Recent Evolution of Surge-related Events in the Northern Adriatic Area

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ABSTRACT

The recent increase in the frequency of coastal flooding in Venice mainly depends on loss of land elevation (subsidence and eustasy) and man-induced hydrodynamic changes in the lagoon area, but can also be strengthened in the near future by changes in climate.

In this paper, after a short review of recent changes in the relative mean and maximal levels of the sea and their causes, the main meteorological factors (atmospheric pressure and winds of sirocco and bora), which produce sea surges in the Gulf of Venice, are identified statistically. The recent evolution of these meteorological factors in the Adriatic area shows some favorable trends (the atmospheric pressure is increasing, thus provisionally masking eustatic sea-level rise, and bora is sharply lessening). However, the effects of sirocco, which is increasing in frequency in the mid-Adriatic, seem to be prevailing.

On the whole, the frequency of sea surges ≥5 cm to ≥30 cm, which are the most frequent, is increasing in the North Adriatic and this implies more “moderately high tide levels”, which are however liable to flood the lowest parts of the city of Venice. Such increase in frequency seems related to recent climatic changes (possibly related to global warming) and may therefore be expected to worsen in the near future.

ADDITIONAL INDEX WORDS: Lagoon hydrodynamics, flooding, surges, global warming.

INTRODUCTION

Flooding by sea surges (locally called “acqua alta”, literally “high water”) is a frequent phenomenon along the low coastal areas of the northern Adriatic. In lagoon areas, coastal flooding is known to have occurred occasionally at least since the descriptions by Cassiodorus (6th c. AD), but in the city of Venice the phenomenon has much worsened during the 20th century. The worsening can be ascribed to the superposition of several causes: lowering of the elevation of the land in relation to the sea (BONDESAN et al., 1995); changes in the propagation of the sea (tide and surges) inside lagoon basins (PIRAZZOLI, 1987, 1991); and possible changes in the climatic factors which tend to produce surge events. In this paper, after a brief summary on some factors which have affected the land elevation and the lagoon hydrodynamics, a statistical study is presented of hourly surges (differences between the observed tide and the astronomical tide at the same moment) and of the recent evolution of the meteorological factors which contribute to surge development and to “acqua alta” occurrences.

CHANGES IN LAND ELEVATION AND IN LAGOON HYDRODYNAMICS

In the city of Venice the ground level is today very close to sea level. Compared to the astronomical tidal range, that may reach about one meter at spring tide, and to storm surges, which exceed a height of one meter once every five years on average, the lowest point of the city (in St. Mark’s Square, just outside the basilica) is now only 40 cm above the present MSL (which is today about 23 cm above the local Datum). This means that all surges in the Adriatic, even moderate, may produce some flooding. At street level, about 30% of the city is lower than the elevation of 120 cm (above Datum), which is reached by sea level (tide plus surge) 1.3 times per year on average. This makes that each centimeter of elevation is precious. All the events with tide level ≥110 cm are officially considered “acqua alta”.

Regular tide-gauge records are available in Venice since 1872 (DORIGO, 1961; PIRAZZOLI, 1982) and in Trieste (at the northern end of the Adriatic, Figure 1) since 1890 (MOSSETTI, 1961). In Figure 2 the MSL evolution in the two stations is compared. A 19-year running mean has been used to filter the effects of the astronomical cycles of lunar declination (18.6 years), Saros (18 years and 11 days) and Meton (about 19 years). It can be observed that the 19-yr curves of Venice
and Trieste are almost parallel until the first half of the 1920s and then again from the second half of the 1960s. The difference in level that gradually increases between Trieste and Venice, reaching about 10 cm in the late 1960s, is ascribed mostly to land subsidence in the Venice area, caused by excessive pumping of ground water, especially in the industrial zone of Marghera (Carbone et al., 1976). Significant land sinking phenomena, due to methane extraction, occur in other coastal areas of the northern Adriatic (Battisti et al., 2000), resulting in extensive lowlands below MSL (Boninsegna et al., 1995).

From the tide-gauge records of the period 1872–2000, it appears that the total loss in elevation of Venice has been about 25 cm from 1881 to 1991 (with a mean running over 19 years, the first and the last 9 years of the series are lost in averaging operations), of which about 10 cm can be ascribed to man-induced land subsidence and about 15 cm (at Venice and Trieste) to eustasy and regional tectonics. It has also been observed that during the last three decades MSL remained on average almost stable in both Trieste and Venice. This is in contrast not only with the gradual sea-level rise of the preceding decades, but also with the presently expected global sea-level rise.

The recent apparent sea-level stability at Trieste and Venice may be short-lived however. Tsimpis and Baker (2000) have suggested that a recent sea-level decrease in Mediterranean stations may be the result of increases in temperature and salinity of Mediterranean Deep Water. However, since the northern Adriatic Sea is not deep (less than 50 m) other causes for the recent interruption in the sea-level rise should be advocated. It will be shown below (Figure 12) that there has been in the Adriatic area an increase in the average surface atmospheric pressure of about 2 hPa during the second part of the 20th century and that most of this increase occurred since the 1960s. The hydrostatic effect of such an increase in pressure was
to depress sea level about 2 cm, thus explaining the recent apparent sea-level stability.

In Figure 3 the maximal annual sea-level heights recorded in Venice from 1872 to 2000 are considered. Though single values leave an impression of dispersion, the 19-yr running mean enables to distinguish significant evolution trends. The overall increase of the maximal annual tide levels from the end of the 19th century to the middle of the 1970s has amounted to about 39 cm, i.e. 14 cm more than the corresponding MSL rise (Figure 2). This difference can be ascribed to the increased easiness with which the highest Adriatic storm surges could enter and propagate into the lagoon, following a deepening of the lagoon inlets and of the main navigation channels (for a summary of some of these works, see Pirazzoli, 1987). Since the middle of the 1970s the situation has slightly improved, though the increase of extreme tide levels (about 33 cm) remains much larger than the MSL rise.

Correlation between periods of deepening and of major works and the worsening of flooding has been confirmed by several authors. For example, this point can be verified intuitively from the evolution of the differences in level between the maximal annual tide levels recorded at Diga Sud Lido (DSL), at the end of a jetty, just outside the lagoon, and the ones in Venice at Punta della Salute (PDS) (Figure 4). These had already been analysed previously (Pirazzoli, 1970, 1991).

They are here updated and corrected for 3-cm subsidence since 1969 at DSL that was revealed by a comparison of MSLs at the two stations (Canestrelli and Pirazzoli, 1999) and plotted in Figure 5, together with their 7-yr and 19-yr running means. The two series of extreme events are compiled separately and are therefore statistically independent, though in many cases they correspond to the same events. It can be seen that the differences decrease i.e. surges penetrate more easily inside the lagoon) in the 1930s (after the creation of a new industrial harbor at Marghera) and in the 1950s (new deepening of navigation channels after the last world war), whereas they increase (i.e. the surge crest is partially cut in the inlet area by the interruption of maintenance dredging) around the second world-wartime period and since the middle of the 1970s, after the removal of the oil traffic from the Lido inlet. On the whole, it can be said, in spite of some missing data, that still in the 1960s, till' maximal tide levels were on average 5 cm higher in Venice than at DSL, while they are now some 3 cm higher at DSL. This change is probably due to the hydrodynamic resistance offered by some new sand banks, which have formed in some areas of the Lido inlet, thus contributing by about 8 cm to lower surge levels in Venice in relation to DSL.

Recently, a mathematical model of the lagoon (Umgässer, 1999) has demonstrated that the morphology of the inlets is essential to control the propagation of storm surges inside the
It is therefore possible to estimate, from a comparison between Figures 2 and 3, that the morphological changes which have affected the lagoon of Venice after 1872 have caused an increase in flooding levels, which is at present still about 8 cm, but after a maximum of 14 cm in the 1970s. Such increase is of the same order of that caused by subsidence due to groundwater exploitation (about 10 cm) or to eustasy and regional tectonics (about 15 cm).

**Figure 3.** Maximal annual heights recorded in Venice from 1872 to 2000 and running means over 7 and 19 years.

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**SURGES**

In spite of the recent loss in altimetric elevation, a spring high tide is still usually unable to cause extensive flooding in Venice. A sea surge of meteorological origin will also add its effects to the astronomical tide. However, important surges may occur also at low tide and in this case their effects are much reduced. Nevertheless, at any tide level, surges result
from a limited set of meteorological factors which are more frequent than flooding events. The study of their evolution may therefore provide useful indications not only on present-day climate changes but also on foreseeable evolution of "acqua alta" occurrences. It should also be noted that if in the open sea surge amount and frequency depend mostly on meteorological and hydrological conditions, inside a lagoon they depend also on hydrodynamic resistance, especially in the inlets, which, as discussed above, may slow the tide propagation and contribute to lower their height.

Tide-gauge data used here are hourly records digitized at Punta della Salute (1940–2000), Trieste (1939–2000) and Diga Sud Lido (1968–2000). In order to make possible a comparison of surges from different years, inter-annual changes in sea level (which may vary from one station to another) have been taken into account by subtracting the local yearly MSL from the data of each station.


Out of over half a million hourly tide data available at Punta della Salute between March 1940 and December 2000, observed tide was identical to the astronomical tide (with ±1 cm accuracy) only for 3.4% of observations and missing data (in the sense that they are not available to the authors) are of the same order. In 225,173 cases the tide has been higher than the astronomical tide and in 269,324 cases lower, but in about 70% of the cases the deviation has been less than ±5 cm. The distribution (at 5 cm intervals) of all positive and negative surges is summarized in Figure 6. For deviations smaller than 10 cm, negative surges are more frequent than positive ones, whereas for greater (absolute) values, positive surges clearly predominate and may reach heights more than twice those of negative surges. For example, there are 9 occurrences of negative surges ≤ −65 cm, but 732 occurrences with positive surges ≥ +65 cm, 8 of which are ≥ +130 cm.

**METEOROLOGICAL CAUSES OF SURGES**

It is well known that the main meteorological factors involved in coastal surges are air pressure and wind. In marginal basins, significant contributions can also be due to rainfall and river down-flow. Air pressure changes cause a "static" response of the sea, which reacts as an inverted barometer, with about 1 cm rise corresponding to a pressure
Differences in level between the highest annual tide levels recorded at Diga Sud Lido (DSL) and the ones at Venice (Punta della Salute), from 1924 to 2000

Figure 5. Evolution since 1924 of differences in extreme sea levels between the sea (DSL) and the lagoon (PDS).

Decay of 1 hPa. Such a correlation, generally well established on the open sea, becomes however approximate near the coast, owing to hydrodynamic effects depending on the coastal topography, which may strengthen or attenuate the "static" response. To simplify, when air pressure is <1013

hPa (mean world value at sea level), the sea surface rises (surge) and when it is ~1013 hPa, it tends to fall (negative surge).

Wind is also an important parameter that causes piling up of water at the coast. Its effects, which added to those of the pressure, depend on three parameters: the direction from which the wind is blowing (which may push the water towards the coast); its velocity (which amplifies the effect); and its lasting, which controls how long the phenomenon will occur and may cause basin-scale oscillations of sea level.

The impact of a surge on the coast will depend on the tide level at the moment of the surge peak and impacts will be at a maximum for surges occurring at spring high tide, whereas significant surges may escape notice when they occur at lower tide levels. PIGOT and VASSIE (1979) have shown that surges and tides are statistically independent. It is possible to calculate their probabilities and trends separately using hourly tide records.

Figure 7 shows that at the time of the highest surges at PDS, atmospheric pressure is usually at a minimum over the northern Adriatic.

Wind distribution in the Venice area, as deduced from the Tessera three-hourly data, shows a higher frequency from the first (bora), then from the second (sirocco) quadrant (Figure 8). It can be observed that during the 24 hours preceding a surge of at least 80 cm at PDS (219 cases observed, to which
Figure 7. Atmospheric pressure in various Adriatic stations at the time of surges at PDS greater or equal to 100 cm (A), 80 cm (B), and 50 cm (C).
correspond 97 occurrences with observed tide ≥110 cm), wind from 20°–70° angle (bora) is clearly predominant, whereas wind from SE (110°–150°) only starts to be present a few hours before the surge peak. In other Adriatic areas more to the S, sirocco is everywhere predominant (Figure 9) at the time of surges in Venice. More locally, if observations during the hours immediately preceding the surges are considered, prevailing directions are from 110°–220° at Rimini, 120°–180° at Falconara, 130–200° at Termoli, 120°–200° at Bari and 130°–180° at Leuca. For lesser surges the wind distribution remains essentially the same, with however a slight leveling of the peaks in the graphics.

Sirocco, and to a less degree bora, are determining factors for surge development in the Gulf of Venice. Bora, generally strong and persistent, tends to displace northern Adriatic water towards the lagoon of Venice with a fetch of about 110 km. According to a numerical model proposed by Štravisić (1977), a stationary wind of 10 m/s from NE will cause a sea-level fall of about 7 cm at Trieste and a rise of 5 cm out of the Chioggia inlet. According to another model, proposed by ORLIĆ et al. (1994), when bora has a stress of 0.5 N/m², differences in level in the northern Adriatic increase, with a rise of 12 centimeters outside the Venice Lagoon. However, in the absence of channeling, surges due to bora tend to move southwards along the Italian coast. Inside the lagoon of Venice, bora, which blows following the main axis of the basin, may produce differences in level of several decimeters, with falls in its northern part and rises in its southern part, near Chioggia (PIRAZZOLI, 1981; DAZZI et al., 1987; FERLA and RUSCONI, 1994; ZECCHETTO et al., 1997).

In Figure 10, bora evolution in the northern Adriatic during the 48 hours preceding surges ≥80 cm in Venice is described. At Trieste changes are limited and bora frequency (about 30% of the cases) is less than normal (45% of the cases). The situation is different at Ronchi and Tessera, where bora frequency before surges is greater than normal frequency. During the immediate hours before surges, however, it tends to reduce rapidly and to be replaced by sirocco. Twelve hours before a surge peak ≥80 cm at PDS, bora is still blowing at Tessera in 75% of the cases.

Generally less strong than bora, sirocco blows along the longitudinal axis of the Adriatic, with a fetch which can be greater than 800 km. Sirocco tends therefore to be channelled between the Apennines and the Dinaric Alps and to create surges in all the Adriatic, with maximal values in the Gulf of Venice, from where no way out is possible. According to the model by ORLIĆ et al. (1994), sirocco with a stress of 0.5 N/m² causes a surge of about 30 cm along the Venetian coast.

Sirocco is predominant in all the stations of the middle and southern Adriatic during the 48 hours preceding surges ≥80 cm in Venice (Figure 11). At Tessera, however, it is only dur-
**Wind directions on the Adriatic coast**

for sea surges $\geq 0.8$ m at Venice

![Histograms showing wind directions at various locations](image)

- **Trieste** (calms = 0%)
- **Rimini** (calms = 13%)
- **Falconara** (calms = 5%)
- **Termoli** (calms = 0%)
- **Bari** (calms = 2%)
- **Leuca** (calms = 0%)

Figure 9. Wind directions at Trieste, Rimini, Falconara, Termoli, Bari and Leuca at the moment of surge peaks $\geq 80$ cm in Venice.

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**Bora evolution in the northern Adriatic during 48 hours preceding surges $\geq 80$ cm at Venice**

![Graph showing bora evolution](image)

Figure 10. Evolution of bora wind in the northern Adriatic before surge peaks $\geq 80$ cm in Venice.
ing the immediate hours before the surge peak that sirocco replaces bora. Simultaneous blowing of bora on the northern Adriatic and sirocco on the middle and southern Adriatic is not rare (locally called scontriura, i.e. collision situation) and also the two wind-driven wave systems may superimpose their set up along the Venetian coast, increasing the flooding risk.

**RECENT EVOLUTION OF SEA-LEVEL AIR PRESSURE AND OF BORA AND SIROCCO WINDS**

When all the available digitized air pressure records are considered, a clear increasing trend appears during the last decades over all the Italian Adriatic coast (Figure 12), for high values (e.g. the 95th percentile of all the values of each year), as well as for mean values, or for low values (5th percentile). Only at Termoli, for the 5th percentile, the increasing trend was not significant. The 5-year running means indicate that the rising trend include: oscillations, with peaks at the end of the 1950s, in the first half of the 1970s and around 1981; troughs of oscillations are observed in the first half of the 1950s, between 1964 and 1967 and around 1979 and 1986; and next trough seems imminent.

Since the end of the 1960s the average surface pressure on the northern Adriatic has increased about 2hPa, the "static" effect of which has been to lower the MSL by about 2 cm, thus masking an eustatic rise of the same amount. The apparent recent stability of sea level (Figure 1) depends therefore on the variability of atmospheric circulation, which is essentially unstable, and may be not lasting.

During the second half of the 20th century, bora and other easterlies have shown a strong decrease in both frequency and velocity and a similar trend may exist since the beginning of instrumental observations (PIRAZZOLI and TOMASIN, 1999). At Trieste, for example, the frequency of winds from 50°–90° has sharply decreased since 1951, in number of three-hourly records, as well (to take into account missing data) as in percent of all the records available. In particular typical bora records from 70° have almost disappeared (from about 700 three-hourly observations per year at the beginning of the 1950s, to less than 100 observations in recent years) (Figure 13). Such a decrease is not accompanied by a strengthening of winds from other directions, but by more frequent calm situations (from 26% of total observations in the 1950s, to 44% during the last ten years, and even to over 60% of calms during the early 1980s). In addition, all wind velocities

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1 In the following, trends are determined mainly as regression lines, the slopes of which are compared to the slope standard deviation (±σ), in order to estimate their statistical significance. As is already known, σ gives the likelihood of the real slope with 68% probability (or 1.96σ gives 95%; or 2.58σ gives 99%). Because a good confidence is required for a positive/negative trend, as seen as the slope turns out to be positive/negative, and >σ (or 1.96σ, or 2.58σ), one can trust that a clear tendency exists with 68% (or 95%, or 99%) probability. According to criteria of trend detection used in IPCC (2001) estimations, it will be assumed here that with a confidence >99% a trend will be virtually certain, with 90–99% very likely, 66–90% likely, 33–66% possible, 10–33% unlikely, 0.01–10% very unlikely and <0.01% virtually impossible.

2 In wind records at certain stations, sudden drops in the number of calms occur which probably depend on changes in instrumentation. Such discontinuities disappear however if lowest wind velocities are not considered. For this reason, when analysing wind evolution in time, frequencies and average velocities will often correspond in this paper to wind velocities ≥4 knots.
Sea-level air pressure on the Adriatic area

A: 95th three-hourly percentile (1951-1996)

B: three-hourly mean (1951-1996)

C: 5th three-hourly percentile (1951-1996)

Figure 12. Sea-level air pressure variations at Trieste, Rimini, Termoli and Leuca from 1951 to 1996: running means over 5 years and linear regressions for the 95th percentile, the mean, and the 5th percentile of all three-hourly records.

from 50°-90° show at Trieste, with >0.99 probability, a clear deceleration (Figure 14)³. Similar, although weaker, declining trends for the easterlies can be observed also at Ronchi and Tessera (PIAZZOLI and TOMASIN, 1999).

Sirocco evolution is not the same all over the Adriatic.

³ All wind speeds reported in this paper correspond to records from coastal stations. Offshore winds may however be much stronger: about 40% stronger in the southern Adriatic (NANIA, 1969), and even 80% stronger in the middle and northern Adriatic (ACCERONI and MANCA, 1973).
Evolution of bora >4 knots at Trieste

Figure 13. Evolution of the bora components from 60°, 70°, and 80°N at Trieste, for wind velocities >4 knots (from Pirazzoli and Tomasin, 1999), adapted.

Evolution of wind velocities from 50°-90° N at Trieste

Figure 14. Evolution of bora wind velocities from 50°-90° angles at Trieste: maximal daily gust, 95th percentile of maximal daily gusts, maximal three-hourly measurement, 95th percentile of three-hourly measurements and mean of three-hourly measurements with velocity >4 knots.
Figure 15. Frequency (1961 to 1996) of wind >4 knots from 110°-150° at Tessera.

Figure 16. Frequency (1960-1996) of wind >4 knots from 120°-180° at Falconara.
Figure 17. Frequency (1951–1996) of wind >=4 knots from 130°–200° at Termoli.

Figure 18. Frequency (1951–1996) of wind >=4 knots from 130°–180° at Leuca.
At Tessera (Figure 15), as well as in the central Adriatic at Falconara (Figure 16) and as far as at Termoli (Figure 17), south-easterly winds that cause surges in Venice show, with >0.97 probability, an increase in frequency trend, in the total number as well as in the percent of observations, whereas their velocities do not show statistically significant trend of change. In the southern Adriatic, on the other hand, the frequency of surge-related south-easterlies decreases sharply, at Bari, as well as (with >0.99 probability) at Leuca (Figure 18). The various observed trends are summarized in Figure 19.

**SURGE EVOLUTION IN THE ADRIATIC AND IN THE LAGOON OF VENICE**

Since 1968, simultaneous digitized records of hourly tide are available from various tidal stations: DSL (45°25' N–12°26' E) immediately outside the lagoon of Venice, PDS (45°26' N–12°20' E), in the city of Venice, and Trieste (45°39' N–13°46' E), at the north-eastern border of the

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**Wind name** | **Station (see Fig. 1)** and wind direction (x°=angle) | **Frequency trend** | **Velocity trend** | **General trend**
---|---|---|---|---
**Bora** | Trieste (50°-90°) | | | 
| Ronchi (20°-70°) | | | 
| Tessera (20°-70°) | | | 
| **Sirocco** | Tessera (110°-150°) | | | 
| Rimini (110°-120°) | | | 
| Falconara (120°-180°) | | | 
| Termoli (130°-200°) | | | 
| Bari (120-200°) | | | 
| Leuca (130°-180°) | | | 

**LEGEND:** falling; steady; increasing; insignificant trend.

Figure 19. Summary of recent trends for winds related to surges ≥80 cm at Punta della Salute.
Adriatic Sea. In Venice, the years since 1968 are especially interesting to deduce natural surge variations because they are later than the last man-induced main morphological changes in the lagoon (deepening of the Malamocco inlet and dredging of the “Oil Channel” across the lagoon in the early 1960s). In a first approximation, the trends observed since 1968 can therefore be tentatively ascribed to climate variability also in the lagoon.

At each station, all the surges for the period considered have been analyzed and divided into classes at 5-cm intervals. Greater surges (≥35 cm) did not show statistically significant evolution trends, indicating that the climate variability observed has not yet reached a noticeable impact on major flooding events. If however lower surges (≥5 cm to ≥30 cm, which are most frequent) are considered, trends are more alarming. At DSL, the frequency of hourly surges ≥5 cm tends to increase over 12 hours per year and that of surges ≥30 cm still 2 hours per year (Figure 20).
This means that they are respectively over 400 hours and 60 hours more frequent today than in 1968, with a significance level of increase greater than 99% for surges ≥5 and ≥10 cm and greater than 95% for surges ≥15 cm. In the Gulf of Venice, the sirocco increase (favorable to surges) seems therefore predominant in relation to the contrary effects produced by the bora abatement and the increase in atmospheric pressure.

Inside the lagoon the increasing surge trends are slightly smaller in relation to DSL, probably due to the hydrodynamic resistance provided by the Lido inlet, which, as discussed above (Figure 5), has been increasing since the end of the 1970s. At Punta della Salute, surges ≥5 cm tend to increase 9 hours per year, whereas the variability of surges ≥30 cm is less statistically significant than at the pier projecting into the sea (Figure 21). Due to its geographical situation, the Trieste station is relatively sheltered from direct set up from sirocco, though exposed to general surges produced by sirocco in the northern Adriatic. As concerns the bora decrease, it implies a decrease of negative surges (i.e. an increase of the positive ones). The result is that at Trieste the frequency of surges ≥5 cm tends to increase by 6 hours per year and the surges ≥30 cm by over 2 hours per year (Figure 22).

CONCLUSIONS

A decrease in the northern Adriatic Sea area of bora frequency and velocity means less-frequent invasions of arctic cold air over central/eastern Europe, and less-frequent strong atmospheric pressure gradients between the highs usually accompanying such polar drifts, and air pressure lows developing in the central Mediterranean area (PIRAZZOLI and TOMASIN, 1999). This reduction may be correlated with the gradual rise in the global surface air temperature, which has been recently documented not only in the Adriatic area (e.g. STRAVISI, 1987), but also on a global scale (HOUGHTON et al., 1996; IPCC, 2001) during the same period.

Knowing that in the northern hemisphere winds usually turn anti-clockwise around depression centers, the sirocco decrease in the southern Adriatic, accompanied by an increase in the central and northern Adriatic and by the bora decline can be partly explained by a slight northward displacement of storm trajectories in the Adriatic area. This suggests that the recent increase in Adriatic moderate surges has a climatic origin, possibly related to the recent global warming (IPCC, 2001), and that, if this conclusion is correct, it may be expected to worsen and become less moderate in the near future, also disregarding the possible effects of a near-future sea-level rise of climatic origin, which would be especially of concern in the Venice area.

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