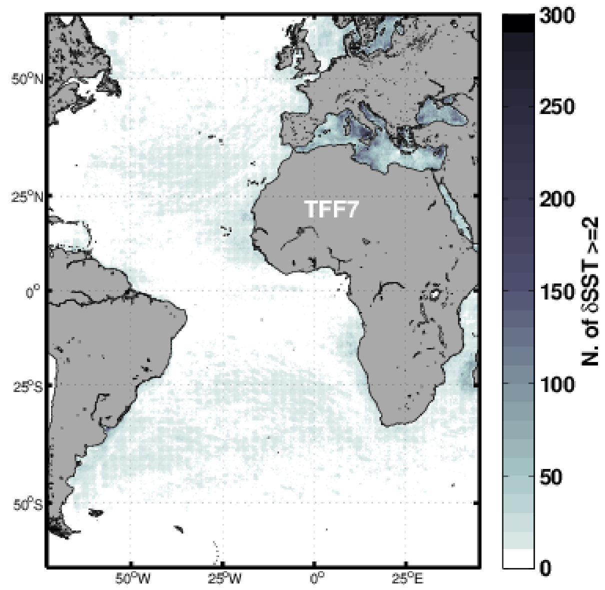

Figure 6. Spatial distribution of cases with δSST$\geq$2, over the period 2006–2011.

America 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.

4.4. Modelling

GOTM evaluated at the location of the NDBC buoy 41043 is shown in Figure 7 against the buoy measurements at 0.6 m (black solid line) shifted by 0.35 K. 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.

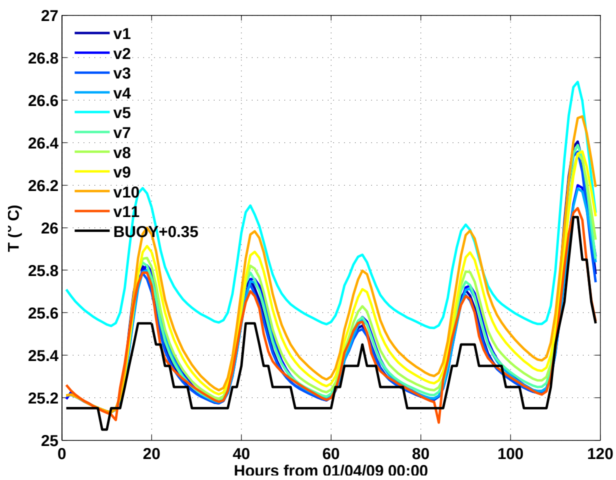

Figure 7. GOTM at 21.06°N,64.97°W from 01/04/2009 to 05/04/2009.

In terms of the different GOTM versions, v5 (cyan) is shifted by ∼0.05 K, indicating warmer temperatures caused by 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 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 Filipiak model (see Karagali & Høyer [9]). Figure 8 shows evolution of temperature from the 1st to the 5th of July 2009.

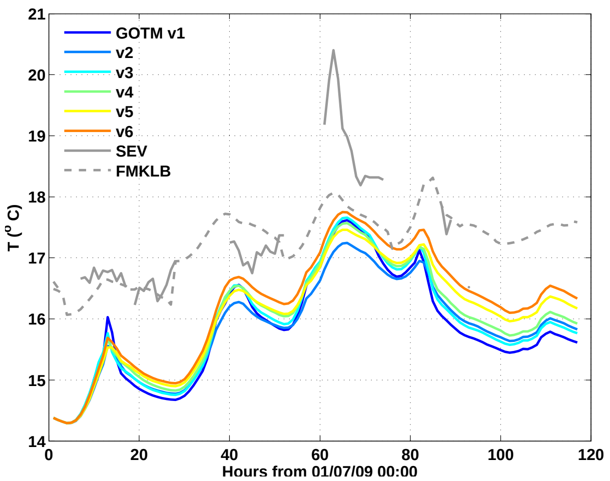

Figure 8. GOTM, SEVIRI and the XXXX model at 57.3°N,7.7°E from 01/07/2009 to 05/07/2009.

The grey solid line shows the SEVIRI SST with gaps due to very low quality retrievals. SEVIRI shows a peak warming on the 3rd of July which exceeds 3 K from the cool part of the cycle. The dashed grey line shows the computed output from the Filipiak et al. model that uses atmospheric variables from the HIRLAM NWP model. The Filipiak et al. model shows a generally well captured diurnal cycle with a maximum amplitude coincident in time with the one from SEVIRI but with reduced magnitude.

GOTM runs are represented by the coloured solid lines and the 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 Filipiak et al. 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.

5. DISCUSSION

This study describes the preliminary results of the ESA SSTDV:REX-IMAM project. At this phase, the aim is to characterize SEVIRI regional accuracies against AATSR SSTs. An AATSR product reprocessed for climate studies (ARC) was used. Embury et al. [5] demonstrated that the ARC dataset has well documented and low biases in the order of 0.3 K compared to in situ measurements. Current findings indicate overall SEVIRI−AATSR biases are around −0.1 K and the standard deviation is 0.51 K. The spatial extend of the SEVIRI−AATSR biases (not shown) reveal strong positive signals around the cold surface currents like the Portugal, Canary, Benguela and Argentina. The latter is also at the edge of the SEVIRI disk where accuracy is reduced. Strong negative biases are found around the Equator and the North Atlantic, related to the complicated vertical profiles of water vapour.

Day-time vs. night-time SEVIRI-AATSR match-ups (not shown) indicate that for local times extending 5 hours around the AATSR equatorial crossing time (thus also for retrievals near the sub-satellite track) that negative biases are mostly occurring at night-time. This may be related to the cloud masking in SEVIRI, that at night-time mistakes clouds as clear-sky pixels thus resulting at colder SST values. When the biases are binned according to the SEVIRI quality flags it is found that the quality 3 and 4 data contribute to the larger biases and standard deviations. When only quality 5 data are considered, the bias is zero and the standard deviation does not exceed 0.4 K.

The SEVIRI processing chain has recently been updated to accommodate retrieval biases at some of the problematic areas mentioned above. 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.

Prior to the estimation of diurnal signals, test foundation SST fields are composed from SEVIRI night-time SSTs and are validated against SEVIRI pre-dawn SSTS and night-time composites from drifting buoys. 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 increase the bias by approximately 0.1–0.2 K. These results are in accordance with findings from the SEVIRI−AATSR validation, which showed that quality 5 SEVIRI data are warmer than quality 3 and 4. This is associated with the SEVIRI cloud masking scheme where lower quality data have higher chances of cloud contamination, which will lower the pixel SST.

Validated with drifter composites, SEVIRI SST$_{found}$ are, on average, colder by approximately 0.2 K in the extra-Tropics and by 0.4–0.6 K in the Tropics. SEVIRI quality 5 SST are warmer and show better statistics with drifter composites. Thus, SEVIRI−Drifter biases are partly associated with the potential cloud coverage of SEVIRI pixels for qualities of 4 and lower. Another bias contribution arises from the reference depth of drifting buoys (20 cm) and SEVIRI SSTs (sub-skin estimated as skin+0.2 K).

The introduced variability by creating multi-day composite foundation fields is evident from the statistics with the 1-day, SEVIRI pre-dawn SSTs and it may contaminate the quantified diurnal warming signals. Especially in areas with strong currents and oceanic variability care must be taken when interpreting the diurnal signals. Nonetheless, using 1-day composite foundation fields reduces this variability without significantly impact the amount of quantified anomalies.

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) or start-up. In addition, the turbulent scheme has an impact on the peak amplitude of the diurnal signal along with the light extinction scheme.

For the latter, GOTM currently includes a 2-band parametrisation which has already proven insufficient when the diurnal cycle is of interest [7, 13]. Therefore, it is of relevance to include a wider band parametrisation light extinction scheme similar to [7]. 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.

6. CONCLUSIONS

This study has focused on the preliminary results on the regional extend of diurnal warming in the SEVIRI disc. Prior to the estimation of diurnal signals from the geostationary platform a validation of the 6-year long dataset with AATSR derived SSTs is performed. The mean SEVIRI−AATSR bias is −0.07 K and its standard deviation 0.51 K.

Test night-time foundation fields validated against SEVIRI pre-dawn SSTs showed that the warm bias introduced by only using quality 5 data versus using qualities 3–5, is on the order of 0.2 K. Variability decreases when using 1-day composites against multi-day ones, in particular for areas where strong existing oceanic variability (currents) may contaminate the diurnal signals.

Diurnal warming estimates showed that while δSST$\geq$1 K occurred to 6% of the total observed SEVIRI SST with quality 5, only 1% was $\geq$2 K. Despite that, monthly distributions are consistent, independent of the threshold. With the summer months in both hemispheres showing more diurnal warming occurrences. 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$\geq$2 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, Angulhas, 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 particular sensitivity to the light extinction scheme used.

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REFERENCES

[1] Bellenger H., Takayabu Y.N., Ushiyama T., Yoneyama K., Role of diurnal warm layers in the diurnal cycle of convection over the tropical Indian Ocean during MISMO, Mon. Wea. Rev. 138, 2426-2433, 2010.

[2] Bellenger H., Duvel J.P., An analysis of ocean diurnal warm layers over tropical oceans, J. Climate, 22, 3629-3646, 2009.

[3] Donlon C., Robinson I., Casey K.S., et al., The Global Ocean Data Assimilation Experiment High-resolution Sea Surface Temperature Pilot Project, Bull. Am. Met. Soc. 88(8), 1197-1213, 2007.

[4] Eastwood S., Le Borgne P., Péré S., Poulter D., Diurnal variability in sea surface in the Arctic, Rem. Sens. Environ. 115, 2594-2602, 2011.

[5] Embury O., Merchant C.J., Corlett G.K., A reprocessing for climate of sea surface temperature from the along-track scanning radiometers: Initial

validation, accounting for skin and diurnal variability effects, Rem. Sens. Env., 116, 62-78, 2012.

[6] Filipiak M.J., Merchant C.J., Kettle H., et al., A statistical model for sea surface diurnal warming driven by numerical weather prediction fluxes and winds, Ocean Sci., 8, 197-209, 2010.

[7] Hallsworth S., Modelling the diurnal variation of sea surface temperature using a one-dimensional ocean turbulence model. PhD Thesis, University of Edinburgh, 2005.

[8] Karagali I., Hoeyer J., Hasager C.B., SST Diurnal Variability in the North Sea and the Baltic Sea, Rem. Sens. Env. 112 (513), 159-170, 2012.

[9] Karagali I. and Høyer J., Observations and modelling of the diurnal SST cycle in the North and Baltic Seas, J. Geophys. Res. Oceans 118, 1-16, 2013.

[10] Le Borgne P., Roquet H., Merchant C.J., Estimation of Sea Surface Temperature from the Spinning Enhanced Visible and Infrared Imager improved using numerical weather prediction, Rem. Sens. Env. 115, 55-65, 2011.

[11] Le Borgne P., Legendre G., Péré S., Comparison of MSG/SEVIRI and drifting buoy derived diurnal warming estimates, Rem. Sens. Env. 124, 622-626, 2012.

[12] Merchant C.J., Filipiak M.J., Le Borgne P., et al., Diurnal warm-layer events in the western Mediterranean and European shelf seas, Geophysical Research Letters, 35, L04601, 2008.

[13] Price J., Weller R., Bowers C., et al., Diurnal Response of Sea Surface Temperature Observed at the Long-Term Upper Ocean Study (34o N, 70o W) in the Sargasso Sea, J. Geophys. Res., 92(C13), 14480-14490, 1987.

[14] Pimentel S., Estimation of the Diurnal Variability of Sea Surface Temperatures using Numerical Modelling and the Assimilation of Satellite Observations. Ph.D. Thesis, University of Reading, 2007.

[15] Webster P.J., Clayson C.A., Curry J.A., Clouds, radiation, and the diurnal cycle of sea surface temperature in the Tropical Western Pacific, J. Clim. 9, 1712-1730, 1996.

[16] Ward B., Near-surface ocean temperature, J. Geophys. Res. 111, C02004, 2006.