IMPROVING REGIONAL AVHRR SST MEASUREMENTS USING AATSR SST DATA

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Abstract

The sea surface temperature (SST) is an important parameter in many disciplines (e.g., oceanography, meteorology or climatology). Satellite SST measurements from different sensors are available but such data collected over the same area often exhibit considerable mutual differences. Advanced Along Track Scanning Radiometer (AATSR) onboard the European Space Agency (ESA) ENVISAT platform currently provides the most accurate and precise measurements for deriving SST, whereas Advanced Very High Resolution Radiometer (AVHRR), MODerate resolution Imaging Spectroradiometer (MODIS), and Spinning Enhanced Visible Infra-Red Imager (SEVIRI) sensors render spatially and temporally denser coverage of a given area.

In this study five different SST L2 products/datasets (NOAA17/AVHRR, METOPA/AVHRR, Terra/MODIS SST, Terra/MODIS SST4 and MSG/SEVIRI) and two auxiliary L2 products (MODIS Water vapour, MODIS Aerosol) were combined with a view to obtain better satellite estimates of the Adriatic Sea surface temperature. To that end, the AATSR-derived SST was used to improve estimates based on local collection of NOAA 17 AVHRR High Resolution Picture Transmission (HRPT) data stream. More specifically, six years (2003 – 2008) of AATSR and AVHRR SST L2 data were analyzed together with auxiliary aerosol and water vapour data from MODIS sensor aboard Terra platform for generation of new algorithms, while extension to 2010 was performed only for validation purposes of global SST products. The matchup data were stored in a relational SQL database to ensure smoother manipulation of couple of million data pairs. The analysis has shown that the application of all global SST night-time products to Adriatic Sea produces seasonality in the SST residuals (global SST - AATSR SST). A new set of AVHRR monthly-variable coefficients has produced an improvement in overall statistical parameters (night-time scatter is decreased from 0.46 to 0.34 K and bias from -0.07 K to -0.03 K) while eliminating noted seasonality in the residuals.

INTRODUCTION

Application of global SST algorithms to Adriatic Sea radiances exhibit discrepancies compared to in situ measurements, but also compared between different SST satellite products (Tomažić et al. 2011). Advanced Along Track Scanning Radiometer (AATSR) onboard the European Space Agency (ESA) ENVISAT platform currently provides the most accurate and precise measurements for deriving SST, whereas data from Advanced Very High Resolution Radiometer (AVHRR) sensor aboard NOAA and METOP-A platforms render spatially and temporally denser coverage. Due to the lack of long term, spatially dense in situ SST measurements and exploiting the advantages of the AATSR sensor, the data from the two sensors are combined to improve the quality of satellite estimates over Adriatic Sea. Locally received NOAA 17/AVHRR data and data from ENVISAT/AATSR were analysed together with auxiliary aerosol and water vapour data from MODerate resolution Imaging Spectroradiometer (MODIS) instrument aboard the Terra platform. The data used in this study is presented in the Data section. Analysis was performed by implementing Multi-Source Matchup Database (MSMDB, Tomažić 2010) that allowed generic comparison of different satellite, model and in situ datasets and smoother manipulation of huge number of matchup pairs (>10 millions). This methodology is described in the Methodology section. Validation of global products and algorithms in Adriatic Sea is presented in section: Validation of global SST products, whereas the derivation of new algorithms, corresponding coefficients and overall improvements in regional SST estimation is presented in section entitled Improvement of regional sst retrieval.
DATA

This study focused on Adriatic Sea (Figure 1) uses SST data from several satellite sensors (AATSR, AVHRR, MODIS, SEVIRI) that are combined with auxiliary variables and products with a view to assess the origin of errors in Adriatic SST retrievals. The main analysis period is from the beginning of 2003 to the end of 2008, where the extension to 2010 is performed only for validation purposes. Main SST product is NOAA 17/AVHRR working files (Tomažič et al. 2011) produced and processed at Rudjer Boskovic Institute (IRB) that contains derived SST and observed brightness temperature (BTs) fields over Adriatic Sea. Two different algorithms were used, nonlinear SST algorithm (NLSST) during day and night, and multi-channel triple (MCTriple) for night-time only. The reference AATSR data were retrieved as L2 orbit files from ESA, subsetted to Adriatic Sea. The AATSR data were used as a reference due to their superior quality compared to data obtained with other infrared (IR) sensors (O’Carroll et al. 2006; Le Borgne et al. 2010), but also due to the lack of continuous quality in situ measurements in Adriatic Sea. The AATSR dataset is used to improve the quality of the NOAA 17/AVHRR based SST retrievals, but also in validation of other available Adriatic Sea SST products. The following products are used only in validation exercise showing that all SST products are affected by inadequate atmospheric correction: METOPA/AVHRR SST L2 and MSG/SEVIRI SST product retrieved through Meteo-France/CMS, MODIS SST and SST4 L2 products retrieved from Ocean Biology Processing Group (OBPG) data centre. The METOPA/AVHRR SST product uses different algorithms for day (NLSST based) and night (MCTriple based), while MSG/SEVIRI uses single algorithm (NLSST based) both for day and night. The MODIS SST data are also derived with two algorithms, utilizing long wave IR (LWIR) channels (MODSST) for both day and night and short wave IR channels (SWIR, MODSST4) only for night-time. In addition to SST data, auxiliary data were used to further assess and analyse the errors between the validated and referenced SST. For that purpose, total column water vapour and aerosol data were retrieved from National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC), as MODIS L2 products from Terra satellites.

METHODOLOGY

Comparing coincident satellite L2 data entails analysis of huge number of matchup pairs; their storing and manipulation requires implementation of a relational database, for which open source PostgreSQL database was used. To ease the comparison of several different SST and auxiliary products with the reference dataset (AATSR SST) a generic approach was used allowing creation of matchup pairs for any type of data with longitude, latitude and date/time triplets. This effort further on led to development of a complete information system for generation and analysis of MSMD. The entity relationship diagram of the current MSMD is shown in Figure 2 (not all listed products were used in this analysis).
Initial procedure requires ingestion of the reference dataset into the MSMDB. Further on, all other datasets are paired with the reference data based on dataset-defined spatial and temporal coincident criteria. Due to the large number of satellite measurements, initial reference dataset is optionally reduced by defining percentage of data to be randomly extracted from each satellite overpass. All SST data (MODIS, AVHRR, SEVIRI) were paired and ingested into the MSMDB with temporal criteria of 4 h absolute time difference, whereas later in the analysis the matchup time window was decreased to 1 h. The spatial difference was always set to be within-pixel distance. The system allows extraction of NxN data matrix surrounding the central matchup pixel and its ingestion into the database for further analysis, but this approach was not used in the present study. This generic approach allows matchup of any type of data with longitude, latitude and date/time triplets (including model output and in situ measurements), and also to focus on different regions. The only prerequisites are the downloaded and prepared datasets for the region of interests.

Since the system automatically (after pre-setting necessary information defined for each product) creates matchup pairs and ingests them into MSMDB it is relatively simple to add new products in single MSMDB analysis, or even create multiple MSMDBs. Couple of MSMDBs were created with different percentage of extracted reference data from each scene, to allow independent derivation and validation of new algorithms. In this study three independent MSMDBs were created, with 1%, 2% and 3% of randomly extracted reference data.

All polar satellites used in this analysis have mid-morning orbit and pass over the Adriatic Sea within the maximum 2 hour absolute mutual time difference. Therefore, it was possible to combine data from
ENVISAT/AATSR and other polar orbit satellites (NOAA 17, METOP A, Terra) and constrain the
coincident measurements within 1 hour. More accurate analysis would require correction for the
overpass time-difference which is mainly a problem in day-time conditions while this study focuses
more on night-time analysis.

Five different SST L2 products/datasets (NOAA17/AVHRR, METOPA/AVHRR, Terra/MODIS SST,
Terra/MODIS SST4 and MSG/SEVIRI) and four auxiliary L2 products (MODIS Water vapour, MODIS
Aerosol, QuikSCAT Wind, ASCAT Wind) were paired and ingested into the MSMDB. For all SST
products, data in full resolution (1 km nominal) were used, producing couple of million matchup pairs
per product/dataset. Since each product comes with its own quality flags, combining them together
and filtering only for the highest quality ones increases the quality of the analysis at the expense of
reducing the number of data. Since the reference SST dataset is provided as skin SST, all other “bulk”
SST products (METOP-A/NLSST/MCTriple, MSG/NLSST, NOAA 17/NLSST) were converted to skin
SST by subtracting 0.17 K from the bulk values.

VALIDATION OF GLOBAL SST PRODUCTS

The Adriatic Sea SST products derived with the global algorithms were compared by producing overall
residual statistics and by analysing residuals in time. Overall statistics (Table 1) depends on day or
night-time analysis algorithm form (SWIR or LWIR) and type of algorithm coefficients (constant or
time-dependant) (Tomažiće et al. 2011). In the day-time analyses, standard deviation (SD) is above
0.5 K for all products, with biases in the range between -0.18 and +0.07 K. The night-time results for
LWIR based algorithms give SD below 0.5 K for all products (NLSST, MSG/SEVIRI and MODSST),
with higher positive bias (+0.25 K) for the MSG/SEVIRI data. Night-time SWIR based algorithms
(MCTriple, MODSST4) give the smallest SD (below 0.3 K) with relatively high biases (-0.27 K; +0.14
K).

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Bias (K)</th>
<th>Stdev(K)</th>
<th># pairs</th>
<th># scenes</th>
<th>Bias (K)</th>
<th>Stdev(K)</th>
<th># pairs</th>
<th># scenes</th>
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Table 1: Overall statistics for analysed products, separately for day and night. Dotted line in the night-time results
separate LWIR based algorithms (upper part) from SWIR based algorithms (lower part).

The time series of residuals give more comprehensive view (Figure 3). It is clear from the figure that
night-time NOAA17/NLSST residuals have strong seasonal oscillation. Each point in the plot
represents single residual. To enhance the seasonal signal and reduce the noise, the spatial scene-
averaging of all residuals was performed over the single Adriatic scene (overpass). This is justified
since Adriatic Sea has relatively small geographical extent (800x200 km) and it was shown (Tomažiće
et al. 2011) that residual latitude dependence could be neglected over Adriatic Sea. The night-time
scene-averaged residuals and corresponding SD are shown for NOAA 17/NLSST in Figure 4, where
both signals (bias and SD) exhibit seasonality. During summer time maximal positive variability
amplitude value is 0.8 K, while during winter time maximal values are negative (-0.5 K). This gives
absolute difference of ~1.5 K between summer and winter time extremes. Standard deviations show
higher values in summer (~0.5 K) and lower values in winter (~0.3 K). Seasonality in both bias and SD
is in accord with the seasonality of water vapour over Adriatic Sea (Tomažiće and Kuzmić 2009;
Merchant et al. 2009). To highlight the significant periods in observed time series periodograms of
unevenly sampled data, periodograms are derived together with significant levels. For the night-time
NOAA 17/NLSST residuals, periodogram (Figure 5) shows the main annual period (above the
significant level of 0.001) that corresponds to the annual atmospheric water vapour signal due to
inadequate atmospheric correction applied in NLSST algorithm; also seen is a semiannual period
(above the significant level of 0.05).
Figure 3: Time-series of night-time NLSST residuals.

Figure 4: Night-time NLSST residuals (upper figure) averaged over single scene and their corresponding standard deviation (lower figure).

Figure 5: Periodogram of night-time NLSST residuals scene-averaged.

Noted annual periods are also visible in other products (Figure 6), mainly in the METOP-A/NLSST (although data are available only for two years) and MSG/SEVIRI, and to a lesser extent in NOAA 17/MCTriple (smaller amplitude). The least annual residual variability is observed in
Terra/MODIS based SST (MODSST and MODSST4). The main reason of the superior performance of the MODIS SST derives from the fact that the MODIS SST algorithm coefficients are time and water vapour dependant (Brown and Minnett 1999), effectively reducing noted seasonality. Daily residuals for all products (not shown) do not exhibit such a prominent annual periodicity, due to the fact that inadequate atmospheric correction is additionally masked with the diurnal warming (DW) influence.

Figure 6: Night-time series of scene-averaged residuals with corresponding periodograms for following SST products (from top to the bottom row): MSG/SEVIRI; NOAA 17/MCTriple; METOP-A/SWIR; Terra/MODSST; Terra/MODSST4.
IMPROVEMENT OF REGIONAL SST RETRIEVAL

The possibility to improve the AVHRR based SST retrieval using reference AATSR data was also explored. New sets of coefficients for NLSST and MCTriple NOAA 17 algorithm were derived by regressing AVHRR brightness temperatures and AATSR SST data from independent MSMDBv2. Different types of coefficients were derived for NLSST (day and night) and MCTriple (only night) algorithms: coefficients constant in time, monthly variable coefficients (prefix M) and monthly and inter-annually variable coefficients (prefix YM). To ensure high quality, new coefficients are derived with the following conditions: aerosol optical depth between 0 and 0.3, highest quality of aerosol product (quality flags 0) and water vapour product (quality flag 2 and 3), absolute time difference less than 1 h, satellite zenith angle less than 50°. Robust multi-linear regression was used to reduce the influence of possible outliers which improved the SD for about 0.05 K, compared to standard multilinear regression.

Overall statistics for all types of algorithms and coefficients, applied on smaller MSMDBv1 database, is shown in Table 2, and time series analysis together with corresponding periodogram is shown on Figure 7, but only for AA_YM_NLSST algorithm (where “AA” depicts Adriatic algorithms based on AATSR data). As expected, overall error is progressively decreasing with the increase in coefficients variability, giving the smallest error for the AA_YM types of algorithms. The biggest improvement for the NLSST type of algorithms is in SD where the value is reduced for 0.07 and 0.1 K, for the day and night respectively. For MCTriple type of algorithms, the best improvements comes in reducing the bias (from -0.26 K to ±0.01 K), while the SD improvements is 0.03 K and totals to 0.25 K. Besides improvement in overall statistical parameters, the main contribution of implementing new algorithms is in complete absence of seasonality in residuals. This is especially emphasized in night-time conditions when the atmospheric parameterisation is separated from the diurnal warming.

<table>
<thead>
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<th></th>
<th>DAY</th>
<th>NIGHT</th>
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<tr>
<td></td>
<td>NLSST (LWIR)</td>
<td>NLSST (LWIR)</td>
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<tr>
<td>Coefficients</td>
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<tr>
<td>Global</td>
<td>Bias (K)</td>
<td>Stdev (K)</td>
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</tr>
<tr>
<td>AA_YM</td>
<td>-0.03</td>
<td>0.39</td>
</tr>
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</table>

Table 2: Overall statistics for different types of regional algorithms compared to the global one.

Figure 7: Night-time AA_YM_NLSST residuals and corresponding periodogram.

CONCLUSIONS

This study is focused on the Adriatic Sea seeking improvement of locally received and processed NOAA 17/AVHRR SST data using ENVISAT/AATSR SST data as the reference. In addition, other available global SST datasets (METOP-A/AVHRR, MODIS/Terra, MSG/SEVIRI) were compared to AATSR SST data in the period from 2003 to 2010 with the view to elucidate the origin of errors in the Adriatic SST retrievals. Comparison results show seasonality in SST residuals for all analysed products, especially for night-time.

The largest statistical errors are obtained for daytime with standard deviations of all products above 0.5 K and biases ranging from -0.18 to +0.07 K. Night-time results show the smallest standard deviation for SWIR algorithms (~0.3 K), but larger increase in biases (from -0.3 to 0.14 K). The results also exhibit dependence on type of algorithm (SWIR, LWIR) and type of coefficients (constant or variable). Three types of new coefficients were derived for NOAA 17 NLSST and MCTriple based...
algorithms: constant in time, monthly variable but same for every year, and monthly and yearly variable. Expectedly, the best results and the smallest errors were obtained with coefficients accounting for monthly and interannual variability, with standard deviation reduced for 0.1 K for NLSST types of algorithm, and with near-zero bias both for day- and night-time. For MCTriple type of algorithm, bias was reduced from -0.26 K to +0.01 K with the SD of 0.25 K. The important improvement is also complete lack of seasonality in residual time-series for the new coefficients, particularly for the night-time data. Methodology used to validate and analyse the Adriatic SST data allowed inter-comparison of five different SST products and several other auxiliary dataset giving possibility to combine initially independent datasets into single result. Moreover, the technology of automated generation of MSMDB systems allows relatively simple generation of several independent databases, with possibility to focus on different regions or even analysis of different types of data.

ACKNOWLEDGMENTS

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REFERENCES


