Technical University of Denmark

SST Diurnal Variability: Regional Extent & Implications in Atmospheric Modelling

Karagali, Ioanna; Høyer, Jacob L.

Published in:
Proceedings GHRSST XIV Meeting

Publication date:
2013

SST DIURNAL VARIABILITY: REGIONAL EXTENT & IMPLICATIONS IN ATMOSPHERIC MODELLING

Ioanna Karagali[(1)], Jacob L. Høyer[(2)]

(1) DTU Wind Energy, Technical University of Denmark, Frederiksborgvej 399, Roskilde, 4000, Denmark, Email:ioka@dtu.dk

(2) COI, Danish Meteorological Institute, Lyngbyvej 100, Copenhagen Ø, 2000, Denmark, Email:jlh@dmi.dk

1. ABSTRACT

The project Sea Surface Temperature Diurnal Variability: Regional Extent and Implications in Atmospheric Modeling (SSTDV: R.EX.- IM.A.M.) was initiated within the framework of the European Space Agency's Support to Science Element (ESA STSE). The main focus is twofold: i) to characterize and quantify regional diurnal warming from the experimental MSG/SEVIRI hourly SST fields, for the period 2006-2012. ii) To investigate the impact of the increased SST temporal resolution in the atmospheric model WRF, in terms of modeled 10-m winds and surface heat fluxes.

Withing this context, 3 main tasks have been identified. The first task includes the validation and inter-comparison of SEVIRI and AATSR data, the construction of the night-time foundation temperature fields and the characterization of the regional diurnal warming.

The second task focuses on modeling the diurnal SST variability using the General Ocean Turbulence Model (GOTM). The activities within this task include sensitivity tests on the GOTM set-up, comparison of GOTM, SEVIRI and buoys in point locations and a focus in the North Sea/Baltic Sea with comparisons of GOTM, SEVIRI and 3 diurnal variability schemes.

The impact of the diurnal SST variability on atmospheric modeling is the prime goal of the third and final task. This will be examined by increasing the temporal resolution of the SST initial conditions in WRF and by evaluating the WRF included diurnal scheme. Validation of the modeled winds will be performed against 10m ASAR winds and heat flux error estimates will be derived.

This study will briefly describe the overall project structure and focus on the first results from WP1. Validation results between the SEVIRI and AATSR Re-processing for Climate (ARC) datasets will be presented. In order to characterize and quantify regional diurnal warming over the SEVIRI disk, a SEVIRI derived reference field representative of the well mixed night-time conditions is required. Different methodologies are tested and the results are validated against SEVIRI pre-dawn SSTs and in situ data from moored and drifting buoys.

2. Introduction

During day time and under favorable 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 millimeters 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 (Merchant et al., 2008), western North Atlantic (Price et al. 1987), and the Gulf of California (Ward, 2006) 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 (Le Borgne et al., 2012). 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 (Eastwood et al., 2011; Karagali et al., 2012).

The diurnal variability of SST is currently not properly understood. Atmospheric, oceanic and climate models are currently not adequately resolving the daily SST variability, resulting in biases of the total heat budget estimates (Webster et al.,1996; Ward, 2006; Bellenger & Duvel, 2009; Bellenger et al., 2010) 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 (Donlon et al., 2007). 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 modeling 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 modeling 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 modeling. 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 modeling. Hourly SST fields, when available, will be used to initialize the high resolution Weather Research & Forecasting (WRF) model, currently operational in DTU. Modeled 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.

3. Data

3.1 AATSR

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.

3.2 SEVIRI

SEVIRI experimental hourly fields from CMS have been obtained for the period 2006-2012 in order to analyze the regional diurnal warming in the SEVIRI disk. The selected domain extends from 73 W-45 E and 60S-60N. 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.

3.3 Drifting Buoys

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.

4. Methods

4.1 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>=3 and AATSR SST with uncertainty <=0.8 are selected, iii) SEVIRI-AATSR latitude and longitude difference <= 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}.

4.2 Test SST_{Found} 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 January-December 2010 using a moving local time window and different ranges of the MSG quality flags (qf). Five different TFFs are composed:

1. TFF1: LT 00-03, QF 3-5, +/- 3 days
2. TFF2: LT 00-04, QF 3-5, +/- 3 days
3. TFF3: LT 00-04, QF 5, +/- 3 days
4. TFF4: LT 22-04, QF 3-5, +/- 3 days
5. TFF5: LT 22-06, QF 3-5, +/- 3 days

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. (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 drifter foundation fields as the TFFs for the same test year. The SEVIRI TFFs are also compared against the drifter TFFs.

5. Results

5.1 Validation of 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+/-4*σ. 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 1), 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. (2011) have shown such negative SEVIRI biases in the Tropics and relate them with the anomalous vertical distribution of water vapor 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 10^0 N. Most match-ups are between 30^0 and 40^0 N while the lowest match-up availability is found in the high latitudes of both hemispheres and between 5^0 and 10^0 N.

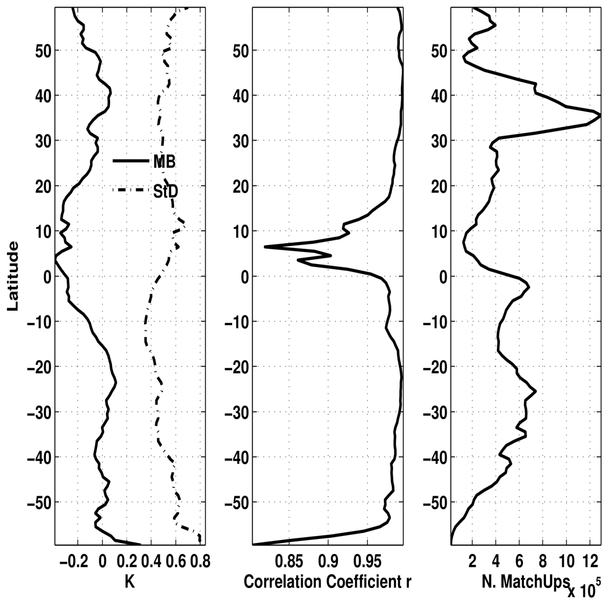

Figure 1: Latitude dependent statistics of the SEVIRI-AATSR match-ups.

5.2 Test SST$_{Found}$ fields

Figure 2 shows the latitude dependent statistics of the SEVIRI TFFs vs the SEVIRI VF1 for 2010. All the TFFs have a similar behavior with latitude. A small positive bias is identified in the southern Atlantic which slightly increases at the Equator, without exceeding 0.05 K. Immediately north of the Equator the bias turns negative. An increase is observed around 5° N, when the bias turns positive again followed by a decrease between 10^0 and 30^0 N, when the bias becomes negative. From 30^0 N and up, the bias is slightly positive without exceeding 0.05 K. This is a consistent behavior for all the TFF-VF1 biases, including TFF3 which nonetheless, shows larger positive amplitudes and does not turn negative. The standard deviation is fluctuating around 0.4 K with lowest values between 40^0 S and the Equator. From 0^0 to 25^0 N, standard deviations exceed 0.4 K and decrease again from 25^0 to 40^0. Data availability is similar for the TFFs that use the same type of quality flags but TFF3 has clearly lower data availability. Lowest data availability is observed for the high latitudes, more for the South compared to the North hemisphere. Maximum data availability for the mid-latitudes of both hemispheres.

Summarizing, the validation of the multi-day, night-time SST composites against single-day, pre-dawn SSTs which are assumed to represent the coldest SST during a day, shows almost zero biases and standard deviations around 0.4 K. Thus, the night-time fields can accurately represent cold, night-time foundation temperatures. Only using quality 5 SEVIRI data decreases the availability in the foundation field. Results on the statistics between the TFFs and VF2 (pre-dawn, quality 5 SST) show a lower data availability which also varies strongly with the latitude and this is associated with the quality of data used in the validation field. 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. In addition, a warm bias may be introduced using only quality 5 data (see blue line in Figure 2) 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.

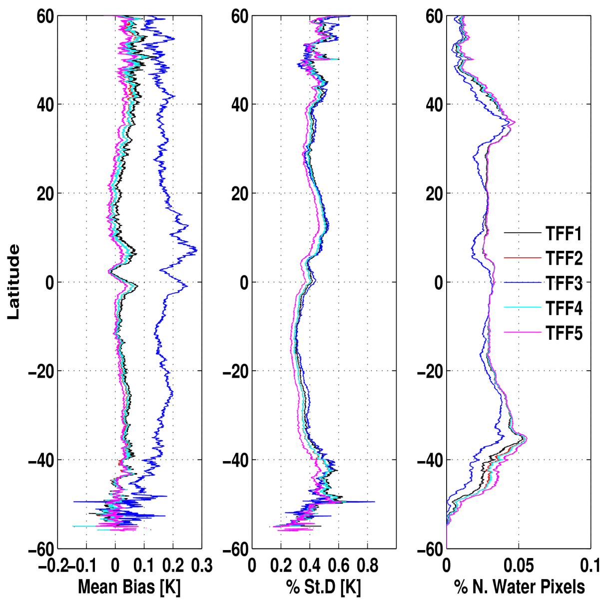

Figure 2: Latitude dependent statistics of the SEVIRI TFF minus pre-dawn Validation match-ups for 2010.

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 3, binned every 10^0. The mean biases are mostly negative indicating that the SEVIRI TFFs are colder than the drifter ones. Highest mean absolute biases are identified for the Tropics and especially the North Hemisphere between the Equator and 20^0 N. In this region standard deviations are also highest and the correlation r is lowest. Lower biases and standard deviation is found for TFF3 (dark blue line), which only has quality 5 SEVIRI SSTs but the data availability is significantly reduced. From the TFFs that include quality 3-5 SEVIRI SSTs, biases are similar for all. Standard deviations are slightly different in 3 regions. In the southern latitudes (40^0-60^0 S), standard deviations are significantly lower for TFF1 and TFF2 compared to TFF4, TFF5. In the Tropics, between 10^0 S-5^0 N, TFF4 and TFF5 have marginally lower standard deviation. Above 40^0 N, all standard deviations increase but TFF5 has a slightly higher standard deviation. The latitudinal extend of the SEVIRI-Drifter TFFs biases is similar to the one of SEVIRI-AATSR but has a higher amplitude.

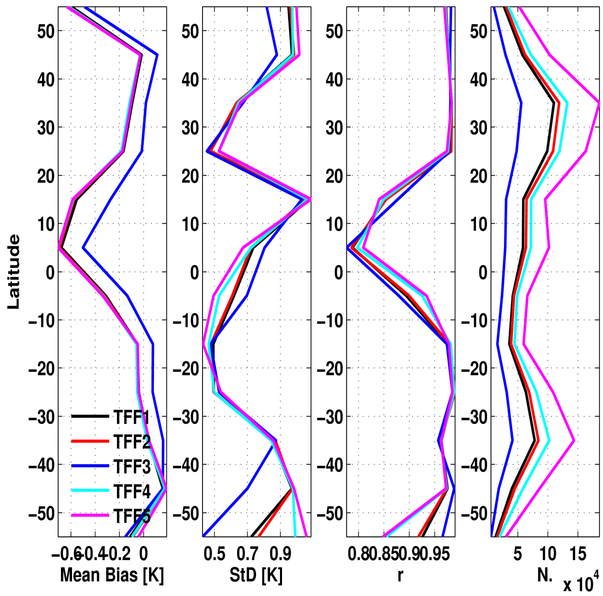

Figure 3: Latitude dependent statistics of the SEVIRI TFF minus Drifter TFF for 2010.

When the spatial distribution of the biases is examined (not shown), it is found that large negative biases occur mainly between the Equator and 20^0 N and in the North Atlantic, indicating colder SEVIRI foundation fields. Positive SEVIRI biases in the South Hemisphere are associated with major regions of cold currents (Malvinas, Benguela). Strong positive biases are also found in the Bay of Biscay and the Mediterranean Sea.

6. 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. (2012) 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 show strong positive signals around the cold surface currents like the Portugal, Canary, Benguela and Malvinas. 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 vapor.

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. Finally, when the biases are binned according to the SEVIRI quality flags it is found that it is the quality 3 and 4 data that 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.

Regarding the test foundation fields, different methodologies have been examined that utilize different quality flags and night-time windows. Validation of this test foundation fields against SEVIRI pre-dawn values, indicates that on average the test foundation fields may be warmer by a maximum of 0.4 K when quality 3-5 data are used. Using only quality 5 data may increase this bias by an additional 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.

7. Conclusion

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. While in the mid-latitudes of both hemispheres SEVIRI-AATSR biases are almost zero and the standard deviation shows minimum values, in the Tropics and high latitudes the bias becomes negative and the standard deviation increases

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. While the validation of SEVIRI night-time composites with pre-dawn SSTs shows almost zero biases and standard deviations of 0.4 K indicating a good description of night-time, mixed conditions. When the SEVIRI composites are validated with drifter composites it is found that they are, on average, colder by approximately 0.2 K in the extra-Tropics and by 0.4-0.6 K in the Tropics. An impact of the SEVIRI quality flags is also identified, where quality 5 data are warmer and show better statistics with drifter composites. Thus, the SEVIRI-Drifter differences are partly associated with the potential partial 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).

8. References

Bellenger, H., Y. N. Takayabu, T. Ushiyama, and K. Yoneyama, 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.

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

Donlon C, Robinson I, Casey KS, Vazquez-Cuervo J, Armstrong E, Arino O, and co-authors, The Global Ocean Data Assimilation Experiment High-resolution Sea Surface Temperature Pilot Project, *Bull. Am. Met. Soc.* **88(8)**, 1197-1213, 2007.

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

Embury, O., Merchant, C.J., and G. K. Corlett, 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.

Karagali, I., Hoeyer J., and C. B. Hasager, SST Diurnal Variability in the North Sea and the Baltic Sea, *Rem. Sens. Env.* **112** (513), 1195-1225, 2012.

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

Merchant, C. J., Filipiak, M. J., Le Borgne, P., Roquet. H., Autret. E., et al.. Diurnal warm-layer events in the western Mediterranean and European shelf seas. *Geophysical Research Letters,* **35**, L04601, 2008.

Price, J., Weller, R. , Bowers, C. , and M. Briscoe, Diurnal Response of Sea Surface Temperature Observed at the Long-Term Upper Ocean Study (34° N, 70° W) in the Sargasso Sea. *J. Geophys. Res.,* **92(C13)***,* 14480-14490*,* 1987.

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

Ward B, Near-surface ocean temperature, *J. Geophys. Res.* **111***,* C02004, 2006.