Time variability of atmospheric and marine parameters over the Adriatic region

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Summary. — The time evolution of atmospheric and marine parameters over the Adriatic region is studied for the period 1946-1996 on different time-scales. On the interannual and interdecadal time-scales evidence is found of the inverted barometer effect on sea level and the strong connection between air and sea temperatures. By contrast, opposite relationships are found on longer (secular) time-scales, which might be explained as different results of global climatic fluctuations on the atmospheric and marine parameters involved. On the interannual time-scale a correlation is found between sea-level pressure gradient along the basin and the water inflow/outflow through the Otranto Channel, in terms of sea level and sea temperature.

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1. – Introduction

The Adriatic Sea is a semi-enclosed marginal basin of the Mediterranean Sea (fig. 1). It is exposed to the influence of air masses of different origins and, as a consequence, exhibits remarkable variability, both in space and time. In the past, time series of atmospheric and marine parameters observed in the Adriatic region were studied in conjunction mainly to describe and interpret notable events occurring on daily time-scales, as is the case of storm-surges and seiches [1-3], and to model surface fluxes on monthly time-scale [4] and climatological time-scale [5, 6]. A study on a multi-year climatic anomaly is reported in [7].

The study of climate variability on different time-scales is an important tool to understand the climate system as a whole, as specific experiments have demonstrated (*e.g.*, TOGA, Tropical Ocean Global Atmosphere). The Mediterranean region has proven to be a natural laboratory for climate studies [8, 9], but the availability of continuous marine data with high time resolution is usually limited to the last few decades and to few areas. For historical reasons, the time series of atmospheric and

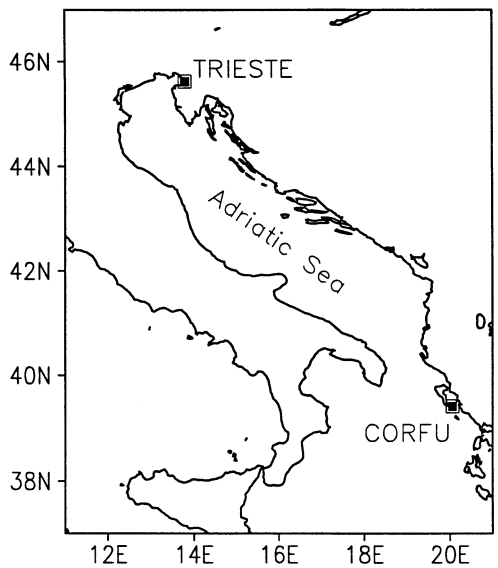

Fig. 1. – Map of the area of interest.

marine data for the Adriatic region are longer and more detailed than for most of the remainder of the Mediterranean basin. Therefore, the Adriatic represents a region suitable for studying the long-term evolution of coupled air and sea parameters on various time scales.

In this paper we aim to analyse selected atmospheric and marine parameters on interannual to decadal time-scales, with emphasis on their interrelations, in the period 1946-1996. The following parameters are examined: atmospheric pressure at sea-level (SLP), sea-level elevation (SL), air temperature (AT) and sea temperature (ST), all of which observed at Trieste; difference of pressure at sea level between Corfu and Trieste (SLPD) and modulus of this difference (MPD). SLPD is related to the mean pressure gradient along the longitudinal axis of the Adriatic Sea, and is related to the mean geostrophic wind field across the basin. The choice of Trieste as the main observation site is justified by the fact that all time-series are uninterrupted and homogeneous, and that the data represent the Adriatic area where air-sea interactions are most relevant.

2. – Data and methods

All data observed at Trieste are archived at the Istituto Talassografico: SLP, AT and ST are also published in [10-13]; SL data is published in [11] and can also be found in the Permanent Service for Mean Sea Level data bank [14]. Corfu SLP is taken from [15] and covers the period 1951-1996 only.

Figure 2 shows the time series of the parameters under study. A time series consists of anomalies for periods of 12 consecutive months, with 1-month time-step, computed from individual monthly anomalies; an anomaly is defined as the difference between the observed value and the mean, for that month, in the entire period examined. In this way the mean annual cycle is removed. In order to discriminate the short-period (interannual) and long-period (interdecadal) fluctuations, the time-series are filtered by means of the technique described in [16, 17]. The separation between short- and long-period fluctuations is set at about 11 years. The long-period time series are shown in fig. 2 as dashed lines.

The relative weights of the components are reported in table I as percentages of total variance (the long-period component is furtherly decomposed as explained in sect. 4). It can be seen that for all the parameters most of the variance is related to interannual variability, namely about 2/3 for SLP and SL, 3/4 for AT and ST, up to almost 9/10 for SLPD and MPD.

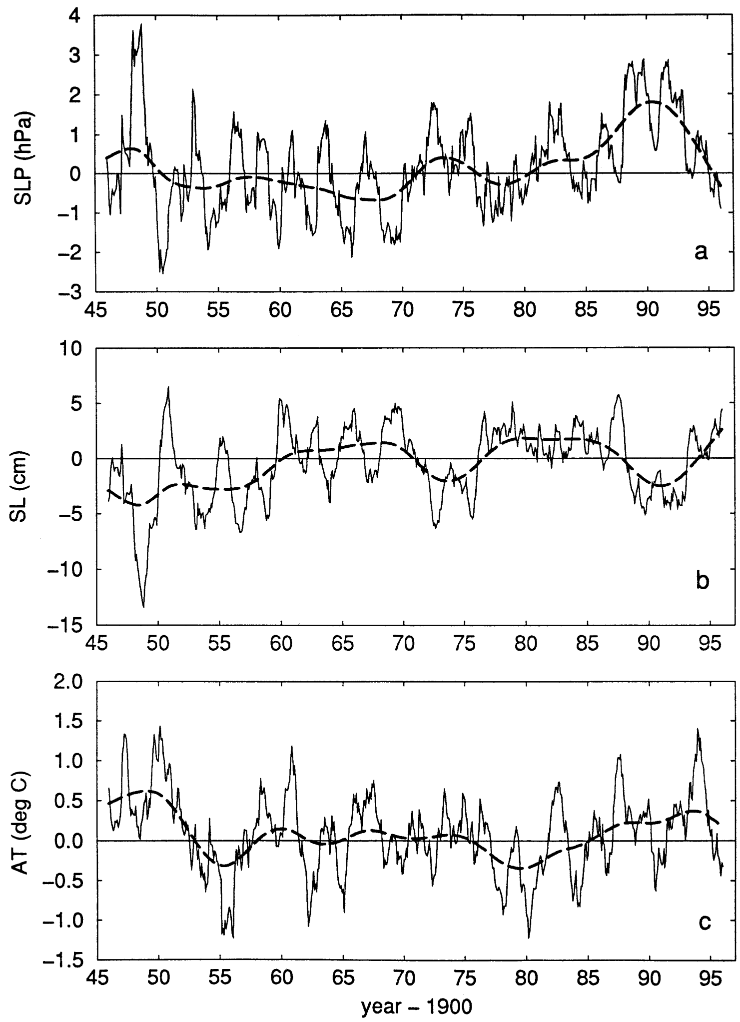

Fig. 2. – Time-series of 12-month anomalies relative to the mean (m) over the period under study. a) SLP, $m = 1017.66$ hPa, b) SL, $m = 160.80$ cm, c) AT, $m = 14.22\,°C$. See text for symbol explanation.

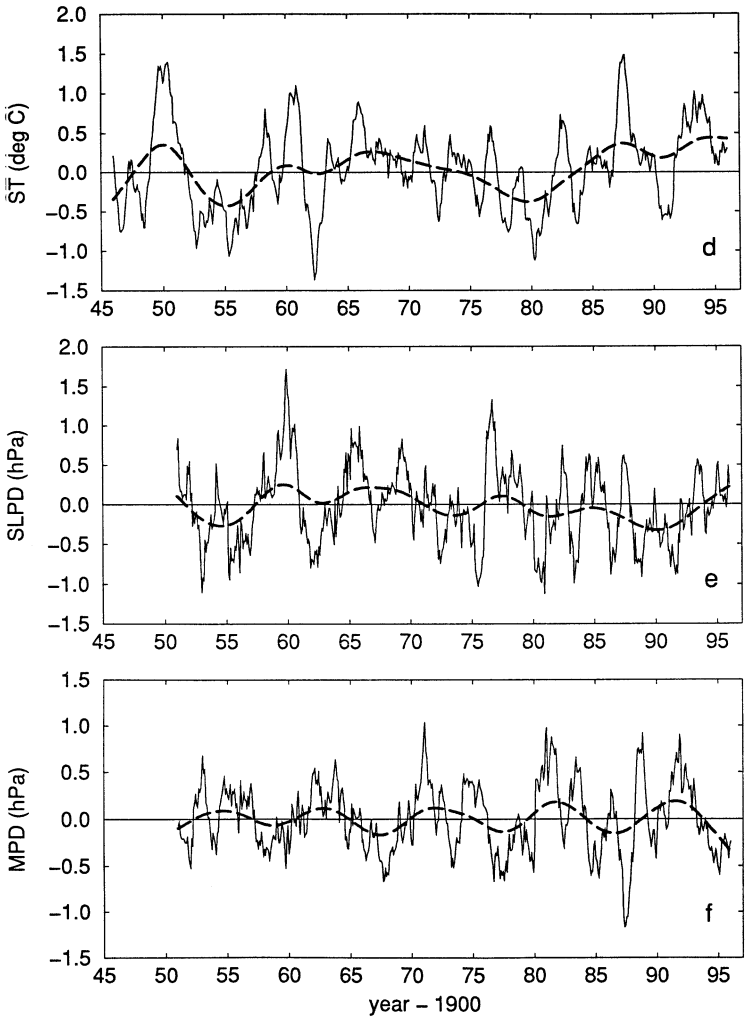

Fig. 2. – Time-series of 12-month anomalies relative to the mean (m) over the period under study. d) ST, $m = 15.67\,°\mathrm{C}$, e) SLPD, $m = -2.77$ hPa and f) MPD, $m = 1.75$ hPa. See text for symbol explanation.

3. – Short-period variability

Interannual variability is represented by a time-series obtained as the difference between the original time-series (fig. 2, solid line) and the long-period component (fig. 2, dashed line). In order to compare different parameters, each interannual time-series is standardized by removing the mean over the period under study and dividing the result by the standard deviation.

The scatter plots of fig. 3-5 illustrate examples of correlation between pairs of physically linked parameters. For practical purposes three correlation ranges are identified: The correlation is defined "high" when the modulus of the correlation

TABLE I. – *Percentages of total variance for each component of the time series studied in this work.*

Parameter	Interannual	Interdecadal	Linear trend
SLP	65.7	24.3	10.1
SL	64.4	25.9	9.8
AT	72.5	27.0	0.6
ST	75.6	21.3	3.1
SLPD	87.5	11.3	1.2
MPD	90.0	10.0	< 0.1

coefficient (r) is larger than 0.7 (fig. 3), "medium" when $r \sim 0.5$-0.6 (fig. 4) and "low" when $r \sim 0.3$-0.4 (fig. 5). Despite the large number of data pairs used in the computation of the correlation coefficients, namely 541 (time series starting in 1951) or 601 (time series starting in 1946), their statistical significance is difficult to assess, because the autocorrelation in the original time-series reduces the effective number of degrees of freedom, although most of the autocorrelation is included in the long-period component and therefore removed from the interannual component. However, here the correlation coefficient is not used as a rigorous statistical parameter, but rather as an index of similarity between two time-series.

High correlations are obtained from the SLP-SL pair ($r = -0.80$, fig. 3a) and AT-ST pair ($r = 0.80$, fig. 3b). The first is a consequence of the inverted barometer effect, and the second is due to the fast response to air temperature fluctuations, since the Northern Adriatic basin is very shallow (less than 30 m depth).

Medium correlations involve SLPD. According to the definition given in sect. **1**, a positive SLPD anomaly corresponds to relatively high SLP to the South and/or low SLP to the North; it enhances the water inflow from the Ionian Sea and limits the outflow, implying higher SL in the northern basin ($r = 0.60$, fig. 4a), due to the inverted barometer effect, and a ST increase ($r = 0.52$, fig. 4b), since on average the Ionian waters are warmer. A negative SLPD anomaly (relatively low SLP to the South and/or high SLP to the North) is related to a positive MPD anomaly ($r = -0.56$, fig. 4c), that is a stronger wind across the basin. This fact is consistent with the observation that,

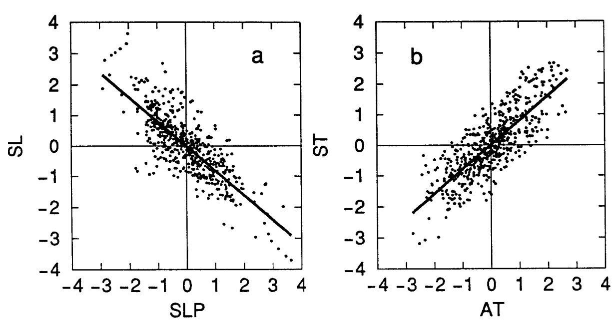

Fig. 3. – Scatter plot of standardized interannual components. a) SLP-SL, $r = -0.80$; b) AT-ST, $r = 0.80$.

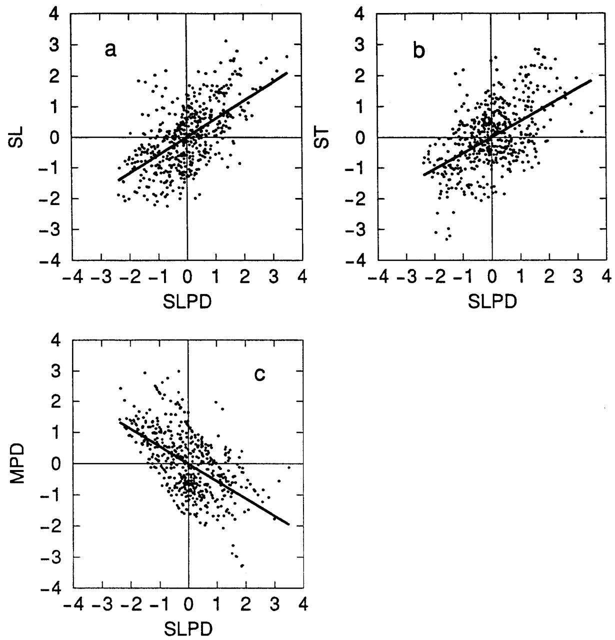

Fig. 4. – As fig. 3, but: a) SLPD-SL, $r = 0.60$; b) SLPD-ST, $r = 0.52$; c) SLPD-MPD, $r = -0.56$.

at Trieste, winds blowing from East or North-East exhibit higher speed than southerly and westerly winds.

Low correlations are found for the MPD-ST pair ($r = -0.33$, fig. 5a) and the SL-ST pair ($r = 0.32$, fig. 5b). The first is a true correlation, which can be ascribed to the wind-induced cooling of the sea surface mainly via latent heat loss. Concerning the second correlation, a direct relationship between SL and ST would be consistent with the fact that higher ST implies a thermal expansion of sea water and therefore a SL increase. Instead, we would rather interpret it as a spurious correlation for the following reasons: a) it could be an indirect consequence of the stronger SLPD-SL and

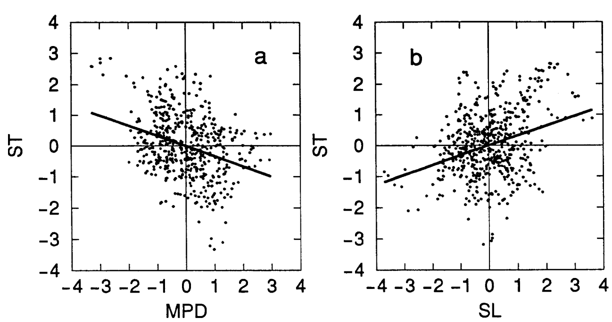

Fig. 5. – As fig. 3, but: a) SLPD-ST, $r = -0.33$; b) SL-ST, $r = 0.32$.

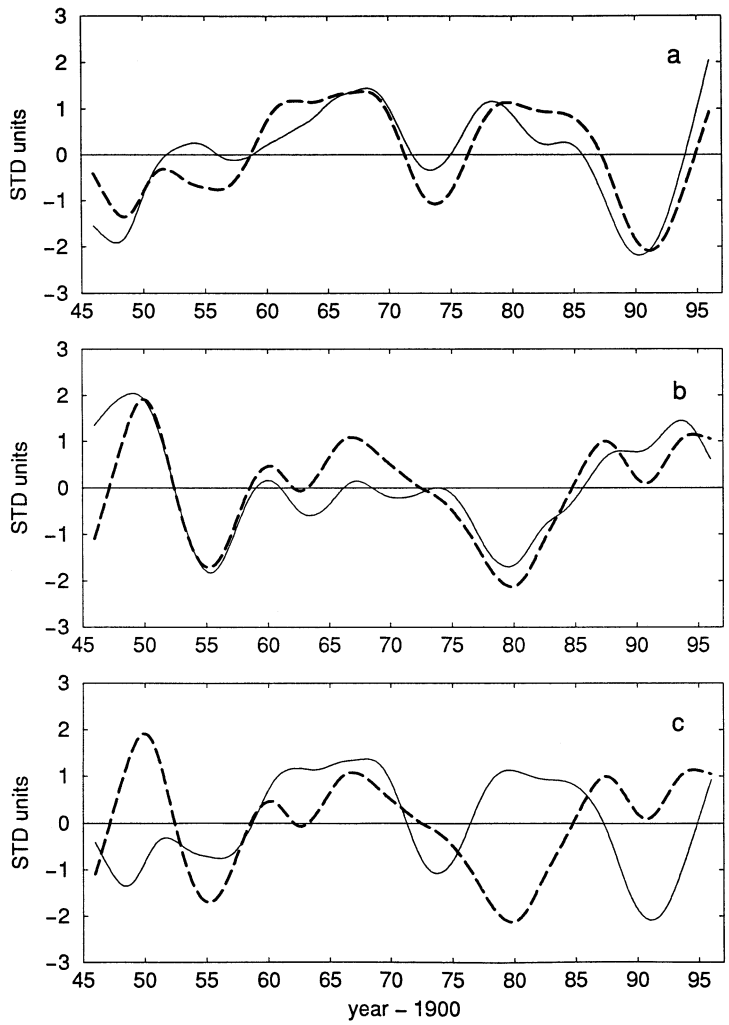

Fig. 6. – Comparisons between standardized interdecadal components. a) SLP (reversed, solid line) *vs.* SL (dashed line); b) AT (solid) *vs.* ST (dashed); c) SL (solid) *vs.* ST (dashed).

SLPD-ST correlations outlined above; b) moreover, on the interannual time-scale SL changes are strongly related to local atmospheric forcing, as we saw in the relationship with SLP.

4. – Long-period variability

Figure 6 illustrates examples of long-period variability. Each time series represented by a component shown in fig. 2 as a dashed line, is furtherly decomposed into a linear trend, obtained by fitting a straight line to the time series over the period 1946-1996, and an interdecadal component, which is the difference between the time series and the linear trend. The slope of the linear trend represents an estimate of the change occurred on a "secular" time-scale. Again, the time-series are standardized for better visual comparison.

On the interdecadal time-scale the behaviours of SLP-SL and AT-ST pairs resemble those on the interannual time-scale, with common major fluctuations in both cases (fig. 6a, b). By contrast, the linear trend slopes show that a SLP increase of 1.2 hPa (over 50 years) corresponds to a SL increase too, not a decrease, of 3.4 cm, and that an AT decrease of 0.12 °C corresponds to a ST increase of 0.30 °C. Thus, on the interdecadal time-scale the mechanisms by which the atmospheric forcing (SLP and AT) prevailingly affects the marine parameters (SL and ST, respectively) appear to be approximately as effective as on the interannual time-scales, while on a secular time-scale no relationship is apparent.

A different situation is found by comparing SL and ST. On the interdecadal time-scale no common fluctuations are observed (fig. 6c), while the linear trends reveal that both parameters increase, by 0.06 °C and 0.07 cm per year, respectively.

Our interpretation of linear trend analysis is that the effect of local forcing on sea properties, namely the inverted barometer effect on sea level and air-sea heat exchange on sea temperature, is still prevailing on the interdecadal time-scale, while on longer time-scales a major role is probably played by long-term global forcing, resulting in the increase of both SL and ST, both depending on the slow redistribution of such sea properties in the global ocean. The annual SL rise of 0.07 cm, as deduced from the Trieste data used in this work, is consistent with the global estimate of 0.08 ± 0.11 cm reported in [18]. Note that no significant vertical ground displacements are reported for Trieste area over the period under study [19].

Clearly, the linear trends computed in this work strictly depend on the analysed period (1946-1996) and can be very different for other time intervals; here they are just used to compare the secular evolutions of paired atmospheric and marine parameters.

5. – Conclusions

The time evolution of selected atmospheric and marine parameters observed in the Adriatic region is studied on interannual, interdecadal and secular time-scales.

On the interannual and interdecadal time-scales, we recognize close relationships between SLP and SL, due to the inverted barometer effect, and between AT and ST, as a consequence of air-sea heat exchange. On the interannual time-scale the SLPD along the Adriatic Sea is found to be related to fluctuations in SL and ST, as a consequence of the modulation of the water inflow/outflow through the Otranto Channel.

On secular time-scales such relationships are not observed, since the atmosphere responds to global forcing much faster than the sea, which instead acts as an integrator. According to [19], the long-period SL response to AT fluctuations is delayed by about 20-30 years; unfortunately, the period we studied is not long enough to recognize and assess such time-lag.

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