MONTHLY AVERAGE OF SEA SURFACE TEMPERATURES OVER THE TUSCAN SEA

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ABSTRACT

This paper examines the time variation of regional Sea Surface Temperature (SST) mean measurements by using AVHRR data collected over a seven-year period. An automatic calculation chain implements the algorithm for estimating the temperature using sub-pixel resolution and proper geolocation. This procedure also performs a cloudy pixel detection based on regional temperature maps. For average computation, the data from NOAA 12, 15, 17 and 18 satellites in the period from July 2005 to September 2008, collected in real time at the Satellite Receiving Station of the University of Florence (Prato Campus, located in 43° 53'.134 N – 11° 05'.942 E), were used, for a total of 2164 passes; only those passes, with maximum elevation over 50°, were considered. The zone under study is the sea around the Tuscan Archipelago (Italy), which was divided into 23 sub-zones. Such a detail in analysing can highlight certain trends of SST, e.g. those caused by the Magra and Arno Rivers' influence during the winter in the Versilia area or those originated by the phenomena retraceable to local currents in the area of Punta Ala and Castiglione della Pescaia.
Keywords: SST, cloud filtering, precise geolocation, land/sea interpolation, coastal zone analysis

INTRODUCTION

The detection of spatial and temporal variation in Sea Surface Temperature (SST) plays a very important role in determining climatic behaviour and consequent environmental alterations (i).

This work reports results obtained with an automatic procedure developed for determining the SST monthly mean and its temporal evolution on a particular sea area, in which different zones are considered. The region taken into account is the sea between Tuscany and the coast of Corsica, including the islands of the Tuscan Archipelago, whose area spans from 42°12'N to 44°30'N in latitude and from 9°12'E to 12°24'E in longitude. The period under investigation is from July 2001 to September 2008.

NOAA/AVHRR data are directly received by the Satellite Receiving Station at University of Florence (Prato Campus, located in 43°53'.134N – 11°05'.942E), and processed with an owner suite software called "AMEDIT" (Daily SST maps are available at http://maresat.ing.unifi.it/). In order to enhance the accuracy of SST estimations, results from processed satellite data were compared with *in-situ* measurements, furnished by the Sea Department of ARPAT (Regional Agency for the Environmental Protection in Tuscany).

With the developed processing technique, the spatial and temporal behaviour of SST monthly means is obtained; this technique was applied to data received from the different NOAA satellites, and the results were compared among the different sensors. The technique includes processing through the use of original algorithms, such as: geolocation of the acquired pixels, minimizing clock errors and errors connected to estimated sensor position (Yaw, Pitch, Roll) (ii); determination of cloudy pixels, based on the obtained average temperature values; data registration on Mercator maps using segmented interpolation and sea-land-cloud mask (iii).

The SST monthly mean maps were produced on a pixel basis from a set of day-time, night-time and whole-day satellite passes.

Elliptic and rectangular sub-zones are selected from the considered region of the Tuscan Sea, in order to compare the different results obtained. The elliptical zones have a surface of about 102 square nM, while the rectangular ones have a surface of about 543 square nM.

1. Data processing

The Satellite Receiving Station is equipped for collecting and processing remote sensing data from different satellite systems. NOAA/AVHRR data are received and elaborated in real-time by an automatic procedure, performing the following steps:

- extraction of the geographical area of interest from received satellite raw data (count);
- clock error correction (iv);
- data geolocation, based on orbital parameters and scanning geometry (v);
- calculation of sun distance, sun-satellite elevation and azimuth angles;
- count radiometric calibration for obtaining sensor brightness temperature;
- SST measurements with cloud filtering and land-sea masking, obtained by segmented interpolation, in order to improve SST detection near the coast (iii);
- data registration in Mercator projection, using WGS-84 Datum;
- computation of SST monthly average maps on a pixel basis;
- SST mean evaluation in elliptic or rectangular sub-zones of the region of interest;
- SST monthly mean plotting in the considered time interval in order to compare the behaviour of the different sub-zones.

2. Sea Surface Temperature evaluation and cloud filtering algorithm

Multichannel Sea Surface Temperature (MCSST) is obtained by the following formula (vi):

$$MCSST = B_1 (T_4) + B_2(T_4-T_5) + B_3(T_4-T_5)[\sec(\square) - 1] - B_4 \quad [K]$$

where:

MCSST	SST evaluated with a multi-channel algorithm
T_4	Brightness temperature for channel 4 (10.8 μm)
T_5	Brightness temperature for channel 5 (12 μm)
$\sec(\square)$	Secant of satellite zenith angle
B_i	i = 1, …, 4, MCSST coefficients are obtained from (vii)

The technique for identifying cloud-contaminated pixels was developed at the Telecommunications Laboratory of the University of Florence; it performs two tests: the first (Thermal Gross Cloud Test) evaluates differences in SST values between cloudy and normal SST pixels, the second (Thermal Uniformity Test) detects spatial gradients in SST images, according to a simplified version of Cayula's algorithm (viii).

Specifically, the first test flags a pixel as cloudy if the difference between the calculated SST and a temperature value, considered to be typical for the month under evaluation, is less than a suitable value (ScTM) in Kelvin degrees; the typical values for this comparison are obtained from the previous year monthly average temperatures. In this optimum procedure the reference value, SSTm, is obtained from the same image by applying tighter thresholds in the search for clouds.

The second test appraises the SST spatial uniformity in a 3x3 pixel region, centred on the element (i, j) to be examined, using the Sobel filter through the spatial gradient calculation. A high SST spatial variation is attributable to cloud presence. This algorithm can fail in the presence of warm or cold sea fronts, which are characterized by large SST variation.

The strategy of the cloud detection procedure is to determine the final value of a parameter, CLD, initially equal to zero, which is assigned to every pixel in the image. Both test 1 and test 2 can increase the CLD value according to procedures illustrated in corresponding table 1 and table 2.

Test1 on MCSST(u,v) [K]	**CLD_1 (Cloud index of test 1)**
MCSST < 274,16	4
274,16 < MCSST ≤ (SSTm – ScTM)	3
(SSTm – ScTM) < MCSST ≤ SSTm	2
MCSST > (SSTm + ScTM)	3

Table 1: Thresholds used in Test1 for cloud identification on the sea. SSTm is the SST monthly mean for Tuscany calculated from AVHRR data; ScTM is the maximum error accepted for the SSTm (10°K).

Test 2 on Grad(MCSST) [K]	**CLD_2 (Cloud index of test 2)**
Grad(MCSST) ≥ 2,00	3
1,50 ≤ Grad(MCSST) < 2,00	2
Grad(MCSST) < 1,50	0

Table 2: Thresholds used in Test 2, for cloud identification on the sea.

If the final value of CLD ($CLD = CLD_1 + CLD_2$) is greater than or equal to 3, the pixel is flagged as cloudy. Fig. 2 shows the processing chain for evaluating the SST is shown: the first block in the diagram calculates the virtual Sea Surface Temperature (MCSST); the following process performs cloud filtering, land-sea masking obtained with segmented interpolation and re-projection in Mercator map, using WGS-84 Datum.

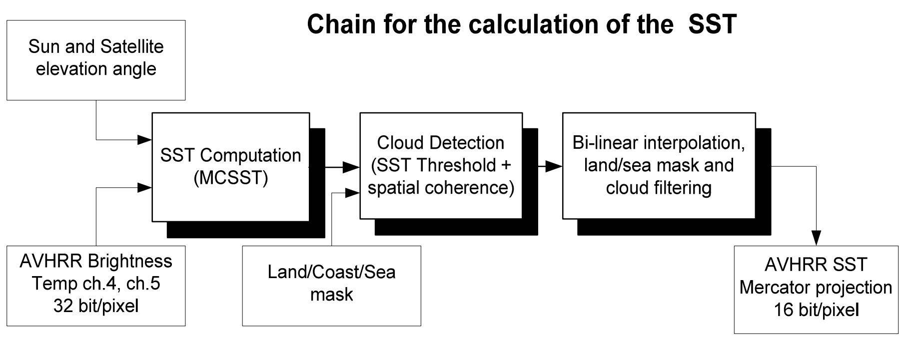


Figure 2: Procedure scheme for SST calculation.

3. Evaluation of the SST monthly mean

Maps of the Sea Surface Temperature monthly mean have been obtained by 16 bit/pixel SST images, with the satellite's maximum elevation greater than 50° for every pixel on the grid, where value $z_i(u,v)$ of coordinate pixel (u,v) for image i-th is:

$$z_i(u,v) = \begin{cases} 0 & \text{coast line pixel} \\ 1 & \text{land pixel} \\ 3 & \text{cloud pixel} \\ 4 & \text{error pixel} \\ T_{SST}[0.01\ K], & \text{otherwise} \end{cases}$$

T_{SST} is considered between SST_{min} (equivalent to 274.16 K) and SST_{max} (equivalent to 305.16 K). If T_{SST} is greater than SST_{max}, the pixel is classified as an error pixel.

For every point (u,v) on the map, a weight quantity p(u,v) is then determined, as shown in the following formula, by counting valid SST for pixels (u,v), which are present on the k-maps used for SST mean calculations.

$$p(u,v) = \begin{cases} \sum_{j=1}^{k} 1 \cdot b_j \\ 1 & \text{if } z_j(u,v) = 1 \text{ (land) or } z_j(u,v) = 0 \text{ (coastline)} \end{cases}$$

with:

$$b_j = \begin{cases} 1 & \text{if } z_j(u,v) \in [SST_{min}, SST_{max}] \\ 0 & \text{if } z_j(u,v) = \begin{cases} 3 \text{ (cloud)} \\ 4 \text{ (error)} \end{cases} \end{cases}$$

A sum matrix is also determined according to the following equation, with the same meaning for parameters b_j

$$s(u,v) = \begin{cases} \sum_{j=1}^{k} z_j(u,v) \cdot b_j \\ z_j(u,v) & z_j(u,v) = 1 \text{ (land) or } z_j(u,v) = 0 \text{ (coastline)} \end{cases}$$

For pixels (u,v), the SST monthly mean formula m(u,v) is: $m(u,v) = \dfrac{s(u,v)}{p(u,v)}$

3. Analysis of results

After the average monthly SST maps were obtained (see the example in Table 4 left), the average monthly temperature value is calculated for the 23 selected sub-zones of Tuscan Sea: 11 elliptical coastal areas, or the Tuscany Longshore Sea, and 12 rectangular areas of the open sea, or the Tuscany Offshore Sea (see Table 4 right).

The analysis was performed considering the two different periods and dates: AVHRR data from NOAA16 was processed in the 2001 to 2005 period, whereas those from NOAA15, NOAA17 and NOAA18 were processed from 2005 to 2008.

The figures in tables 5 and 7 give the results obtained comparing average monthly SST value for the coastal and open sea areas for NOAA15, 17 and 18 and NOAA16 respectively.

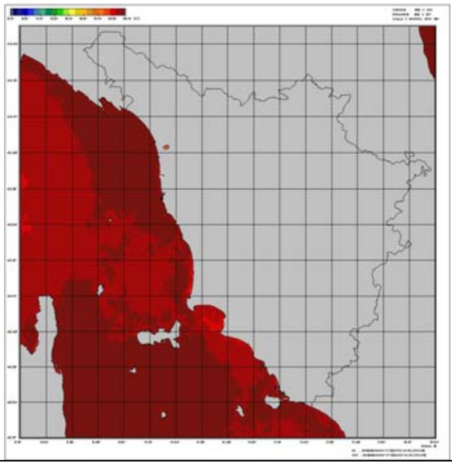
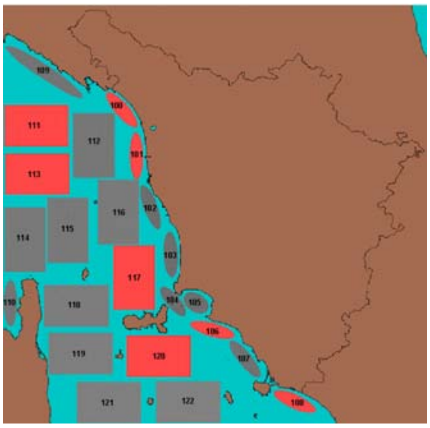
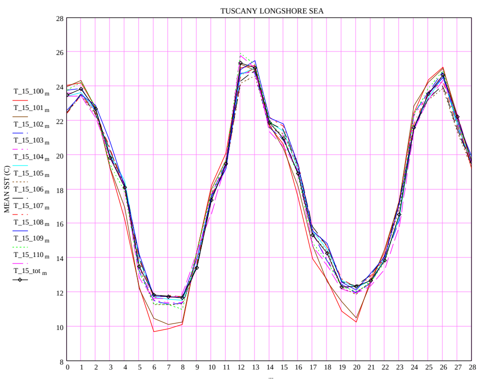
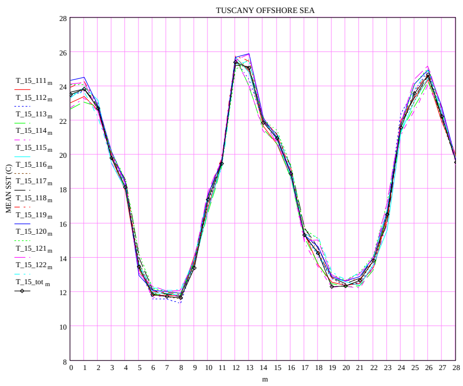
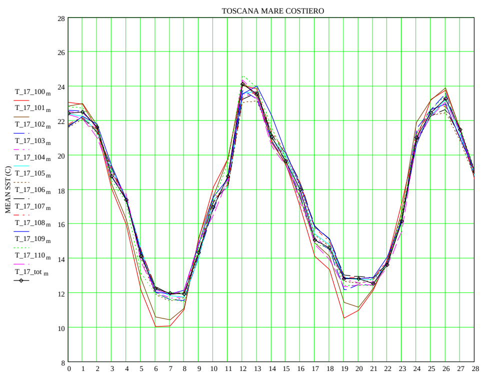
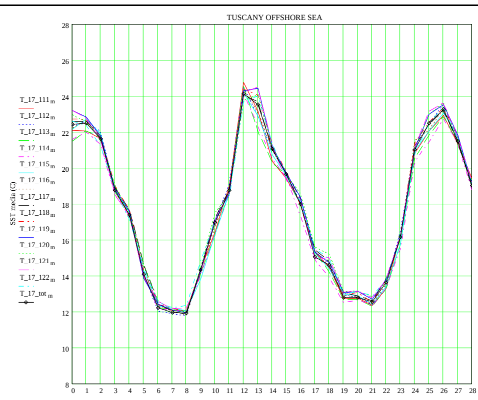
	

Table 4: On the left: example of the average SST maps obtained by the AVHRR sensor on board NOAA18 for August 2008. On the right: position of the 23 considered sub-zones, 11 elliptical coastal, 12 rectangular open sea.

The figures in Table 6 show the results obtained for the coastal sea areas for NOAA17 and 18 processing the day-time passages only and the night-time passages only.

	TUSCAN LONGSHORE SEA	**TUSCAN OFFSHORE SEA**
NOAA 15		
NOAA 17		

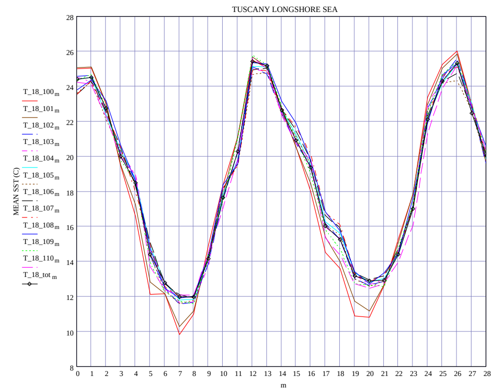
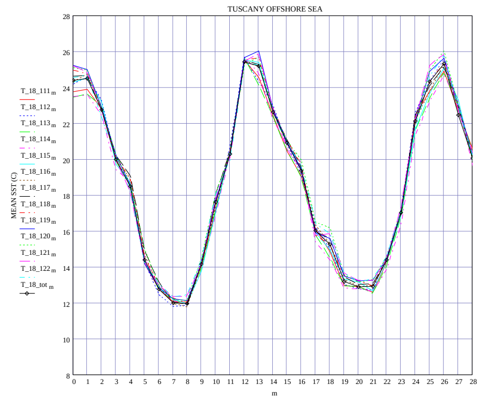
NOAA 18		

Table 5: Average SST trends calculated for the 23 selected sub-zones of Tuscan Sea for the July 2005 – October 2008 period with Noaa-15 (row 1), Noaa-17 (row 2), Noaa-18 (row 3) AVHRR data.

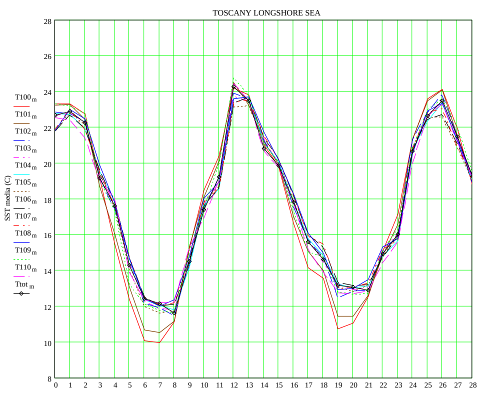
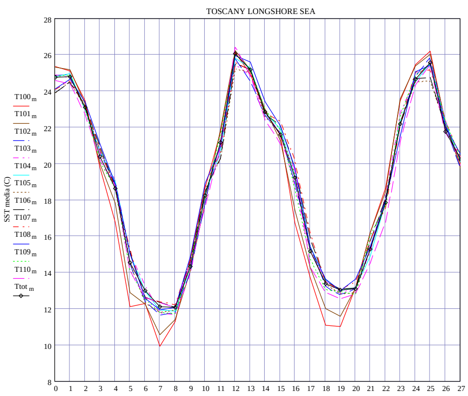
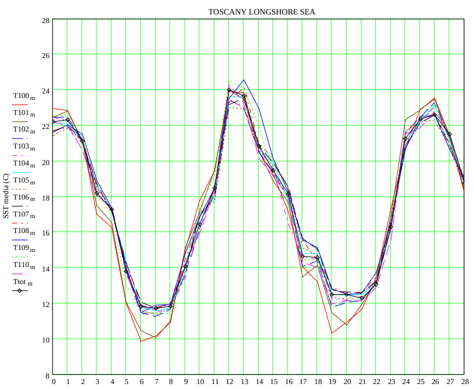
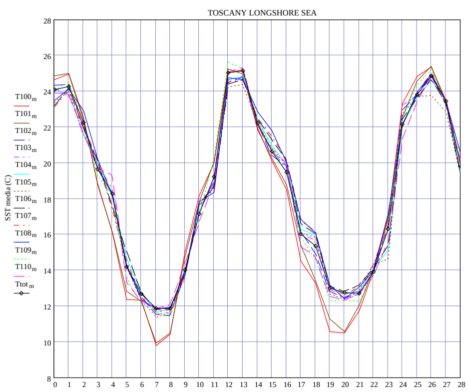
	NOAA 17	**NOAA 18**
DAY-TIME		
NIGHT-TIME		

Table 6: Average SST trends calculated for the longshore sub-zones of Tuscan Sea for the July 2005 – October 2008 period with day-time (row 1) and night-time (row 2) data from Noaa-17 and Noaa-18.

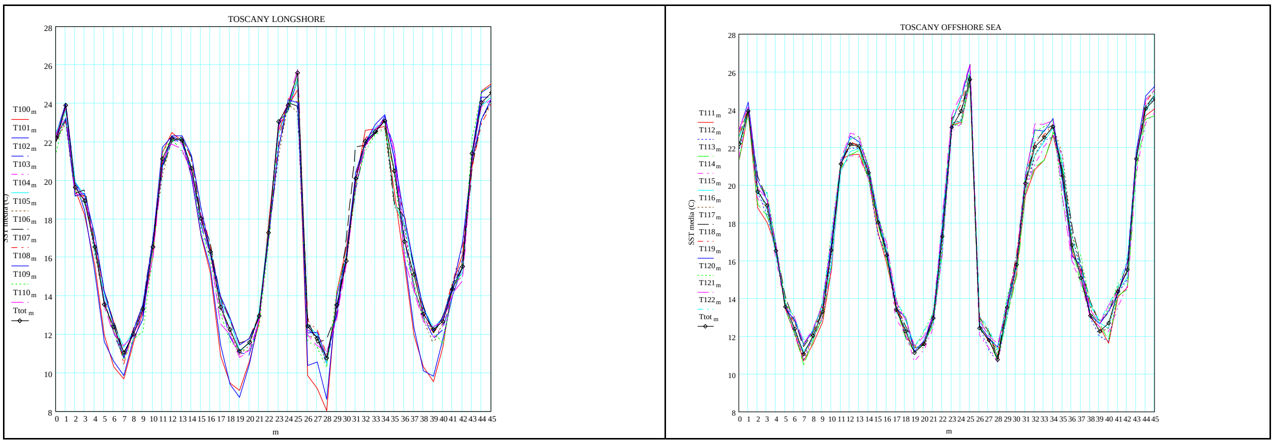


Table 7: Average SST trends calculated for the July 2001 – August 2005 period with Noaa-16 data in the coastal areas (left) and the open sea areas of the Tuscan Sea.

Conclusions

The analyses of the SST monthly mean regarding the Tuscan Sea show that:

a. Temperatures were colder (up to more than 2 °C) from the mouth of Magra river up to Livorno, than the average of the total Tuscan sea format or of the other coastal zones between Piombino and the south of the Argentario;
b. There are substantial differences (up to of 2 °C) between the various offshore zones, mainly in September and October. An example is the open sea between Corsica and Cinque Terre and the northern and southern regions of Elba;
c. Results of elaborations carried out on NOAA-17 show colder temperatures in summer than those from other satellite sensors. Specifically, SST means from NOAA-15 and NOAA-18 are warmer, up to 2 degrees, than those from NOAA-17. Winter temperatures from the different sensors are comparable;
d. A difference between day and night temperatures from NOAA-17 is detectable in summer, whereas it is not evident in winter. A larger difference between day and night temperatures is obtained from NOAA-18 data;

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