Comparison analysis between bulk sea water temperature, as measured by drifters, and sea surface temperature derived by satellite measurements

by

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1. Introduction

The use of infrared radiometers (Advanced Very High Resolution Radiometer-AVHRR), on board NOAA polar orbiting satellites, provides a global coverage of the sea surface temperature (SST) data. In order to increase the accuracy of this kind of data in the Adriatic Sea it is necessary to compare the temperature measured by satellite instruments with the bulk temperature measured in situ by drifting buoys. Drifters must have as sparse geographic and temporal distribution as possible to permit a comparison with the satellite SST.

Satellite measurements correspond to a very thin surface skin layer of the sea while the bulk temperature is measured by a sensor (thermistor) mounted on the drifting buoys nearly 0.5 meters below the surface. This depth varies slightly as the buoy bounces in the turbulent environment of the sea surface. So, the ocean surface as seen by a radiometer has a skin temperature that differs by some tenths of a degree from the water below [Schluessel et al., 1990]. In any case the in situ measurements have to be considered the most reliable ones and so in this work the drifters temperature data are assumed to be the "true values".

A comparison analysis was performed between drifter temperature data and satellite SST data having the same position and time. The comparison was done for the period ranging from September 2002 to December 2003 and divided into categories defined by the satellite number and the time of the day (day or night). A linear regression was applied to each of these groups of points. A correction was only necessary (subtraction of 0.76) to improve the accuracy of the NOAA-16 derived SST during nightly passes.

2. Data

2.1. Advanced Very High Resolution Radiometer (AVHRR) data

AVHRR data, used to compute the SST, are those transmitted by NOAA 12, 14, 15, 16 and 17 satellites (Figure 1) from September 2002 to December 2003. These data have been received at OGS (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale) and processed as explained in Notarstefano et al. (2003). During the processing it is necessary to take into account the attenuation of the sea temperature signal by atmospheric water vapor. To do this we use the procedure introduced by McClain [1985] in which SST values are computed using the Multi Channel Sea Surface Temperature (MCSST) algorithm. To have the best SST estimate, a good cloud masking has been utilized in our processing [Notarstefano et al., 2003] and improved for those satellites having channel 3a in daytime passes.

Figure 1. NOAA satellite.

2.2. Drifter data

For this study we selected only drifter released in the Adriatic Sea from September 2002 to December 2003, having a latitude north of 40.517° N (approximately the location of the Strait of Otranto) in order not to include the Gulf of Taranto (Figure 2).

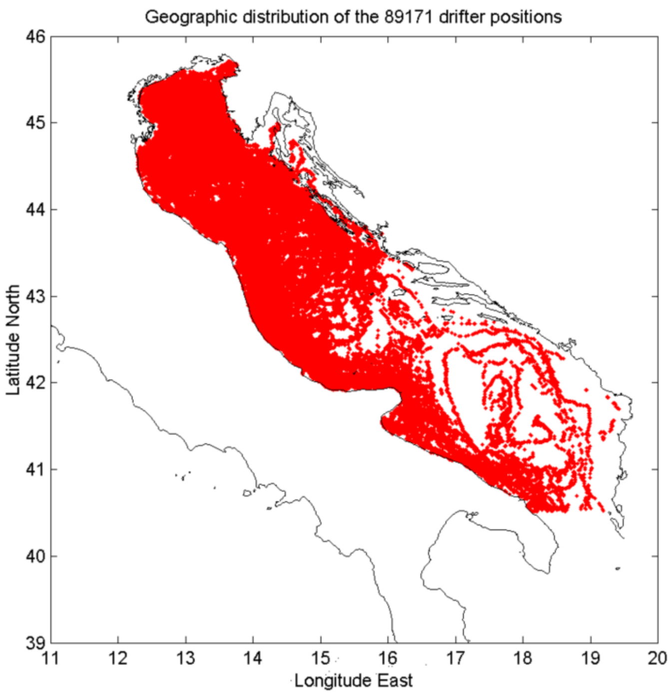

Figure 2. Adriatic Sea and drifter positions from September 2002 and December 2003.

Most of the drifter types used (107 over 118) are CODE (Coastal Ocean Dynamics Experiment – Figure 3). They consist of a slender, vertical, 1 meter long negatively buoyant tube with four drag-producing vanes extending radially from the tube over its entire length and four small spherical surface floats attached to the upper extremities of the vanes to provide buoyancy [Poulain, 2001]. Inside the tube, a thermistor is positioned 40 cm below the sea surface. It provides temperature readings ranging from –5 to 39 °C, accurate to within ±0.1 °C [Leitz, 1999]. Other drifter types used are the SVP (5), SVP-OCM (2), CMOD (2) and MINIMET (2) [Poulain, 2001 and Poulain et al., 2003]. In these drifter types the temperature sensor is positioned about 40 cm (CMOD) and about 20 cm (SVP, SVP-OCM and MINIMET) below the sea surface.

Figure 3. Surface drifter (CODE).

Drifters are tracked by the Argos Data Location and Collection System (DCLS) carried by the NOAA polar-orbiting satellites [Poulain et al., 2001b]. Drifter position is computed from the Doppler shift caused by the relative motion between the drifter and the satellite. After editing for outliers, the drifter position accuracy is 200-300 meters. Some drifters, in addition, are equipped with a GPS (Global Positioning System) system. In this case the drifter GPS position is transmitted from the drifter to the NOAA satellite and finally to the earth receiving station. The geographical location accuracy is within ±50 meters.

3. Methods

In order to compare the two temperature data sets (satellite SST and drifter bulk temperature) it is necessary to have data at the same positions and times. So we need to have:

- A good number of satellite passes over the area of interest
- Cloud-free conditions
- Availability of drifters in the same area of interest

A large number of satellite passes per day with a low percentage of cloudy pixels per image and a large quantity of drifter positions per day increases the probability that a pair of satellite and drifter temperatures can be compared.

The mean number of satellite passes per day (Figure 4), during the period of study, is 10.32 (with a maximal value of 15), while the mean number of drifter positions per day (Figure 5) potentially available (with the same time and location of the satellite pixels) is 64.86 (with a maximal of 240). The mean number of good locations per day (Figure 6) that allowed us to find a match between satellite and drifter data is 12.49 (maximal value of 81). In Figure 7 these co-located and co-temporal satellite-drifter pairs are geographically depicted and they have been distinguished by satellite number and time of the day (day or night).

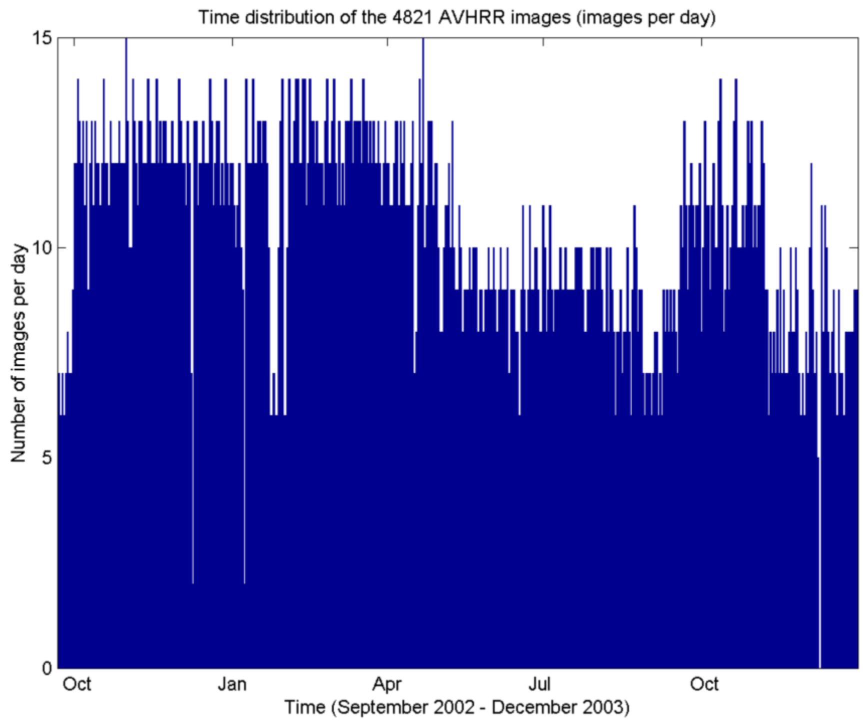

Figure 4. Time distribution of satellite SST images per day from September 2002 and December 2003.

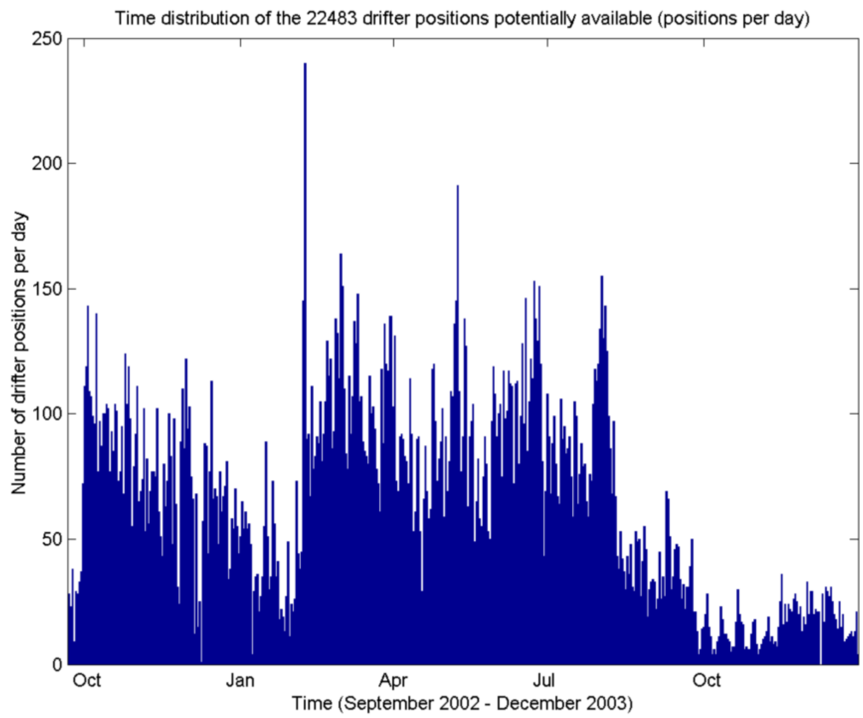

Figure 5. Time distribution of drifter positions per day, potentially available to find a match between drifter and satellite data, from September 2002 and December 2003.

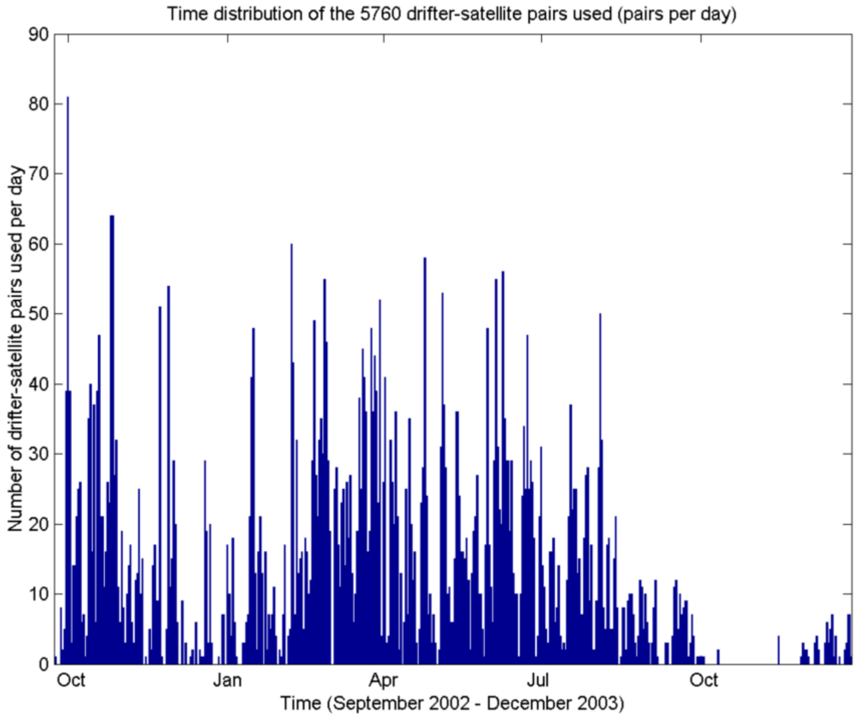

Figure 6. Time distribution of the drifter-satellite pairs per day used.

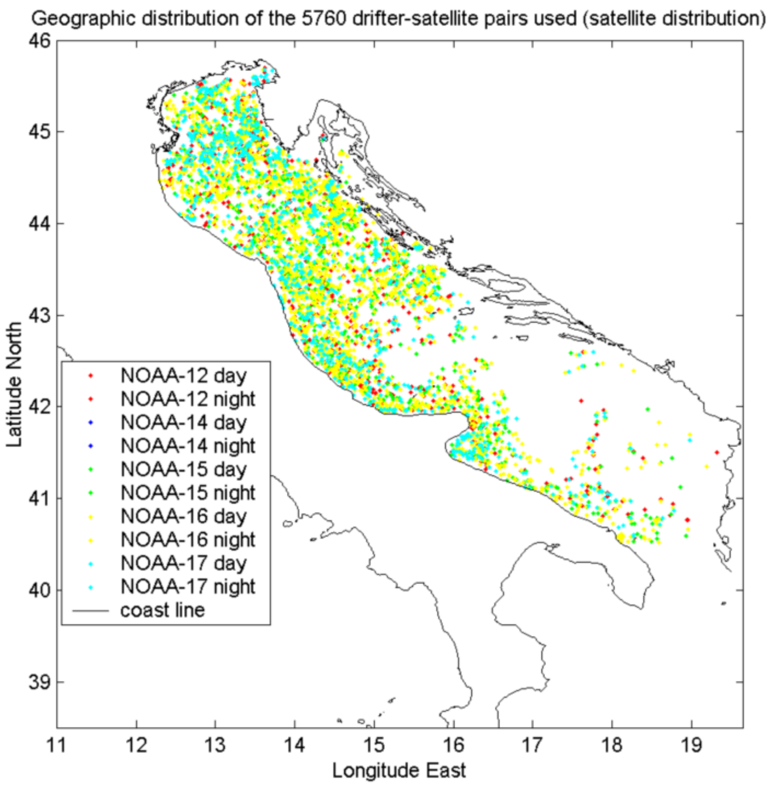

Figure 7. Geographic distribution of the co-located and co-temporal drifter-satellite pairs used to compute comparison statistics.

Each satellite image was processed, with our TeraScan programs [Notarstefano et al., 2003], to identify cloudy areas and to compute the sea surface temperature. ASCII files were made and processed with Matlab programs, specifically created for this work. Drifter data were compared with satellite images to find a match within the time windows of each satellite pass (about 15 minutes). The data were then processed to remove data pairs for which the temperature difference (difference between temperature computed with MCSST algorithm and temperature measured by drifter) is less or equal to -2 to discard values corresponding to pixels still contaminated by clouds.
Finally, the good data pairs were analyzed using the linear regression technique that has been applied to categories of points defined by the satellite number and the time of the day (day or night).

4. Results

Results are summarized in Tables 1 and 2. Results corresponding to data pairs whose satellite is NOAA-14 are not reported in the following tables because of the limited numbers of observations and the poor reliability of the results. In Figures 8-15, linear regression curves for AVHRR data versus drifter data are depicted.

satellite	***time***	***number of common points***	***mean differences (°C)*** ***($SST_{sat} - SST_{drifter}$)***	***standard deviation of differences***
NOAA-12	day	660	0.1834	0.6984
	night	319	0.1064	0.7256
NOAA-15	day	570	-0.1079	0.6054
	night	544	-0.1310	0.6955
NOAA-16	day	1045	0.1295	0.8138
	night	1661	0.7572	0.8265
NOAA-17	day	461	0.1676	0.7970
	night	495	-0.1661	0.6486

Table 1. Difference statistics for temperature pairs in the Adriatic Sea for the four NOAA satellites.

satellite	*time*	*intercept*	*slope*	*coefficient of determination*	*standard error of slope*	*standard error of intercept*
NOAA-12	day	1.1121	0.9568	0.9885	0.0040	0.6512
	night	0.1168	0.9993	0.9647	0.0107	0.7466
NOAA-15	day	-0.0561	0.9966	0.9643	0.0080	0.6186
	night	-0.5553	1.028	0.9578	0.0093	0.7051
NOAA-16	day	-0.8510	1.0535	0.9831	0.0043	0.7635
	night	-0.0420	1.0432	0.9812	0.0035	0.7949
NOAA-17	day	-0.2562	1.0211	0.9830	0.0063	0.7990
	night	-0.9534	1.0375	0.9900	0.0047	0.6194

Table 2. Linear regression results for Adriatic Sea for the four NOAA satellites.

The general trend of the NOAA satellite is to well estimate the sea surface temperature. NOAA-12 derived SST during daily passes (Figure 8) is slightly over-estimated (a few tenths of a degree) at lower temperature values (between 5 and 15 °C); the same analysis can be done for the NOAA-16 derived SST during daily passes (Figure 12) that is over-estimated by a few tenths of a degree at higher temperature values (between 20 and 30 °C). Finally, NOAA-17 derived SST during nightly passes (Figure 15) is slightly under-estimated at lower temperature values (between 5 and 15 °C). Only for the NOAA-16 derived SST during nightly passes has been necessary to do a correction in order to improve the accuracy of the data. Indeed, SST is over-estimated by a mean value of about 0.76 °C (Figure 13). This mean temperature difference is the bias that was applied to all NOAA-16 AVHRR nightly data.

In Figures 16–23, histograms of the distribution of differences between SST and bulk water temperature are depicted. It is interesting to note that the distribution of most of the data shows almost in all cases a variation between –1 °C and 1 °C. As to the NOAA-16 histograms (Figures 20-21), the distributions follow a nearly symmetric distribution with a slightly positive skewness for daytime data and a bit stronger negative skewness for nighttime data. The mean value is 0.13 °C for daytime data and 0.76 °C for nighttime data. The histograms of NOAA-16 nighttime data exhibit distribution of most of the data with a variation between 0 °C and 2 °C. The daytime mode value of ΔT is between 0 and 0.25 °C, while at night the value is between 0.9 and 1.15 °C.

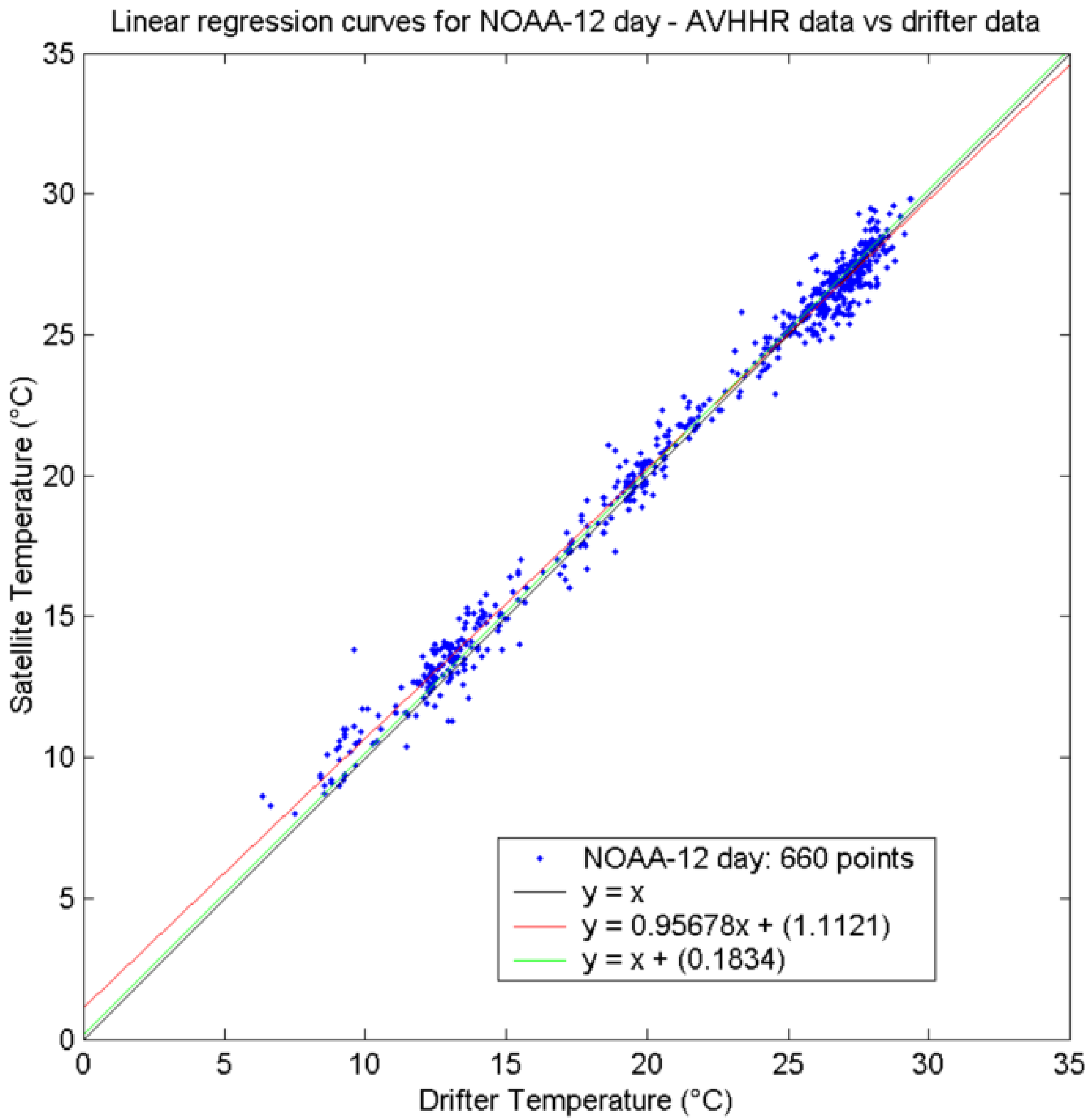

Figure 8. Linear regression curves for NOAA-12 day SST data versus drifter bulk temperature data.

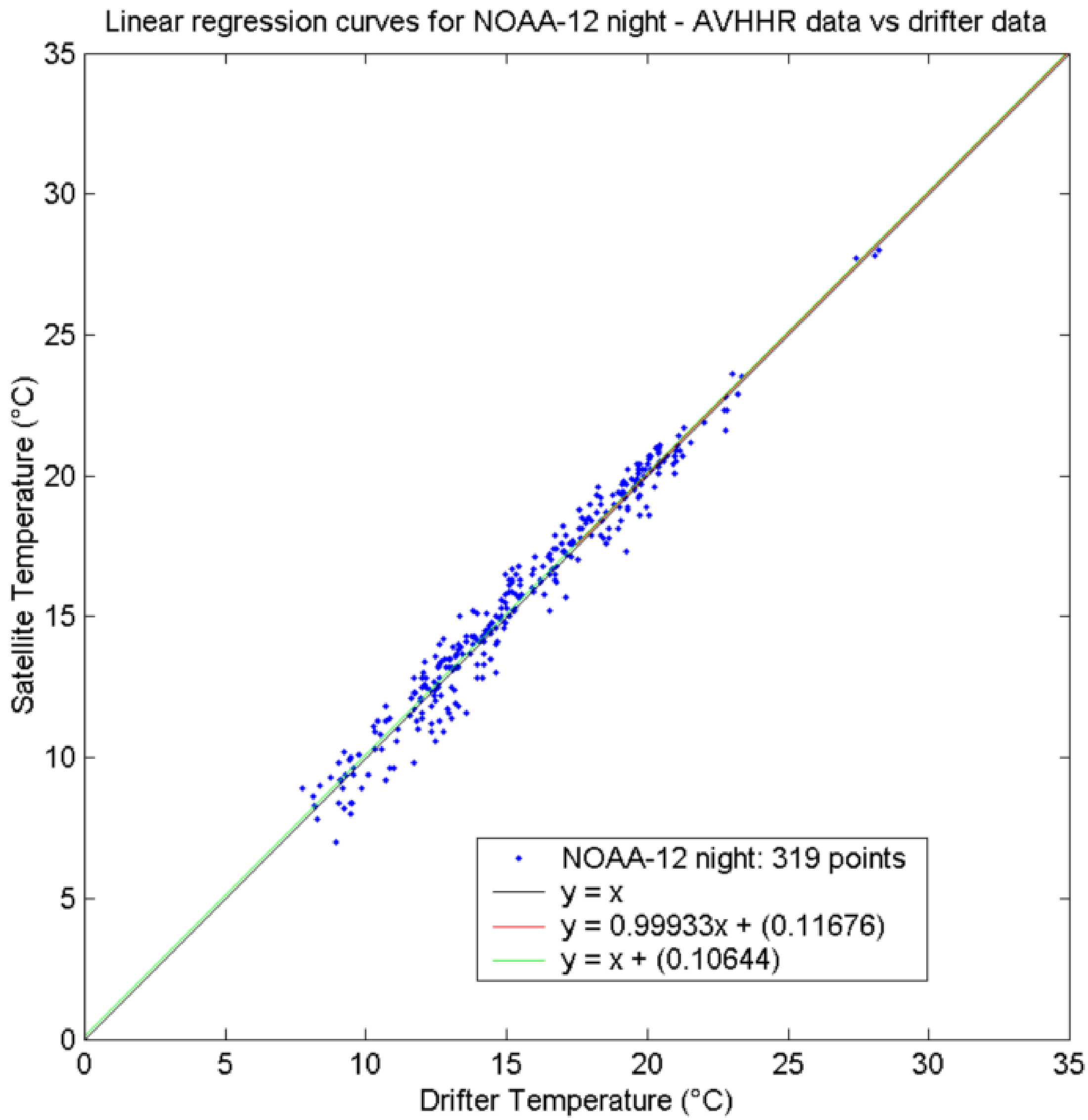

Figure 9. Linear regression curves for NOAA-12 night SST data versus drifter bulk temperature data.

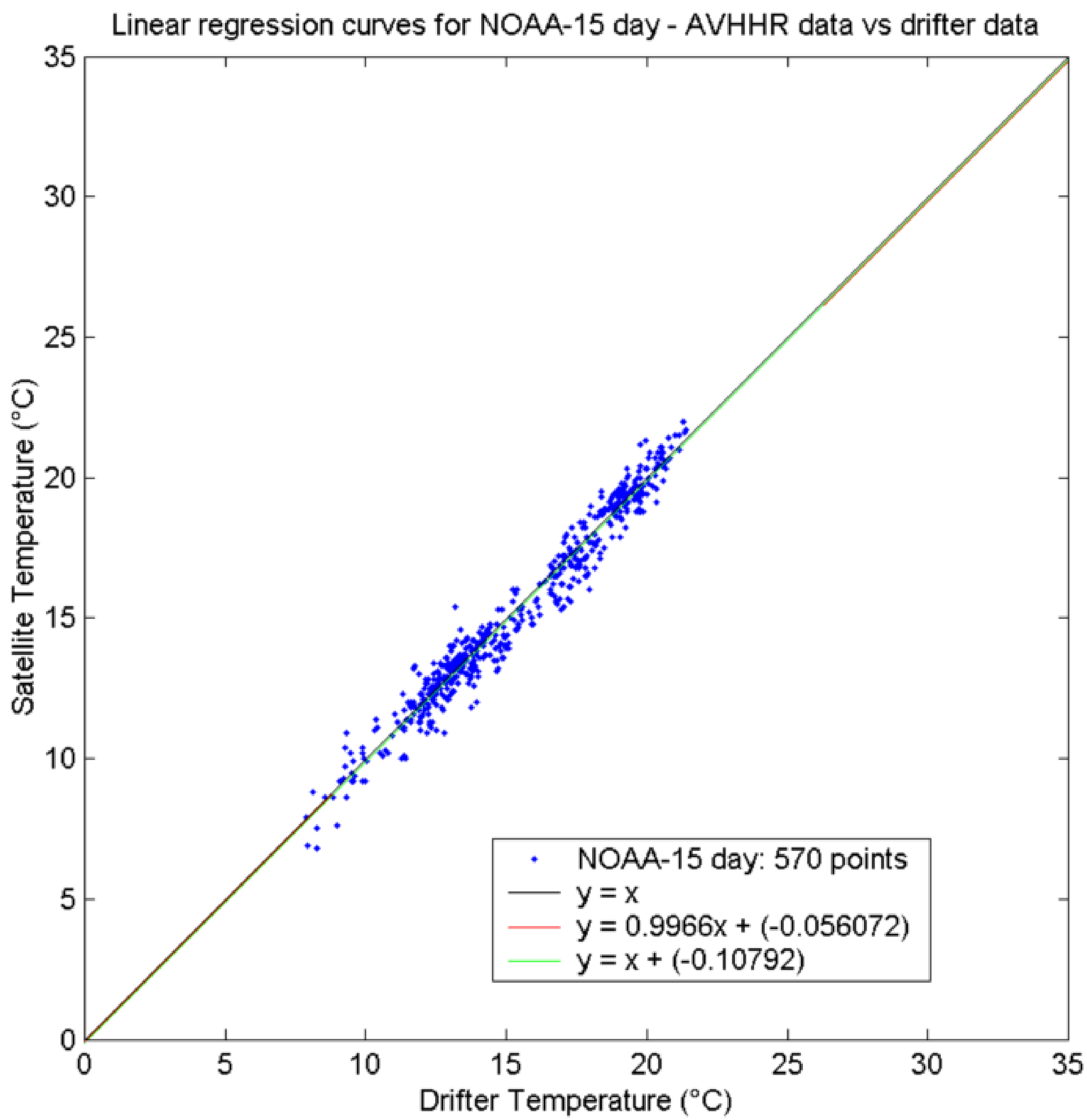

Figure 10. Linear regression curves for NOAA-15 day SST data versus drifter bulk temperature data.

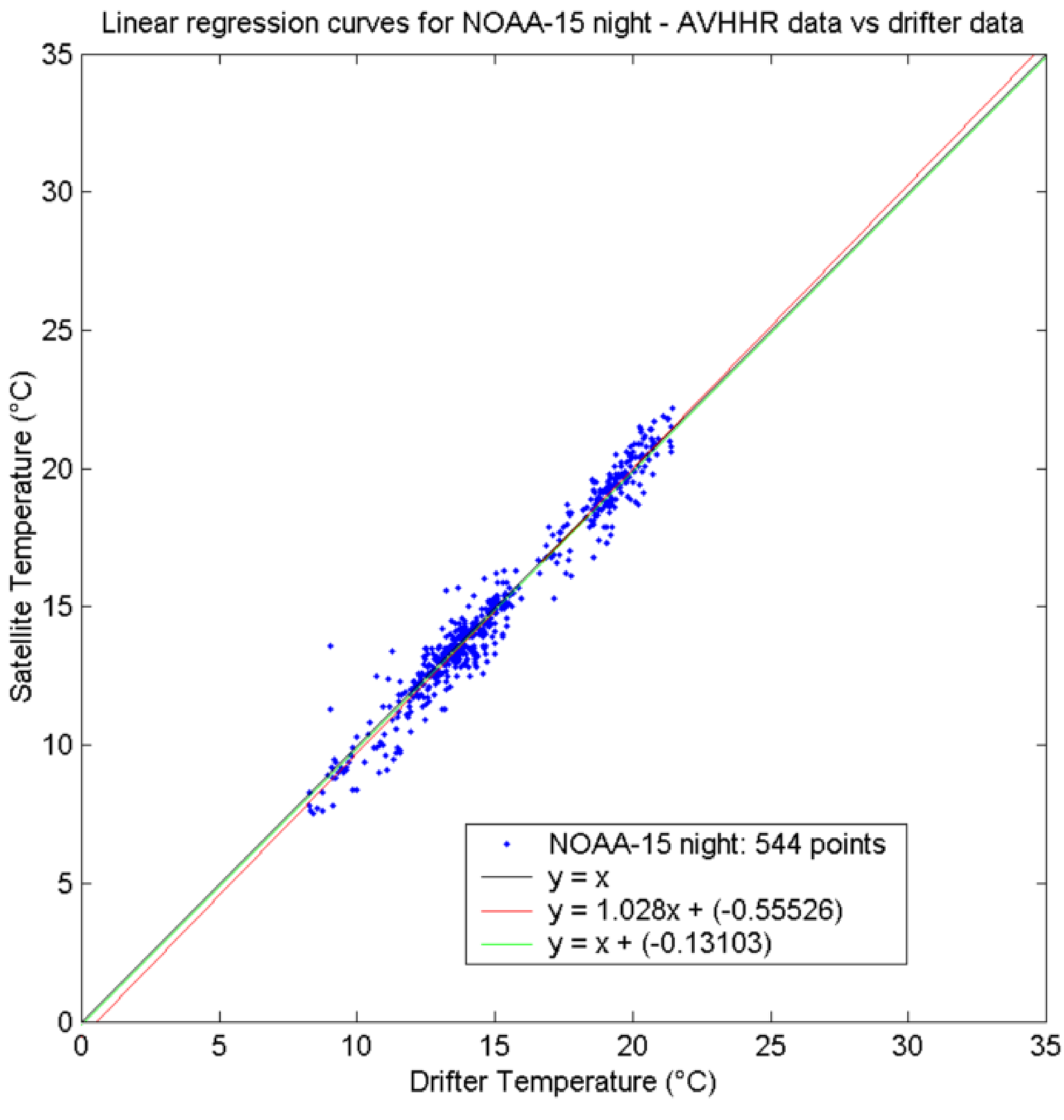

Figure 11. Linear regression curves for NOAA-15 night SST data versus drifter bulk temperature data.

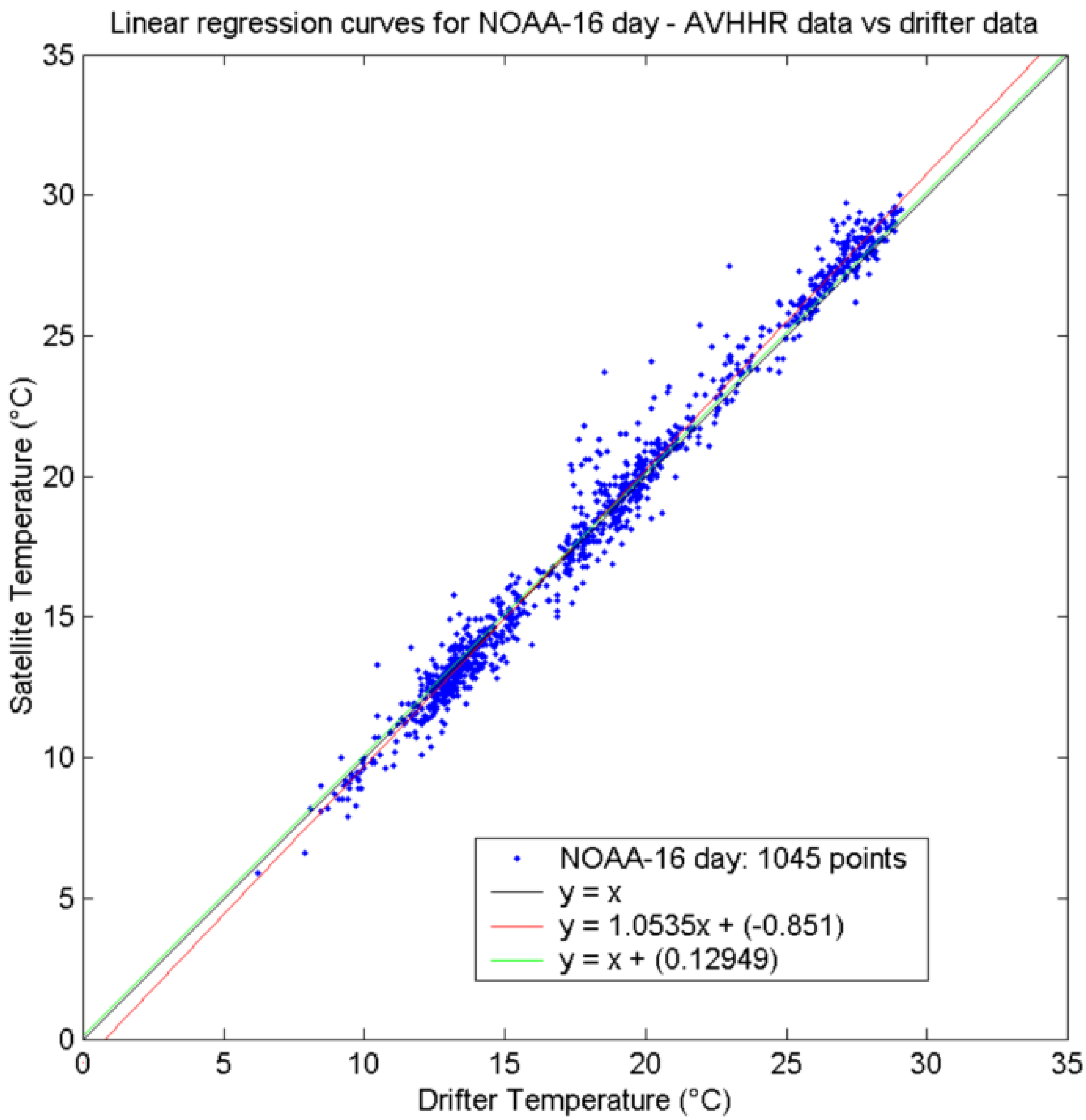

Figure 12. Linear regression curves for NOAA-16 day SST data versus drifter bulk temperature data.

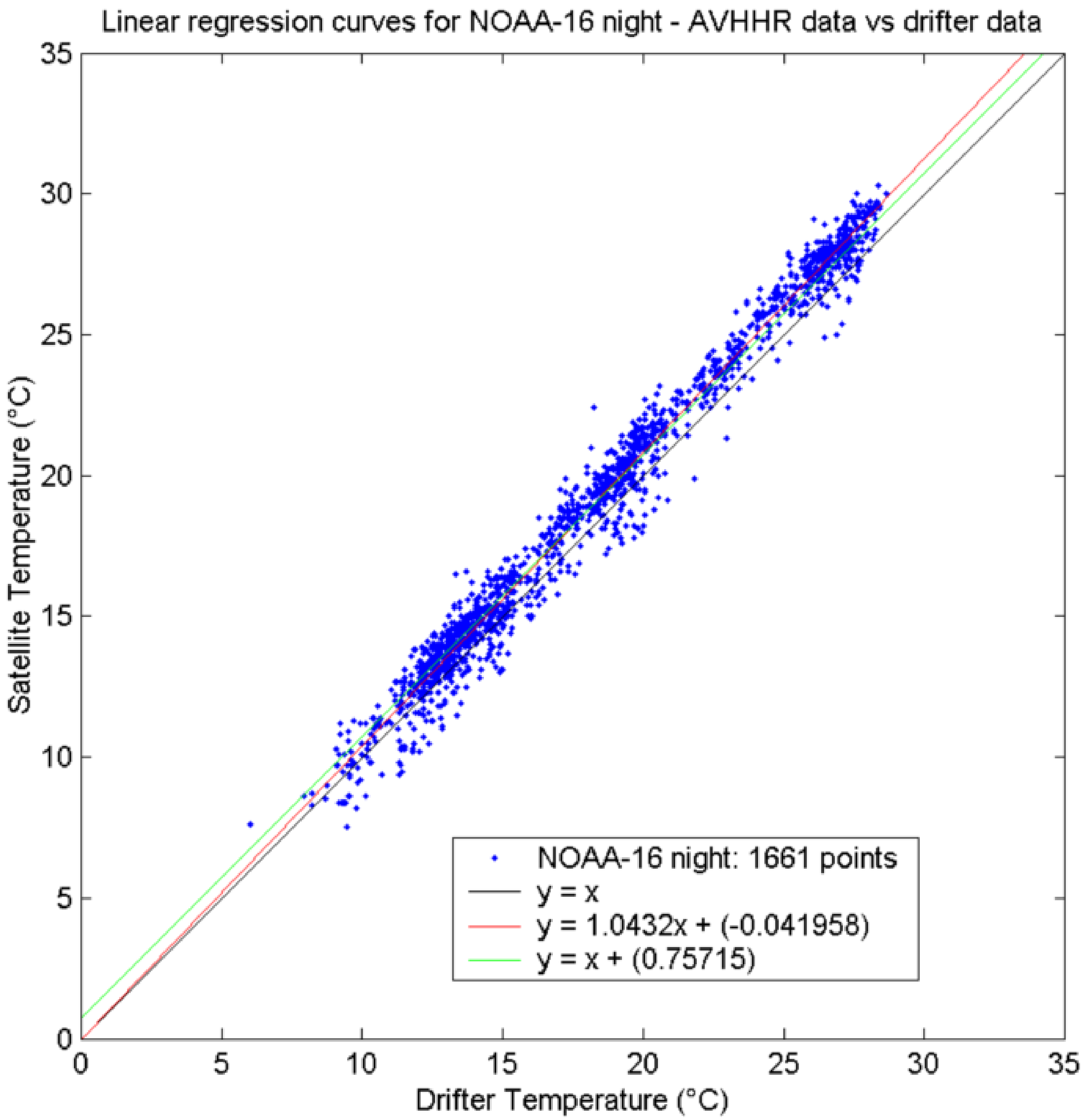

Figure 13. Linear regression curves for NOAA-16 night SST data versus drifter bulk temperature data.

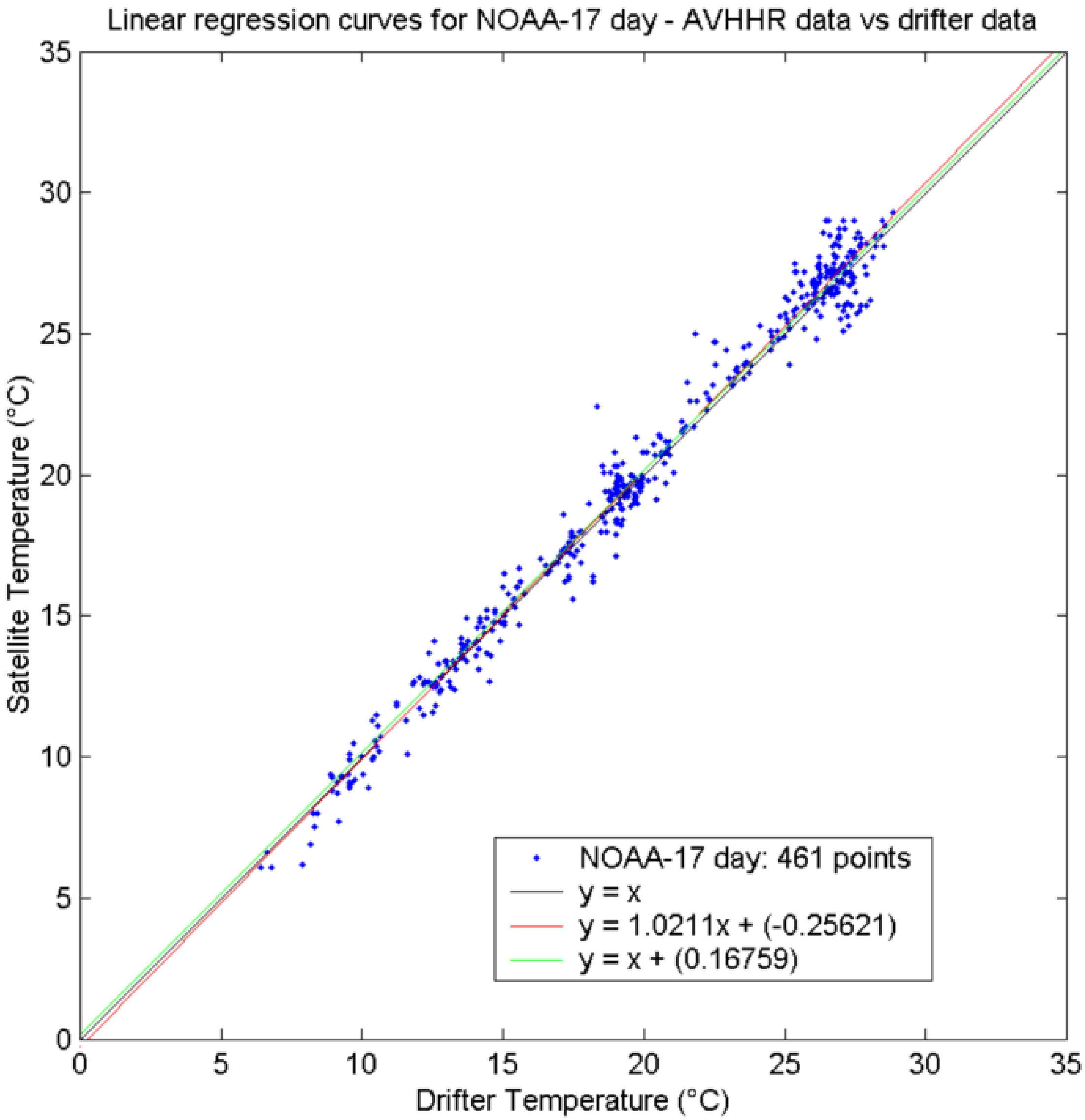

Figure 14. Linear regression curves for NOAA-17 day SST data versus drifter bulk temperature data.

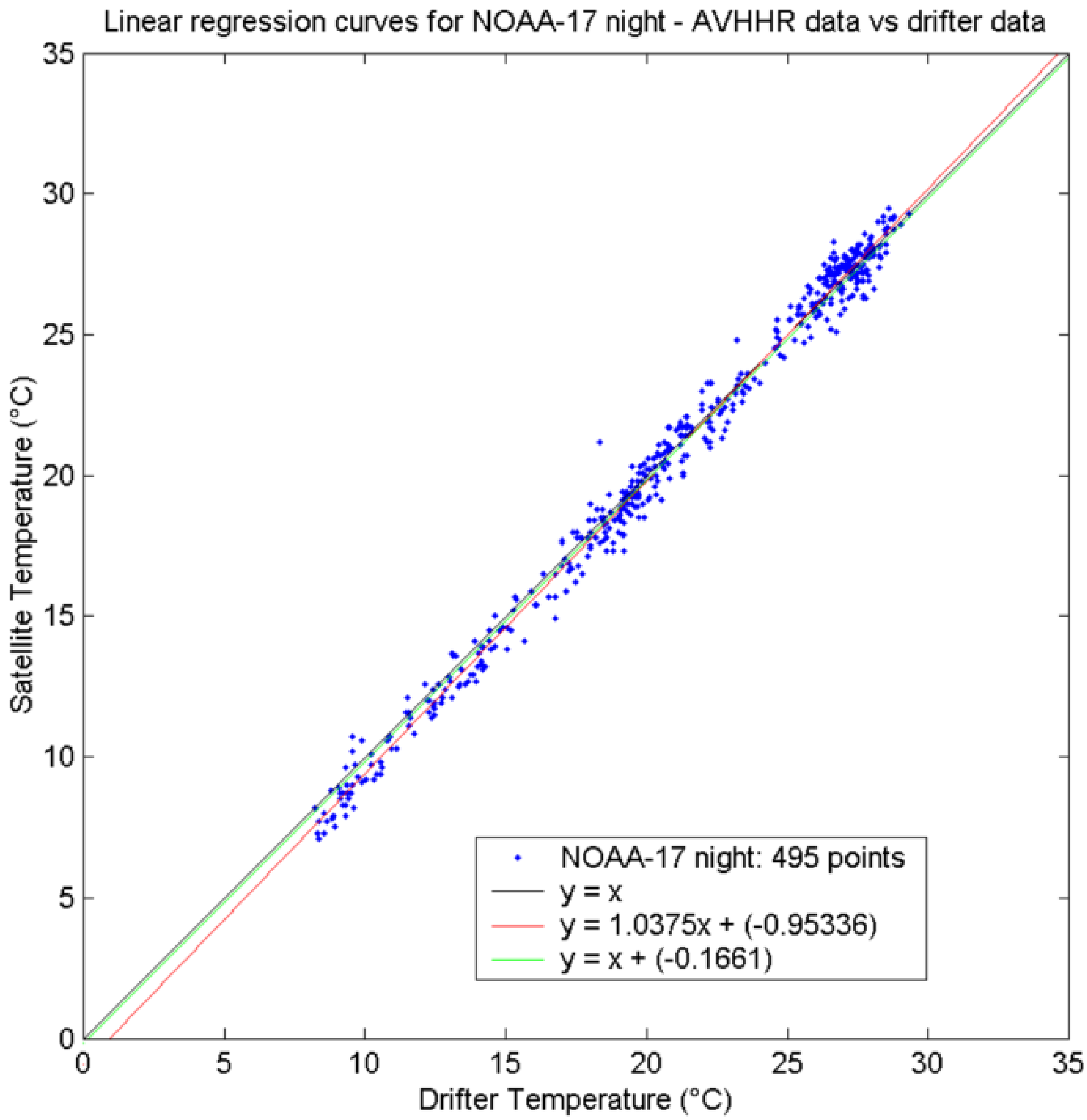

Figure 15. Linear regression curves for NOAA-17 night SST data versus drifter bulk temperature data.

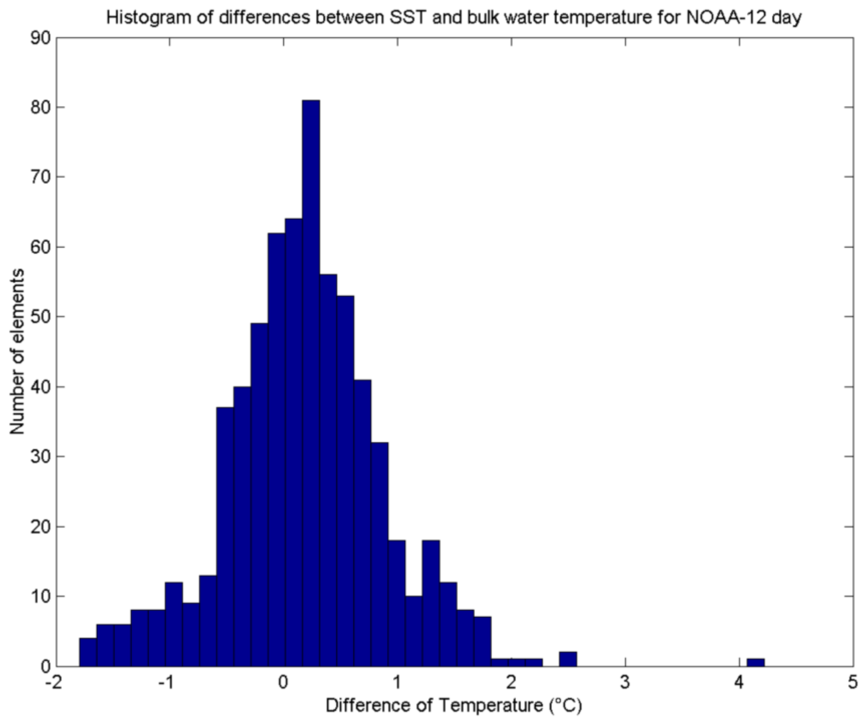

Figure 16. Distribution of differences between NOAA-12 day SST and bulk water temperature.

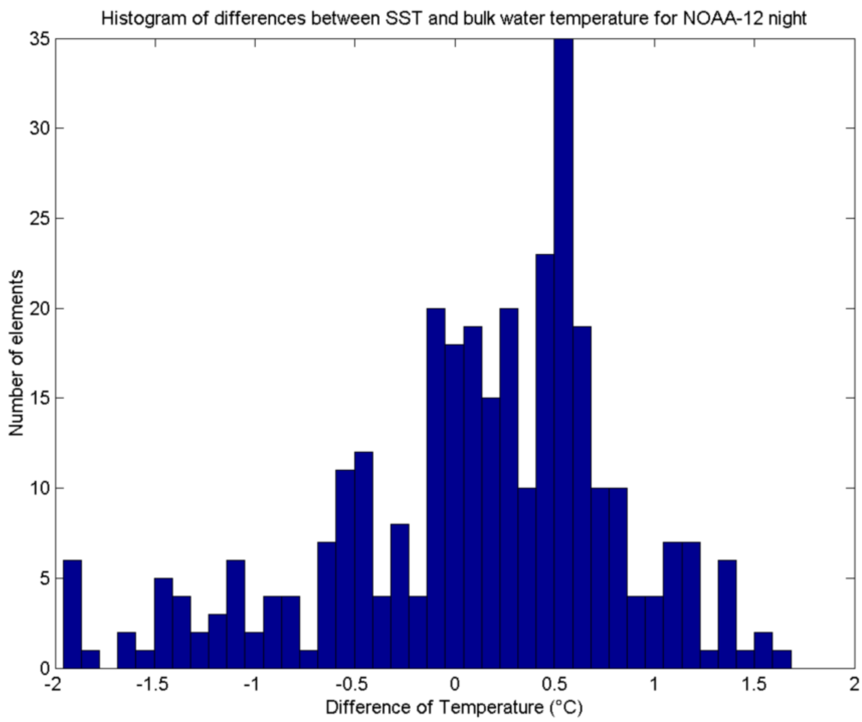

Figure 17. Distribution of differences between NOAA-12 night SST and bulk water temperature.

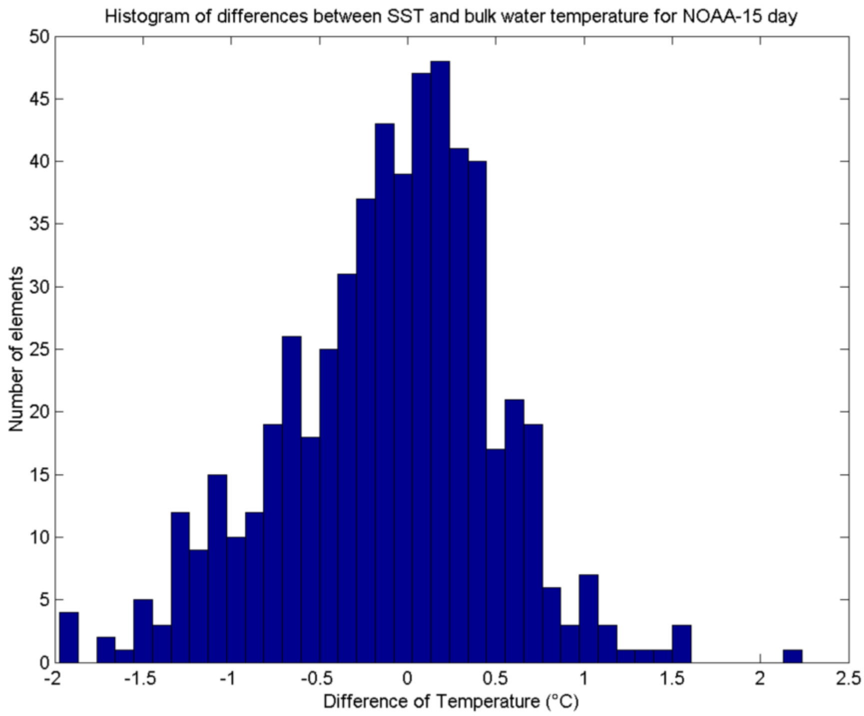

Figure 18. Distribution of differences between NOAA-15 day SST and bulk water temperature.

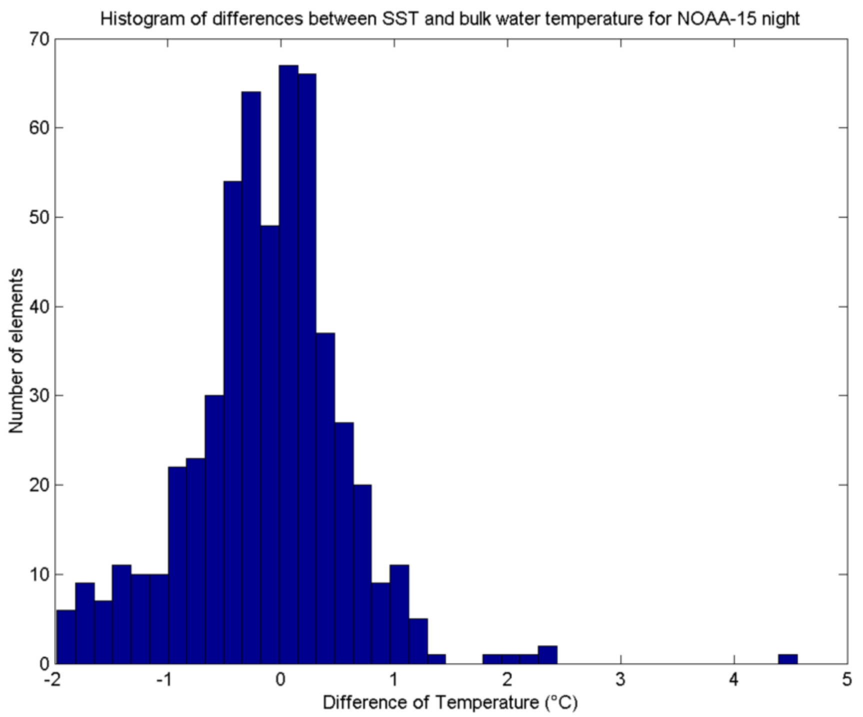

Figure 19. Distribution of differences between NOAA-15 night SST and bulk water temperature.

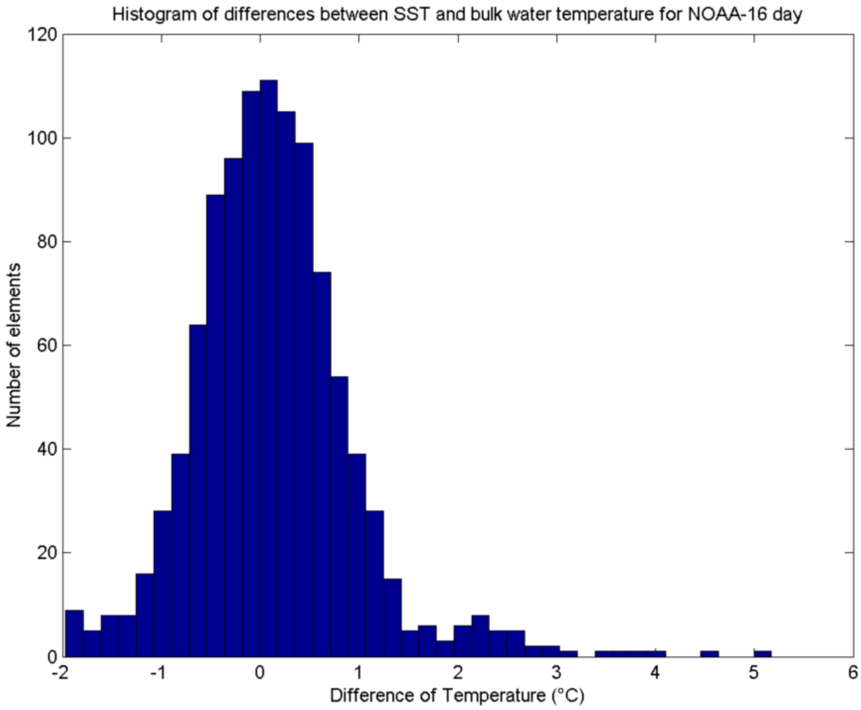

Figure 20. Distribution of differences between NOAA-16 day SST and bulk water temperature.

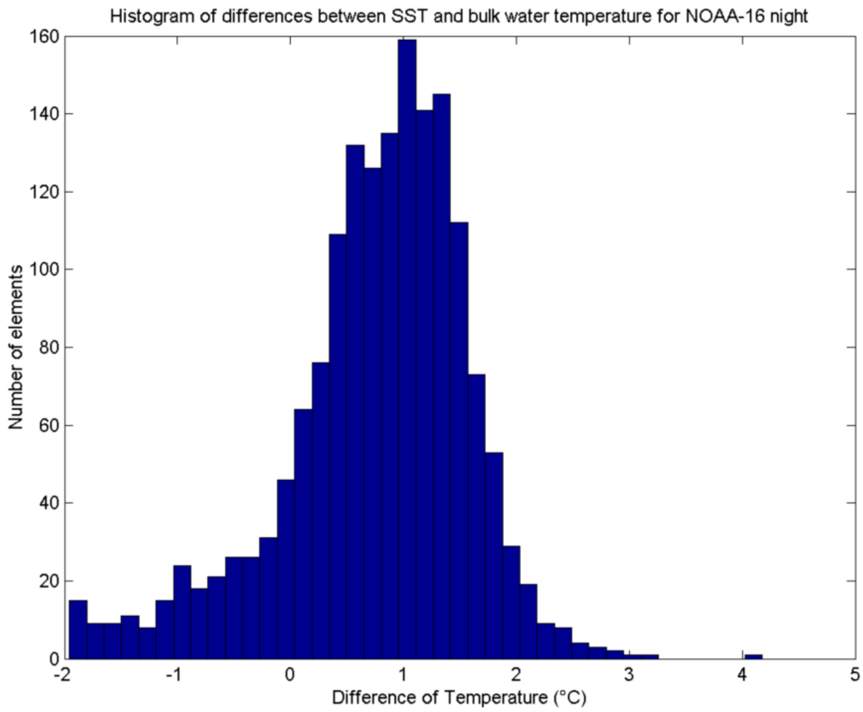

Figure 21. Distribution of differences between NOAA-16 night SST and bulk water temperature.

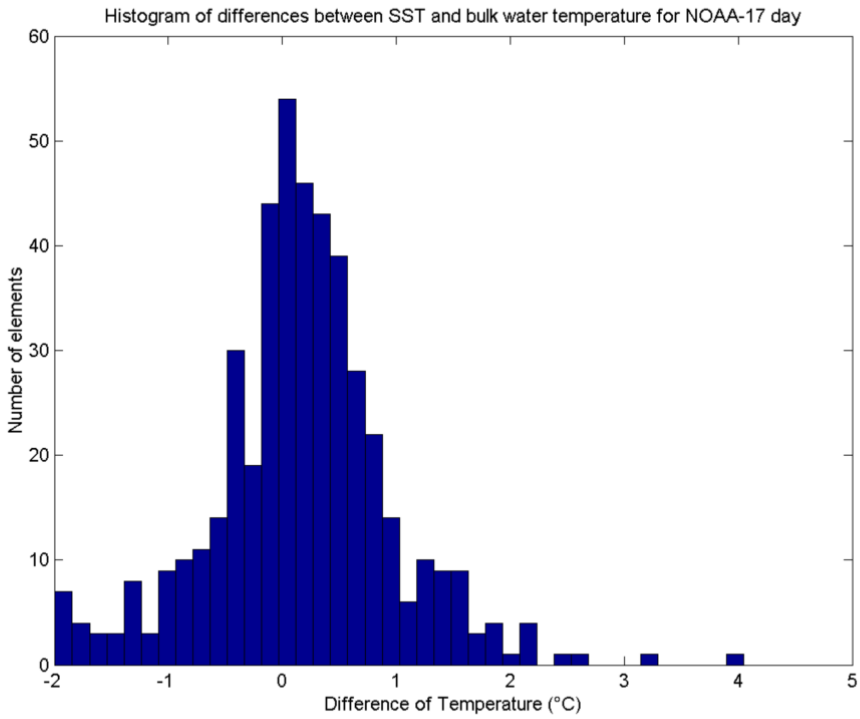

Figure 22. Distribution of differences between NOAA-17 day SST and bulk water temperature.

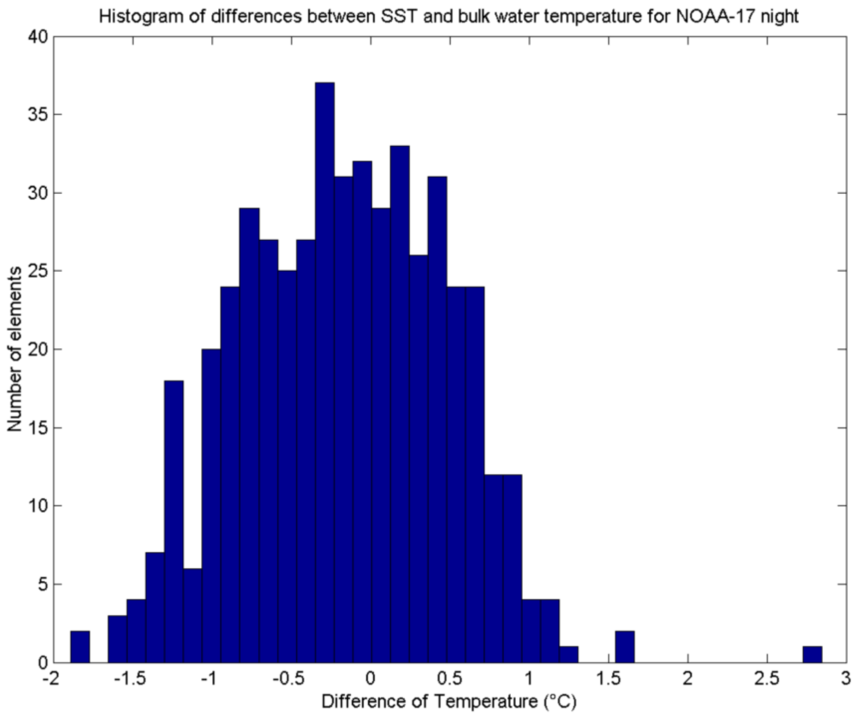

Figure 23. Distribution of differences between NOAA-17 night SST and bulk water temperature.

5. Conclusions

Thanks to the large number of drifter positions during the period of study and to a complete and frequent satellite coverage, it has been possible to find a lot of matches of co-located and co-temporal satellite and drifter data. Computation of almost all the satellite-derived SST estimates indicates that there is a very good accuracy in comparison with drifter-derived bulk water temperature that is assumed to be the "true value". Only the comparison of the NOAA-16-derived SST during nightly passes with the in situ measurements reveal a significant bias (a mean values of 0.76 °C) in the AVHRR SST estimates. This bias has been applied to all NOAA-16 AVHRR nightly data.

The discrepancy found between the NOAA-16-derived SST data during nightly passes and the drifter bulk temperature data could be due to atmospheric effects. However, this kind of errors induced by atmospheric water vapor and aerosol particles can lead to temperature differences values of several tenths of a degree and need to be corrected. Since this problem is only present for the night time passes of the NOAA-16, it could be reasonably related to a problem in the MCSST algorithm coefficients for our area of study. In fact, it is unlikely to have over-estimation of SST during the night when there is a cooling of the sea surface and not high stratification of the near-surface water column (specially compared to the daytime one). A better match up between SST and bulk temperatures is expected.

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