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Sea Surface Temperature monitoring in Italian Seas: analysis of long-term trends and short-term dynamics

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***Abstract* – The aim of this paper is to give an overview of the various elements that contribute to the observation of Sea Surface Temperature in Italian Seas. Long term time series are collected since the 19th century but are affected by a large systematic errors. Despite the lack of accuracy, their contribution to the analysis of trends is fundamental into the climate change context. On the other hand, recent systematic observations are more accurate and continuous in space and time. Short term time series better define the status of the temperature during the last years in term of variability and dynamics.**

Keywords: Sea Surface Temperature, In-situ data, Long-Term Time Series, Short-Term time series, Italian Seas

I. INTRODUCTION

Sea Surface Temperature (SST) is one of the most important physical parameter in marine climatological studies. It is a relevant predictor of a number of meteorological variables, such as parameters of general circulation and windstorm formation, it is fundamental in climate modelling, for studying earth heat balance, and to detect atmospheric and oceanic circulation patterns and anomalies, moreover it is critical in the evaluation of the biological component. Quality of long time series is variable, several different methods of measuring have been used over the years through different instruments including ships, buoys, coastal platforms, or oceanographic tools. Datasets are often limited in space and time, especially at the beginning of the twentieth century and during the world wars. In the last decades, quality of in situ and remote sensed data has improved significantly in parallel with the increase of marine observations and a large number of studies have been implemented in order to investigate the long term SST changes and the effects of spatial variability over the marine system.

Long term time series are extracted from the International Comprehensive Ocean–Atmosphere Data Set (ICOADS; [1]). It represents the most complete and heterogeneous existing collection of surface marine data, based on records from ships, buoys and other platform types. It includes 2°x2° gridded monthly data (“ICOADS 2 Degree”) extending from 1800 forward and 1°x1° grid data since 1960 (“ICOADS 1 Degree”).

Since 1900, time series in Mediterranean Sea appear almost complete. The observations are heterogeneous because over these years the spatial and temporal coverage is variable, in some case extremely poor. Furthermore different measuring methods have been used, each with different characteristics, instrumentations and practices. This critical point introduces a bias in long-term analysis and trend evaluations that could dominate the uncertainties [2].

The largest systematic errors are found in the firsts decades since 1940s, when SST measurements were mostly made using buckets or with “not well identified” practices [3]. These measurements are taken from ships and in some cases SST values could be misallocated and misassigned. The following decades present weaker issues, in particular when the observed SST is the temperature of the engine-room cooling water intake. Several works have been implemented in order to homogenise data ([4], [5], [6]) and the last releases of ICOADS introduce quality control procedures that take into account these suggestions [1].

The weak points highlighted in “ICOADS 2 Degree” are mitigated in “ICOADS 1 Degree”. This dataset starts from 1960 up to 2016, when modern techniques of observation and an increasing number of fixed and drifted platforms improve data coverage and accuracy. So it is characterised by complete and almost correct information on monthly mean SST.

The increased spatial resolution allows to describe better the complexity of semi-enclosed basins typical of the Italian seas, which physical conditions are influenced by the orography of the coast. Although this improvement, the measurements along the coastal areas are still affected by lack of accuracy.

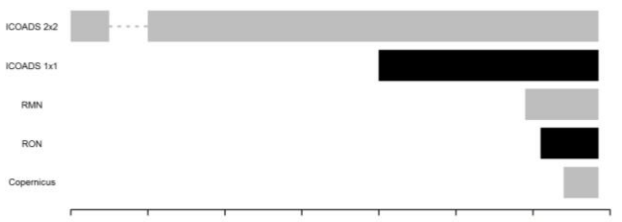

Fig. 1. SST Time Series from 1800

In ISPRA (Italian Institute for the Environmental Protection and Research) systematic in-situ SST measurements started from the mid-nineties, with the upgrading of marine monitoring networks already collecting several meteorological and physical parameters along the Italian coasts.

The Italian tide-gauge monitoring network (Rete Mareografica Nazionale - RMN, [7]) is composed by 36 measuring stations mainly located in the harbours. The sea temperature is measured through a sensor located at 1.0m depth. The Italian data buoy network (Rete Ondametrica Nazionale - RON, [8]) consists of 15 instruments in open sea. Buoys are moored approximately at the 100m bathymetry and the gauge is positioned below the hull (about 1.0m under the sea level).

During the last years, both networks continuously collected SST data, measured through a thermistor.

Different kind of errors related to malfunctioning temperature thermistors, interferences on transmission and uncalibrated sensors are often difficult to detect from isolated stations. Additional information from other datasets can help significantly to identify such problems.

Quality control checks are applied to these data and periodic maintenance activity is performed on monitoring gauges in order to reduce outliers and gaps.

The development of satellite and remote systems allows to improve the spatial resolution of SST observations. However, without reference to in situ measurements most satellite-based SST products will contain large-scale biases due to varying atmospheric composition and imperfect instrumental calibration [2].

In the framework of Copernicus program, the CNR MED Sea Surface Temperature provides daily gap-free maps (L4) at 0.0625 degrees resolution over the Mediterranean Sea. The data are obtained from infrared measurements collected by satellite radiometers and statistical interpolation. The Mediterranean L4 operational products have then been validated using in situ SST measurements from drifting buoys, covering two years of data (2010–2011) [9]. This dataset represent the state of art and probably it is the best calibrated and validated SST dataset available.

II. MATERIAL AND METHODS

A. Long-term SST series

The “ICOADS 2 Degree” monthly mean SST dataset starts in 1850. However data used in this study start from 1900 up to present days covering over about 120 years. Data are restricted to the Italian Seas (latitude 35°N-46°N, longitude 7°E-20°E) and the two principal basins, Tyrrhenian and Adriatic, are analysed separately.

In the selected period, the dataset counts 2.5% of missing values gathered in small gaps during the world wars (1917-1918 and 1940-1943).

Since the well-known limitations of this dataset, only a qualitative evaluation of standard thirty-year periods (1900-1929; 1930-1959; 1960-1989) in terms of SST distribution has been performed. Series of deviation from the mean SST in 1960-1989 have been computed and compared with the measurement of 2016.

The temporal trend of the whole SST series has been analysed by fitting a local polynomial regression in order to evaluate the temperature variability over the years respect to the mean level.

B. Short-term SST series

RMN tide gauges SST data involved in the analysis start from 2000 up to 2014. Respect to the ICOADS datasets, this kind of data could reproduce the local variability of SST allowing to describe the dynamic of the parameter along the coast. Furthermore, the analysis of the stations belonging to the same sea helps to detect typical basin regimes over the years. A representation of these time series is presented in order to individuate the local and general behaviour of the main basins.

CNR-MED SST data are available from 2008 up to 2016. This set of data is very useful to extrapolate spatial and temporal dynamics at different scales (local, regional, basins, seasonal, annual, etc.). At the moment, these series have limited temporal span and it affects a long term analysis. However it could represent the target for future long term studies.

The spatial distribution and anomalies of the SST are calculated in order to provide climatology and to investigate relevant phenomena at different spatial and temporal scales. On the other hand, maps of frequencies of moving window minimum and maximum SST values have been reported. These plots are useful to show areas mainly exposed to extreme values.

C. Comparison of SST time series

The comparison of presented long-term and short-term spatial SST series is affected by a number of limitations, in particular:

- the different spatial resolutions: all spatial datasets have different resolution and the extrapolation of in situ data on regular grids and vice versa could introduce great bias.
- the different temporal domain: in particular the most informative dataset (CNR MED) is limited a few years of measures and this limits a comparison with long-term ICOADS datasets
- the well known limitations of ICOADS measurements already described.

For these reasons, in order to perform a possible comparison, only the two datasets “ICOADS 1 Degree” and “CNR-MED” have been selected starting from 2008.

Boxplots of residuals between ICOADS and CNR-MED sets have been drawn for the Tyrrhenian and the Adriatic Sea to highlight the different temperature distributions in the two basins.

Moreover the linear regression of the residuals versus the seasonal variability has been performed. To define the seasonal component, three variables have been introduced:

- Cold season (December, January, February, March)

- Warm season (June, July, August, September)
- Mild season (April, May, October, November)

The estimated coefficients, while statistically significant, have been used to correct the time series and trends.

Clearly, this is a preliminary analysis and it should be upgraded with longer time series.

III. RESULTS

A. Long-term SST series

Thirty-year period distributions of deviation from the monthly mean SST in 1960-1989 have been reported in Fig. 2. The differences between the first period (1900-1929) and the others are relevant, especially from August to January when the distance between mode distributions is about 1°C. The distance between monthly mean values in 2016 and the past years is even more significant. These differences are higher in winter (1.4°C from referring level) and close to zero in summer.

SST Trend in Tyrrhenian Sea is shown in Fig. 3. Respect to the whole average SST (about 19°C), there is a cooling of 0.5°C in 1970-1990, while a warming of 0.9°C during the last 10 years.

B. Short-term SST series

Annual means of sea surface temperature in the period 2001-2014 are computed from RMN observations, and reported as difference from the mean SST in 2000. The distribution of these values (Fig. 4) for five measurement stations (Civitavecchia, Napoli, Palinuro, Palermo, Cagliari) shows a large interannual variability, emphasised for stations influenced by warm and cold circulations coming from the western Mediterranean sea. For all gauges, the period 2011-2014 is the warmest, with maximum in 2014 (+0.7°C respect to SST in 2000).

Fig. 5(a) shows the average spatial distribution of SST in 2008-2015 and Fig. 5(b) the anomaly field in 2016 with respect to previous period. The total anomaly is +0.14°C with warmest areas around the western Mediterranean sea, the Ionian Sea and the Strait of Bonifacio.

Using a moving window of 1x1 degrees, frequency of maximum and minimum are detected and reported in Figures 6. Maximum in Fig. 6(a) are mainly concentrated in particular areas along the coasts and in the central Tyrrhenian and Ionian Sea. Similarly, minimum SST values in Fig. 6(b) are located along shore in correspondence of the major river mouths, and distributed along a passageway between Strait of Messina and Strait of Bonifacio.

C. Comparison of SST time series

Despite the bias related to different sources of data, ICOADS 1 Degree and CNR-MED datasets present a good agreement.

Annual boxplots of monthly mean SST residuals (Fig. 7) allow to describe different regimes in Adriatic and Tyrrhenian Sea.

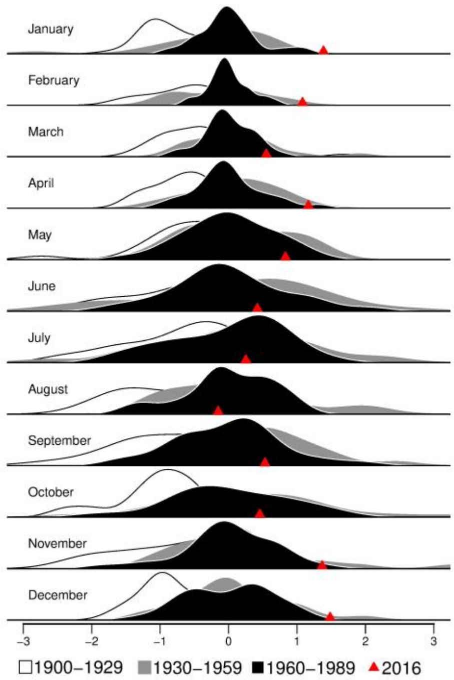

Fig. 2. Thirty-year periods of monthly means SST distribution in Tyrrhenian Sea. Red dots refer to monthly means of 2016 (ICOADS 2 Degree dataset)

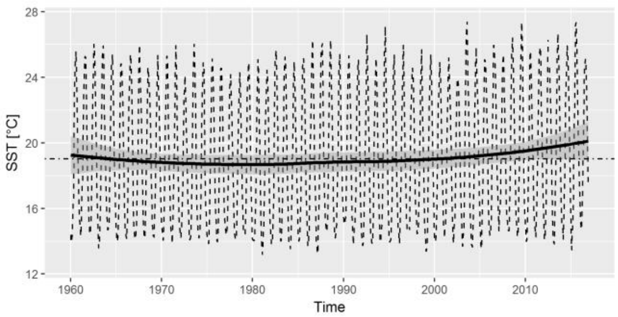

Fig. 3. Trend in Tyrrhenian Sea (ICOADS 1 Degree dataset)

Fig. 4. SST Annual means distributions in Tyrrhenian Sea (RMN dataset)

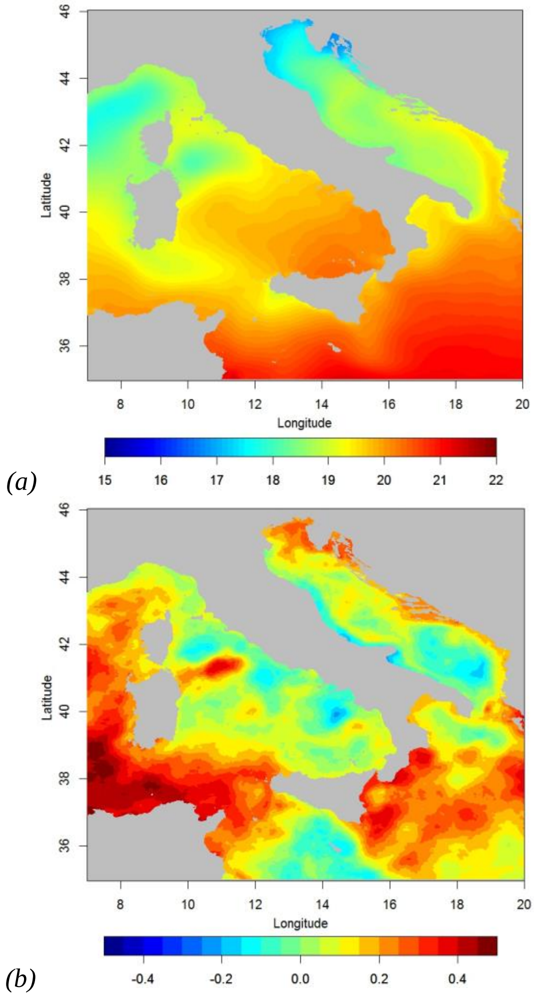

Fig. 5. SST spatial distribution in 2008-2015 (a) and anomaly in 2016 (b) (CNR-MED dataset)

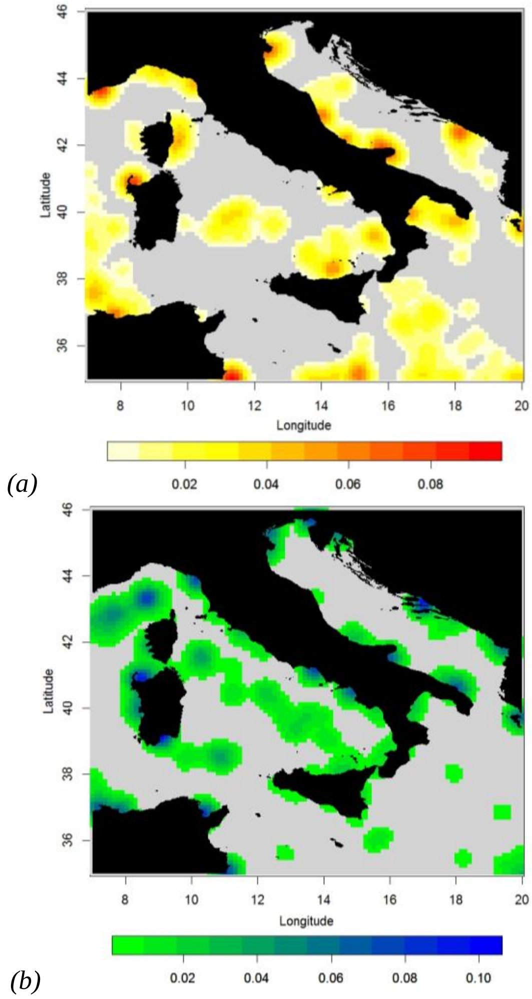

Fig. 6. Frequency distribution of moving window maximum (a) and minimum (b) of SST (CNR-MED dataset)

While in the Tyrrhenian Sea residuals are more homogeneous with medians positive but close to zero, on the other hand, in Adriatic Sea the same values are spread with positive and higher median than in the Tyrrhenian Sea.

The analysis of the time series suggests the need of introduce the seasonal component because the ICOADS dataset overestimate colder temperatures and underestimate warmer ones. Table 1 reports the coefficient estimates of a linear regression where residuals are the predictors and seasons are regressors.

This relation has been used to process the whole time series since 1960 in order to calibrate the trend analysis already presented in Fig. 3.

All estimates are highly significant except to the warm season in Adriatic Sea and are positive in cold and mild seasons while negative in the warm one. In particular in the Tyrrhenian Sea, estimate values are lower, confirming a good agreement between the two datasets in open seas.

On the other hand, higher values in Adriatic estimates suggest the difficulty in ICOADS dataset to represent the variability of SST in semi enclosed basins.

It is possible to extend this result to the trends shown in Fig. 8. While the correction in Tyrrhenian Sea is minimal, in the Adriatic Sea it is more relevant and approximately of 0.5°C.

Table 1. Coefficient estimates of linear model between residuals (SST_{ICOADS}-$SST_{CNR-MED}$) vs seasons.

Tyrrhenian Sea			
Season	Estimate	Std. Error	Sig. Level
Cold	0.25824	0.06372	<0.001
Warm	-0.31482	0.06372	<0.001
Mild	0.17424	0.06372	0.01-0.001
Adriatic Sea			
Season	Estimate	Std. Error	Sig. Level
Cold	1.1079	0.1183	<0.001
Warm	-0.2108	0.1183	0.05-0.1
Mild	0.6997	0.1183	<0.001

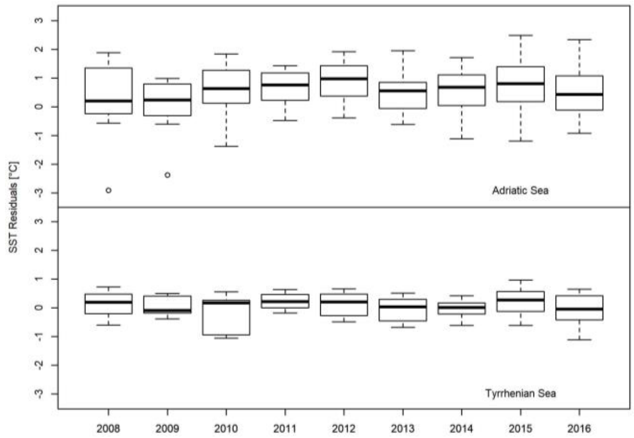

Fig. 7. Annual boxplots of monthly mean SST residuals (ICOADS 1 Degree - CNR-MED datasets)

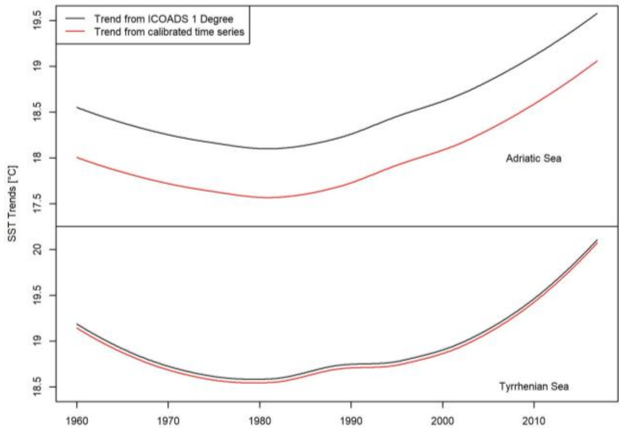

Fig. 8. Trends from ICOADS 1 Degree (black) and calibrated SST time series (red)

IV. CONCLUSIONS

The study is an attempt to use multiple data source, with different spatial and temporal resolution, in order to describe significant SST regimes in Italian Seas.

Despite the different characteristics of data involved in these analyses and the limits highlighted, the SST series present a good agreement.

As expected, a better agreement is evident in Tyrrhenian Sea due to the homogeneous hydrographical conditions typical of the open sea basins. On the other hand, the performance in the Adriatic Sea reflects the complexity of local dynamics in semi-enclosed basins related to the orography and the freshwater inputs.

More work is required to extend results to all Italian seas and to confirm evidences. It is fundamental to carry on with a rigorous SST monitoring in the following years from multiple sources in order to have a better calibration of the past decades and to have correct trend estimation.

V. ACKNOWLEDGEMENT

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