A near-surface sea temperature time series from Trieste, north Adriatic Sea (1899-2015)

Fabio Raicich[1], Renato R. Colucci[1]

[1]CNR, Institute ~~for~~ of Marine Sciences, Trieste, I-34149, Italy

Correspondence to: Fabio Raicich (fabio.raicich@ts.ismar.cnr.it)

Abstract. A time series of near-surface sea temperature was built from observations performed in the harbour of Trieste from 14 July 1899 to 31 December 2015. The description of the observation sites and instruments was possible thanks to historical documents. The measurements ~~compose~~ consist of two data set: The first consists of analogue data obtained by means of thermometers and thermographs, one or two times per day, in the periods 1899–1923 and 1934–2008; the second consists of digital records obtained by thermistors on hourly basis in the period 1986–2015. A quasi-homogeneous time series of daily temperatures at 2-m depth is formed from direct observations at that depth and from temperatures estimated from observations at shallower depths. From this time series a mean temperature rise rate of 1.1±0.3 °C per century was estimated, while in 1946-2015 it is 1.3±0.5 °C per century. The data are available through SEANOE (doi: 10.17882/58728; Raicich and Colucci, 2019).

1 Introduction

~~The k~~Knowledge of the processes and evolution of the earth system depends on observations. As the oceans cover most of the ~~earth's~~ Earth's surface, marine data are particularly valuable and, therefore, are in high demand by public authorities, private enterprises, the scientific community and ~~the~~ civil society, in a wide range of research fields and applications. The public release of marine data and related products has been fostered in the framework of several European initiatives, as, for instance, EMODNet (www.emodnet.eu) and SeaDataNet (www.seadatanet.org) (Shepherd, 2018).

Long time series of observations represent a key element in climate studies, both based on both data analysis and model reconstructions, and thus the sustainability of suitable observing systems is critical, as emphasized by IFSOO (2012). Although sea-temperature measurements date back to over 150 years ago (International Comprehensive Ocean-Atmosphere Data Set, Woodruff et al, 2011), time series longer than a few decades are uncommon, even in coastal areas.

Thanks to data retrieved from the archives of the Institute for Marine Sciences of CNR in Trieste, a quasi-homogeneous time series of daily temperature at 2-m depth was formed from near-surface sea temperatures measured in Trieste harbour, at the northernmost end of the Adriatic Sea, from 1899 to 2015. Even though these data are coastal and, therefore, sensitive to local natural and anthropogenic processes, the considerable length of the time series makes it not only useful for local studies but also a long-term indicator of climate change in the northern Mediterranean.

The observation site is located in the Gulf of Trieste, which is a bay of about 20×25 km^2 with a maximum depth of 25 m (Fig. 1). The shallowness and semi-enclosed character of the basin make near-surface temperature strongly dependent on the atmospheric forcing. As a result, a marked seasonal cycle is observed, ranging from 9 °C in February and to 25 °C in July (period 1991-2003; Malačič et al., 2006); moreover, fast temperature changes often occur on synoptic time scales, due to bursts of north-easterly Bora wind, that causes coastal upwelling (e.g., Crisciani and Raicich, 2004; Crise et al., 2006) and intense air-sea heat fluxes (Stravisi and Crisciani, 1986; Picco, 1991; Supić and Orlić, 1999; Malačič and Petelin, 2001; Raicich et al., 2013). No significant influence on sea temperature is expected from the fresh water discharge in the Gulf of Trieste. The river runoff is concentrated in the northern part of the gulf, about 20 km from Trieste, where the mean annual discharge is 114 m^3 s^{-1}, i.e. over 95% of the total, while only 5 m^3 s^{-1} discharge occurs from small streams along the Slovenian coast, at about 10 km from Trieste (Cozzi et al., 2012).

In the next section the data used in this work and their sources will be described. The methods used to derive the 2-m temperature time series and to estimate the related errors will be outlined in Sect. 3. Section 4 will include basic information on the data availability. Concluding remarks will be presented in Sect. 5.

2 Data description

2.1 Measurement sites and instruments

All the sites are located in Trieste harbour (Fig. 1) within an area of approximately 0.1 km^2; their geographical positions are summarized in Table 1. Molo (Pier) Sartorio (SAR) and Molo Santa Teresa (TER) face a semi-enclosed bay, while Bagno (bathing establishment) Savoia (SAV), Porto (harbour) Lido (LID) and Molo Bandiera (BAN) face the open sea. For each site, Table 1 summarizes the depths of measurement, the instruments used and the periods of observation.

The earliest regular observations of sea temperature date back to summer 1899. The first instrument used was a *Pinsel-Thermometer*, literally translated as brush-thermometer, manufactured by the H. Kappeller firm in Vienna, with scale pitch of 0.2 °C. In order to measure water temperature, its bulb was wrapped in a sort of brush which could absorb water and, after the thermal equilibrium was reached, keep it insulated from the surrounding environment while the instrument was extracted from the water and read In order to measure temperature, the instrument was manually deployed to the prescribed depth and kept there until thermal equilibrium was reached. Its bulb was wrapped in a sort of brush which could absorb water and keep it insulated from the surrounding environment while the thermometer was being extracted from water and read (Attlmayr, 1883). On 8 January 1934 a thermograph was put into operation., manufactured by the P. Wegener firm in Ballenstedt, Germany. The instrument was connected by a 5-m long capillary to a bulb placed at 2 m below the mean sea level at about 70 m from the shore, with chart (fixed on a rotating drum) speed of 45 mm d^{-1} (~1.9 mm hr^{-1}) and non-linear vertical scale corresponding to 2.1 mm °C^{-1} at 15 °C; the chart was changed weekly. Figure 2 shows the chart for 1–8 July 1935. On 19 June 1943 the observations ended because the connection between bulb and capillary was broken and the bulb was lost; attempts to obtain a replacement failed probably because of the ongoing Second World War (Geophysical Institute, 1943). Another thermograph was employed from 27 April 1948 to 1 December 1952 (Picotti, 1955). It was manufactured by the SIAP firm in Bologna, Italy, with chart speed of 40 mm d^{-1} (~1.7 mm hr^{-1}) and linear vertical scale corresponding to 1.5 mm $°C^{-1}$.

~~Because~~ While manual measurements were performed at prescribed depths below the sea surface, the thermograph bulbs were at fixed heights, therefore~~,~~ their depths would change according to sea level variations. In few cases a very low sea level caused the bulb to be close to the sea surface, thus affecting the measurements. Trieste harbour is subject to a range of ~~the~~ astronomical tide up to 1.2 m on syzygies, and a mean seasonal sea-level range of approximately 15 cm, mainly modulated by the atmospheric forcing (pressure and dominant winds) and the steric effect. On synoptic time scales the atmospheric forcing has produced positive sea-level surges (storm surges) up to 1.7 m above the mean sea level and negative surges up to 1 m below (Beretta et al., 2005; Tsimplis et al., 2009; Raicich, 2010).

The effect on temperature would consist of an anomalous increase due to solar heating of the surface layer, observed at low tide and in weak wind conditions, particularly during late spring and summer sunny days. We know that in the 1934–1943 period the curve was usually interpolated or smoothed manually to correct the anomalous temperature values (Polli, 1946). Although no explicit information is available for the 1948–1952 period, the same procedure was also likely adopted.

Well thermometers have been usually employed for direct measurements, generally to fill gaps in the thermograph records. The instruments were manufactured by SIAP and their scale pitch was 0.1 °C.

In 1986 automatic temperature recording started at Molo Bandiera using PT100 thermistors, having a nominal accuracy of approximately 0.1 °C. Usually, ocean temperature ~~should be measured~~ is reported to ~~the~~ 0.01 °C ~~accuracy~~ precision, i.e. one order of magnitude better~~,~~; nevertheless, the PT100 accuracy is considered sufficient to measure the highly variable near-surface sea temperature in Trieste harbour, which is strongly influenced by ~~the~~ atmospheric forcing.

We will distinguish two main data sets. Set A consists of manual and analogue automatic measurements performed from 14 July 1899 to 31 December 2008. Set B consists of digital records from 18 November 1986 to 31 December 2015. Several gaps exist due to instrumental malfunctions and failures, particularly in the earlier years of each data set, and some missing data may have simply been lost.

2.2 Data set A (1899-2008)

The Maritime Observatory (Osservatorio Marittimo) of Trieste managed the earliest sea-temperature observations from 14 July 1899 to 31 December 1920. They were either reported as an additional column on tables of hourly air temperature data, obtained from the digitization of thermograph charts, or on separate sheets. The sheet for 1916 is shown in Fig. 3. The data for 1905, 1909–1914, and 1918–1919 are missing. According to archive documents, the observations were also performed at least in the second half of 1918 and the first half of 1919 (Maritime Observatory, 1919), but the data could not be found. No information is available for the other data gaps.

The data sheet for July 1899 reports that the measurements were performed at the head of Molo Sartorio at 0.75-m depth at 9 AM (Central European Time). This was the situation until 1904, while in 1906–1908 the time changed to 10:30 AM. In 1915–

1917 the site was moved by approximately 300 m to Molo Santa Teresa near the lighthouse and the observation time was 8 AM. In 1920 temperature was measured at 9 AM, again at Molo Sartorio.

We can only assume that the nominal depth remained 0.75 m, as after the very first data sheet of 1899 no further information was provided. This assumption seems reasonable because the instrument was only suitable for near-surface water measurements. In 1915-1917 the data were also published in the daily telegraphic weather bulletin (Bollettino Meteorologico Telegrafico) issued by the Maritime Observatory (Maritime Observatory, 1915-1917).

No data are available for the 1921-1933 period except few sparse measurements in 1922-1923.

In 1934 the observations were resumed by the Geophysical Institute (Istituto Geofisico), which was renamed the Thalassographic Institute (Istituto Talassografico) in 1941. Temperature at 12 Noon was usually extracted from the thermograph records for publication. Manual measurements with a well thermometer were performed in case of thermograph failure~~,~~; nevertheless, several gaps still affect the record, particularly during 1941-1944.

Manual observations continued until 2008 and daily values were reported in monthly summaries alongside the meteorological data. From 1944 to 1979 they were performed at Bagno Savoia at 8 AM and 7 PM; in 1952–1957 an additional observation was added at 12 Noon. From 1964 to ~~1970~~ 1968 temperature was also measured at Molo Sartorio in the morning (times were reported). On an unknown date between 1971 and 1975 the site was moved to Porto Lido, 180 m from Bagno Savoia (Fig. 1). From 1980 to 2008 the observation was nominally made at 10 AM.

The measurement sites can be divided in two groups. The first consists of Molo Sartorio and Molo Santa Teresa, located inside the Sacchetta Basin (Fig. 1); the second is composed of Bagno Savoia, Porto Lido and Molo Bandiera, outside the Sacchetta, facing the open sea. Almost simultaneous (within half an hour) observations allow to compare Molo Sartorio with Bagno Savoia (using 1295 ‘surface’ data in 1964–1968) and with Porto Lido (using 299 data at 2 m depth in 1983–1986). The average temperature differences are negligible in both cases (0.0±0.6 °C) and it is therefore possible to merge the different data records into a quasi-homogeneous time series.

Regarding the times of observation, it is certain that permanent staff was on duty ~~until 1919 at Molo Sartorio and Molo Santa Teresa~~ in offices close to the observation sites at Molo Sartorio (in 1899-1908) and at Molo Santa Teresa (in 1915-1917 and, probably, in 1920), thus deviations from nominal times were probably a few minutes. By contrast, from 1934 onwards direct measurements required the observer to move from his office to the observation site; therefore, the observation time was variable and sometimes weather conditions were so bad to prevent the observations from being performed. The actual time was reported in many cases, but this was not ~~the rule~~ always the case.

These analogue records were reported to ~~the~~ 0.1 °C precision, and occasionally to 0.05 °C.

2.3 Data set B (1986-2015)

From 1986 to 1989 a PT100 probe was used at 0.4-m depth, which can be deemed equivalent to the ‘surface’ depth of data set A (Table 1). ~~In~~ Observations were interrupted until 1992, when the depth was changed to 2 m, and in 1994 temperature began being measured at both 0.4- and 2-m depths. In 1999 three probes were installed at 0.4-, 2- and 6-m (sea bottom) depths; this configuration was kept since. These probes were attached to a float in order to keep their depth constant.

The original data record consists of hourly temperatures, represented by 10-min averages at the end of the hour; from mid-2008 onwards average, minimum and maximum temperatures were recorded every 10 minutes. The record is affected by several interruptions due to system failures; sometimes the probes were damaged or torn away by waves during storms. The measurements were originally reported to ~~the~~ 0.01 °C precision.

3 The time series at 2-m depth

A composite long-term time series of mean daily temperatures at 2-m depth was built merging the two data sets described in in the previous section. When not available from direct measurements, the 2-m temperature was estimated from the observations at other depths, as explained in Sect. 3.1.

3.1 The estimate of mean daily temperature

A provisional daily mean was first obtained by averaging the original observations for each calendar day, even when only one observation was available. Although the mean daily temperature range is generally ~~within~~ less than 0.5 °C, ~~the daily means computed with few observations may significantly differ from those obtained with 24 hourly data, which can be regarded as a standard~~ a daily mean computed with few observations may significantly differ from a mean accounting for the full daily cycle, which is well represented by 24 hourly observations. To account for the bias, mean corrections were estimated using data set B (see Sect. 2.3).

For each depth (0.4, 2 and 6 m) and each calendar day (1 January-31 December), climatological values for the 1999–2015 period were obtained by averaging hourly (0-23) temperatures and mean daily temperatures of days when all the 24 hourly observations were available, in order to account for the complete daily cycle.

If h represents the hour, d the day, m the month, y the year, and z the depth, let $T_o(h,d,m,y,z)$ be the observed temperature, $T_c(h,d,m,z)$ the climatological hourly temperature and $T_{24c}(d,m,z)$ the climatological mean daily temperature:

$$T_c(h,d,m,z) = \sum_{y=1999}^{2015}[T_o(h,d,m,y,z) \cdot p(h,d,m,y,z)] \Big/ \sum_{y=1999}^{2015} p(h,d,m,y,z), \quad (1)$$

$$T_{24c}(d,m,z) = \sum_{h=0}^{23} T_c(h,d,m,z)/24, \quad (2)$$

p being a weighing factor, equal to 1 if T_o is available and 0 if it is not. For a given (h,d,m,z), in 1999–2015 there are generally between 13 and 17 values of T_o. A 31-day running mean is subsequently applied to T_c and T_{24c} in order to smooth out the effect of outliers. The values for 0.75-m depth are obtained by linear interpolation between those of 0.4- and 2-m depths, and the values for 29 February are interpolated using those of 28 February and 1 March.

The mean daily temperature $T(d,m,y,z)$ is estimated as:

$$T(d,m,y,z) = T_{24c}(d,m,z) + \frac{1}{N}\sum_{k=1}^{N}[T_o(t_k,d,m,y,z) - T_c(t_k,d,m,z)], \quad (3)$$

Where $N=N(d,m,y,z)$ is the number of available observations on the relevant day and t_k is the time of observation; when T_c is not a full hour, it is interpolated at the proper time using the nearest hourly values. The term in square brackets of Eq. 3 represents the departure of the observed value from climatology. Note that, if T_o is available at full hour from 0 to 23, then T is the arithmetic average of the 24 observations.

In other words, the difference between an observation and the corresponding climatological value provides a constant that is used to re-scale the climatological daily cycle; then, the average of the re-scaled daily cycle represents the estimated daily temperature. If more observations are available in a given day, the final estimate is the average of the individual estimated values.

When the 2-m observations are unavailable, the daily means are ~~possibly~~ estimated from data at other depths when possible. Let $Z=2$ m, then:

$$T(d,m,y,Z) = T(d,m,y,z) - [T_{24c}(d,m,z) - T_{24c}(d,m,Z)], \quad (4)$$

therefore:

$$T(d,m,y,Z) = T_{24c}(d,m,Z) + \frac{1}{N}\sum_{k=1}^{N}[T_o(t_k,d,m,y,z) - T_c(t_k,d,m,z)], \quad (5)$$

The term in square brackets on the right-hand side of Eq. 4 represents the correction that accounts for the incomplete representation of the daily cycle. Considering that, overall, the observations were made in the 8 AM–7 PM interval (sect. 2.2, above), the largest corrections, in absolute value, occur in June and July when values between -0.3 and 0.4 °C are expected, depending on the time of observation, with an average of +0.1 °C; the smallest corrections are found between mid-October and mid-February with values between -0.1 and +0.1 °C and average around 0.0 °C. These corrections ~~concern~~ are associated to estimates from single observations, as in data set A, while they are negligible in data set B where the complete daily cycle is generally available.

The term in square brackets on the right-hand side of Eq. 5 represents the correction related to the daily temperature estimate from data at depths other that 2 m. In this case, the corrections range between 0.02 °C in late November-early December and 0.68 °C in late June-early July. Larger corrections are a consequence of the water column stratification which typically occurs in summer.

3.2 The error on mean daily temperature

The error on T, namely σ, is computed from ~~those~~ the errors on the observation, σ_o, and on the climatologies, σ_{24c} and σ_c, respectively. ~~They~~ These errors are assessed semi-empirically as follows.

An observation is ~~basically~~ affected by an instrumental error and an environmental error. The error on temperature measured with manual thermometers can be estimated in half the scale pitch, namely 0.05 or 0.1 °C, depending on the instrument. In the case of thermographs, the distance of 1.5-2 mm between the chart markings and the curve thickness ~~probably~~ determines a reading error of approximately 0.2 °C. The environmental error is caused by small temperature fluctuations occurring in the water body at sub-hourly frequencies, due to turbulence and circulation~~,~~. ~~therefore~~ Therefore, an instantaneous measurement may not be ~~really~~ representative of the hourly value. In order to estimate this error, average hourly temperature ranges are computed using the temperature extremes that are available for 2008–2015. The mean 1-hr temperature ranges turn out to be 0.24, 0.30 and 0.29 °C at 0.4, 2 and 6 m, respectively. A ±0.15 °C error (0.3 °C band) can be adopted for all depths.

An additional error often affects the observations of data set A because only nominal times, and not the actual observation times ~~but only nominal times~~ are reported. This time uncertainty ~~reflects on~~ affects temperature because of the involvement of T_c, which is a function of h, in Eq. 1. As discussed in Sect. 2.2, the time uncertainty until 1917 can be considered negligible since the observation site and the observers' office were nearby. An estimate of the time uncertainty on manual observations from 1920 onwards can be made from the known observation times in 1964-1968 and 1983-1986, obtaining approximately ±2 hours. Temperature data can be reliably obtained from the thermograph curves every half an hour~~,~~ ; therefore, the time error can be estimated in about ±15 minutes. The time-related error is estimated in the same way used for the environmental error, in this case by analysing 4-hr and 0.5-hr intervals. The mean 4-hr temperature ranges are 0.50, 0.54 and 0.52 °C and the mean 0.5-hr ranges are 0.17, 0.23 and 0.21 °C, at 0.4, 2 and 6 m, respectively. ~~Errors~~ Representative errors of ±0.25 °C (0.5 °C band) and ±0.1 °C (0.2 °C band) can be adopted in these cases. Time uncertainty does not affect data set B significantly, because time is correct within a few minutes (at worst) depending on clock stability.

Table 2 summarizes the errors that can be expected in the different cases, as a function of σ_T, which is related to a known or nominal observation time, and the number of daily data available. Provided that T_c and T_{24c} are computed from Eq. 1 and 2, from the observational error σ_o ~~=0.18 °C~~ =0.18 °C we obtain σ_c ~~=0.05 °C~~ =0.05 °C and σ_{24c} ~~=0.01 °C~~ =0.01 °C. Finally, the overall error on the daily temperature estimate (Eq. 3) can be written:

$$\sigma(d,m,y,Z) = \left[\sigma_{24c}^2 + \frac{1}{N^2}\sum_{k=1}^{N}(\sigma_o^2 + \sigma_c^2)\right]^{\frac{1}{2}}, \quad (4)$$

Again, $N=N(d,m,y,z)$ is the number of available observations. To the precision of 0.1 °C, the daily means at 2-m depth are characterized by overall errors between 0.2 and 0.4 °C for data set A and between 0.1 and 0.2 °C for data set B.

3.3 The composite time series

Before merging data sets A and B a consistency check was done by comparing ~~each other~~ the data sets in the 1986–2008 period, when temperature was measured both at Porto Lido (LID) and Molo Bandiera (BAN) (Fig. 1). We computed mean temperature differences ($\Delta T = T_A$-T_B) when simultaneous measurements were available. Two periods can be distinguished, namely 18 November 1986–30 November 1989, in which ΔT ~~= 0.5±0.5 °C~~ = 0.5±0.5 °C, and 1 March 1993–31 December 2008, with ΔT ~~= -0.1±0.4 °C~~ = -0.1±0.4 °C, respectively. As the procedures and instruments used for direct measurements (data set A) have not significantly changed before and after 1986, the temperature difference in the first period is likely related to the early digital records (data set B), perhaps due to instrumental drifts or inaccurate calibration. In the second period ΔT is negligible.

The composite time series was built using data set A as a basis and data set B to fill gaps and extend the time series after 2008. For a few gaps in 1987–1989 the temperature from data set B was increased by 0.5 °C, ~~as discussed above~~ on the basis of the above-mentioned temperature difference.

4 Data availability

~~Figure 4 illustrates the data availability on a monthly basis as percentage of valid days. Mean annual temperatures were computed for complete years, i.e. having 12 valid months; a valid month has at least 80% valid days (Fig. 5). The threshold was chosen arbitrarily. Figure 4 illustrates the data availability on a monthly basis as percentage of valid days.~~ Figure 4 illustrates the monthly data availability as the percentage of the number of days with temperature estimate to the number of days per month. Mean annual temperatures were computed for complete years, i.e. having no missing months; a missing month has less than 80% available days (Fig. 5). The threshold was chosen arbitrarily.

The 1899–2015 composite time series is characterized by fluctuations on decadal time scales and a linear trend of 1.1±0.3 °C per century (at the 95% confidence level). The effect of the biases induced by poor time samplings, discussed in Sect. 3.1, can be estimated by analysing the time series of the original observations; in this case, the trend is 1.0±0.3 °C per century. Because of the many missing years in the first part of the time series, this result should be taken with caution. The trend of the continuous 1946–2015 period is 1.3±0.5 °C per century, both using the normalized and the original data.

The data used in this work are available from SEANOE as "Trieste 1899-2015 near-surface sea temperature", which includes the composite time series, data sets A and B and the monthly and annual mean temperatures (doi: 10.17882/58728; Raicich and Colucci, 2019).

5 Conclusive remarks

Near-surface sea temperature~~s~~ data measured at different sites in the harbour of Trieste were collected, forming two data sets. The first consists of analogue data from 1899 to 2008, while the second consists of digital records from 1986 to 2015. Their merger allowed to build a 117-year-long quasi-homogeneous time series of mean daily temperature at 2-m depth. Although the data accuracy is lower than the modern standards for ocean temperature measurements, these data sets represent a valuable tool to study sea-temperature variability on time scales from the synoptic ~~time scale~~, connected to the meteorological forcing, to decadal and ~~secular time scales~~century-timescales, related to climate changes.

The search for undiscovered data will continue, in order to possibly fill the existing gaps.

Author contribution

FR retrieved the archived data, prepared the data sets and ~~lead~~ led the writing of the paper. RRC was involved in temperature measurement and processing, and collaborated ~~to~~ on the paper writing.

Competing interests

The authors declare that they have no conflict of interests.

Acknowledgements

The authors acknowledge the work done during over a century by the previous staff of the Maritime Observatory, the Geophysical Institute, the Thalassographic Institute, and the Institute for Marine Sciences, who managed and performed the observations, and processed and preserved the data used to build the data set. In particular, the authors would like to thank M. Iorio and E. Caterini, in the current staff of the Institute ~~for~~ of Marine Sciences of CNR.

References

Attlmayr, F., Köttstorfer, J., Luksch, J., Mayer, E., Salcher, P., and Wolf, J.: Handbuch der Oceanographie und Maritimen Meteorologie, Band I, k.-k. Hof- und Staatsdruckerei, Vienna, Austria, available at: http://archive.org (last access: 12 November 2018), 1883.

Beretta, A., Roman, H.E., Crisciani, F., and Raicich, F.: Long-time correlations of sea-level and atmospheric pressure fluctuations at Trieste, Physica A, 347, 695–703, doi: 10.1016/j.physa.2004.08.027, 2005.

Cozzi, S., Falconi, C., Comici, C., Čermelj, B., Kovac, N., Turk, V., and Giani, M.: Recent evolution of river discharges in the Gulf of Trieste and their potential response to climate changes and anthropogenic pressure, Estuar. Coast. Shelf Sci., 115, 14-24, doi: 10.1016/j.ecss.2012.03.005, 2012.

Crisciani, F., and Raicich, F.: A minimal model of adiabatic isotherms surfacing in very shallow waters, Environ. Fluid Mech., 4, 113–125, 2004.

Crise, A., Querin, S., and Malačič, V.: A strong bora event in the Gulf of Trieste: a numerical study of wind driven circulation in stratified conditions with a preoperational model, Acta Adriatica, 47 (Suppl.), 185–206, 2006.

Geophysical Institute: Letter dated 1 July 1943, CNR-ISMAR Archive, Trieste, Italy, 1943.

IFSOO: Framework for Ocean Observing. By the Task Team for an Integrated Framework for Sustained Ocean Observing, UNESCO, IOC/INF-1284 rev., doi: 10.5270/OceanObs09-FOO, 2012.

Malačič, V., and Petelin, B.:. Gulf of Trieste, in: Physical Oceanography of the Adriatic Sea. Past, Present and Future, edited by Cushman-Roisin, B., Gačić, M., Poulain, P.-M., and Artegiani, A., Kluwer Acad., Dordrecht, The Netherlands, 167–181, 2001.

Malačič, V., Celio, M., Čermelj, B., Bussani, A., and Comici, C.:, Interannual evolution of seasonal thermohaline properties in the Gulf of Trieste (northern Adriatic) 1991–2003, J. Geophys. Res., 111, C08009, doi:10.1029/2005JC003267, 2006.

Maritime Observatory: Bollettino Meteorologico Telegrafico, Trieste, Italy , 1915–1917.

Maritime Observatory: Letter dated 29 July 1919, I.R. Governo Marittimo, Fasc. 10/8, N. 854, 5507, State Archive, Trieste, Italy, 1919.

Picco, P.: Evaporation and heat exchanges between the sea and the atmosphere in the Gulf of Trieste during 1988, N. Cimento C, 14, 335–345.

Picotti, M.: La temperatura del mare a Trieste durante il periodo 1948–1954, Publ. no. 317, Istituto Geofisico, Trieste, Italy, 1955.

Polli, S.: La temperatura del mare a Trieste in un decennio di osservazioni, Publ. no. 215, Istituto Sperimentale Talassografico, Trieste, Italy, 1946.

Raicich, F.: On the contributions of atmospheric pressure and wind to daily sea level in the Northern Adriatic Sea, Cont. Shelf. Res., 30, 1575–1581, doi: 10.1016/j.csr.2010.05.017, 2010.

Raicich, F., Malačič, V., Celio, M., Giaiotti, D., Cantoni, C., Colucci, R. R., Čermelj, B., and Pucillo, A.: Extreme air-sea interactions in the Gulf of Trieste (North Adriatic) during the strong Bora event in winter 2012, J. Geophys. Res. Oceans, 118, 5238–5250, doi:10.1002/jgrc.20398, 2013.

Raicich, F., and Colucci, R.R.: Trieste 1899-2015 near-surface sea temperature, SEANOE, https://doi.org/10.17882/58728, 2019.

Shepherd, I.: European efforts to make marine data more accessible, Ethics in Science and Environmental Politics, 18, 75-81, doi: 10.3354/esep.00181, 2018.

Stravisi, F., and Crisciani, F.: Estimation of surface heat and buoyancy fluxes in the Gulf of Trieste by means of bulk formulas, Boll. Oceanol. Teor. Appl., 4, 55–61, 1986.

Supić, N., and Orlić, M.: Seasonal and interannual variability of the northern Adriatic surface fluxes, J. Mar. Syst., 20, 205–229, doi: 10.1016/S0924-7963(98)00083-9, 1999.

Tsimplis, M.N, Marcos, M., Pérez, B., Challenor, P., Garcia-Fernandez, M.J., and Raicich, F.: On the effect of the sampling frequency of sea level measurements on return period estimate of extremes – Southern European examples, Cont. Shelf. Res., 29, 2214–2221, doi: 10.1016/j.csr.2009.08.015, 2009.

Woodruff, S. D., and Coauthors: ICOADS release 2.5: Extensions and enhancements to the surface marine meteorological archive. Int. J. Climatol., 31, 951–967, doi:10.1002/joc.2103, 2011.

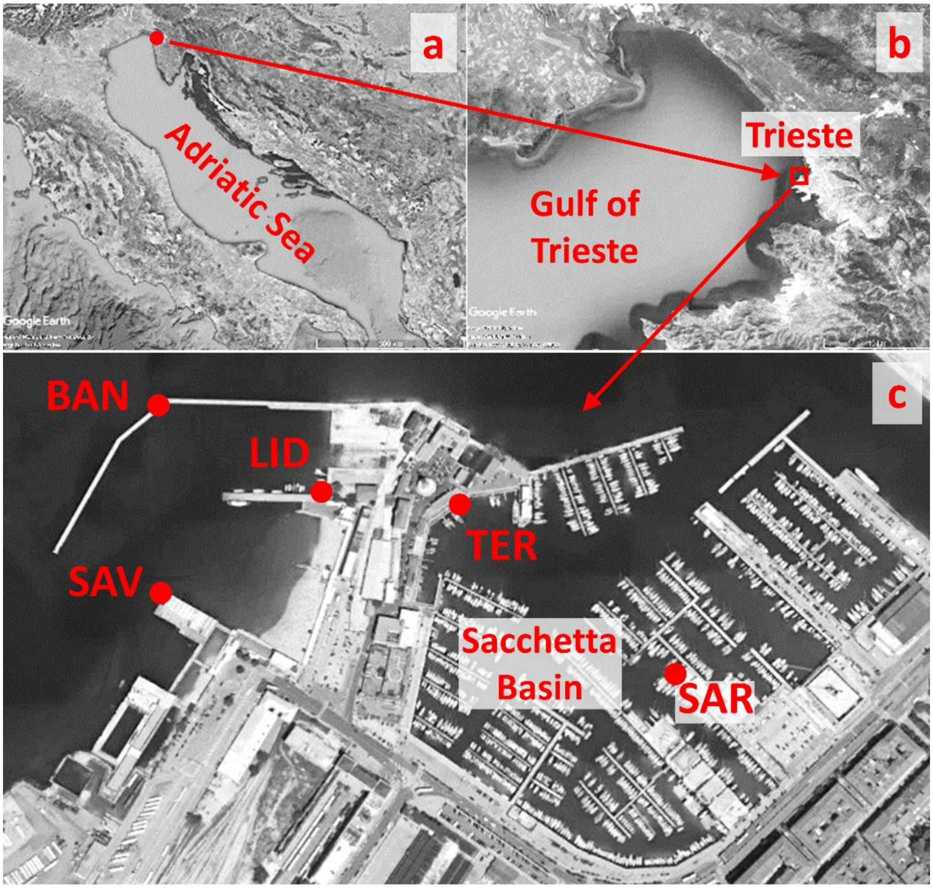
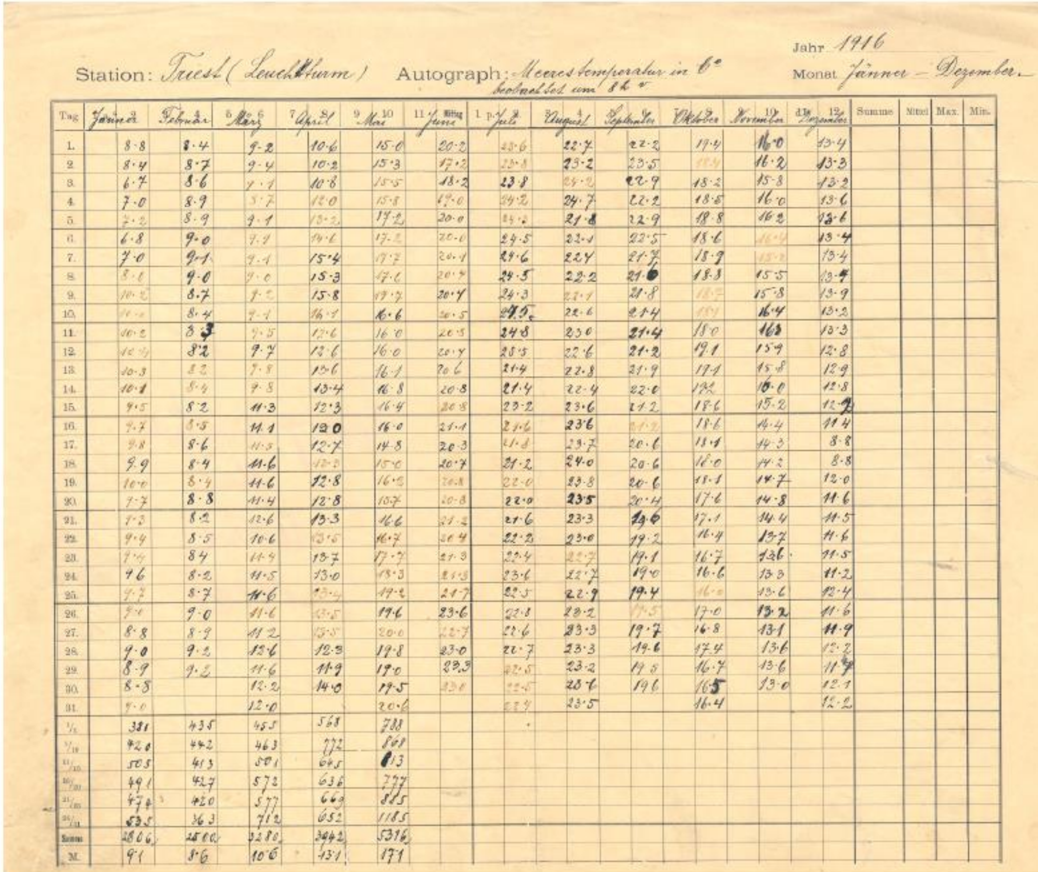


Figure 1: Aerial image of the area of Trieste harbour with the observation sites: Molo Sartorio (SAR), Molo Santa Teresa (TER), Bagno Savoia (SAV), Porto Lido (LID) and Molo Bandiera (BAN). (Images extracted from Google Earth; © 2018 Landsat/Copernicus, © 2018 CNES/Airbus, © 2018 Digital Globe, © 2018 TerraMetric.)



Station: Triest (Leuchtturm) Autograph: Meerestemperatur in C° beobachtet um 8h Jahr 1916 Monat Jänner – Dezember

Tag	Jänner	Februar	März	April	Mai	Juni	Juli	August	September	Oktober	November	Dezember	Summe	Mittel	Max.	Min.
1.	8.8	8.4	9.2	10.6	15.0	20.2	23.6	22.7	22.2	19.4	16.0	13.4				
2.	8.4	8.7	9.4	10.2	15.3	17.2	23.8	23.2	23.5	19.4	16.2	13.3				
3.	6.7	8.6	9.1	10.8	15.5	18.2	23.8	24.2	22.9	18.2	15.8	13.2				
4.	7.0	8.9	9.7	12.0	15.8	19.0	24.2	24.7	22.2	18.5	16.0	13.6				
5.	7.2	8.9	9.1	13.2	17.2	20.0	24.2	21.8	22.9	18.8	16.2	13.6				
6.	6.8	9.0	9.9	14.6	17.2	20.0	24.5	22.1	22.5	18.6	16.4	13.4				
7.	7.0	9.1	9.1	15.4	17.7	20.1	24.6	22.4	21.7	18.9	15.2	13.4				
8.	8.6	9.0	9.0	15.3	17.6	20.7	24.5	22.2	21.6	18.3	15.5	13.7				
9.	10.2	8.7	9.2	15.8	17.7	20.4	24.3	23.1	21.8	18.2	15.8	13.9				
10.	[illegible]	8.4	9.1	16.1	16.6	20.5	24.5	22.6	21.4	18.1	16.4	13.2				
11.	10.2	8.3	9.5	12.6	16.0	20.5	24.8	23.0	21.4	18.0	16.3	13.3				
12.	10.4	8.2	9.7	12.6	16.0	20.4	23.5	22.6	21.2	19.1	15.9	12.8				
13.	10.3	8.2	9.8	13.6	16.1	20.6	21.4	22.8	21.9	19.1	15.8	12.9				
14.	10.1	8.4	9.8	13.4	16.8	20.8	21.4	22.4	22.0	19.2	16.0	12.8				
15.	9.5	8.2	11.3	12.3	16.4	20.8	23.2	23.6	21.2	18.6	15.2	12.9				
16.	9.7	8.5	11.1	12.0	16.0	21.1	21.6	23.6	21.2	18.6	14.4	11.4				
17.	9.8	8.6	11.5	12.7	14.8	20.3	21.8	23.7	20.6	18.1	14.3	8.8				
18.	9.9	8.4	11.6	12.3	15.0	20.7	21.2	24.0	20.6	18.0	14.2	8.8				
19.	10.0	8.4	11.6	12.8	16.5	20.8	22.0	23.8	20.6	18.1	14.7	12.0				
20.	9.7	8.8	11.4	12.8	15.7	20.8	22.0	23.5	20.4	17.6	14.8	11.6				
21.	9.3	8.2	12.6	13.3	16.6	21.2	21.6	23.3	19.6	17.1	14.4	11.5				
22.	9.4	8.5	10.6	13.5	16.7	20.4	22.2	23.0	19.2	16.4	13.7	11.6				
23.	9.4	8.4	11.4	13.7	17.7	21.3	22.4	22.7	19.1	16.7	13.6	11.5				
24.	9.6	8.2	11.5	13.0	18.3	21.3	23.6	22.7	19.0	16.6	13.3	11.2				
25.	9.7	8.7	11.6	13.4	19.2	21.7	22.5	22.9	19.4	16.0	13.6	12.4				
26.	9.1	9.0	11.6	13.5	19.6	23.6	22.8	23.2	19.5	17.0	13.2	11.6				
27.	8.8	8.9	11.2	13.5	20.0	22.7	22.6	23.3	19.7	16.8	13.1	11.9				
28.	9.0	9.2	12.6	12.3	19.8	23.0	22.7	23.3	19.6	17.4	13.6	12.2				
29.	8.9	9.2	11.6	11.9	19.0	23.3	22.5	23.2	19.5	16.7	13.6	11.9				
30.	8.8		12.2	14.0	19.5	23.0	22.5	23.6	19.6	16.5	13.0	12.1				
31.	9.0		12.0		20.6		22.4	23.5		16.4		12.2				
1/5	381	435	455	568	788											
6/10	420	442	463	772	868											
11/15	505	413	501	645	813											
16/20	491	427	572	636	777											
21/25	474	420	577	669	885											
26/31	535	363	712	652	1185											
Summe	2806	2500	3280	3942	5316											
M.	9.1	8.6	10.6	13.1	17.1											

~~Figure 2: Sea temperature summary sheet for 1916. On top the indication of site and observation time: "Trieste (Lighthouse)", "Sea temperature in °C observed at 8h".~~

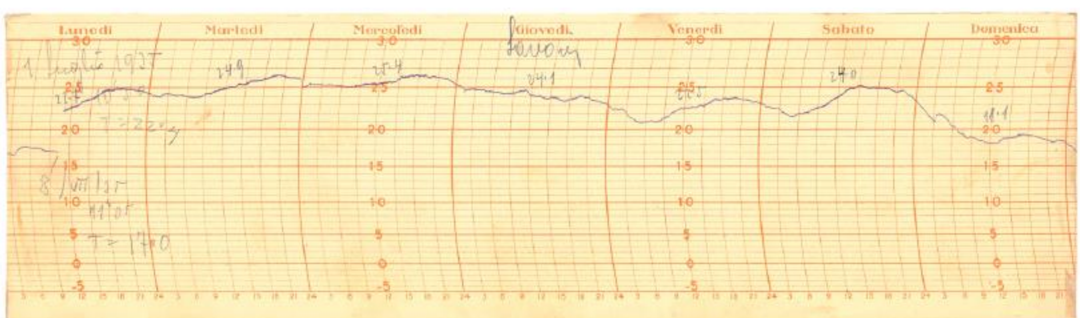
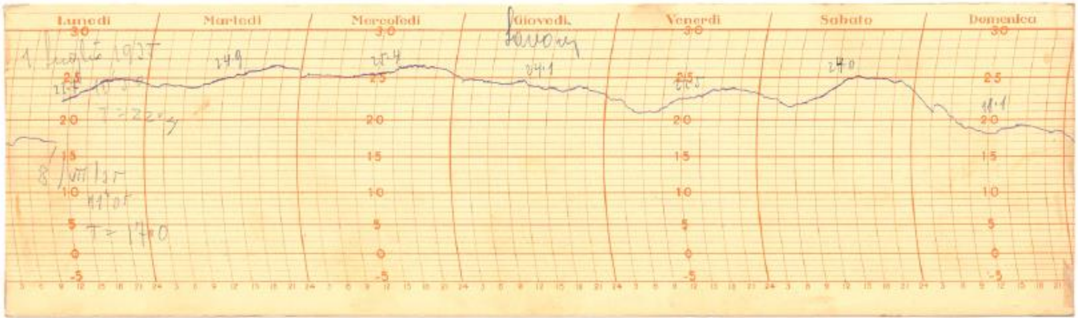


Figure 2: Weekly thermograph chart from Bagno Savoia for 1–8 July 1935. Values written above the curve are temperatures at 12 Noon. A remarkable cooling from 25 to 18 °C, due to Bora-induced upwelling, is evident on 6–7 July.



~~**Figure 3: Weekly thermograph chart from Bagno Savoia for 1–8 July 1935. Values written above the curve are temperatures at 12 Noon. A remarkable cooling from 25 to 18 °C, due to Bora-induced upwelling, is evident on 6–7 July.**~~

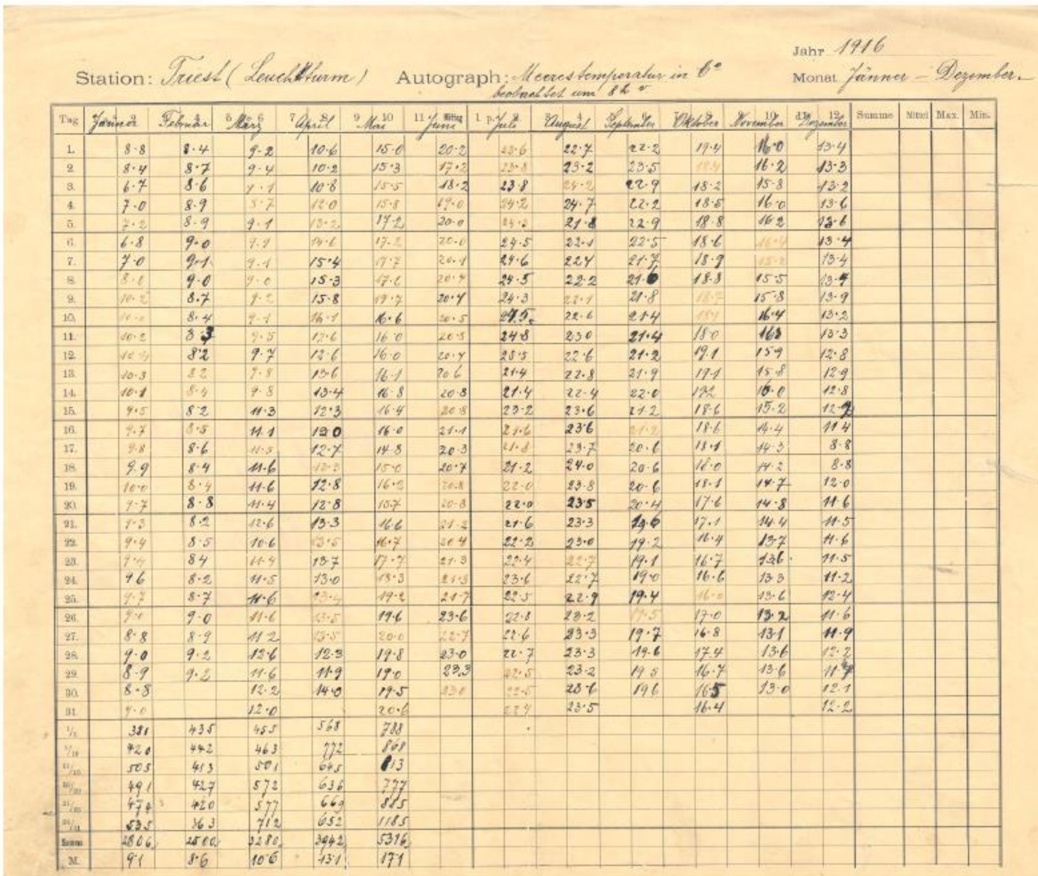


Figure 3: Sea temperature summary sheet for 1916. On top the indication of site and observation time: “Trieste (Lighthouse)”, “Sea temperature in °C observed at 8h”.

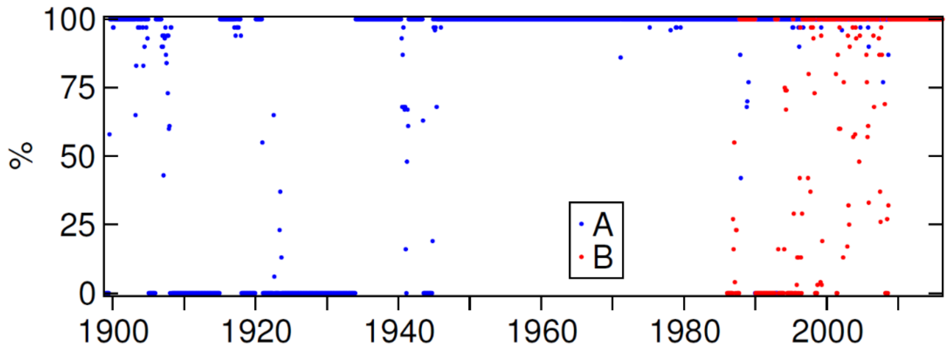


Figure 4: Data availability on a monthly basis for data set A (1899–2008) and data set B (1986–2015).

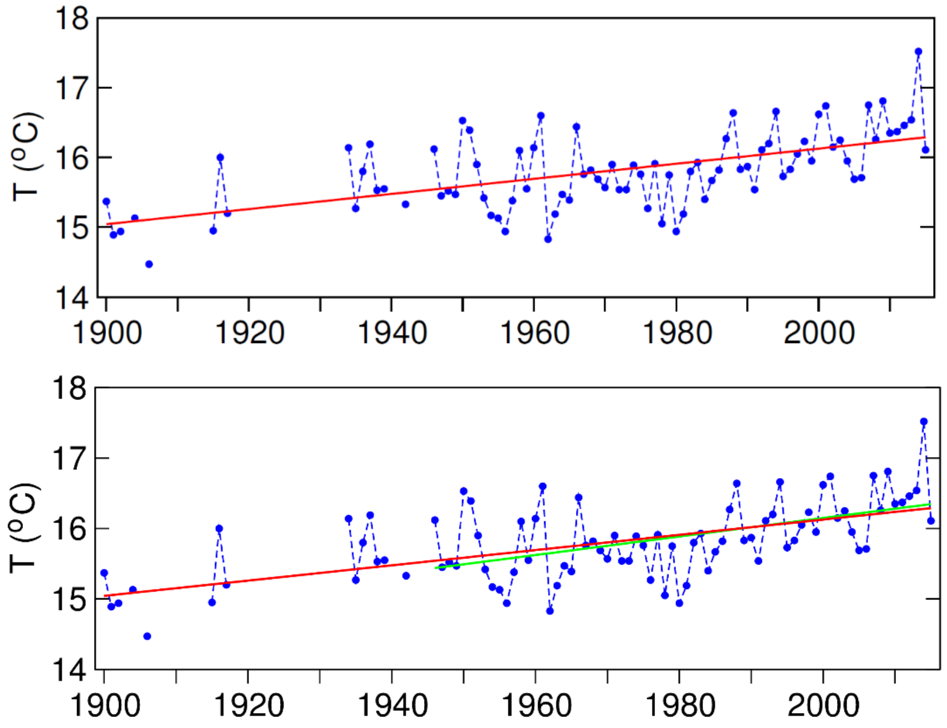


Figure 5: Annual mean sea temperature at 2-m depth from 1900 to 2015 (blue dots and dashed curve) and linear trends for 1899-2015 (red line) and 1946-2015 (green line).

Table 1: Summary of observation sites, their geographical position and instruments.

Site	Lat N (°)	Long E (°)	Depths	Instruments	Time interval
SAR – Molo Sartorio	45.6473	13.7595	0.75 m	'Pinsel-Thermometer'	1899–1908
			'surface'	well thermometer	1964–1968
TER – Molo Santa Teresa	45.6489	13.7563	0.75 m	'Pinsel-Thermometer'	1915–1920
SAV – Bagno Savoia	45.6481	13.7527	'surface'	well thermometer	1964–1970
			2 m below MSL	thermograph	1934–1943
			2 m	well thermometer	1934–1964
			2 m below MSL	thermograph	1948–1952
			2 m	well thermometer	1966–(1971–75)
			5 m	well thermometer	1965–1966
LID – Porto Lido	45.6491	13.7546	2 m	well thermometer	(1971–75)–1990
BAN – Molo Bandiera	45.6500	13.7522	0.4, 2, 6 m	thermistor	1986–2015

Table 1: Summary of observation sites, their geographical position and instruments. (bMSL: below Mean Sea Level)

Data set A	Site	Lat (°)	Long (°)	Depths	Instruments	Time interval
	SAR - Molo Sartorio	45.6473	13.7595	0.75 m	*Pinsel-Thermometer*	1899–1908
				'surface'	well thermometer	1964–1968
				'surface'	well thermometer	1983–1986
	TER - Molo S. Teresa	45.6489	13.7563	0.75 m	*Pinsel-Thermometer*	1915–1920
	SAV - Bagno Savoia	45.6481	13.7527	'surface'	well thermometer	1964–1970
				2 m bMSL	thermograph	1934–1943
				2 m	well thermometer	1934–1964
				2 m bMSL	thermograph	1948–1952
				2 m	well thermometer	1966–(1971–75)
				5 m	well thermometer	1965–1966
	LID - Porto Lido	45.6491	13.7546	2 m	well thermometer	(1971–75)–2008
Data set B	BAN - Molo Bandiera	45.6500	13.7522	0.4, 2, 6 m	thermistor	1986–2015

Table 2: Errors on estimated mean daily temperature. See text for the explanation of different options for time-related error and number of observation. (σ_I: instrumental accuracy, σ_E: environmental error, σ_T: time-related error, σ_o: observational error, n. obs.: number of observations per day, σ: error on estimated daily mean.)

Instrument	σ_I (°C)	σ_E (°C)	σ_T (°C)	σ_o (°C)	n. obs.	σ (°C)
Pinsel-Thermometer	0.1	0.15	0; 0.25	0.18; 0.31	1; 1	0.18; 0.31
Thermograph	0.2	0.15	0.1	0.27	1	0.40
Well thermometer	0.05	0.15	0; 0.25	0.16; 0.30	1; 1-3	0.16; 0.30-0.22
Thermistor	0.1	0.15	0	0.18	1-24	0.18-0.08

Table 2: Errors on estimated mean daily temperature. σ_I is the instrumental error, σ_E is the environmental error, σ_T is the time-related error, σ_o is the observational error, n. obs. is the number of observations per day, σ is the error on the estimated daily mean.

Labels a) and b) correspond to zero and non-zero uncertainties on time, respectively. When n.obs. is characterized by a range, the corresponding σ range is shown. See Sect. 3.2 for detailed explanations.

	Instrument		σ_I (°C)	σ_E (°C)	σ_T (°C)	σ_o (°C)	n. obs.	σ (°C)
Data set A	*Pinsel-Thermometer*	a)	0.1	0.15	0	0.18	1	0.18
		b)	0.1	0.15	0.25	0.31	1	0.31
	Thermograph		0.2	0.15	0.1	0.27	1	0.40
	Well thermometer	a)	0.05	0.15	0	0.16	1	0.16
		b)	0.05	0.15	0.25	0.30	1-3	0.30-0.22
Data set B	Thermistor		0.1	0.15	0	0.18	1-24	0.18-0.08

Answers to Reviewer #1 (pages and lines of the marked-up manuscript, above, unless otherwise stated)

SPECIFIC COMMENTS

--Page 1

--Line 12: “1.1+/-0.3 C per century was estimated”: Could you mention here also the 1946-2015 1.3+/-0.5C per century trend, as that is a more continuous and thus robust trend?

Answer: The relevant sentence was completed as follows: “… was estimated, while in 1946-2015 it is 1.3±0.5 °C per century.” (Page 1, lines 12-13)

--Line 26: “Even though these data are coastal”: What is meant by this? That coastal data may not be most useful for climate change indicators? Why? Please explain in manuscript.

A: The sentence was completed as follows: “… coastal and, therefore, sensitive to local natural and anthropogenic processes, the considerable …”. (Page 1, lines 26-27)

--Page 3

--Lines 1-10: How were the Pinsel thermometer measurements taken? Were they affected by sea level change similar to how the thermographs were affected?

A: The text was modified in two places, as follows:

1) Page 2, lines 24-26: “In order to measure temperature, the instrument was manually deployed to the prescribed depth and kept there until thermal equilibrium was reached. Its bulb was wrapped in a sort of brush which could absorb water and keep it insulated from the surrounding environment while the thermometer was being extracted from water and read.”.

2) Page 3, lines 3-4: “While manual measurements were performed at prescribed depths below the sea surface, the thermograph bulbs were at fixed heights, therefore their depths would change according to sea level variations.”

--Line 14: “Usually, ocean temperature should be measured to the 0.01 C accuracy”: can you provide a reference for this? Seems to me that this accuracy would change based on the end user.

A: We agree that the concept was too strong. The sentence was modified as: “Usually, ocean temperature is reported with the precision of 0.01 °C, i.e. …” (Page 3, line 17)

--Lines 28-31: Are the time (9 am to 10:30 am to 8 am to 9 am) and space (300 m apart) changes too large to produce a sufficiently homogeneous dataset here? Please comment in the manuscript.

A: As several changes occurred in observation times, depths, sites and sampling frequencies, we could not assume the time series to be homogeneous. The only way to say if time and space changes introduced significant biases or not, was to estimate them, and this is what we did. The reviewer’s question, which we believe concerns the time and space changes in general, is answered in three places:

1) At page 4, line 17 (original manuscript), where differences are shown to be negligible between sites inside and outside the Sacchetta basin.

2) At page 6, lines 6-12 (original manuscript), where the influence of time sampling turns out to be small but not negligible in summer (relative to a daily mean obtained from 24 observations per day).

3) At page 7, line 18 (original manuscript), where differences are shown to be negligible also between the manual measurements at Porto Lido and the digital records at Molo Bandiera.

In order to assess the possible effect of the biases, we also computed the long-term trends of the time series without any normalization. The text in section 4 was rewritten as: “The effect of the biases induced by poor time samplings, discussed in Sect. 3.1, can be estimated by analysing the time series of the original observations; in this case, the trend is 1.0±0.5 °C per century. Because of the many missing years in the first part of the time series, this result should be taken with caution. The trend over the continuous 1946–2015 period is 1.3±0.5 °C per century, both using the normalized and the original data.” (Page 8, lines 14-17)

--Page 4:

--Lines 1-12: This is very difficult to follow along with Table 1. Suggest somehow adding “Data set A” and “Data set B” to Table 1 to make it clearer what is indicated by what in Table 1.

A: Unfortunately, Table 1 was affected by errors and we are sorry for that. The table was rewritten accepting the reviewer’s remarks. (Page 15)

--Line 8: “Manual observations continued until 2008” where is 2008 in Table 1? I only see dates after 1990 on the last row of Table 1, and nowhere else.

A: Corrected. (Page 15)

--Line 10: “From 1964 to 1970”: isn’t it 1968 in Table 1 row 2?

A: Corrected. (Page 4, line 14)

--Line 12: “From 1980 to 2008” where is 2008 in Table 1 besides at the bottom?

A: The line starting with “LID-Porto Lido” was corrected. (Page 15)

--Line 16: Where is 1983-1986 in Molo Sartorio in Table 1?

A: This information was actually missing; it was inserted before the line starting with “TER-Molo S. Teresa”. (Page 15)

--Line 19: Where is 1919 in Molo Sartorio in Table 1?

A: In order to clarify the point, the text was modified as follows: “… duty in offices close to the observation sites at Molo Sartorio (in 1899-1908) and at Molo Santa Teresa (in 1915-1917 and, probably, in 1920), thus …”. (Page 4, lines 24-25)

--Line 25: “2.3 Data set B (1986-2015)”: Is this all in just the last row of Table 1? If so, how is Data set A going to 2008? (can’t find this in Table 1).

A: The line starting with “LID-Porto Lido” was corrected. (Page 15)

--Line 27: “In 1992” What about 1989-1992?

A: The text was modified to clarify that there was an interruption of the observations: “Observations were interrupted until 1992, when the depth was changed …” (Page 4, line 32)

--Page 5

--Lines 3-4: How was 2-m temperature estimated from the observations at other depths? Please briefly explain in manuscript.

A: Sect. 3.1 describes the method. In particular, eq. 4 and 5 show how 2-m temperature was estimated. The sentence was completed as: "… other depths, as explained in Sect. 3.1.". (Page 5, line 10)

--Line 7: "Although the mean daily temperature range is generally within 0.5 C" What does this mean? How is "mean daily temperature range generally within 0.5 C"?

and

--Line 8: "24 hourly data" what is this? Hourly data (24 per day)? Please clarify in text. Also, what does "which can be regarded as a standard" mean? Awkwardly worded.

A: The text was unclear and the whole sentence was modified as: "Although the mean daily temperature range is generally less than 0.5 °C, a daily mean computed with few observations may be significantly differ from a mean accounting for the full daily cycle, which is well represented by 24 hourly observations." (Page 5, line 13-16)

--Page 7:

--Line 4: Is rounding occurring here to get +/- 0.25 C (0.5 C band) and +/- 0.1 C (0.2 C band)? What about using the maximum range, e.g. 0.54 and 0.23 C bands?

A: We can only provide representative errors and we believe that precisions of 0.01 °C could suggest an unrealistically high accuracy. For clarity, we changed the start of the sentence at line 4 as: "Representative errors of …". (Page 7, line 15)

--Line 9: Where is 0.18 C in Table 2? Please clarify as there are several within the 4th column.

and

--Line 13: Where are the overall errors between 0.2 and 0.4 C for data set A and 0.1 and 0.2 C for data set B in Table 2?

A: The table was redesigned and, to clarify both points, its caption was rewritten as: "Table 2: Errors on estimated mean daily temperature. σ_I is the instrumental error, σ_E is the environmental error, σ_T is the time-related error, σ_o is the observational error, n. obs. is the number of observations per day, σ is the error on the estimated daily mean. Labels a) and b) correspond to zero and non-zero uncertainties on time, respectively. When n.obs. is characterized by a range, the corresponding σ range is shown. See Sect. 3.2 for detailed explanations." (Pages 15-16)

--Line 15: "1986-2008" again, where is this for data set A in Table 1?

A: As explained in the answer to the remarks to page 4, lines 12 and 25, this was corrected. (Page 15)

Technical Corrections

Abstract

--Line 8: "The measurements compose two data set": suggest changing to "The measurements are comprised of two data sets"

A: We corrected using "consist of" instead of the suggested "are comprised of". (Page 1, line 8)

Short Summary

-"We described" should be "We describe"

and

-"variability on different time scale" should be "variability on different time scales"

A: Both corrections will have to be made online.

1. Introduction

--Page 1

--Line 15: should be "Knowledge of the processes and evolution of the Earth system…"

A: Corrected. (Page 1, line 15)

--Line 16: "earth's" should be "Earth's"

A: Corrected. (Page 1, line 16)

--Line 17: "the scientific community, and civil society"

A: Corrected. (Page 1, line 17)

--Lines 20-21: "a key element in climate studies, based on **both** data analysis and model reconstructions, and **thus** the sustainability of suitable observing systems is critical"

A: Corrected. (Page 1, lines 20-21)

--Page 2

--Line 3: "February **to** 25…" (not **and**)

A: Corrected. (Page 2, line 3)

2. Data description

--Line 28: "Figure 2 shows the chart for 1-8 July 1935" should this be "Figure 3"? If so, will likely want to change order of figures so they are referenced in order.

A: We are sorry for the mistake. The text was correct, while Figures 2 and 3 at the end of the manuscript were swapped and identified by wrong numbers. The mistake was corrected. (Pages 12-13)

--Line 32: "linear vertical scale corresponding to 1.5 mm C^{-1}" is this at 15 C like the first thermograph which had a vertical scale of 2.1 mm C^{-1} at 15 C? If so, please indicate.

A: The indication "at 15 °C" was required for the first instrument which has a non-linear scale (line 28), while it is redundant for the second instrument, having a linear scale. The text was not modified.

--Page 3

--Line 3: "to a range of astronomical tide"

A: Corrected. (Page 3, line 5)

--Line 15: "better; nevertheless" (change comma to semicolon)

A: Corrected. (Page 3, line 18)

--Line 16: "which is strongly influenced by atmospheric forcing" (delete "the")

A: Corrected. (Page 3, line 19)

--Line 21: "2.2 Data set A (1899-2008)" where is 2008 in Table 1?

A: The table was corrected (see previous answers to remarks to page 4, lines 12 and 25).

--Line 24: "The sheet for 1916 is shown in Fig. 2" (not Fig. 3—see Line 28 comment above, may want to switch Figures 2 and 3)

A: See previous answer to remark to page 2, line 28.

--Line 25: "1909-1914, **and** 1918-1919 are missing"

A: Corrected. (Page 3, line 28)

--Page 4

--Line 7: "failure;" change comma to semicolon

A: Corrected. (Page 4, line 11)

--Line 16: What are 1295 and 299 indicating?

A: They are the numbers of data used for comparisons. In order to avoid confusion, we rephrased the text in brackets as: "using 1295 'surface' observations in 1964-1968" and "using 299 observations at 2-m depth in 1983-1986". (Page 4, line 20)

--Line 23: "but this was not **always the case**"

A: The sentence was rephrased as suggested (Page 4, line 28)

--Line 24: "These analogue records were reported to 0.1 C precision, **and** occasionally **to** 0.05 C"

A: Corrected. (Page 4, line 29)

--Line 33: "reported to 0.01 C precision." (remove "the")

A: Corrected. (Page 5, line 6)

3. The time series at 2-m depth

--Page 6

--Line 1: "the daily means are possibly estimated" "possibly" is awkwardly worded, please change

A: The text was modified as follows: "… the daily means are estimated from data at other depths when possible.". (Page 6, line 10)

--Line 9: "These corrections concern estimates" "concern" is awkward, perhaps use "affect"?

A: We replaced "concern" with "are associated to". (Page 6, lines 19-20)

--Line 17: "computed from those on the observation" is awkwardly worded, please change. Also, why do you need "respectively" here?

A: The text was rephrased as follows: "The error on T, namely σ, is computed from the errors on the observation, σ_o, and on the climatologies, σ_{24C} and σ_C. These errors are assessed semi-empirically as follows." (Page 6, lines 27-28)

--Line 19: "An observation is affected by" (delete "basically")

A: Corrected. (Page 6, line 29)

--Line 21: "the curve thickness determine a reading error" (delete "probably")

A: Corrected. (Page 7, line 1)

--Line 23: "due to turbulence and circulation. Therefore…"

A: Corrected. (Page 7, line 3)

--Line 24: "representative of the hourly value" (delete "really")

A: Corrected. (Page 7, line 4)

--Line 27: change to "only nominal times, and not the actual observation times, are reported."

A: Corrected. (Page 7, line 7)

--Line 28: "This time uncertainty **affects** temperature…"

A: Corrected. (Page 7, line 8)

--Line 29: "the time uncertainty until 1917" should this be 1919 or 1934 based on section 2.2?

A: As stated at page 3, line 25 (original manuscript) data for 1918-1919 are missing. Uncertainty is negligible until 1917 and sometimes non-negligible from 1920 onwards. The text seems clear enough and it was not modified.

--Page 7

--Line 1: “half an hour; therefore” (change comma to semicolon)

A: Corrected. (Page 7, line 12)

--Line 15: “by comparing **the data sets**”

A: Corrected. (Page 7, line 26)

--Line 23: “as discussed **in the above paragraph**”?

A: No, it is discussed a few lines above. In order to avoid confusion, we modified the sentence as follows: “… increased by 0.5 °C on the basis of the above-mentioned temperature difference.” (Page 8, lines 4-5)

4. Data availability

--Line 25: “as **a** percentage of valid days” also, valid is awkward, maybe use “total days”?

A: The text was modified as follows: “Figure 4 illustrates the monthly data availability as the percentage of the number of days with temperature estimate to the number of days per month.” (Page 8, lines 9-11)

--Line 26: what is meant by 80% valid days here? Same question for “valid months”?

A: Although “valid” is often used to indicate that the day or month is non-missing, we rephrased the relevant sentence as follows: “Mean annual temperatures were computed for complete years, i.e. having no missing months; a missing month has less than 80% available days (Fig. 5).” (Page 8, lines 11-12)

--Line 27: better word for arbitrarily? Seems very unofficial. Also, remove the repeat “Figure 4 illustrates…” sentence.

A: We do not think that another word would be better. To the authors’ knowledge no official or standard percentages are generally adopted to define a monthly mean estimate reliable. It depends on the dominant time scales of variability of the specific variable. We chose 80% because it is a high percentage (corresponding to less than one week missing in a month) although not necessarily optimal. As an example, to compute reliable monthly mean sea levels, the Permanent Service for Mean Sea Level adopts 50%. The repetition was removed.

--Page 8

--Line 2: "in the first part **of the period**"?

A: We used "of the time series". (Page 8, line 16)

5. Conclusive remarks

--Line 8: "Near-surface sea temperature data" (remove the "s" in temperatures)

A: Corrected. (Page 8, line 22)

--Line 9: "from 1899 to 2008, **while** the second consists…"

A: Corrected. (Page 8, line 23)

--Lines 12-13: "study sea-temperature variability **on** the synoptic time scale connected to meteorological forcing, and on decadal and secular time scales related to climate changes." Also, what is meant by "secular time scales"?

A: There are other time scales between the synoptic and decadal ones as, for instance, those connected to atmospheric planetary waves (10-100 days), the seasonal cycle (1 year), and those connected to the variability of large-scale atmospheric patterns like ENSO (few years). We modified the sentence as follows: "… study sea-temperature variability on time scales from the synoptic, connected to the meteorological forcing, to decadal and century-timescales related to climate changes". (Page 8, lines 26-27)

--Line 14: "The search for undiscovered data will continue**, in order** to possibly fill the existing gaps."

A: Corrected. (Page 8, line 28)

Author contribution

--Line 16: "the data sets and **led**"

A: Corrected. (Page 9, line 2)

--Line 17: "and collaborated **on** the paper writing"

A: Corrected. (Page 9, line 3)

Figures

Figures 2 and 3: these are somewhat difficult to read, may want to ensure very high quality images of these are included so readers can clearly read them.

A: We checked that the original 300-dpi pdf images can be magnified at least to 3 times the original size without loss of definition.

Figure 5: Can you add the 1946-2015 trend line on this figure? Also, should the caption read "from 1899 to 2015"?

A: Corrected accordingly. (Page 14)

Tables

Table 1: several comments as indicated above

A: The table was redesigned. (Page 15)

Table 2:

--Line 5: "number of observation**s**". "instrumental **error**"

and

--What are the 1st and 2nd numbers before and after the semicolons, e.g. 0.18; 0.31? Finally, can you somehow indicate that the errors are ½ the band (e.g. +/- 0.15 C)?

A: The table was redesigned and the caption rewritten. Concerning the errors, they are always ½ the band (see sect. 3.2), therefore there should not be any confusion. (Pages 15-16)

Answers to Reviewer #2 (pages and lines of the marked-up manuscript, above, unless otherwise stated)

It seems that the paper could gain in relevance if two points would be added.

I.

There is no comparison with the trend of (surface) sea temperatures of either coastal, nor ‘global’ ocean sea surface temperature data. This ‘global warming trend’ is a hot topic, relevant nowadays. Authors confined themselves mostly to the methodology of ‘combining’ the data of different measurements techniques, of different sea temperature ‘sampling’, on elaborating the time series (filtering the data) and on the trend of sea temperature rise that they reveal from those data. There are certainly many research papers that describe centennially temperature trends elsewhere. Moreover, there are reports of IPCC (although quality reports are lately blurred with reports of IPCC meetings…) that still somehow ‘matter’, e.g. the IPCC Report ‘Global warming of 1.5°C’, in Chapter 1: [Allen, M.R., et al., 2018: *Framing and Context. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, et al. (eds.)]. In Press.]. There one may find a few ‘useful sentences’ already at the beginning, e.g.: ‘Human-induced warming reached approximately 1°C (likely between 0.8°C and 1.2°C) above pre-industrial levels in 2017, increasing at 0.2°C (likely between 0.1°C and 0.3°C) per decade (high confidence)’, and also ‘Accordingly, warming from preindustrial levels to the decade 2006–2015 is assessed to be 0.87°C 2 (likely between 0.75°C and 0.99°C).’ These sentences are just very modest examples about how the result (the temperature trend in the ‘intestines’ of the central middle Europe, facing the sea) of authors makes sense and is ‘in line’ with the trends others have found. There are also differences (e.g. in the trend within last 30 years) with other findings, which would well be described in Discussion. In the Introduction, though, the relevance of this particular, long time series has to be emphasized and compared with other very long term studies.

II. The second topic for which it seems just to be linked to the paper, is the matter of the sea-level rise. A brief look on publications of authors clearly shows that at least one of them has a solid reputation in ’knowing this matter well’. Authors may relatively easily combine their sea temperature rise finding with the sea level rise simply due to steric effect – they can estimate it and may also estimate the error of the estimation (they showed how nicely they know how to estimate errors…) of sea level rise due to temperature expansion of water (e.g. the effect of salinity (variability)). There is quite a large number of papers over the Adriatic and the Mediterranean Sea that handle separately the sea level rise and the temperature rise, but only a few link these two trends. This is a good chance ‘to do it right’!

Answer (to both I and II): We did not extend the paper because in the journal's website (www.earth-system-science-data.net/about/aims_and_scope.html) it is written that "Any interpretation of data is outside the scope of regular articles.". The comparison of the trends obtained for different locations and from the global ocean requires data interpretation. The connection of sea-temperature rise with sea-level rise is a subject deserving a paper on its own. That is why we did not include in the article anything but the data description and the time series homogenization. We think that the text should not be extended the include the reviewer's suggestions.

Specific comments

Page, 1. Line 16: is the text in this line in 'bold'?
A: This question is unclear. However, from the pdf version it does not seem so.

Page 3, line 24: Fig. 3 is referred. Should it be the Fig. 2? There was no Fig. 2 before in the text and it looks from Figure and figure caption of Fig. 2 that this should be Fig. 2.
A: We are sorry for the mistake. Figures 2 and 3 at the end of the manuscript were swapped and identified by the wrong number. The mistake was corrected. (Pages 12-13)

Page 5, line 13: $T_0(h,d,m,y,z) \rightarrow T_0(h,d,m,y,z)$
A: This remark is unclear.

Page 5, line 18: '…between 13 and 17 values of T_0.' Could it be added 'out of (?) 24 × 365.25' on average per year?
A: In equation 1 it is clearly written that $T_c(h,d,m,z)$ is the ratio of two sums over y from 1999 to 2015, i.e. 17 elements, while '24 x 365.25' is the average number of hours per year, which is not involved. The text was not modified as it seems clear enough.

Page 5, expression (3): In the expression (2) T_{24c} is written down. However, it somehow follows from the expression (3) and the comment below it that T_{24c} should be expressed as the average of N values od T_c the number of available observations on the relevant day, and not the average of '24' values (expression (2)). Correct?
A: No. The text at page 5, lines 11-12 reads "obtained by averaging hourly (0-23) temperatures and mean daily temperatures of days when all the 24 hourly observations were available". Therefore, 24 values are always available for the average.

Page 6, expression (5): It looks OK…
A: This remark is very unclear.

Page 7, line 9: ‘observational error $\sigma_{0}=0.18\ °C$, we obtain $\sigma_{c}=0.05\ °C$ and $\sigma_{24c}=0.01\ °C$‘ → observational error σ_0=0.18 °C, we obtain σ_c=0.05 °C and σ_{24c}=0.01 °C.

A: If we understand it correctly, the reviewer suggests to remove italics for numbers. It has been corrected. (Page 7, line 20)

Page 7, line 23: ‘…was increased by 0.5 °C, as discussed above.’. Do authors refer to the line 18 in which $\Delta T = 0.5 \pm 0.5\ °C$ is written? If so, then they could write this more clearly and on line 18: $\Delta T = 0.5 \pm 0.5\ °C$ → ↳T = 0.5 ± 0.5 °C. The same for another ΔTin the same line.

A: In order to avoid confusion, we modified the sentence as follows: “… increased by 0.5 °C on the basis of the above-mentioned temperature difference.” Also in this case we removed italics from numbers. (Page 7, lines 29-30)

Page 7, line 27: there is a redundant copy of the sentence about Figure 4 from the line 25….

A: The repeated text was removed. (Page 8, line 12)