MODERN AGE CLIMATIC FLUCTUATIONS IN THE AREA OF THE GULF OF TRIESTE

NOVOVEŠKE SPREMEMBE KLIME NA OBMOČJU TRŽAŠKEGA ZALIVA

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Abstract UDC 551.4 (262.3)

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According to the historical chronicles the severe winters were more frequent in the periods: 800 - 865, 1300 - 1570, and 1680 - 1865. In the period 1475 - 1491 the winters were cooler by 0.8° C than nowadays, and in the first half of the 18th century by 0.5° C. There are no records on severe winters for the 865 - 1300 and 1570 - 1675 periods.

Droughts in vegetation seasons were frequent in the 1540-1660 period, in the first half of the 18th century, and between 1820 and 1848. For the reconstruction of summer precipitation conditions in the first half of the 19th century, data on salt production in the Piran saltworks were also used.

In the period 1841 - 1991 winter temperatures showed a statistically significant increase of 0.52° C/100 years, and a similar decreasing trend was evident in summer temperatures. A significant decrease in autumn precipitation and annual precipitation quantities was calculated for the same period, with the rate of 98 mm/100 years.

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Novoveške spremembe klime na območju Tržaškega zaliva

Iz kronologije izrednih vremenskih in klimatskih dogodkov od 7. do srede 19. st. je razvidno, da so bile ostre zime pogostejše med leti 800 in 865, med 1300 in 1570 ter med 1680 in 1865. V letih 1475 - 1491 so bile zime ob Severnem Jadranu hladnejše od današnjih za 0,8° C, v prvi polovici 18. st. pa za 0,5° C. Brez poročil o ostrih zimah sta obdobji 865 - 1300 in 1570 - 1675.

Suše v vegetacijski dobi so bile pogoste med 1540 in 1660, v prvi polovici 18. stoletja ter med 1820 in 1848. Za rekonstrukcijo padavinskih razmer poleti v prvi polovici 19. stoletja so bili uporabljeni tudi podatki o proizvodnji soli v Piranskih solinah.

V obdobju 1841 - 1991 so v Trstu s statistično pomembno stopnjo naraščale zimske temperature (trend 0,52° C/100 let) in se s podobnim trendom zniževale poletne temperature. Jesenske in letne padavine pa so se zmanjševale s stopnjo 98 mm/100 let.

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1. INTRODUCTION

The last twenty years have seen growing scientific interest in "historical climatology" which involves the study of climatic conditions in the past. One of the main reasons for the growing interest is most certainly the regional and global climatic changes and fluctuations currently taking place. Among other examples, these are manifested in increases in the aridity of the Sahel, in the irregularity of the monsoon cycle in India, in the anomalies in the occurrence of the El Nino, and, in our region, in the "green winter" phenomenon and the very hot summers of recent years. For their assessment and for the preparation of future climatic scenarios, as precise a knowledge as possible of historical climatic conditions is necessary, as much from before the period of instrument measurements as during it.

Geographers have made a major contribution to research on climatic changes. The number of studies on the subject has particularly increased since 1970. In his introduction delivered at the International Conference on Climatic Changes in the Last 200 Years (1991), M. Pinna observed that the majority of these studies cover three main areas: (a) climatic changes of the Middle Ages and the early centuries of the modern age, (b) climatic developments from the beginning of the 19th century to the present day based on research on the climatic series, and (c) climatic problems of recent decades where special attention has been given to changes in the atmosphere and their ecological consequences.

During the 1950's and 1960's, research was primarily directed toward discovering the natural causes of climatic changes and later toward climatic changes as a consequence of human activity. On the one hand, the complexity of research requiring the use of modern computer technology and the relevant software increased, while on the other, due to ever-increasing public awareness, the need arose to present the results of complex research in a way that would be accessible to the general public.

Discussions stressing anthropological explanations for climatic changes have recently taken the forefront in Slovenia too, primarily the fact that the amount of CO_2 and other triatomic gases in the atmosphere began to increase with the beginning of the industrial revolution. This has led to increases in the greenhouse effect and in atmospheric heating in general. With this in mind, numerous scenarios have been prepared of climatic conditions for the first half of the 21st century, by which time, according to predictions, the concentration of CO_2 in the atmosphere will have doubled.

Despite the widespread belief regarding the relationship between the increased concentration of triatomic gases in the atmosphere and global warming, the question still remains as to whether anthropological causes of modern climatic changes are more significant than natural causes and, if so, when did their significance begin to grow? Was it after 1880 as the result of industrialization that atmospheric CO_2 began to increase, or was it around 1970 when the amount of atmospheric CO_2 began to increase steeply?

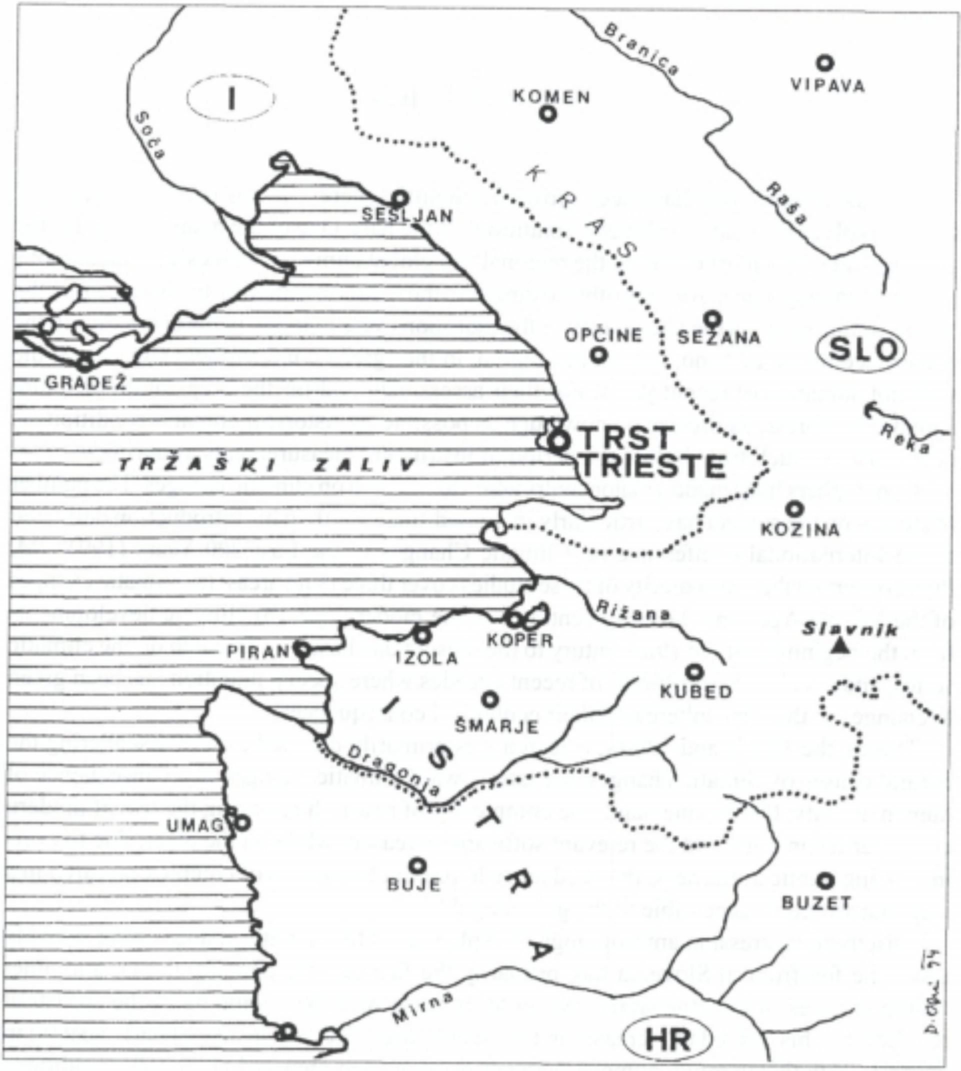


Fig.1: Geographic position of the investigated area.
Sl.1: Geografski položaj obravnavanega območja.

Some of the results in this study also point to this question. In Trieste, for example, the average annual temperatures, since the lowest recorded in the middle of the second half of the last century, continued to rise until the 1940's when the highest temperatures in the history of the Trieste meteorological station were recorded. Having fallen below the long-term average by the beginning of the 1980's, these temperatures again started to rise during the last decade.

This and similar questions clearly indicate that the relationship between increased concentrations of triatomic gases in the atmosphere and global warming is not as simple as widely thought. On the contrary, numerous and profound research is demanded.

In Slovenia, relatively few studies have dealt with the problem of climatic change (M. Krevs, 1986; I. Gams, 1988; I. Gams, M. Krevs, 1990; L. Kajfež-Bogataj, 1990, 1992, 1992a; J. Roškar, 1992; A. Hočevar, 1993). Studies to investigate climatic fluctuations in the sub-Mediterranean region of Slovenia and compare the findings with those of neighbouring climatic regions have not yet been carried out. The present study is intended to at least partially fill this gap.

In doing this study I received the support and understanding of many individuals. First of all, I am greatly indebted to my mentor, Dr. Ivan Gams. Dr. M. Pinna from the University of Pisa, and Dr. F. Crisiani and Dr. S. Ferraro from the Oceanographic Institute in Trieste assisted greatly by providing literature and data. I was offered considerable help as well by the staff at the archives of HMZ Slovenia, at the Piran archives and at Droga Portorož where I am, particularly, grateful to dipl. ing. D. Čendak. My thanks also go to my coworkers Mare Krevs and Mauro Hrvatin without whose assistance I would have had many problems with some computing procedures. I would like to express my thanks, too, to Vanda Šprager and Marino Ogrin, as well as to Zdenka Šimonovič for her assistance with language expressions, and general support.

2. ANALYSIS OF PAST CLIMATE IN THE GULF OF TRIESTE BASED ON RECORDS OF EXTRAORDINARY WEATHER AND CLIMATIC EVENTS IN HISTORICAL CHRONICLES

We have attempted, at least partly, to reconstruct the past climate during the period from the 7th century to the middle of the 19th century with the help of the chronicle of extraordinary climatic events which we have compiled mainly from secondary (and tertiary) historical sources. The chronicle covers primarily events in Istria, Trieste, Slovenia's karst region, and partly those in Gorizia and eastern Friulia. In the case of Venice, we have considered only the freezing of the lagoon. We have used the record of events which G. Braun (1934) prepared for Trieste, Istria, and eastern Friulia as the starting point for the preparation of our chronicle.

For his work, Braun used mainly published and handwritten chronicles covering events of political, military, and church history, including records of emergency climatic events. His principle sources were L. Jenner's Annals for Trieste from the Birth of Christ to 1846 (the manuscript is kept in the Archivio Diplomatico di Trieste), The Chronology of Gorizia to 1500 published by G. D. Della Bonna in 1856, the Trieste Annals to 1695 by D. V. Scussa and the Trieste Annals from 1695 to 1848 by P. Kandler, both published in Trieste in 1863, the History of Trieste from 1000 to 1702 by P. F. Ireneo della Croce (manuscript in Archivio Diplomatico di Trieste), the Trieste Chronicle from the 11th Century to the Beginning of the 19th Century by P.G.D. Mainati (published in Venice 1817-1818), the Annals of Friulia by F.D. Manzano (Udine, 1858-1879), the Chronicle of Rovinj from 1760 to 1806 by P.A. Biancini (Poreč, 1910), and the Weather Diary for Trieste from 1815 to 1858 by L. Kert (manuscript in Biblioteca Civica di Trieste).

We have supplemented Braun's chronicle with other sources which he did not include and as well as with those sources from which he extracted material but excluded data which was not directly relevant to the territory under consideration. In the first place, we should mention the chronicle of A. Schiavuzzi (1889) on hygienic and demographic conditions in the province (Istria), which was partly prepared from Kandler's annals. We once again reviewed D.V. Scussa's annals to which Braun makes reference. Another good source of data was Fasti Istriani, a chronicle of events which published in the newspaper L'Istria (1846-1852). As for the interior of Slovenia, we have extracted data from Dolničar's Ljubljana Chronicle of 1660-1718 published by J. Pučnik (1980) and data from Glory of the Duchy of Carniola by Valvasor (1984 edition). We summarized data on the freezing of the Venice lagoon from a work by D. Camuffo (1990) who, in turn, compiled his data from various chronicles of Venice.

The chronological review of climatic events mainly consists of data on the hydrological effects of the weather (floods, intermittence of springs and wells), on the consequences with respect to farming (abundant or failed harvests, early or late blossoming or ripening), economic consequences (shortages, price changes, famine), and direct climatic effects (freezing, droughts, storms, etc.).

There is a shortage of data covering the period between the 7th and 16th centuries. According to D. Camuffo (1990), who investigated the freezing of the Venice lagoon, this data is also less reliable. On the other hand, there is more data available for the 17th century and even more so for the 18th century. In some cases, there is even overlapping data for these two centuries from two or more independent sources, which increases its reliability.

It may also be observed that some sources have recorded the same relatively rare event (e.g., the freezing of the Venice lagoon) in two successive years (e.g. G. Braun, with reference to P. Kandler has dated the freezing of the lagoon in 1122 while D. Camuffo dates the event in 1123). Camuffo argues that these differences are the result of the different calendars that were in use, a fact some authors neglected while dating events later. Camuffo observes that until its collapse in 1797, the Venetian Republic began its year on today's March 1st. At the same time, the Julian Calendar and the Annunciation Calendar (Callendario dell' Indizione) according to which the year began with today's September 1st and the Magistrata Calendar (Callendario dell' Magistrati) according to which the year began on St. Michael's Day were also in use.

2.1 THE CHRONOLOGY OF OUTSTANDING WEATHER AND CLIMATIC EVENTS

603: Exceptionally severe cold (B. Schiavuzzi, G. Braun).
763: Exceptionally cold (B. Schiavuzzi).
Severe winter (G. Braun with reference to Della Bona).
793: Great shortages and famine (B. Schiavuzzi).
811: Exceptionally cold (B. Schiavuzzi).
853: Very severe cold, Venice lagoon froze (D. Camuffo)*.
858: Severe cold, Venice lagoon froze (B. Schiavuzzi).
859: Intense cold caused the Adriatic Sea to freeze for several days (G. Braun with reference to Di Manzano).
Venice lagoon froze (D. Camuffo).
860: Venice lagoon froze (D. Camuffo)*.
864: Venice lagoon froze (D. Camuffo).
1118: Venice lagoon froze (D. Camuffo)*.
1122: Severe cold, Venice lagoon froze (B. Schiavuzzi, G. Braun with reference to P. Kandler).
1123: Venice lagoon froze (D. Camuffo).
1186: Abnormal nature: corn ripens in May, grape harvest in August. Winter is early and lasts until the middle of the following year (Fasti Istriani).
1224: Venice lagoon froze (D. Camuffo).
1234: Exceptionally severe cold (B. Schiavuzzi). Venice lagoon froze (D. Camuffo).
1238: Exceptionally severe cold which caused the breaking of numerous trees and vines, great shortages, and the death of animals (B. Schiavuzzi).
1304: An exceptional year in terms of amount of snow in Friulia (G. Braun, with reference to Della Bona).
1310: The beginning of the year was so cold that ice was exceptionally thick (G. Braun with reference to Di Manzano).
1312: Friulia experienced a very cold winter (G. Braun, with reference to Di Manzano).
1324: Drought from March to end of July, apart from exceptionally heavy rains at the beginning of June. From July 22nd until Christmas there was almost no rain at all (G. Braun, with reference to Di Manzano).
1339: Severe cold which also caused severe famine (Schiavuzzi).
1348: Poor grape harvest in Istria (B. Schiavuzzi).
1349: Poor grape harvest in Istria (B. Schiavuzzi).
1350: Poor grape harvest in Istria (B. Schiavuzzi).
1352: Poor grape harvest in Istria (B. Schiavuzzi).
1355: Poor grape harvest in Istria (B. Schiavuzzi).
1356: Poor grape harvest in Istria (B. Schiavuzzi).
1368: The Venetians besieged Trieste with a large army. Many soldiers died of cold that winter (G. Braun, with reference to Ireneo).

1408: Severe cold in Istria (B. Schiavuzzi).

1408: Severely cold winter during which rivers and lakes froze throughout Italy (G. Braun, with reference to di Manzano and Della Bona).

1432: Venice lagoon froze (D. Camuffo)*.

1441: Raging bora wind with snow in Trieste between January 16th and 20th (A. Tamaro). Severe cold in Istria (B. Schiavuzzi).

1441: "The evening before St. Antony Opat Day, January 16, 1441, merciless and cruel fate rose over Trieste with snow, cold, and such strong winds that, withered or uprooted, almost all the olive trees in the territory were destroyed." (G. Braun, with reference to Ireneo and Mainati).

1441: January 16th was so cold in Trieste that all the olive trees froze (D.V. Scussa).

1442: "An exceptionally large swarm of locusts covering more than five miles of the country, attacked Ljubljana territory on August 20th from where they spread toward Rijeka, Pazin, and Istria not only destroying the millet, maize, and buckwheat but also all the grass. The locusts also did great damage to the grass in the territory of Trieste but left the olives, grapes, and other fruit untouched. They then spread into Friulia, Trevisio, and Padua and to the surroundings of Venice where they found themselves in the sea. This calamity lasted until September 12th. The following year there were great shortages in Trieste followed, according to one manuscript, by the plague." (G. Braun, with reference to Ireneo and Mainati).

1443: Venice lagoon froze (D. Camuffo)*.

1475: "Large swarms of locusts descended in areas of Carniola, the karst region, Friulia, and Trieste continuously for three days in 1475 eating all the cereals and grass and leaving their eggs on the land which hatched new generations which caused similar damage (G. Braun, with reference to Ireneo, Mainati, and Jenner; also D.V. Scussa).

1475: Venice lagoon froze (D. Camuffo)*.

1476: Venice lagoon froze (D. Camuffo)*.

1480: Heavy rains caused floods in Cividale and surrounding areas (G. Braun, with reference to Di Manzano).

1487: Venice lagoon froze (D. Camuffo)*.

1488-1489: "Both years, violent storms raged over Trieste. Instead of the usual 100 urn of wine, only four were produced in these two years. Life was very difficult." (D.V. Scussa).

1489: "During this and the previous year, frequent continuous and large thunderstorms so struck Trieste and its surroundings that all those who normally produced 100 urn of wine from the vineyards and fields produced only four. This led to shortages in the city and almost to destruction; The following year 1490, wheat sold for 40 soldos per quarter." (G. Braun, with reference to Ireneo and Mainati).

1491: Venice lagoon froze (D. Camuffo)*.

1503: Winter was long and severe (G. Braun, with reference to Di Manzano).

1510: Major shortages and famine in Istria (B. Schiavuzzi).

1515: Long and severe winter (G. Braun, with reference to Di Manzano). Venice lagoon froze (D. Camuffo).

1525: Rich cereal harvest in the Gorizia Region (G. Braun, with reference to Manzano).
1528: A year of shortages in the Gorizia County (G. Braun, with reference to Di Manzano).
1540: "In this year, too, it was exceptionally hot in Carniola, not only turning the land to stone but also setting fires in forests." (J.V. Valvasor).
1546: Severe drought which caused the drying up of fruit trees and destroyed harvests in some parts of Istria (B. Schiavuzzi). Great shortages and famine in Istria (B. Schiavuzzi).
1546: Very rich cereals harvest the Gorizia Province (G. Braun, with reference to Di Manzano).
1548: Severe drought in Istria (B. Schiavuzzi).
1548: Long and cold winter in Friulia (G. Braun, with reference to Di Manzano).
1549: Venice lagoon froze (D. Camuffo)*.
1559: Severe drought in Istria. Fruit-trees dried out and the harvest was destroyed (B. Schiavuzzi).
Major drought in Friulia and throughout Italy, the summer was almost without rainfall. It was a year of great shortages (G. Braun, with reference to Di Manzano).
1560: Great shortages and a scarcity of wine. It was almost impossible to get any wine in March in Trieste, so it was imported from elsewhere (G. Braun, with reference to Ireneo and Mainati). According to D.V. Scussa, wine began to become scarce in May.
1561: Severe drought in Istria (B. Schiavuzzi). Venice lagoon froze (D. Camuffo).
1562: Severe drought in Istria (B. Schiavuzzi).
1563: "Terrible thunderstorm covered Trieste and karst regions on July 13th killing many animals in the fields, breaking many trees and vines, and driving people into such misery that they had to request for help from the imperial authorities." (G. Braun, with reference to Ireneo, Mainati and Jenner).
1563, July 13th: Terrible thunderstorm over Trieste and karst regions which uprooted vines and trees and killed animals (D.V. Scussa).
1569: Venice lagoon froze (D. Camuffo).
1581: Great shortages and famine in Istria (B. Schiavuzzi).
1582: Famine in central Istria (Fasti Istriani).
1590: Great shortages and famine in Istria (B. Schiavuzzi).
1595: Venice lagoon froze (D. Camuffo).
1603: Venice lagoon froze (D. Camuffo).
1616: Istria suffered intense heat and severe drought. Many people fell ill and livestock died (Fasti Istriani).
1617: On the evening of July 19th, a storm raged accompanied by the garbin (southwesterly wind) rain, thunder, and lightning (G. Braun, with reference to Ireneo and Mainati; the same according to D.V. Scussa).
1622: Hail destroyed almost all crops in Istria (B. Schiavuzzi).
1624: An hour before dawn on May 3rd, lightning struck the belfry of St. Jošt Cathedral (San Giusto) in Trieste and started a major fire (G. Braun, with reference to Ireneo and Mainati).

1628: "Winter was so mild this year that it turned into spring, for it was beautiful, pleasant, and not in the least unfavourable to growth" (J.V. Valvasor).
1629: The Loški estate steward reported to the Bishop of Friesing that the wine (črnikalec) went poorly in the villages of Loka, Rožar, and Zvonigrad (Zanigrad) (S. Rutar).
1629: Very high prices (J.V. Valvasor). Major famine (B. Schiavuzzi, Kandler, G. Braun).
1635: Good harvest, low prices. Very productive year (J.V. Valvasor).
1643: March 19th, the tide was so high in the Trieste harbour that the ships were lifted ashore. (G. Braun, with reference to Ireneo and Mainati).
1644: Severe drought in the surroundings of Trieste, the locusts destroying what was left of any vegetation (S. Rutar).
1644: October 25th, a strong "garbin" (SW wind) raised the sea in Trieste, flooding St. Rosario Church and the saltworks. Damage was estimated at 1000 scudi (D.V. Scussa). Great tempests burst out on the sea (B. Schiavuzzi).
1644: Terrible heat with severe drought lasted until June 16th, destroying the millet, maize, melon, and other fruit. There was also an invasion of locusts which ate even the fig leaves (D.V. Scussa).
1644: Due to strong and frequent "garbin" winds, the sea flooded Piazza Vecchia square in Trieste all the way to the Rosary Church. The water level was so high at the Piazza Grande square that boats were able to float quietly on it. Damage to the city caused as a result of the flooded salt water, destroyed goods, the demolished saltworks dikes near the city and the saltworks in Škedenj in Žavlje, amounted to 1000 scudi. Because of the high water level, people climbed through windows out of the saltworks houses into boats. (G. Braun, with reference to Ireneo and Mainati).
1645: On January 29th a violent thunderstorm with strong winds uprooted many trees in the "valley of mills" near Trieste (D. V. Scussa). A terrifying tempest (šijon) drove the sea over the shore way into the city (S. Rutar).
1645: "In the early hours of the evening of January 29, 1645, a terrifying whirlwind, called "Typhon" in Latin, accompanied by a strong wind, thunder, and lightning raged over several areas in Trieste. In the valley of mills, the whirlwinds broke and uprooted many olive trees which lay on the ground in threes or fours side by side. This event caused great marvelling even among the older inhabitants of the area, since they could not remember having seen or heard of anything similar (G. Braun, with reference to Ireneo and Mainati).
1646: Large tempests erupted on the sea (B. Schiavuzzi).
1648: Severe cold (P. Kandler, G. Braun, with reference to Kandler).
1649: A year of great shortages (B. Schiavuzzi).
1650: Great famine and high prices, a "star" of wheat cost Liras 60 (S. Rutar).
1650: The city of Trieste and surrounding areas suffered great shortages. A "star" of wheat sold for 60 liras. There was also a great shortage of cereals in the rest of Italy (G. Braun, with reference to Ireneo and Mainati).
1660: So much snow fell as had not snowed from time immemorial (Dolničar).
Drought all through spring, summer, and autumn until the Emperor's arrival in Trieste. All wells dried out apart from Locatelli's (G. Braun, with reference to Ireneo and

Mainati). September 24th, the Soča riverbed filled by abundant rain (G. Braun, with reference to Ireneo and Mainati).

On Tuesday, September 28th, a raging bora began to blow over Trieste (D.V. Scussa).

1677: At six o'clock in the afternoon of September 10th, very heavy rain with thick hail and strong winds fell for three consecutive hours causing massive damage in the Trieste area. The water levels rose to the height of a man and flooded the roads leading from the Riborgo gate towards Sv. Katarina, Sv. Lazar, Sv. Miklavž, and Veliki Mlin (G. Braun, with reference to Ireneo and Mainati).

1680: Unusually fruitful year for wine and cereals (Dolničar).

1682: January 1st: mild winter, blossoming of trees and flowers, e.g. daffodils (Dolničar). November 21st: strong bora in Trieste (G. Braun, with reference to Ireneo and Mainati).

1683: July 11th, a terrifying and strong levantera (a thunderstorm with easterly winds) caused great damage, especially on Sv. Vito hill where three quarters of the grapes were destroyed and the harvested wheat was scattered in the fields. In the karst area the storm uprooted many oak-trees, huge walnut trees, and other trees and caused great damage to fruit. (G. Braun, with reference to Ireneo and Mainati).

1684: January 9th: It was a terribly cold winter, such as nobody could recall. Many travellers were found dead beside the roads, and many provisions were destroyed (Dolničar).

1684: The year began with such severe and remarkable cold as even the oldest inhabitants of Trieste could not recall. A strong bora blew continuously from January 29th to March 4th. It was accompanied by much snow which the wind sprayed on the ground like flour. At the foot of Starebrech (Stari Breg) hill the cold took the live of one person. The same misfortune befell three Capuchin monks on a journey, to five people who were found in a boat near Ljubljana, and to many others in various places. "It is impossible to satisfactorily express the bitterness of the cold if not to mention that I myself was in Trieste at the time and saw with my own eyes that even with shoes studded with iron cleats, one could hardly walk on the streets." (G. Braun, with reference to Ireneo and Mainati). Venice lagoon froze (D. Camuffo).

1685: January 27th was, like the previous year, severely cold.

Many trees and vines were frost damaged (Dolničar).

1686: Warm winter, worms devoured the cereals, which was probably the cause of high prices (Fasti Istriani).

1687: "At two o'clock in the afternoon of July 14th, the Trieste area was struck by a terrible thunderstorm with hail stones the size of hazelnuts or eggs. Other hail stones were the size of half a scudo bent into the form of tube. This marvel,which has never been seen since in these areas, destroyed almostall the grapes and other fruit. It began in the Sv. Lazar partof the city and afterwards stretched back across Castello (castle) Sv. Vito, and Campo Martio to the other side of the city in Buedo. The greatest damage was done in the parts of thecity known as Sv. Anastazij, Sv. Peter, Rojan, and Creta(Gretti)." (G. Braun, with reference to Ireneo and Mainati).

1688: "Two hours before noon on October 10th, a very heavy rain began falling in the

Trieste area, lasting seven hours without ceasing, which appeared as if all the sluice gates in the sky had been flung open. The storming water, which had risen out of all proportion, broke down the Pondasserski bridge which had just been constructed, demolished part of the wall on the estate of Mr. Simonetti, and caused considerable damage to the neighbouring estates of the counts; the water then turned towards the bishop's estate where among other things it cause deven more damage as it brought down walls, destroyed fields,vineyards, mills, houses, and all that stood in its path, not without the inevitable danger of drowning the many people who had climbed trees to escape death after the water level had reached five feet. The damage in the Trieste area was great everywhere, and one can not remember that our city had ever suffered such destruction by water, which damage they say surpassed fifty thousand ducats" (G. Braun, with reference toIreneo and Mainati).

1690: A bora raged over Trieste on February 8th (G. Braun, with reference to Ireneo and Mainati; the same according to D.V.Scussa).

1690: Two strong thunderstorms struck Trieste. The one of April 2nd damaged the belfry of St. Nikolai at Riborgo, broke the smaller bell and damaged the belfry of the hospital though not the bell, damaged the roof with stones, broke a number of olive trees, and uprooted many others. The one of the evening of July 9th which was accompanied by lightning and continuous thunder started a fire at two o'clock in the night in the armoury (G.Braun, with reference to Ireneo and Mainati).

1691: "From September 22nd to November 24th, the weather was very good, apart from the night of November 3rd when a violent thunderstorm with a bora damaged and broke several olive trees, especially, in the Koper area where the damage reached more than four thousand ducats. In the morning it snowed and lightly rained in Trieste and in the karst region. Very fair weather then followed so that because of drought there was no water in town wells nor for the mills in the Žaveljska valley, so that people had to fetch it from Sv. Kocjan. On the 24th a stron grain began that fell continually for eight days and eight nights followed by lighter rain which continued until December 16th"(G. Braun, with reference to Ireneo).

1701: October - good grape harvest in the Vipava and Dolenjska regions (Dolničar).
Abundant grape harvest in the Gorizia region (G. Braun, with reference to Di Manzano).

1702: "The year was generally healthy, productive with Vipava wines, while the wine from the Dolenjska region had been damaged by frost. The winter was unusually mild, though the extended cold delayed ripening." (Dolničar).

1703: Unusually wet year. There were many floods. It was an average harvest for wine and rye (Dolničar).
This year was exceptional due to continuous rains, the overflowing of river banks, and the great damage caused by water in Gorizia Province (G. Braun, with reference to Di Manzano).

1704: Unusually dry year. Drought destroyed almost all the buckwheat in the Ljubljana basin. There was a lot of Dolenjska wine, less from Vipava but still good (Dolničar).
Summer, especially the month of August, was very dry in the Gorizia region; how-

ever, there was plenty of wine, althought here was a shortage of all types of cereals (G. Braun, with reference to Di Manzano).

1704: Due to the cold that December almost all olive trees in the Trieste area froze. (G. Braun, with reference to Jenner).

1706: "This was a wet year and the south wind blew constantly. The harvest, however, was good, with enough wine and cereals."(Dolničar)
On August 5th, a terrible thunderstorm caused damage to all fields in the country and in the Trieste area, denying people their crops (G. Braun, with reference to Mainati).

1709: Severe cold, olive trees froze. (Fasti Istriani).
Very severe cold, because of which numerous olive trees withered (Schiavuzzi).
Due to very bitter winter almost all olive trees withered in Gorizia Province (G. Braun, with reference to Di Manzano).
Cold with snow and ice on the Day of the Three Kings which lasted twenty and more days destroyed all of the olive trees and some of the vine (D.V. Scussa).
Severe cold, the olive trees froze (Kandler).
Venice lagoon froze (D. Camuffo)*.

1710: "On August 5th a terrible thunderstorm with whirlwind sand snow destroyed all the fields in a few hours, leaving the owners without any crops, which had been expected to be abundant. The country fell into poverty and three years of modest harvests followed. Due to the bitter cold almost all the olive trees and many vines withered (G. Braun, with reference to Jenner).

1711: Extraordinary cold in Istria (Fasti Istriani).
Very severe cold in Trieste and its surroundings (B. Schiavuzzi).
"This year was unusually wet, more than the oldest inhabitants could recall from the past; the south wind dominated almost all year and it always rained, apart from some time during summer. However, the year was productive as regards wine and cereals." (Dolničar).

1713: Very severe cold in Istria (B. Schiavuzzi).

1715: Generally wet year following a long winter. The harvest was average, wine did not do well (Dolničar).

1716: The grape harvest and cereals harvest was average; There was enough wine in the Vipava region and less in the Dolenjska region where the cold had damaged the vines. Fruit was abundant (Dolničar).
January 15th was followed by long lasting severe cold, followed by heavy snow (Dolničar).
Venice lagoon froze (D. Camuffo)*.

1717: A healthy year, cereals harvest was average, while the grape harvest was very good (Dolničar).
The grape harvest was quite modest in the Gorizia region, heat and drought were exceptional (G. Braun, with reference toDi Manzano).

1718: "A dry, hot, and healthy year in which the doctors had almost no business. Apart from the coastal regions where there were shortages, there were enough cereals and

wine. Italian wine failed in Friulia, while the Dolenjska grape harvest was exceptionally good (Dolničar). September: unusually early grape-harvest in Dolenjska, Friulia, and Istria (Dolničar).
Dry weather destroyed all agricultural crops, grapes, and olives, inflicting heavy losses on the citizens of Piran (PAK Piran).

1719: Good wine plentiful in Gorizia County, but much of it spoiled the following year (G. Braun, with reference to Di Manzano).

1720: Locusts caused great damage to the maize. The wheatharvest in Gorizia was good (G. Braun, with reference to DiManzano).

1726: Long and very cold winter. Floods on June 27th and July 23rd. The Vipava River and the Branica stream caused great damage. Generally plentiful grape harvest in Gorizia (G. Braun, with reference to Di Manzano).

1727: Plentiful grape harvest in the Gorizia region (G. Braun, with reference to Manzano).

1728: April 19th: Frost caused immeasurable damage in the fields in Gorizia. Very modest grape harvest, weak wine (G. Braun, with reference to Di Manzano).

1729: July 23rd: A tempest with a strong wind, rain, and hail raged through Gorizia, mostly affecting Brdo. The wheat harvest was quite good, though there was a scarcity of other crops. Very bitter winter which lasted until mid-March. Soča and Vipava rivers completely froze (G. Braun, with reference to Di Manzano).
Venice lagoon froze (D. Camuffo).

1734: March 15th: Severe drought in Trieste. In a period of three months, only a few drops of rain on March 26th and 27th (G. Braun, with reference to D.V. Scussa).
From August 30th to September 3rd, a destructive wind blew over Trieste, destroying grapes and olive trees in the fields. Older people do not recall such strong winds in the past (G. Braun, with reference to D.V. Scussa).
In September, two tempests completely destroyed the grapes in the Trieste area, resulting in a poor grape harvest (G. Braun, with reference to Jenner).

1735: May 22nd: A raging thunderstorm accompanied by lightning and heavy hail destroyed fields in Grignano, Buedo, and Tarstenicho and caused damage in the whole Trieste region. Winds and heavy rain also caused devastation (G. Braun, with reference to D.V. Scussa).
June 14th: Toward noon, a storm with strong rain and thick hail destroyed parts of the fields in Žavlje, Pantalona, Sv.Barbars, and partly in Sesljan (G. Braun, with reference to D.V. Scussa).
September 22nd: no rain for two months in Trieste. It rained in the night from September 24th to 25th (G. Braun, with reference to D.V. Scussa).

1737: February 18th: There was only a little rain in two month sleading to considerable water shortages in the wells (G. Braun, with reference to D.V. Scussa).
The Vipava River and the Branica and Lijak streams overflowed their banks causing considerable damage to fields in Prvačina, Bokaviza, Ranziano, Ajdovščina, Černica, and Šempas.
The grape harvest was generally poor. (G. Braun, with reference to Di Manzano).
December 16th: Towards the north a "burning" sky was observed throughout the whole night until dawn (G. Braun, with reference to D.V. Scussa).

1738: January 9th-13th: Severe cold with wind and freezing snow turns everything in the city (Trieste) and in the fields to ice. The olive trees are covered by ice and greatly damaged. Some recall similar weather in 1709 (G. Braun, with reference to D.V. Scussa).
May 14th-17th: The sea level rises so high during the night that it destroys many goods in warehouses outside of the harbour and in the large square. It also caused considerable damage to the saltworks in Žavlje and Sesljan (G. Braun, with reference to D.V. Scussa).

1739: August 6th: Heavy rain starts at midday in Trieste followed by a severe tempest. One boat is sunk and a thick tree is uprooted near the steps of St. Just Church (G. Braun, with reference to D.V. Scussa).

1740: Severe cold (P. Kandler, Fasti Istriani, B. Schiavuzzi).
From February 6th to 28th it was colder than people could recall (G. Braun, with reference to D.V. Scussa).
Venice lagoon froze (D. Camuffo)*.

1741: April 7th: It snowed almost two feet deep in Gorizia, severe cold (G. Braun, with reference to Di Manzano).
Locusts cause devastation in the karst region; this year was a year of shortages (G. Braun, with reference to Di Manzano).

1745: From January 5th to February 11th, severe cold and drought leading to shortages of water in some wells in Trieste (G. Braun, with reference to D.V. Scussa).

1747: Hot and dry summer (G. Braun, with reference to D.V. Scussa).
Heavy rain in October. On the night of October 2nd rain accompanied by strong winds caused damage to fields, uprooted trees and olive trees, and destroyed trellises (G. Braun, with reference to D.V. Scussa).
Venice lagoon froze (D. Camuffo).
From November to April of 1540 it neither rained nor snowed, but the crop was nonetheless abundant. The same happened in 1747 (G. Braun, with reference to Kert).

1748: From November 1st, 1747, until mid-August 1748 it rarely rained. Spring and summer were very hot in Trieste (G. Braun, with reference to D.V. Scussa).
On the night of September 2nd there was heavy rain accompanied by hail. The high water level caused damage in the fields, mostly in Žavlje and at the saltworks (G. Braun, with reference to D.V. Scussa).

1749: Due to strange weather there was very small crop (G. Braun, with reference to D.V. Scussa).

1752: Famine in Koper (B. Schiavuzzi).

1755: Very severe cold in Istria (B. Schiavuzzi).
Winter was exceptionally cold, rivers froze and even the wine in casks froze. The grape harvest was very poor (G. Braun, with reference to Biancini).
Venice lagoon froze (D. Camuffo)*.

1756: Stormy sea in Trieste (P. Kandler).
At six o'clock in the morning of October 16th, a terrifying and extraordinary rain

began which lasted until four in the afternoon. Streams and rivers in Trieste were so full and so fast that their waters washed wagons of goods and iron into the sea, not to mention other damage estimated at nearly half a million forints (G. Braun, with reference to Mainati).

1761: A high tide greatly damaged the saltworks in Piran (Rutar).

1762: Severe cold in Istria (B. Schiavuzzi).

1763: Severe cold caused the destruction of olive trees (P. Kandler, Fasti Istriani, B. Schiavuzzi, D.V. Scussa).

1764: This year Trieste and the whole of Italy suffered shortages and famine. The calamity ended with the new harvest (G. Braun, with reference to Mainati).

1770: A stormy sirocco (southeast wind) caused devastation in the surroundings of Sipar between Umag and Savudrija and exposed the ruins of an ancient town (P. Kandler, Fasti Istriani).

1772: A stormy sea sank thirteen ships in Trieste (P. Kandler).
Mild winter in Trieste (G. Braun, with reference to Kert).

1782: Severe cold destroyed all the olive trees in Istria (P. Kandler, Fasti Istriani).
Severe cold lasted from February 13th to 16th, many olive trees froze (B. Schiavuzzi).
Exceptionally cold year; olive trees froze, drought in Friulia (G. Braun, with reference to Di Manzano).
On February 15th five soldiers died in Trieste while on guard from severe cold. A few people driving carriages died in Carniola, too (G. Braun, with reference to Biancini).
Not a single olive was picked as almost all olive trees froze from the exceptional and unexpected severe cold of February 13th, 14th, 15th, and 16th (G. Braun, with reference to Biancini).
Severe cold caused the withering of many olive trees all over Istria (G. Braun, with reference to Kandler).

1784: It did not rain in Rovinj from April 30th until August 8th (G. Braun, with reference to Bianchini).

1788: Severe cold in Istria (P. Kandler, B. Schiavuzzi).
Along with the cold, Istria suffered long lasting drought (B. Schiavuzzi).

1789: Severe cold, leaves on olive trees freeze and drop off (B. Schiavuzzi).
Venice lagoon froze (D. Camuffo)*.

1794: Very dry year, especially on Lošinj (B. Schiavuzzi).
Very mild winter (G. Braun, with reference to Di Manzano).
June 15th: Due to major drought lasting from the beginning of the year, there is almost no drinking-water in Istria; it rarely rained and only for short periods (G. Braun, with reference to Biancini).

1795: A high tide destroyed the saltworks in Piran (S. Rutar).
Severe cold, olive leaves froze (B. Schiavuzzi).
Venice lagoon froze (D. Camuffo).
Poor harvest, many olive trees withered in Istria (B.Schiavuzzi).
After July 12th, it rained heavily making it impossible to harvest (B. Schiavuzzi).

Heavy rain led to the flooding of the saltworks in Sečovlje, destroyed all the crops, and shifted the course of the Dragonja River (E. Nicolich).

May 27th: Major drought in the fields (G. Braun, with reference to Biancini).

1802: The great dampness of the previous winter was followed by a long lasting drought which began in the first half of spring and lasted all through the summer. There was drought in Italy and Germany as well. People suffered from the great heat, while the crop was scorched due to the extended lack of moisture. There was a shortage of water in Trieste (G. Braun, with reference to Mainati).

"At around three o'clock on the afternoon of September 12th, all the flood gates opened wide in the sky and it rained tremendously for four hours without a break. The water flooded all the lower parts of Trieste so that it was possible to travel in the city by boat. Considerable damage was caused to the city and to numerous fields." (G. Braun, with reference to Mainati).

1802-1803: "After more than two months of continuous "sirocco", (SE wind) an easterly or northeasterly wind popularly known as the "tramontana" suddenly erupted in the night from January 11th to 12th 1803, accompanied by a powerful whirlwind of snow. It was very cold" (G. Braun, with reference to Kert).

1803: On January 11th a bora in Trieste harbour shipwrecked eight big ships (A. Tamaro).

1813: Severe cold in Istria (B. Schiavuzzi).

1814: Venice lagoon froze (D. Camuffo).

1814-1815: From the end of December 1814 to the end of January 1815, it was exceptionally cold in Trieste, with much snow, ice, and strong bora winds (G. Braun, with reference to Kert).

1815: Heavy rain causes great misfortunes (P. Kandler).

1816: Third unproductive year (G. Braun, with reference to Kert).

1817: This was a year of sadness which people still refer to as "the year of famine" (G. Braun, with reference to Benussi).

The almond-trees are all in blossom, and the old Jew Vitali says that he does not recall such a mild winter since 1772 (G. Braun, with reference to Kert).

1818: Exceptionally cold in Trieste and Istria (P. Kandler).

1819: Severe cold in Istria (B. Schiavuzzi).

On November 22nd the fields were flooded by continuous rain and the sowing was delayed (G. Braun, with reference to Kert).

1820: January, very cold in Trieste. Streets, wine, and water in the houses froze. Olive trees were also damaged.

Drought from August to September (G. Braun, with reference to Kert).

1822: March, great abundance; trees blossom, in fact almonds have already ceased blooming. Very mild winter. Nobody recalls a milder winter in the past. Drought in March and April, and from June to August (G. Braun, with reference to Kert).

1824: Great abundance (G. Braun, with reference to Kert).

1827: Continuous rain in June (G. Braun, with reference to Kert).

1828: Severe drought in Trieste in July and August (G. Braun, with reference to Kert).

1829: Exceptionally cold in January and February (G. Braun, with reference to Kert).

On December 30th, the Soča River froze and the landscape looked like Siberia (G. Braun, with reference to Kert).

1830: Exceptionally cold in January and February. On February 3rd the Soča River froze in Gorizia. Great heat and drought in July and August (G. Braun, with reference to Kert).

1832: Severe cold, the thermometer recorded minus nine degrees Celsius (P. Kandler).
Severe cold in Istria (B. Schiavuzzi).
Severe drought in August (G. Braun, with reference to Kert).

1833: Drought in January and July (G. Braun, with reference to Kert).
At 13:30 on December 26th a powerful tramontana (N wind) caused great damage in Trieste, sinking five boats, one ship, and many small wooden vessels (G. Braun, with reference to Kert).

1834: January 24th: Numerous almond-trees are in full blossom. Drought in Trieste from April to August and in October and November (G. Braun, with reference to Kert).
August 26th: A terrible thunderstorm with hail destroyed many roofs on houses, churches, and public buildings in Trieste. The rainwater which therefore reached the lower floors caused unprecedented damage, destroying furniture, libraries, archives, and other objects (G. Braun, with reference to Kert).

1835: Drought from June to August (G. Braun, with reference to Kert).

1836: Unusual temperatures between May 10th and 17th forced people to again put on winter clothing and wear coats (G. Braun, with reference to Kert).

1838: Very cold January and February in Trieste (G. Braun, with reference to Kert).

1839: The snow reached two and a half feet or even deeper in Trieste (G. Braun, with reference to Luzzati).
Drought in July and August (G. Braun, with reference to Kert).

1840: Cold winter, especially in January and February (G. Braun, with reference to Kert).

1841: Severe drought in Trieste from July to September (G. Braun, with reference to Kert).

1842: Severe drought in August and September (G. Braun, with reference to Kert).

1843: February 12th: almost all trees blossomed. Drought in August and September (G. Braun, with reference to Kert).

1844: March 16th-17th: Some almond-trees begin to blossom. Vegetation in Trieste is five or more weeks late in comparison with the previous year (G. Braun, with reference to Kert).

1845: A mild January and very cold February. On January 6th oak-trees still had their leaves. On March 27th, almond-trees began to blossom, at least six weeks later than in other years (G. Braun, with reference to Kert).

1846: Severe cold in Istria (B. Schiavuzzi).
On February 1st, almond-trees start to blossom. Early blossoming was also recorded in 1821 and 1834 (G. Braun, with reference to Kert).

1847: On March 9th, almond-trees start to blossom (G. Braun, with reference to Kert).
After midnight on August 25th a tempest accompanied by continuous lightning, thunder, and heavy rain began in Trieste and lasted until morning. Water flooded houses, damaged several streets, arcades, houses, walls, the Greek cemetery, and other objects (G. Braun, with reference to Kert).

1848: March 8th, trees blossom. Severe drought in August and September (G. Braun, with reference to Kert).

1849: March 4th, trees start to blossom (G. Braun, with reference to Kert).

1850: January 26th, heavy snow and bitter cold in Trieste. Nobody recalls such amounts of snow in the past. March 9th, trees blossom despite the severe drought (G. Braun, with reference to Kert).

2.2 ATTEMPTS AT PALAEOCLIMATIC RECONSTRUCTIONS

There are many examples of palaeoclimatic reconstructions in the literature in which the authors used historical records of climatic events as their source of information. R. Glaser and R. Walsh (1991) put together some of the latest research with an extensive review of literature on this subject. It is evident from the reconstructions that have been made that their success depends on the amount of data and its reliability. While the amount of data that we collected for the northern Adriatic region may appear at first sight to be quite large, we may discover that it is inadequate for a thorough reconstruction as soon as we start categorizing data into particular groups of events. There is especially a lack of data for the period before the 16th century.

From the collected data we have therefore been unable to make a complete reconstruction following the example of V.W. Shaowu (1991), who reconstructed the ten-year seasonal and annual temperature fluctuations for northern and eastern China between 1380 and 1980 on the basis of historical documents. We have only been able to discover some trends in climate changes for particular time periods, determining periods with more frequent colder or milder winters and dry summers. Because exceptional events affect average values, especially when their occurrence is sufficiently frequent in a short period of time, we have attempted to determine the deviations in the winter temperatures for two short periods (1475-1491 and 1700-1765) from present-day averages.

2.2.1 PERIODS WITH SEVERE AND MILD WINTERS

The largest number of reports in our chronicle are about cold winters. This information is recorded in the form of subjective estimates of the degree of cold (exceptionally severe cold, exceptional cold, bitter winter, severe cold, very cold winter, long and cold winter, intense cold) or in the form of reports on the consequences of the cold (the freezing of olive trees, vines, and fruit-trees, the freezing of the Venice lagoon, the freezing of travellers). Data on the freezing of the Venice lagoon and the freezing of olive trees is particularly useful for reconstructions as we can quantify the degree of cold according to similar events in the present.

We realize that the chronicle is inadequate, especially of the earlier centuries, and that any reconstruction based on it is therefore less reliable. Nevertheless, on the basis of the assembled records showing the frequency of severe winters, we may infer that periods of colder winters occurred between 800 and 865, between 1300 and 1570 (reaching peaks between 1400 and 1450 and 1475 and 1570), and between 1680 and 1865. For the latter period, very frequent records exist regarding severe winters in the first half of the 18th century.

Winters with less frequent data on freezing occurred between 875 and 1300 and between 1570 and 1675.

There are very few records about mild winters, especially from the period before 1700. The greatest number (six) were recorded between 1775 and 1850, the same period in which we have frequent records about severe winters, which suggests the probability that winters were very changeable in this period.

The period from 875 to 1300 during which records of severe winters are very rare and the periods of frequent severe winters between 1300 and 1570 and 1680 and 1865 correspond well with the trends in temperature developments which have been established for Europe.

Apart from its first 100 years, the first period (875-1300) corresponds with the "secondary climatic optimum" which according to A. Henderson-Sellers and P.J. Robinson (1991) lasted from 1000 to 1300 in Western and Central Europe. This was a warm period in which summer temperatures were about 1°C higher than today's temperatures.

The periods of frequent severe winters (1300-1570 and 1680-1865) fall into the "Little Ice Age" which lasted in Europe from 1430 to 1850 and had two cold peaks: the first around 1470 (the Venice lagoon froze four times between 1475 and 1491) and the second at the end of the 17th century (chroniclers recorded severe winters around the Gulf of Trieste in 1684 and 1685).

D. Camuffo (1990) especially marked the years when the winter cold was very bitter and the Venice lagoon froze more than usual (indicated in our chronology with an asterisk). In this century such cold was recorded in 1929. The average winter temperatures in Trieste at the time were 3.3°C lower than the century average (the average for 1841-1940 was 5.2°C; in the winter of 1929, it was 1.9°C - S. Polli, 1942). The Venice lagoon has frozen less severely twice this century, in 1956 and 1985 when according to data from the archives of HMZ RS the average winter temperatures were about 2°C lower than the century average (1956: 4.2°C; 1985: 4.4°C). In all three cases, olive trees froze in the Koper region.

During the great freeze of February 1929, the absolute minimum temperature in Trieste was -14.3°C. In Koper the absolute minimum temperature was -12.8°C during the February 10, 1956, freeze (D. Meze, 1959) and -8.1°C during the January and February freezes of 1985. The lowest temperature recorded in Portorož in January 1985 was -9.3°C and in Kubed -16.0°C, while in 1956 it was -15.0°C .

Around the time of the first cold peak in the Little Ice Age between 1475 and 1491, the Venice lagoon froze intensely some four times in seventeen years. Assuming that the freezing winters were approximately as cold as the winter of 1929 and that the other winters were average, the winters of the 1475-1491 period were 0.8°C colder than present-day averages, while the average temperature of the coldest month was below 0°C.

According to our chronology, one of the cold peaks was between 1700 and 1765. There are sixteen records of severe winters in this period, four of which refer to the freezing of the

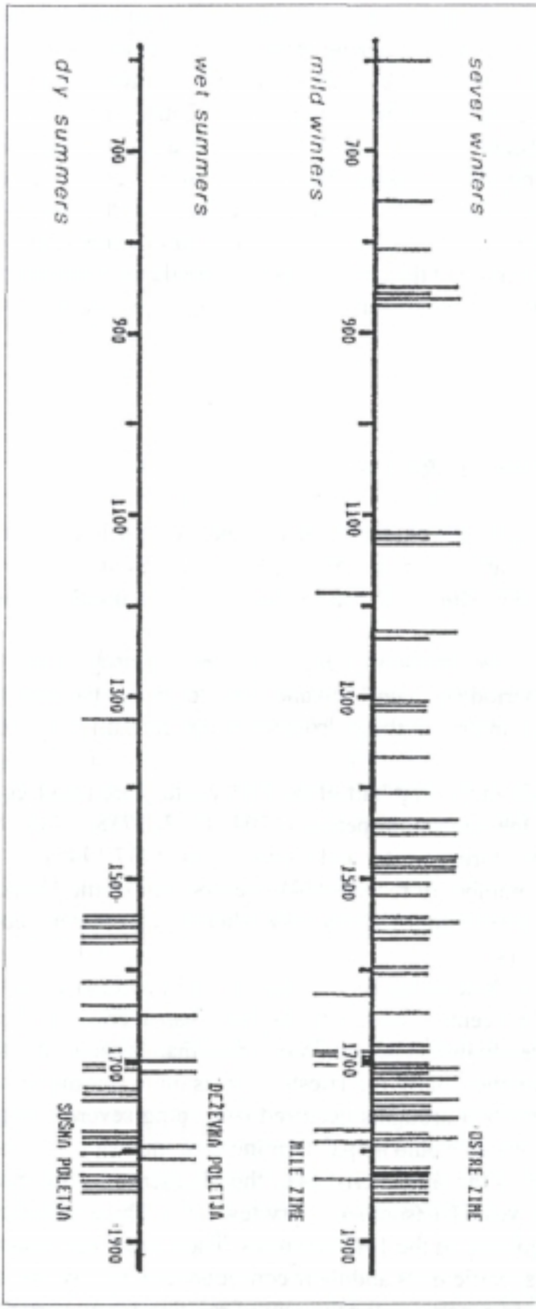


Fig.2: Periods of concentration of certain exceptional climatic conditions.
Sl.2: Obdobja s koncentracijo nekaterih izrednih klimatskih dogodkov.

Venice lagoon. Taking into consideration the relationship between winter temperatures and the freezing of olive trees and the freezing of the Venice lagoon in the 20th century, we may conclude that winters on the coasts of the Gulf of Trieste were about 0.5°C colder in the first half of the 18th century than the average for the 20th century.

The reconstructed data is only a framework since it takes into consideration only severe winters and is based on the assumption that winters in the remaining years were average. Judging from the number of severe winters recorded, we may assume that there were numerous more winters of below average cold which did not, however, have consequences which attracted the attention of the chroniclers. It is similarly very probable that along with the cold winters there were also some above-average warm winters which were not recorded.

2.2.2 DRY AND WET PERIODS

There are considerably fewer records on dry and wet years than on freezing years. The records refer either to various seasons or to only particular days, which makes reconstruction even more difficult. Almost all records date from the middle of the 16th century onwards.

According to the concentration of events, we can identify three periods of frequent drought. First is the period between 1540 and 1660 for which we have nine records. From these records we may infer that these droughts occurred during the vegetation period in particular.

Records of drought in the first half of the 18th century are also frequent. The majority refer to droughts in the vegetation period (1704, 1717, 1718, 1735, 1747, 1748), while three refer to droughts during winter and spring (1734, 1737,1745).

Judging from the number of records (14), the first half of the 19th century also stands out, in particular the period from 1820 to 1848 when the chroniclers recorded twelve years with droughty summers.

It is difficult to conclude on the basis of the chronicle records alone that the summers in the first half of the 19th century were actually drier than average, as the number of written sources increased greatly in this period, in our case thanks especially to L. Kert who systematically kept a weather- diary for Trieste. Kert is quite sparing in his statements as he only mentions times when droughts occurred (including severe droughts) without mentioning their effects, which would help determine their intensity. It is also known that summer droughts are one of the characteristics of the Mediterranean climate.

Records on rainy years (seasons) are very few (six). Three of these refer to the end of the 18th and the beginning of the 19th centuries. There are more reports about exceptionally heavy rains on specific days and their consequences, but we are unable to reach any conclusions from these reports on the amount of rainfall during particular longer periods.

In 1841, a meteorological station began operation in Trieste, and it is possible to compare Kert's records on summer droughts in the 1840s with data from this station (Table 1).

Table 1: Comparison of Kert's records on droughts with data from the Trieste meteorological station.

	Kert's records	Trieste meteorological station data			
				Average 1841-1940	
		Precipitation	No. of Days	Precipitation	No. of Days
1841:	Severe drought from July to September	96 mm	10	168 mm	17
1842:	Severe drought in August and September	252 mm	17	205 mm	17
1843:	Drought in August and September	151 mm	9	205 mm	17
1848:	Severe drought in August and September	13 mm	10	205 mm	17

Kert mentions severe droughts in 1841, 1842, and 1848. Although drought is not dependent only on the amount of rainfall and the number of precipitation days, according to data for Trieste for the months of July and August 1841, there was 57 % of the long-term precipitation total while the number of precipitation days was less by seven days. In August and September of 1848, 55 % of the usual amount of precipitation was recorded, while the number of precipitation days was again less by seven days. If Kert's records for 1842 are accurate, the amount of precipitation during the "severe drought" of August and September was 23 % higher than average, while the number of precipitation days was at the level of the long-term average. On the other hand, measured data for the same year indicates that the drought lasted from June through August when 97 mm of rainfall were recorded, amounting to only 36 % of the usual amount, while the number of precipitation days was twelve days less (normally 28). We may thus conclude that Kert's records are not accurate.

Kert mentions the August and September drought of 1843 with no adjective. Data indicates that the amount of precipitation was 27 % lower than average and the number of precipitation days was less by almost one half.

2.2.3 RECORDS OF FAMINE, SHORTAGES, AND GOOD HARVESTS

Famine, shortages, and high prices were not always the result of bad weather alone (the major shortages of 1442 and 1475 were caused by locusts which destroyed field crops; major shortages were also caused by plagues, wars, and Turkish invasions). The great majority of shortages, however, were the result of modest harvests caused by bad weather. According to chronicle reports, in most cases bad harvests were the result of individual weather incidents (violent thunderstorms with winds, storms, and gales in 1488, 1489, 1563, 1683, 1706, and 1710; droughts in 1559, 1704, 1718, and 1802; and severe winters as in 1339). There are also frequent cases when the causes of famine or shortages were not identified (793, 1510, 1528, 1546, 1581, 1582, 1590, 1629, 1649, 1650, 1752, and 1817).

Due to the great importance of wine in the economy of the time, it is not surprising that quite a number of records refer to poor grape harvests and wine shortages, especially in the middle of the 14th century (1339, 1348, 1349, 1350, 1352, and 1356) and in later centuries in the years 1489, 1560, and 1629. The reasons for poor grape harvests in the middle of the 14th century are not known, since the chronicles do not include any extraordinary weather incidents during this period.

If we set aside the reports concerning poor grape harvests in the middle of the 14th century, almost half the remaining records about general shortages were made in the 16th century. The causes may be found in climatic conditions as well as in political events and plagues. There were seven severe winters in this century (1503, 1515, 1548, 1549, 1561, 1569, and 1595) and six severe droughts (1540, 1546, 1548, 1559, 1561, and 1562). The middle of the century was particularly critical, from 1540 to 1560. At the beginning of the 16th century, the Venice-Austrian wars were being waged (1508-1516), and Turkish invasions were also frequent leaving whole regions of Venetian Istria ravaged, villages razed, and populations massacred. The plagues also took their toll (according to F. Gestrin, 1965, there were plagues in 1511, 1543, 1553, 1557, 1559, and 1573), reducing the population so much that the Venetian authorities had to resettle some of the regions of Istria. The plague of 1553, for example, reduced the population of Koper from 8000 to a mere 2310 (S. Žitko, 1976)

Records of good harvests and prosperity in particular years point to favourable weather conditions. There are very few such records in the chronicles that we reviewed. Two records refer to plentiful harvests in the Gorizia region in 1525 and 1546, several sources mention 1635 as a very productive year, and good grape harvests are recorded at the beginning of the 18th century (1701, 1702, 1706, and 1727).

3. THE USE OF DATA ON THE PRODUCTION OF SALT IN THE PIRAN SALTWORKS FOR THE RECONSTRUCTION OF PRECIPITATION CONDITIONS IN SUMMER MONTHS

The procedure for producing salt at the Piran saltworks, whose origin according to some sources dates back at least to the 10th century (M. Pahor, T. Poberaj, 1964), has essentially not changed to the present day. The basic procedure is to gradually evaporate sea water which is trapped in evaporation basins until it becomes dense enough to be allowed into the crystallizing pans where crystallization and salt production occurs. The main factor that determines the production of salt still remains the weather or rather weather conditions for the evaporation of sea water. Evaporation depends on the amount of solar energy (solar radiation) or on rainfall, the number of cloudy days, and the number of clear days. A successful salt production season requires minimum relative humidity of the atmosphere and windy weather. On windless days, a thin layer of moist air forms above the water level and prevents evaporation.

Weather and climatic conditions in the northern Adriatic region allow the start of the salt season in April or at the beginning of May. At this time it is above all necessary that the weather is clear and sunny without much rainfall. The salt season normally lasts until September or until the first heavy rainfall at the end of the summer when the weather becomes so bad that production is no longer profitable.

The social factors that determine production are the availability of the work force, promptly executed preparation of the saltworks (cleaning channels, repairing dikes and sluice gates, etc.), and political and economic measures and circumstances (limits on production due to state monopolies, periods of peace and war, and the changing of political authorities).

Since the technology for the production of salt has changed relatively little through the centuries and since production is heavily dependent on weather conditions in summer months, especially on rainfall, we felt that with the help of data on salt production in particular years we could reconstruct the weather conditions in summer months during the period before measurements were taken by instruments.

3.1 METHODOLOGICAL APPROACH

The methodological approaches that we adopted are to some extent similar to approaches applied in the reconstructions of past climate with the help of dendrochronology. To start with, we looked for statistical links between salt production and climatic elements and determined the strength of these links during the period for which data from meteorological stations and data on salt production is available.

Table 2: Salt production in the Piran saltworks (1926-1936) and data on precipitation from the Trieste meteorological station.

Year	Salt production (t)	Amount of precipitation May-Sept.(mm)	No. of days of precipitation >=0.1 mm
1926	12 152	611	62
1927	31 483	340	49
1928	38 857	279	50
1929	30 098	284	41
1930	7 871	605	58
1931	32 854	385	51
1932	7 540	575	56
1933	18 208	507	65
1934	6 657	572	60
1935	37 522	157	38
1936	22 077	331	52

Sources: G. Cumin, 1937; S. Polli, 1946

We calculated Pearson's correlation coefficient between annual production and the amount of rainfall in May, June, July, August, and September for the 1926-1936 period, after the First World War and after the limit which had been imposed on salt production by the Austrian authorities had been lifted (G. Cumin, 1937). The relationship is very strong ($r = -0.9221$) and despite the low figure ($N = 11$), it is statistically significant. The relationship between the number of precipitation days during the period from May to September ($r = -0.7593$, $p = 0.01$) is somewhat weaker. It may be concluded from the two relationships that salt production was greater during those years when there were fewer precipitation days and less rain in the summer months. We were able to account for 85 % of the variance in production by the amount of precipitation in summer months and 58 % of the variance by the number of precipitation days.

We also calculated the correlation between salt production and precipitation from May to September for the 1946-1959 period. This period was characterized by a large drop in production due to sociopolitical changes and the abandonment of parts of the saltworks (R. Savnik, 1965). In order to at least partially eliminate the effect of social factors (the reduction of funds for the saltworks, lack of labour force), we calculated the annual production per square meter of the active saltworks. In this case, the correlation was also high and statistically significant ($r = -0.7126$, $p = 0.01$, $N = 14$).

Table 3: Salt production at the Piran saltworks in the 1946-1959 period (in kg/m2) and recorded precipitation in Trieste for the May-September period.

	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	Aver.
Salt production (kg/m^2)	7.00	5.07	1.49	6.03	6.39	4.34	5.57	2.20	3.51	1.83	2.80	2.20	4.82	1.45	3.91
Amount of precipitation May-Sept. (mm)	303	304	517	362	421	410	361	520	67	411	444	430	280	448	398

Sources: Droga Portorož company archives; S. Polli, 1946

We also investigated the relationship between salt production and climatic elements for the 1961-1990 period. Since the social circumstances for salt production were also very unstable during this time, we used annual salt production per square meter of crystallization area as the dependent variable for calculating the correlation coefficient. As the independent variables, we used amount of precipitation from May to September, the number of precipitation days of at least 1 mm, the number of cloudy days, the number of clear days, and the useful evaporation during the salt season. All climatic data, apart from useful evaporation, was taken from the Portorož meteorological station. The salt producers themselves calculate useful evaporation (E kor) according to a formula which takes into consideration the amount of precipitation and the amount of water that evaporates from an evaporimeter:

$$E\ kor = E - 1.3 \times P$$

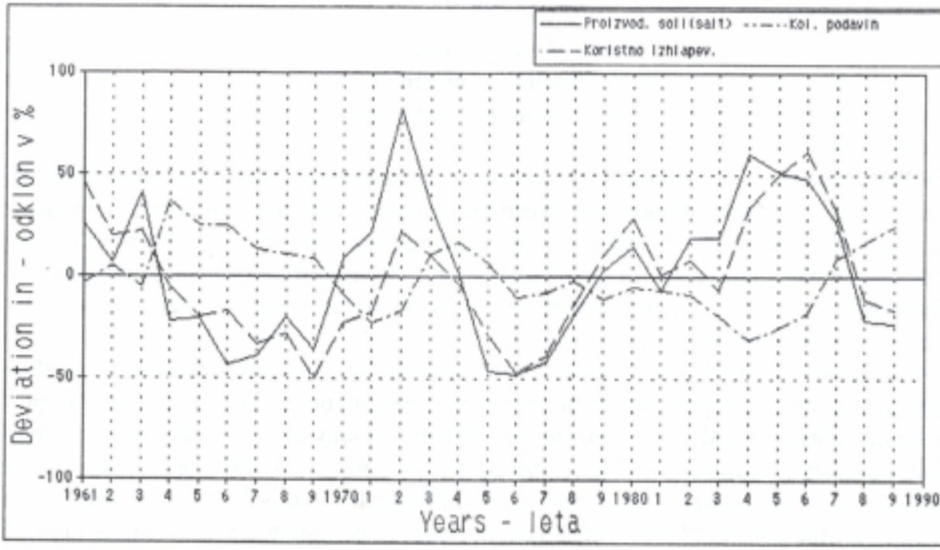
E -- water evaporated from an evaporimeter
P -- amount of precipitation
E kor -- useful evaporation

The calculated correlation coefficients are high and statistically significant (Table 4). The strongest are the relationships between salt production and the number of precipitation days ($r = -0.7178$, $p = 0.001$) and between production and useful evaporation($r = 0.7275$, $p = 0.001$). Somewhat weaker are the relationships between production and precipitation, number of cloudy days, and number of clear days. The relationships between climatic elements are also statistically significant.

Salt production is directly proportional to useful evaporation and to the number of clear days and inversely proportional to the number of precipitation days, to the amount of precipitation during the salt season, and to the number of cloudy days. In other words, production is greater in seasons when conditions for the evaporation of sea water are favourable, that is, when the weather is clear (and windy). Production is less during rainy seasons, in which case the number of precipitation days is more important than the amount of rainfall.

Table 4: Correlation analysis results

	Useful evaporation in the salt: season (mm)	Amount of precipitation May-Sep. (mm)	Number of days of precipi-tation > = 1 mm (May-Sept.)	Number of clear days (May-Sept.)	Number of cloudy days (May-Sep.)
Salt production per m^2 crystallization surface	r = 0.7275 p = 0.001	r = -0.6159 p = 0.001	r = -0.7178 p = 0.001	r = 0.4890 p = 0.01	r = 0.5243 p = 0.01
Useful evaporation in salt season (mm)		r = -0.4474 p = 0.01	r = -0.7204 p = 0.001	r = 0.5449 p = 0.01	r = -0.5590 p = 0.01
Amount of precipitation May-Sept. (mm)			r = 0.7195 p = 0.001	r = -0.4231 p = 0.05	r = 0.3609 p = 0.05
Number of days of precipitation > = 1 (May-Sept.)				r = - 0.6023 p = 0.001	r = 0.5679 p = 0.01
Number of clear days (May-Sept.)	r - Pearson's correlation coefficient p - level of significance				r = -0.7264 p = 0.001



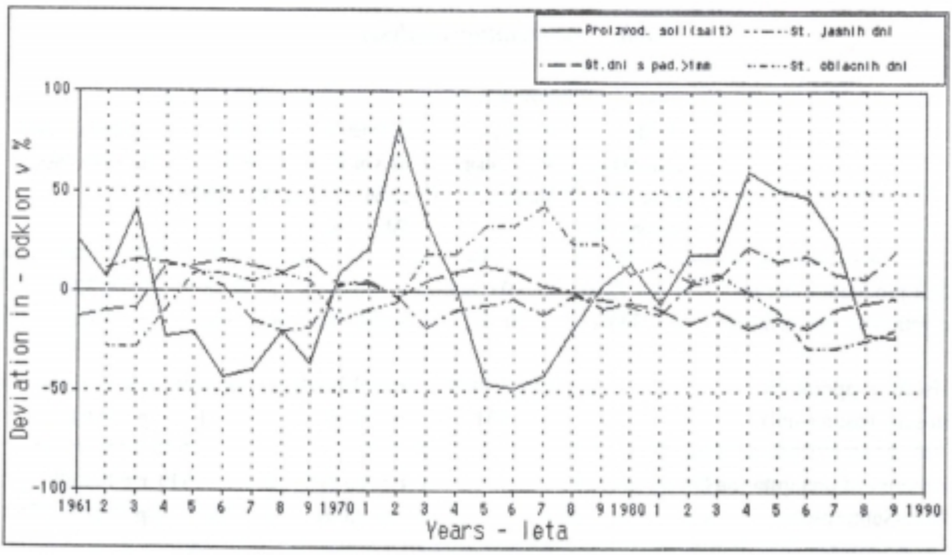


Fig.3,4: Relation between salt production amount of precipation and usefull evaportation. The second diagran; : relation between salt production, number of days with clear sky, number of days with precipitation and number of days with cloudy weather at the salt works of Piran.

Sl.3, 4: Odnos med proizvodnjo soli in klimatskimi elementi

We tested the applicability of the calculated relationships for the reconstruction of precipitation conditions on the case of data on the salt production during the 1961-1990 period. To begin with, we converted the production data into a temporal series of deviations from the average (in %) for the whole period. For easier comparison with the climatic data, we smoothed the time series using a three-year running means and did the same with the climatic data.

Due to the high correlation coefficient in the case of the directly proportional relationship between production and useful evaporation (Figure 3), both curves are very consistent. During periods of above-average useful evaporation, salt production was correspondingly above average and vice versa. The curves for salt production and the number of clear days are less consistent (Figure 4), and we were able to account for only 24 % variance of their mutual relationship.

In the case of inversely proportional relationships, the most reliable reconstruction is for the number of days of precipitation during the April to September period where we were able to account for 51 % variance and somewhat less for the amount of precipitation in this period. On the basis of both relationships, we may nonetheless reconstruct periods with above average and below average precipitation during the salt season, especially longer periods, with considerable reliability.

It is evident from the data and the shape of the curves that salt production is much more variable than the climatic elements on which it depends. During the periods when the number of precipitation days increased or decreased by 20 % from the average or when the amount of precipitation increased or decreased by 30 %, salt production fluctuated by 50 % of the average. Under good weather conditions, it was even 80 % above average. Salt producers protected themselves from larger negative fluctuations in production caused by the weather by storing "heavy water" in special pits ("fossa del cavedin") away from the rain. The water would then be exposed for evaporation when the weather improved (M. Pahor, T. Poberaj, 1964).

3.2. THE RECONSTRUCTION OF PRECIPITATION IN SALT SEASONS DURING THE FIRST HALF OF THE 19TH CENTURY

Because salt production was always an important economic activity in Piran and the production and sale of salt were carefully supervised, we anticipated that we would find necessary data on the production and number of pans in the abundant literature on the subject (N. Gallo, 1856; E. Nicolich, 1882; A. Danielis, 1931; G. Cumin, 1937, M. Pahor, 1957; F. Gestrin, 1965; F. Semi, 1973; D. Mihelič, 1985, and others). Regrettably, data on production and the number of pans in the literature is quite fragmented and refers only to particular years with no surveys covering the longer time periods in which we were particularly interested.

The most interesting periods for the reconstruction of precipitation conditions are primarily the times when salt production was not limited. One such period for which we wanted to obtain data from the Piran archives was between 1749 and 1823. There is a special section in the archives where documents about the Piran saltworks are kept. We began our investigation with box number 29 which contains material for the 1764-1811 period. Unfortunately, data for this period, which was marked by major political changes (the fall of the Venetian Republic, the first period of Austrian control over Istria, and the Napoleonic Illyrian Provinces) is quite lacking, and the first information we found on salt production was from 1806. To be able to read documents from earlier decades kept in this box, a knowledge of Venetian paleography is also necessary.

From the literature (E. Nicolich, 1882) we got data on salt production for the decade 1791-1800 from a copy of a table was compiled on November 20, 1801, by the "Consilium XX salis," the local salt office which, independent from the municipality, represented the collective of salt producers and saltworks owners (M. Pahor, T. Poberaj, 1964). The table was intended to familiarize the new Austrian authorities with the situation at the Piran saltworks.

Without additional help from experts on Venetian paleography, we were unable to examine the rest of the sources from the 18th century. We therefore decided to collect data on salt production in the first half of the 19th century, that is, until 1841, when the Trieste meteorological station began operation, and with the help of this data we attempted to reconstruct the summer precipitation during this period. We obtained most of the data from the documents "Atti della Deputazione de' Sali in Pirano" and "Atti della Presidenza dal Collegio de Venti de Sali di Pirano" covering the years from 1806 to 1841. The documents for this period are kept in the boxes 29 through 68.

There is continuous data for the years following 1805 when Istria became part of the Illyrian Provinces. Weekly production reports were dispatched to the "Consilium XX salis" from the saltworks, separately for the different types of salt (white, mixed, and black). The reports include a reference number, date, conditions of production (description of the weather), weekly production figures, and total production since the beginning of the season. Unfortunately, some of the weekly reports are missing.

By comparing the data on salt production obtained from the archives with that published in the literature, we observed that the data differs considerably for particular years, including even those years for which we were able to find final reports on salt production in the archives. Two such examples are 1822 and 1840. According to the archives, production amounted to 55 380 modius, while according to G. Cumin (1937) it was 43 159 modius. There is a similar difference for the year 1840. Differing also is some of the data on the number of pans. Because we extracted most of our data from the archives, we gave preference to archive sources in these instances.

There may be many reasons for the differences in data sources. We suspect that there were different primary sources available to the authors in which conflicting interests were reflected. For example, it was in the interest of the saltworks owners and of the Piran municipality to produce as much as possible, since the owners were able to keep one fifth of the total production for themselves, one seventh went as a tax to the municipal authority, and the rest was purchased by the state. Owners also hoarded salt to trade on the black market. It was in the interest of the state, especially during periods of limits on production, to ensure that the limits were respected, which the owners always resented and produced more than was allowed.

Differences in data could also be the result of different units of measurement applied for measuring the amount of salt, leading to differences arising from the conversion of the units. During the period of the Venetian Republic and during part of the Austrian period, the unit of measurement was a "modius" of salt and during the Illyrian Provinces period a "Milano Quintal". According to D. Mihelič (1985), a modius of salt was equal to 896 kg, while F. Gestrin (1965), citing A. Ciano from Trieste, maintains that in the 18th and 19th centuries one Istrian modius of salt was equal to 840 kg.

After 1820, the Austrian authorities demanded many times that the modius be abolished and pressed for the introduction of the "Viennese Quintal." Some reports on salt production continued to use the modius for some years, others used the quintal and in many cases both units were used together.

According to A. Ciano (F. Gestrin, 1965), one modius was equal to 15 Austrian quintals. Our calculations for the years during which production was measured in both units revealed that at times one modius was equivalent to 18.1 Austrian quintals. Where we have presented salt production in modius because the majority of data is in this unit, we have used 1 modius = 15 Austrian quintals as the conversion factor.

Apart from the problems that we had with the data, the reconstruction of precipitation conditions during the summer months in the first half of the 19th century was also made difficult by the historical circumstances under which salt was produced as well as by the economic measures imposed by the central authorities.

The general social and economic crisis at the end of the Venetian Republic also affected the Piran saltworks. The number of pans was reduced and the saltworks became increasingly neglected. The new Austrian authorities therefore invested considerable funds in the renewal of the saltworks. In 1802, work was begun on the regulation of the Dragonja River and repairs were made to the exterior dikes. All limits on production were abolished and the purchase price for the salt was increased. By the end of the first Austrian period in Istria, the number of pans had increased from 4484 in 1800 to 4637 in 1805 (E. Nicolich, 1882).

The growth of the saltworks continued during the period of the French occupation of Istria and the Illyrian Provinces (1805-1813). However, problems began to appear in the salt trade since salt consumption in the Illyrian Provinces was lower than the total production from Škedenj, Žavlje, Milje, Koper, and Piran. Just when the French authorities had begun preparing measures intended to abolish the ancient privileges enjoyed by salt producers, after which the saltworks would become a public enterprise in which owners would only have the right to produce salt for the state, the Illyrian Provinces collapsed (E. Nicolich, 1882).

With the establishment of the second Austrian period in Istria, the saltworks began to flourish once more. The number of pans increased to 7034 in 1818 and remained the same until the end of the 19th century. Salt production doubled compared with figures from the beginning of the century. However, problems again arose with the sale of salt, forcing the Austrian authorities to impose limits on production in 1824 amounting to three fifths of the salt produced in 1822 and later to set limits separately each year. Initially, the limits were not very restrictive as Piran salt producers were allowed to produce unlimited amounts of salt of the "granito" type. After 1832, however, limits were imposed on all types of salt. The Piran saltworks could increase production only when the Koper saltworks failed to meet their assigned limit (E. Nicolich, 1882).

The most appropriate period for the reconstruction of precipitation conditions was therefore before the imposition of limits in 1824. In order to eliminate the effect of the increase in the number of saltworks on salt production, we calculated annual production based on a pan which was approximately the same size and covered about 100 m². We then calculated the average production per pan for the whole period as well as divergences from average production, for individual years (in %). We smoothed the curve by calculating a three-year running means.

Taking conditions in the 20th century into consideration, we concluded that the negative divergences ought to correspond to the years when the number of precipitation days

Table 5: Data on salt production and the number of pans in the Piran saltworks for the 1806- 1823 period.

Year	Production in modius	Number of pans	Production per pan (in modius)	Divergence from average (in %)	Three year running means
1806	10 891	4637	2.35	-22.4	
1807	11 764	4637	2.52	-16.8	-4.9
1808	17 948	4655	3.77	24.4	1.7
1809	14 038	4764	2.95	-2.6	20.4
1810	20 138	4764	4.23	39.6	20.1
1811	17 864	4764	3.74	23.4	20.0
1812	14 046	4770	2.94	-2.9	-2.9
1813	10 233	4770	2.14	-29.4	-24.8
1814	8 399	4776	1.75	-42.2	-44.8
1815	5 460	4796	1.12	-63.0	-60.0
1816	4 308	4850	0.68	-77.5	-32.6
1817	27 500	6345	4.32	42.6	-11.3
1818	21 500	6363	3.06	1.0	12.6
1819	20 100	7034	2.86	-5.6	27.6
1820	40 000	7034	5.68	87.4	22.2
1821	18 100	7034	2.57	-15.2	77.3
1822	55 380	7034	7.87	159.7	69.6
1823	35 000	7034	4.98	64.3	

Source: PAK Unit Piran, Piran Saltworks Fund, Box 29-23; E. Nicolich, 1882.

and amounts of moisture were above average during the salt season (April-September). In contrast, the years of positive divergences ought to correspond to seasons which were drier than average. Due to the problems related to data collection and the unstable conditions of production, we verified wherever possible the resulting reconstruction with the help of data from the weather chronicle for the northern Adriatic region and records about the weather made in the salt production reports.

It may be gathered from Figure 5 that there were two periods of drier summers and three periods with more rainy summers. Dry summers with favourable conditions for the evaporation of sea water occurred between 1808 and 1811 and even more so between 1818 and 1822. The chronicles do not include any specific records on dry weather during the summers between 1808 and 1811. In his study of the Piran saltworks, E. Nicolich (1882) states that during the Illyrian Provinces period, the weather was generally favourable for salt production. It was also reported that heavy rain in July 1810 flooded the Fazan saltworks in Lucija, although it evidently had no great effect on total salt production at the Piran saltworks which was around 20 % above average.

There are more reports from the 1818-1822 period. The chronicles refer to 1820 as an exceptionally dry year and to 1822 as favourable for salt production, while all the remaining years had longer periods which were exceptionally productive (the first half of July 1819, the whole of August 1821). The year 1818 was somewhat less productive, as the weekly reports frequently mention that production was hindered by rain. The salt harvest was nonetheless slightly above average.

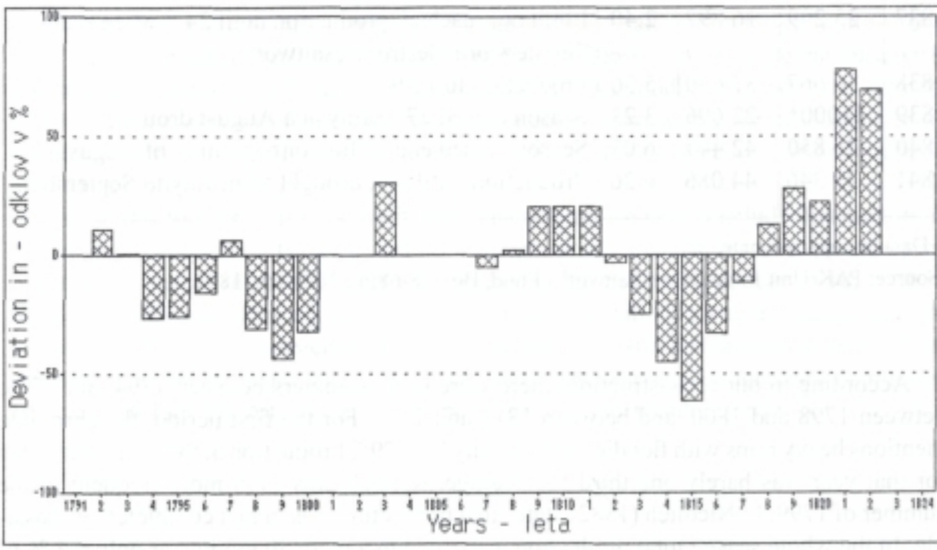


Fig.5: Reconstruction of precipitation for the 1791-1824 April-September seasons by means of data on salt production in the Piran saltworks.

Sl.5: Rekonstrukcija padavin v mesecih april-september v obdobju 1791-1824 s pomočjo podatkov o proizvodnji soli v Piranskih solinah.

Table 6: Some data on salt production for the 1824-1841 period

Year	Limit (in modius)	Salt production (in modius)	Production per pan (in modius)	Comments
1824	25 000	26 221	3.73	Limit reached 23/9.
1825	16 824	22 550	3.20	Production to 20/9; season ended due to rains.
1826	16 000*	24 300	3.45	Production to 26/8.
1827	10 924	11997	1.70	Production to 22/9; rainy June.
1828	10 924	11260	1.60	Season closed 7/7; severe drought
1829	15 772	16 292	2.32	Production to 16/9.
1830	11 429	13 894	1.97	Season closed around 20/7; July and August drought.
1831	11 886	6 415	0.91	Production to 13/9; rainy summer
1832	13 714	14 000*	1.99	Season closed 7/9; August was terribly drought.
1833	12,800	12 800	1.82	Limit reached 4/9; July drought, rain in the middle of August.
1834	11 886	17 859	2.54	Season closed 8/10; production until weather permited it.
1835	10 971	11380	1.62	Season closed 6/7; drought July and August.
1836	19 307	23 081	3.28	Season closed 11/7.
1837	25 209	16 897	2.40	Limit not reached; production until 24/8 when the thunderstorm destroyed saltworks.
1838	36 667	37 680	5.36	Production to 12/9.
1839	21000*	22 696	3.23	Season closed 27/7; July and August drought.
1840	28 850	42 444	6.03	Season closed end of July or beginning of August.
1841	29 346	44 086	6.26	Production until 6/7; drought from July to September.

* Data are approximate

Source: PAK Unit Piran, Piran Saltworks Fund, Box 48-68; E. Nicolich, 1882.

According to our reconstruction, there were rainy summers between 1794 and 1796, between 1798 and 1800, and between 1812 and 1817. For the first period, the chronicle mentions heavy rains with flooding around July 20, 1795. Production at the Piran saltworks for that year was barely one third the average. Rainfall was even more frequent in the summer of 1799. E. Nicolich (1882) states that production was in fact completely impossible. In the whole season total production amounted to a mere 30 modius or only 0.4 % of the usual harvest.

The rainy summers between 1812 and 1817 are also confirmed by archive records. Heavy rain was reported for 1815 and for 1816 when "waters from the hills" and high seas flooded the saltworks. The saltworks were also flooded to one foot above their working surfaces in August of 1817 when the salt season ended as a result of the floods and the destroyed fields.

Because production was limited in 1824, it was not possible to make a reconstruction similar to those made before the imposition of the limit. We were able to deduce the weather conditions during the salt season for the 1824-1841 period from data on the height of the limit, whether or not the limit was achieved, dates when the limit was reached and when the salt season was discontinued, and not least from the records on weather conditions for the production of salt in the weekly reports (Table 6).

The prescribed limit was not reached in 1831 and 1837. According to data from the weekly reports, both seasons were rainy.

In view of the fact that the limit was reached quite late (September or even October) in the years 1824, 1825, 1827, 1829, 1831, 1834, and 1838, it may be deduced that the salt seasons were wetter than average. We must, however, be somewhat more cautious with regard to the first eight years after the imposition of the limit (1824-1832) when the limit did not apply to "granito" type salt and control over production was less strict. Records compiled from the weekly reports state that during these eight years, the most rainy summers were in 1827 (exceptionally rainy in June) and in 1825 (rainy September, as a result of which the season was closed on September 20th). For the remaining years, we were unable to find any specific records about rainy seasons.

After the imposition of the limit on the "granito" type salt, the salt season was longest in 1834 when production continued until October 8th. In 1838, the season was closed on September 12th. For both years, there are no specific records of unfavourable weather conditions. It is a somewhat surprising fact that the 1834 salt season lasted until October since the limit ought to have been reached some months earlier. At the time the season was discontinued, surplus production had reached almost 6000 modius. It is not clear from the sources whether prolonged production was intended to compensate for production in the Koper saltworks which had failed to reach the limit, as was the case in 1840 and probably in 1841 as well.

In contrast to years when the limit was reached late, we may conclude that conditions for salt harvesting (dryness of the season) were favourable in those seasons when the limit was reached early (July). The limit was reached at the beginning of July in 1828, 1835, 1836, and 1841, and at the end of July in 1830. Our expectations about dry summers in the years when the limit was reached early are in accordance with information available from other sources for the years 1828, 1835, and 1841 when severe droughts are mentioned, especially in July and August. There are no records on dry weather for 1836.

4. SEASONAL AND ANNUAL TEMPERATURE AND PRECIPITATION FLUCTUATIONS IN TRIESTE AND KUBED DURING THE PERIOD OF INSTRUMENT MEASUREMENT

The oldest operating station in the Gulf of Trieste is the Trieste meteorological station which began taking temperature and precipitation measurements in 1841. During its more than 150-year history, the site and instruments of the station have changed several times but it has never moved out of the city area. According to the authors whose data we used in our research (S. Polli, *1942, 1946*; F. Stravissi, *1976*), its data represents a homogeneous series even though the site of the station changed. These authors have corrected the data, in particular the temperature data, so that it corresponds to the measurements which would have been recorded had the station permanently operated at its present location not far from the sea in the center of the city near the old railway station.

Until 1891, temperature measurements were taken three times a day, and after this year every hour. For this reason, appropriate corrections were made on the average daily temperatures calculated from the three fixed observations for the period 1841-1891. It was thus possible to obtain averages which correspond to the averages calculated from hourly measurements.

Precipitation data was not corrected since parallel measurements were not taken at the times the station was moved. According to S. Polli (1946), later comparisons of annual precipitation graphs revealed that differences between new and old locations, which were expected to be greatest during the 1903-1920 period, were minimal. There was therefore no need to correct the data.

We compared the trends established at the Trieste station with those at Kubed, which in contrast to Trieste is a rural station more distant from the sea and located at a higher altitude. In Kubed, unfortunately, taking measurements began much later: precipitation in 1925 and temperature measurements only after the Second World War. This is also the time when the station was moved from a location above the village down to the village itself, although in our opinion this did not have any noticeable effect on precipitation measurements.

Because the Kubed station was of a lower rank, measurements were always taken three times a day. During the years 1948, 1949, 1953, 1988, and 1989, measurement was interrupted for longer or shorter periods. We interpolated the missing precipitation data for 1948 and 1949 in accordance with the Trieste station. Interpolations of the missing precipitation and temperature data for 1953, 1988, and 1989 were made at HMZ Slovenia.

In our research we examined annual and seasonal precipitation and temperature changes. We calculated five-, ten-, and thirty-year running means based on the deviations in seasonal and annual values from the average for the whole period for which data was available (1841-1991 for Trieste; 1925-1990 precipitation and 1951-1990 temperatures for Kubed,). Using basic data and unadjusted deviations, we also calculated the linear trends (both trends do not differ from one another) and verified their statistical significance. We used the SPSS/PC+ statistical program to calculate deviations, running means, and linear trends.

4.1 TEMPERATURE VARIATIONS

4.1.1 AVERAGE WINTER TEMPERATURES

The short-term and long-term variations in winter temperatures in Trieste and Kubed are presented in Figures 6, 7, and 8. It is evident from the short-term variations (10-year running means) that for most the second half of the last century winter temperatures in Trieste were lower than the average for the whole 1841-1991 period. The coldest periods occurred around 1860 and 1890 when winter temperatures were about 1°C lower than average, or even as much as 1.5°C lower for short periods within the two minimums (5-year running means).

Rising winter temperatures characterize the 20th century, in which the highest temperatures were reached between 1910 and 1925, 1950 and 1960, and 1970 and 1980. During the mid-1950's, winters in Trieste were about 0.3°C warmer than average and up to 0.5°C warmer around 1915, while the warmest winters in the recent history of the Trieste meteorological station were recorded during the 1970's. Considering 10-year running means, the temperature rise in these years reached 1°C, and up to 1.5°C considering 5-year running means.

Despite the statistically significant linear trend in rising winter temperatures in Trieste since the middle of the last century and especially in the 20th century (amounting to 0.52°C / 100 years), there were also periods in this century when temperatures fell below the 150-year average. The lowest temperatures were recorded in the mid-1940's, and below average temperatures were recorded in the mid-1960's and at the beginning of the 1980's. Each oscillation toward lower temperatures, however, was increasingly small and at the beginning of the 1980's barely reached the lower averages of the 10-year running means, another indication of the gradual warming of winters in Trieste in this century.

Temperature variations in Kubed during the last forty years are similar to those in Trieste except that in Kubed, negative deviations are greater than positive ones in comparison with those in Trieste. Because of the too short observation period for Kubed, we unfortunately can not compare the temperature variations at the two stations over a longer period of time nor can we compare the trends. The winter temperature trend in Kubed for the last forty years shows no statistical significance.

During the last 150 years, Ljubljana has had winter temperature variations similar to those of Trieste (M. Krevs, 1986; I. Gams, M. Krevs, 1990; L. Kajfež-Bogataj, 1990). Winters have become warmer in Ljubljana too, a general characteristic for all central and southern European meteorological stations with 100-year records. In contrast to Trieste, Ljubljana winters during the 1980's were not warmer than those at the beginning of the century, which according to Kajfež-Bogataj (1990), somewhat reduces the significance of the hypothesis on winter temperature rises in Ljubljana during the last 90 years.

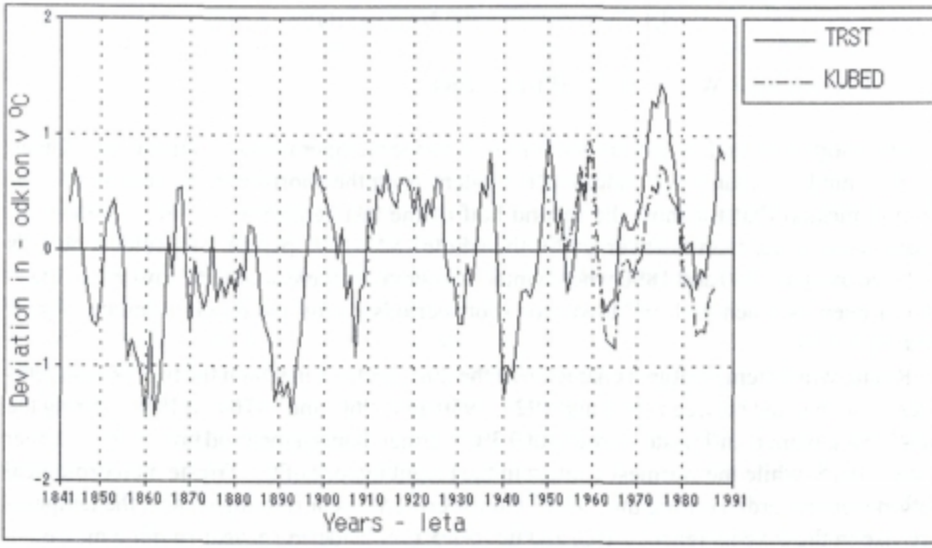


Fig.6: Varying winter temperatures in Trieste (1841-1991) and at Kubed (1951-1990) 5-year running means.

Sl.6: Variiranje zimskih temperatur v Trstu (1841-1991) in v Kubedu (1951-1990) 5 letne drseče sredine.

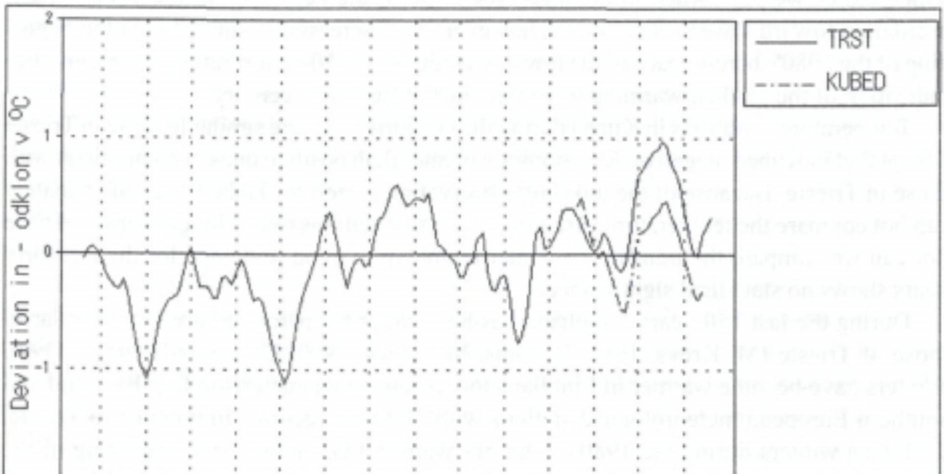


Fig.7: Varying winter temperatures in Trieste (1841-1991) and at Kubed (1951-1990) 10-year running means.

Sl.7: Variiranje zimskih temperatur v Trstu (1841-1991) in v Kubedu (1951-1990) 10 letne drseče sredine.

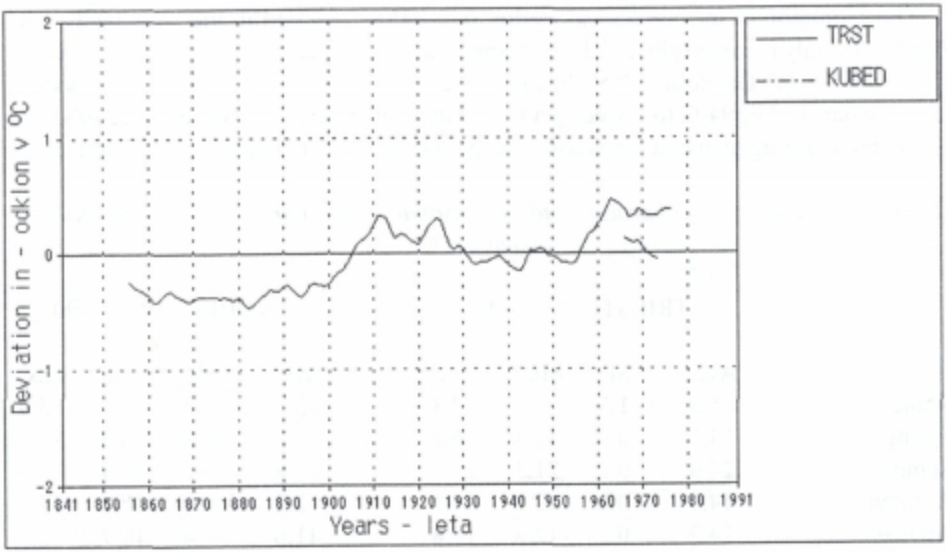


Fig.8: Varying winter temperatures in Trieste (1841-1991) and at Kubed (1951-1990) 30-year running means.

Sl.8: Variiranje zimskih temperatur v Trstu (1841-1991) in v Kubedu (1951-1990) 30 letne drseče sredine.

4.1.2 SPRING TEMPERATURES

Like winter temperatures, spring temperatures in Trieste also varied strongly, within relatively short periods (e.g. between 1940 and 1950 by even more than 2°C). They do not, however, represent any statistically significant trend. Shorter periods of cold springs were recorded during the first half of the 1850's, in the mid-1870's, at the transition from the 1920's to the 1930's, at the transition from the 1930's to the 1940's, and during the mid-1950's.

The warmest springs were recorded in the second half of the 1940's when temperatures were more than 1°C higher than the long-term average. From then on, towards the 1990's, there has been a distinct cooling trend. According to data from the Kubed meteorological station, this trend amounts to 1°C / 100 years or 0.4°C for the last forty years. Because of the short observation period, the trend is not statistically significant. Longer periods of warm springs were recorded between 1910 and 1925, between 1857 and 1870, and before 1850.

Between 1870 and 1910 there was a long period of lower than average spring temperatures. The lowest spring temperatures in the history of the Trieste meteorological station were recorded in the mid-1870's, in four successive years when temperatures were 1.2 to 1.6°C lower than the long-term average of 13.1°C.

The Vallombrosa meteorological station (alt. 955 m) located in the woodlands near Florence in Italy recorded almost identical spring temperatures as those of Trieste between 1872 and 1989 (C. Gandolfo, M. Sulli, 1991). Here too, warmer than average springs were recorded during the 1940's followed by a sharp fall in temperatures towards the 1990's. The Vallombrosa spring temperatures during this period have no statistically significant trend.

Table 7: Basic statistical characteristics of seasonal temperatures in Trieste and Kubed (in degrees C).

	TRIESTE (1841-1991)				KUBED (1951-1990)			
	Ave.	SD	Min.	Max.	Ave.	SD	min.	Max.
Winter	5.5	1.3	1.9	7.8	3.7	1.0	0.7	5.9
Spring	13.1	0.9	11.3	16.1	10.6	0.8	8.9	12.1
Summer	22.9	0.8	21.3	25.0	19.8	0.7	18.4	21.6
Autumn	14.9	0.9	12.0	17.1	12.2	1.0	10.3	14.5
Annual	14.2	0.5	12.8	15.8	11.6	0.4	10.7	12.8

Ave. - average
SD - standard deviation
Min. - minimum value
Max. - maximum value

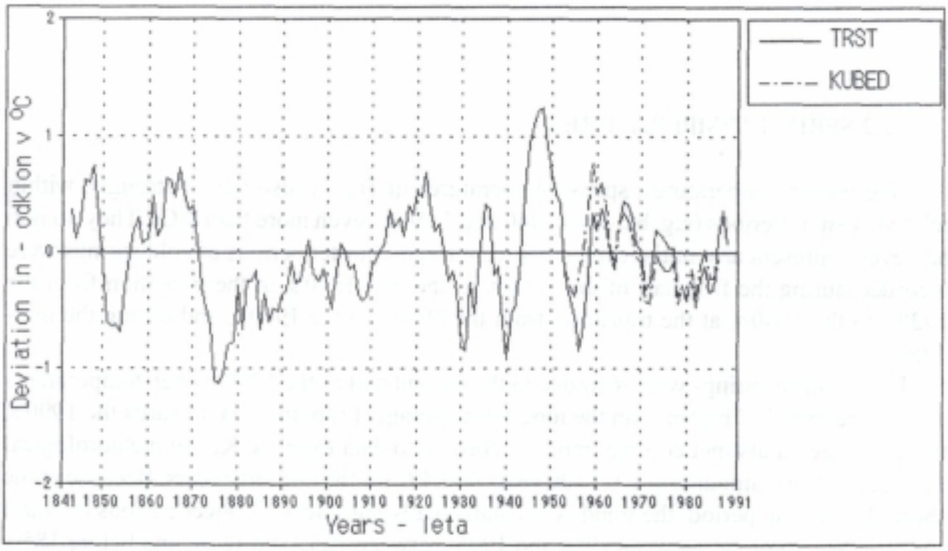


Fig.9: Varying spring temperatures in Trieste (1841-1991) and at Kubed (1951-1990) 5-year running means.
Sl.9: Variiranje spomladanskih temperatur v Trstu (1841-1991) in v Kubedu (1951-1990) 5 letne drseče sredine.

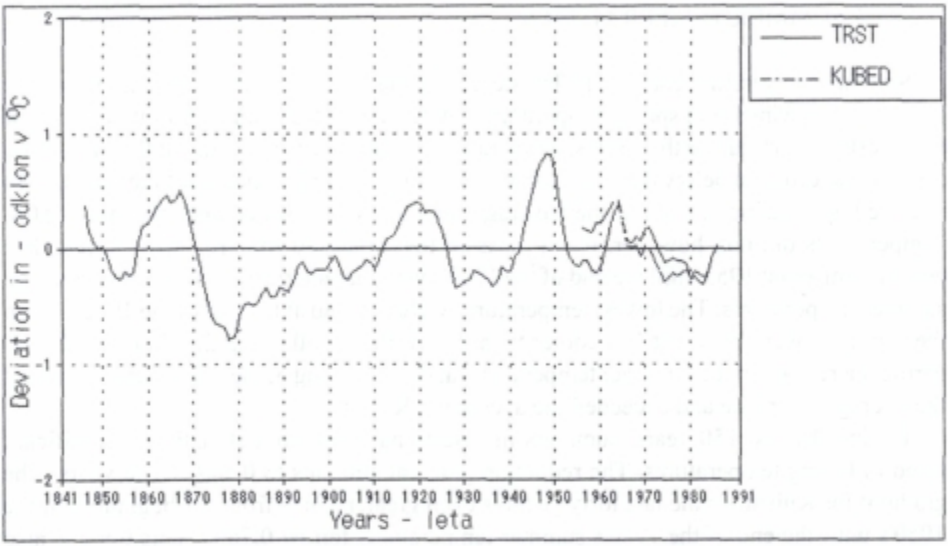


Fig.10: Varying spring temperatures in Trieste (1841-1991) and at Kubed (1951-1990) 10-year running means.

Sl.10: Variiranje spomladanskih temperatur v Trstu (1841-1991) in v Kubedu (1951-1990) 10 letne drseče sredine.

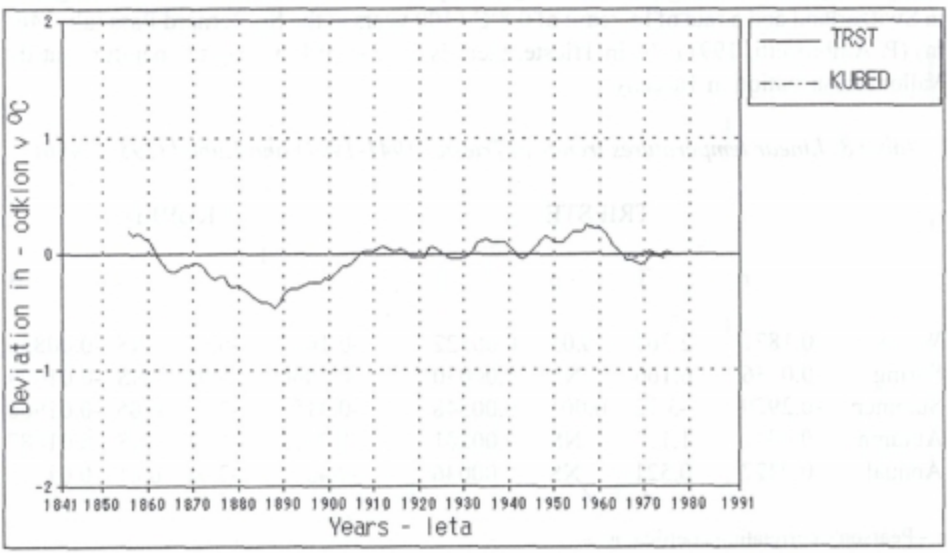


Fig.11: Varying spring temperatures in Trieste (1841-1991) and at Kubed (1951-1990) 30-year running means.

Sl.11: Variiranje spomladanskih temperatur v Trstu (1841-1991) in v Kubedu (1951-1990) 30 letne drseče sredine.

4.1.3 SUMMER TEMPERATURES

Summer temperature changes in Trieste during the last 150 years were somewhat less dynamic than winter and spring temperatures. After the hottest summers in the history of the Trieste station during the 1850's, temperatures steadily decreased and at the turn of the century had dropped below the 150-year average. This state remained until the mid-1930's followed by a period of warmer than average summers which lasted until the mid-1950's. Temperatures did not, however, reach those of the middle of the previous century. The period from about 1955 until the end of the 1980's was characterized by lower than average summer temperatures. The lowest temperatures were reached at the end of the 1970's when the summers were by about 1°C cooler than the average. Following this "cooling down" period, there was a rise in summer temperatures at the beginning of the 1980's which reached the average in Trieste and exceeded the average in Kubed.

During the last 150 years, summers in Trieste have shown a statistically significant trend in falling temperatures. The reduction gradient amounts to 0.54°C / 100 years. The gradient for Kubed for the last forty years is even greater, since from the beginning of the 1950's until the end of the 1980's summer temperatures fell by 0.76°C. This trend is also statistically significant.

Comparing temperature changes in the Gulf of Trieste with those of Ljubljana, the Alps, and Italy, we discover that summer temperatures do not show as uniform a trend as winter temperatures. During the last 150 years, summer temperatures in Ljubljana have shown no specific trend. There was a slight temperature rise in Lugano on Lake Maggiore in Switzerland and a rate of increase of 0.8°C / 100 years at the St. Bernard Pass (alt. 2469 m) (P. Ambrosetti, 1991). As in Trieste, there is a trend of lowering temperatures at the Vallombrosa station in Tuscany.

Table 8: Linear temperatures trends in Trieste (1941-1991) and Kubed (1951-1990).

	TRIESTE				KUBED			
	r	T	p	B	r	T	p	B
Winter	0.1871	2.309	0.05	0.00522	-0.1029	-0.62	NS	-0.00854
Spring	0.0136	0.166	NS	0.00030	-0.1600	-0.98	NS	-0.01099
Summer	-0.2929	-3.72	0.001	-0.00548	-0.3159	-2.02	0.05	-0.01966
Autumn	0.0911	1.113	NS	0.00201	-0.2112	-1.31	NS	-0.01887
Annual	0.0427	0.521	NS	0.00046	-0.4317	-2.91	0.01	-0.01715

r - Pearson's correlation coefficient

B - Regression coefficient

T - t test

p - Level of significance

NS - No Significance

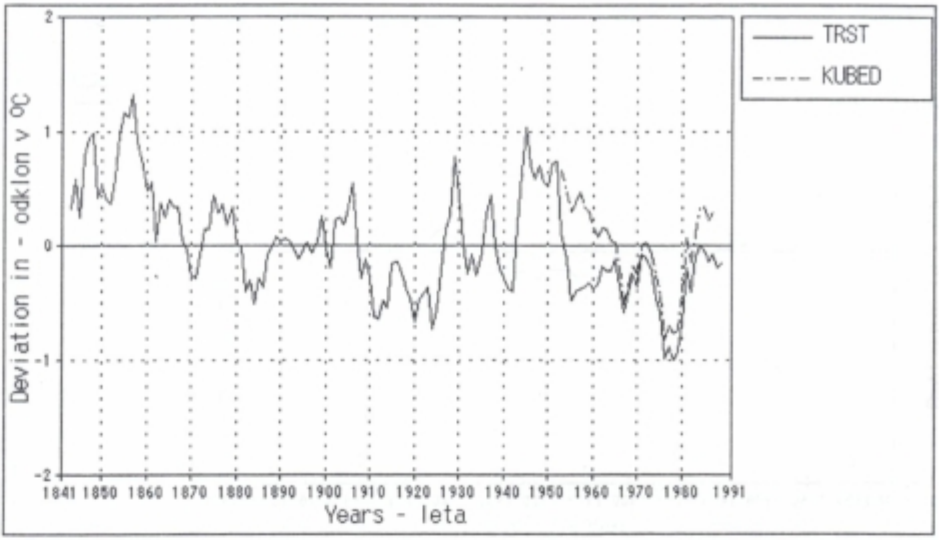


Fig.12: Varying summer temperatures in Trieste (1841-1991) and at Kubed (1951-1990) 5-year running means.

Sl.12: Variiranje poletnih temperatur v Trstu (1841-1991) in v Kubedu (1951-1990) 5 letne drseče sredine.

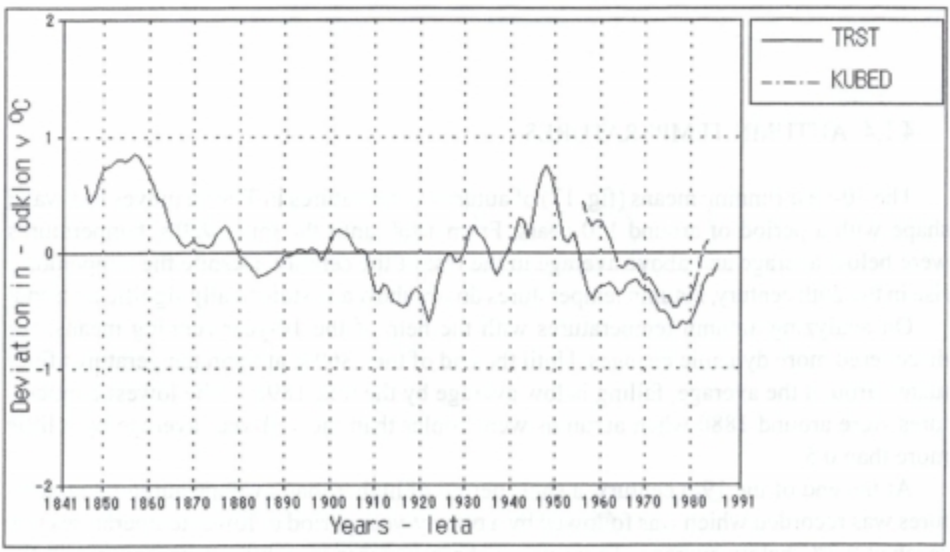


Fig.13: Varying summer temperatures in Trieste (1841-1991) and at Kubed (1951-1990) 10-year running means.

Sl.13: Variiranje poletnih temperatur v Trstu (1841-1991) in v Kubedu (1951-1990) 10 letne drseče sredine.

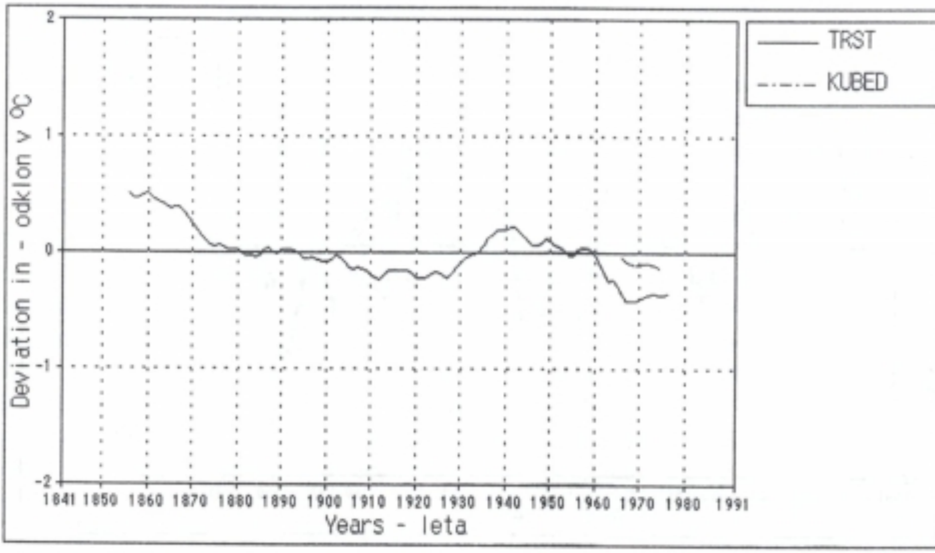


Fig.14: Varying summer temperatures in Trieste (1841-1991) and at Kubed (1951-1990) 30-year running means.
Sl.14: Variiranje poletnih temperatur v Trstu (1841-1991) in v Kubedu (1951-1990) 30 letne drseče sredine.

4.1.4 AUTUMN TEMPERATURES

The 30-year running means (fig. 17) of autumn temperatures in Trieste moves in a wave shape with a period of around 110 years. From 1860 until the mid-1920's, temperatures were below average and above average in the rest of the century. Despite the temperature rise in the 20th century, autumn temperatures do not show any statistically significant trend.

On analyzing autumn temperatures with the help of the 10-year running means, we discovered more dynamic changes. Until the end of the 1860's, autumn temperatures fluctuated around the average, falling below average by the mid-1890's. The lowest temperatures were around 1880 when autumns were cooler than the 150-year average by a little more than 0.5°C.

At the end of the 19th century, a short period of higher than average autumn temperatures was recorded which was followed by a twenty-year period of lower temperatures that reached 0.7°C below average. There was a sharp increase in autumn temperatures in the middle of the first part of this century which ended around 1930. In a period of less than fifteen years, temperatures rose by about 1.5°C. For the rest of the century, with the exception of the 1970's, autumns were, with a few fluctuations, mostly warmer than average.

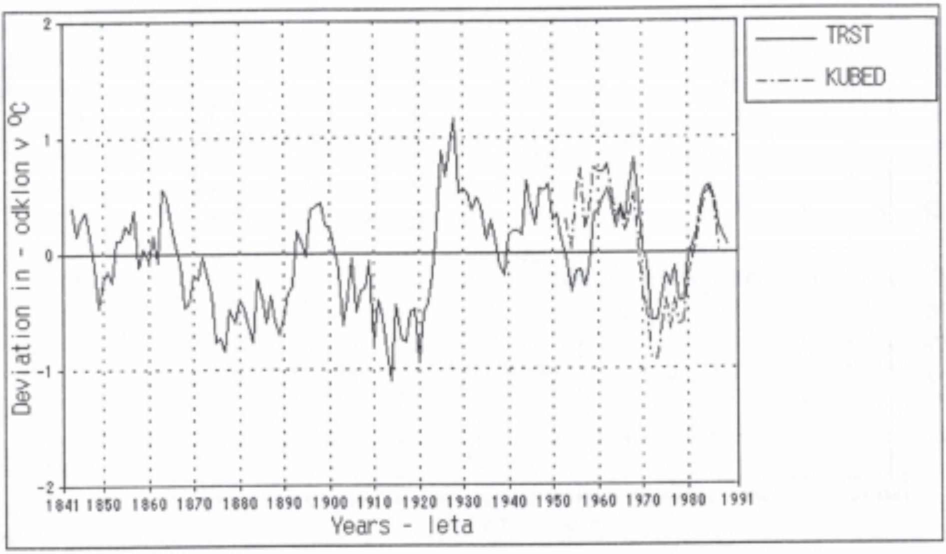


Fig.15: Varying autumn temperatures in Trieste (1841-1991) and at Kubed (1951-1990) 5-year running means.

Sl.15: Variiranje jesenskih temperatur v Trstu (1841-1991) in v Kubedu (1951-1990) 5 letne drseče sredine.

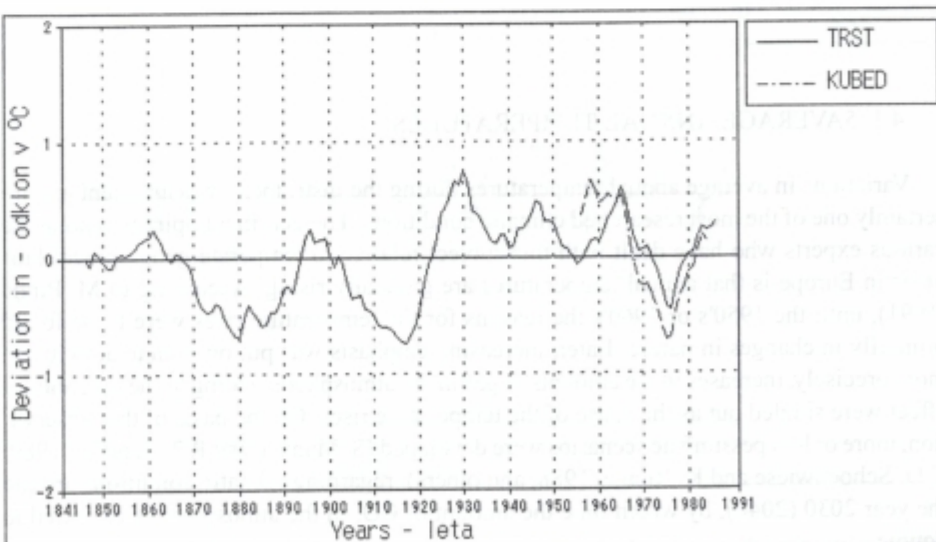


Fig.16: Varying autumn temperatures in Trieste (1841-1991) and at Kubed (1951-1990) 10-year running means.

Sl.16: Variiranje jesenskih temperatur v Trstu (1841-1991) in v Kubedu (1951-1990) 10 letne drseče sredine.

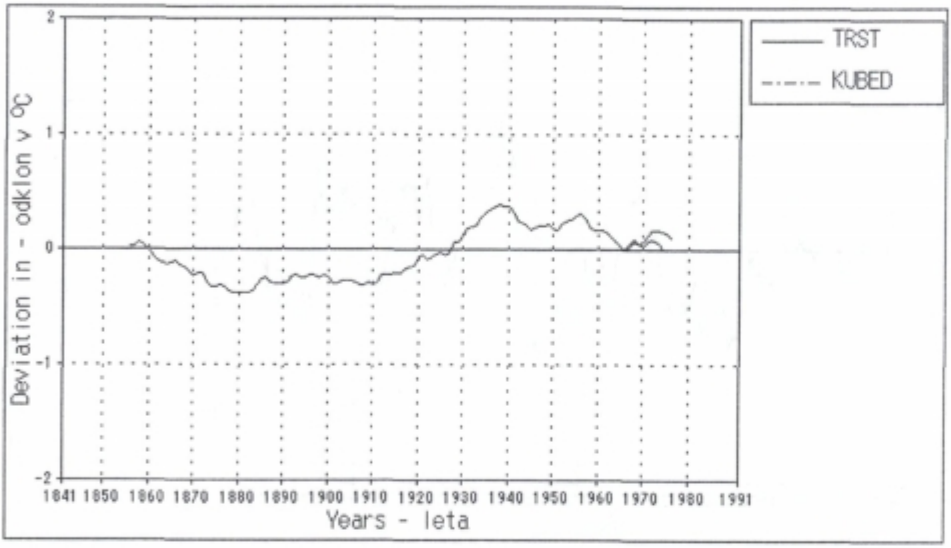


Fig.17: Varying autumn temperatures in Trieste (1841-1991) and at Kubed (1951-1990) 30-year running means.
Sl.17: Variiranje jesenskih temperatur v Trstu (1841-1991) in v Kubedu (1951-1990) 30 letne drseče sredine.

4.1. 5AVERAGE ANNUAL TEMPERATURES

Variations in average annual temperatures during the instrument measurement era are certainly one of the most researched climatic conditions. The dominant opinion among the various experts who have dealt with this subject relative to temperate geographical latitudes in Europe is that annual temperatures are gradually rising. According to M. Pinna (1991), until the 1950's or 1960's the reasons for the temperature rises were to be found primarily in changes in nature. Later, increasing emphasis was put on human activity or, more precisely, increases in the amounts of gas in the atmosphere leading to the greenhouse effect were singled out as the cause of the temperature rises. On the basis of this observation, more or less pessimistic scenarios were developed (S. Manabe and R.T. Stauffer, 1980; C.D. Schoenwiese and K. Runge, 1988, and others), regarding climatic conditions around the year 2030 (2040), by which time the amount of CO_2 in the atmosphere is expected to double.

Calculations of trends in temperature rises are varied. For Ljubljana, M. Krevs (1986) calculated a trend of 0.7°C / 100 years, while the overall trend of temperature rises in Europe is 0.6°C / 100 years (L. Kajfež-Bogataj, 1992). Various research indicates that temperatures have risen mostly in cities and less in rural areas, hence the argument that temperature rises are illusory and that they are the consequence of the growth of cities. In order to counter this objection, in analyzing data for Berlin, the temperatures were reduced proportionally to city growth and with reference to measurements taken at the rural meteorological station in Hohenpeissenberg. Data from Hohenpeissenberg was also compared with data from Munich (M. Kirchner and G. Langer, 1991), and it was determined that the trend in temperature rises in Hohenpeissenberg, which amounted to 0.12°C/100 years, was lower than that of Munich.

The trend that we have calculated for the Trieste annual temperatures is statistically insignificant. On the basis of correlation with time ($r = 0.037$) it may be stated that a trend barely exists. Similar findings were established for the Vallombrosa station in Tuscany where seasonal temperature variations were very similar to those of Trieste (C. Gandolfo, M. Sulli, 1991).

Considering the 30-year running means, the trend of annual temperature rises in Trieste was distinctive only between the 1880's and the 1960's. Before 1880, there was a trend toward falling average annual temperatures as was the case after 1960. During the last forty years, annual temperatures in Kubed have fallen by 0.7°C, similar to those in Trieste.

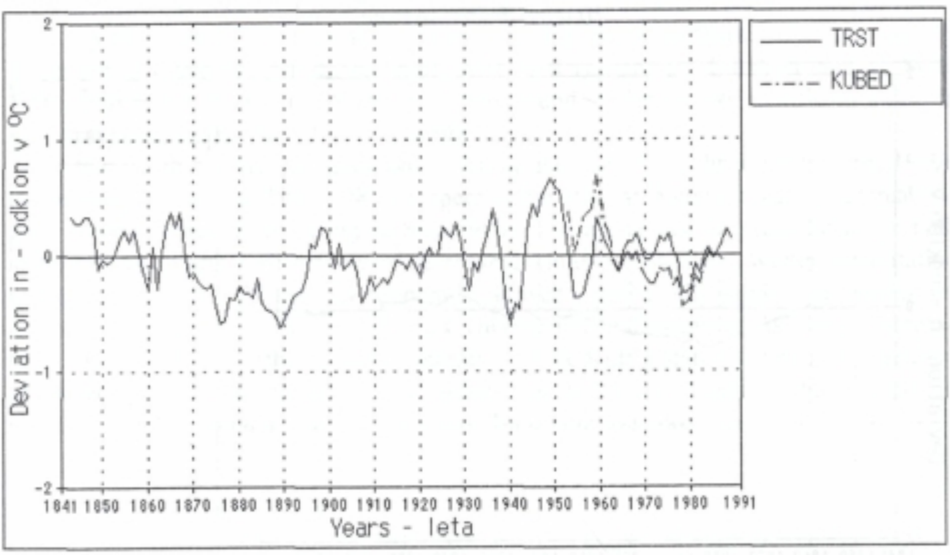


Fig.18: Varying annual temperatures in Trieste (1841-1991) and at Kubed (1951-1990) 5-year running means.
Sl.18: Variiranje letnih temperatur v Trstu (1841-1991) in v Kubedu (1951-1990) 5 letne drseče sredine.

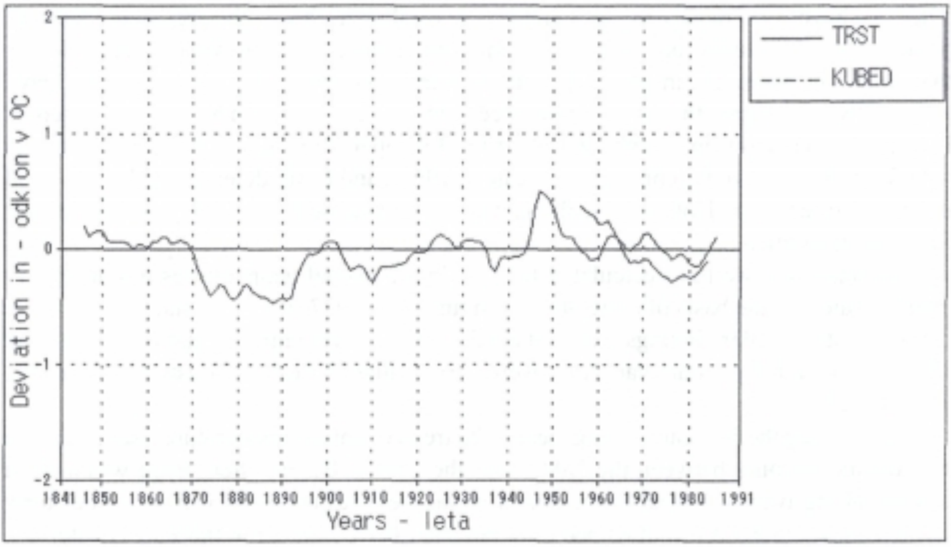


Fig.19: Varying annual temperatures in Trieste (1841-1991) and at Kubed (1951-1990) 10-year running means.
Sl.19: Variiranje letnih temperatur v Trstu (1841-1991) in v Kubedu (1951-1990) 10 letne drseče sredine.

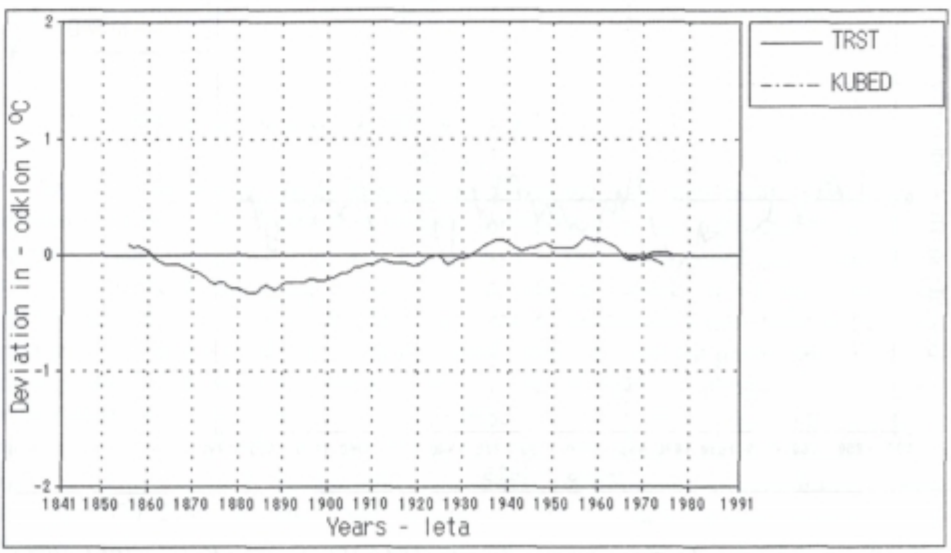


Fig.20: Varying annual temperatures in Trieste (1841-1991) and at Kubed (1951-1990) 30-year running means.
Sl.20: Variiranje letnih temperatur v Trstu (1841-1991) in v Kubedu (1951-1990) 30 letne drseče sredine.

4.2 VARIATIONS IN PRECIPITATION

4.2.1 WINTER PRECIPITATION

Precipitation is a more variable climatic element than temperature and the positive and negative deviations from the long-term average are therefore greater. In Trieste, winter precipitation amounts to more than 200 mm according to the 5-year running means. This means that particular winters are very dry (precipitation below 30 mm) while during other winters precipitation may exceed the long- term average by more than 100 %. In Kubed where the amount of precipitation is greater, so are the deviations.

With reference to the 30-year running means, there have been two longer periods of lower than average winter precipitation in Trieste during the last 150 years (1870-1900, 1930-1945), and two longer and one shorter period of higher than average precipitation (1865-1870, 1905-1925, and a period of increasing precipitation after 1945 which, with respect to the 30-year running means, is still continuing).

For the whole period studied, winter precipitation in Trieste does not show any trend, in contrast to Schoenwiese and Birrong's scheme (1988, cited by C.D. Schoenwiese, 1991) according to which winter precipitation during the 1860-1990 period in regions between 30 and 40 degrees latitude north of the equator shows no trend, while in the region above these latitudes where Trieste is found winter precipitation is increasing. Winter precipitation also does not show any distinct trend in some other regions of northern Italy, for example, Piedmont (A. Biancotti and L. Mercalli, 1991) and Tuscany (C. Gandolfo and M. Sulli, 1991). For Ljubljana as well, M. Krevs (1986) found no statistically significant trends in the winter months for the 1851-1985 period.

In this century, winter precipitations in Trieste and Kubed rose distinctly from the 1930's to the beginning of the 1980's. With respect to the 30-year running means, they reached their highest values so far during the mid-1960's. During the last ten years, however, both stations have recorded a trend toward decreasing winter precipitation. Winter precipitation in Kubed between 1925 and 1990 generally showed a statistically significant trend of increase of 1.8 mm/year (180 mm/100 year). This can not be disregarded, as with an increase of 117 mm in 65 years (the period of operation of the Kubed station) winter precipitation increased by more than one standard deviation. The increase in Trieste for the same period is still within the limits of standard deviation for winter precipitation.

Table 9: Basic statistical characteristics of seasonal precipitation in Trieste and Kubed (in mm)

	TRIESTE (1841-1991)				KUBED (1925-1990)			
	Ave.	SD	Min.	Max.	Ave.	SD	Min.	Max.
Winter	201	94	27	542	255	112	55	546
Spring	237	82	41	510	276	95	106	551
Summer	267	91	86	584	302	124	113	594
Autumn	342	133	70	763	356	127	137	698
Annual	1045	210	600	1611	1190	264	521	1946

Ave. - average
SD - standard deviation
Min. - minimum
Max. - maximum

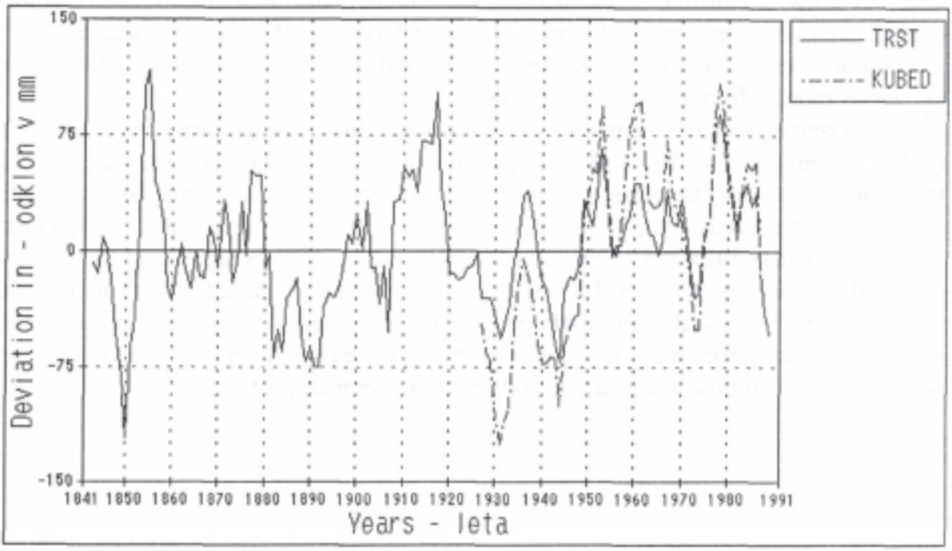


Fig.21: Varying winter precipitation in Trieste (1841-1991) and at Kubed (1925-1990) 5-year running means.

Sl.21: Variiranje zimskih padavin v Trstu (1841-1991) in v Kubedu (1925-1990) 5 letne drseče sredine.

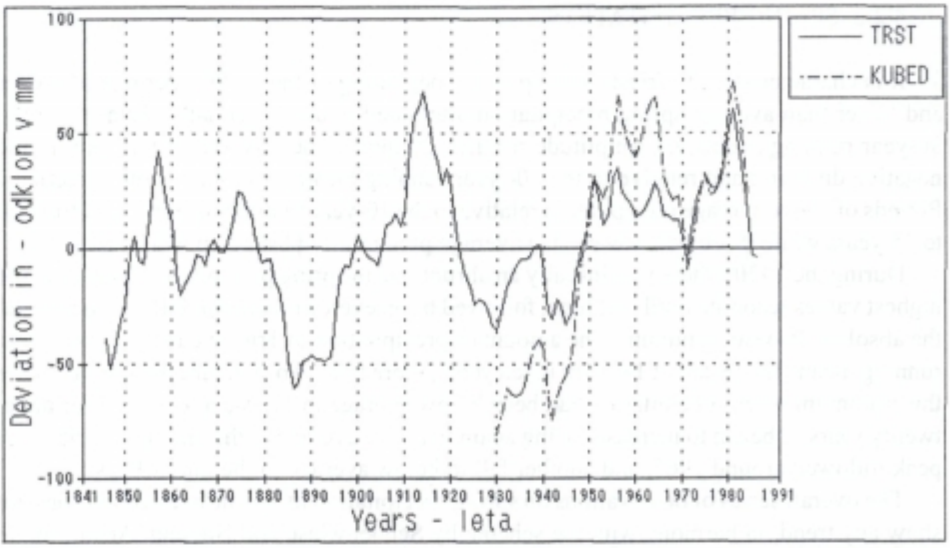


Fig.22: Varying winter precipitation in Trieste (1841-1991) and at Kubed (1925-1990) 10-year running means.

Sl.22: Variiranje zimskih padavin v Trstu (1841-1991) in v Kubedu (1925-1990) 10 letne drseče sredine.

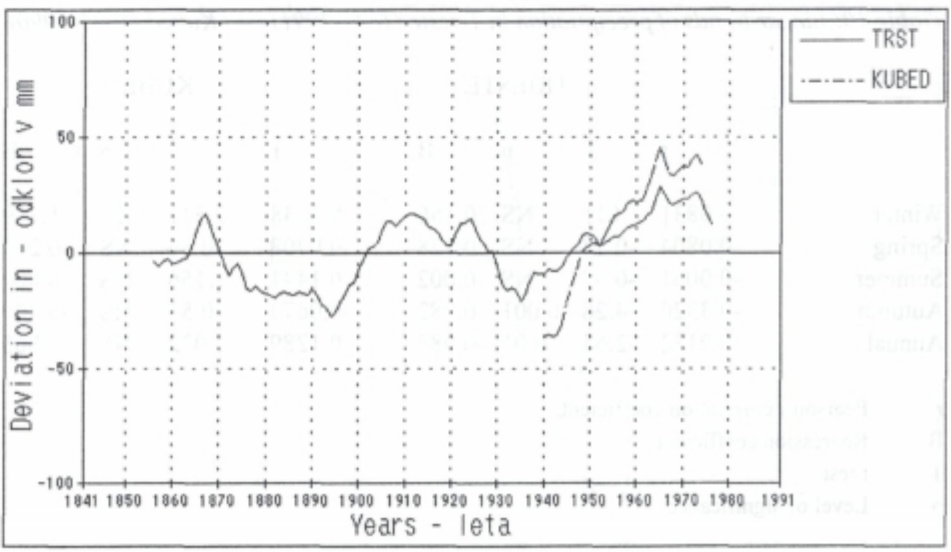


Fig.23: Varying winter precipitation in Trieste (1841-1991) and at Kubed (1925-1990) 30-year running means.

Sl.23: Variiranje zimskih padavin v Trstu (1841-1991) in v Kubedu (1925-1990) 30 letne drseče sredine.

4.2.2 SPRING PRECIPITATION

It is characteristic of Trieste that up to the beginning of the 1920's, periods of higher and lower than average spring precipitation alternated relatively equally. Relative to the 30-year running means, the amplitude reached 20 mm in the positive and 10 mm in the negative direction and relative to the 10- year running means, 50 mm in both directions. Periods of above average precipitation relative to the 10-year running means lasted from 10 to 15 years while those with lower than average precipitation lasted up to 10 years.

During the 1920's there was initially an abrupt rise in spring precipitation, reaching the highest values recorded until that time, followed by an even more abrupt fall which reached the absolute 40-year minimum. The amount of precipitation in Trieste based on the 5-year running means fell by about 180 mm in ten years, more than two standard deviations. After this minimum when precipitation had been below average in Trieste and Kubed for about twenty years, it began to increase, rising again to above average at the end of the 1950's. A peak followed around 1965, and another fall to below average in the mid-1970's.

The overall series of observations on spring precipitation in Trieste and Kubed does not show any trend, in harmony with the scheme by Schoenwiese and Birrong. According to their scheme, spring precipitation between 35 and 65 degrees north latitude does not show any trend, between 65 and 70 degrees north latitude it increases, and between 35 and 30 degrees north latitude it decreases.

Table 10: Linear trends of precipitation in Trieste (1841-1991) and Kubed (1925-1990)

	TRIESTE				KUBED			
	r	T	p	B	r	T	p	B
Winter	0.0831	1.011	NS	0.156	0.3038	2.511	0.05	1.769
Spring	-0.0804	-0.98	NS	0.128	-0.0708	-0.56	NS	-0.269
Summer	-0.0061	-0.07	NS	0.002	0.1441	1.156	NS	0.884
Autumn	-0.3320	-4.28	0.001	-0.982	-0.0673	-0.53	NS	-0.400
Annual	-0.2132	-2.65	0.01	-0.985	0.1289	1.032	NS	1.865

r Pearson's correlation coefficient
B Regression coefficient
T t test
p Level of significance

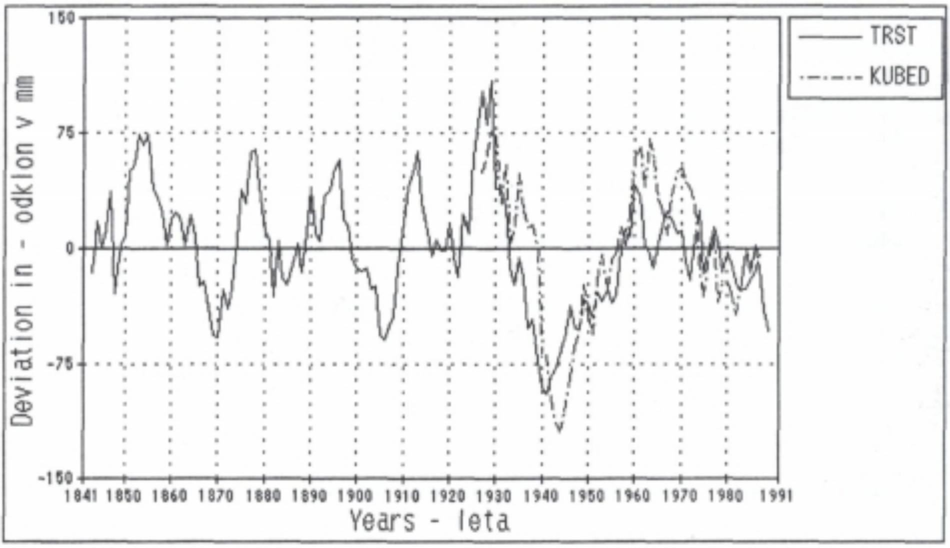


Fig.24: Varying spring precipitation in Trieste (1841-1991) and at Kubed (1925-1990) 5-year running means.

Sl.24: Variiranje spomladanskih padavin v Trstu (1841-1991) in v Kubedu (1925-1990) 5 letne drseče sredine.

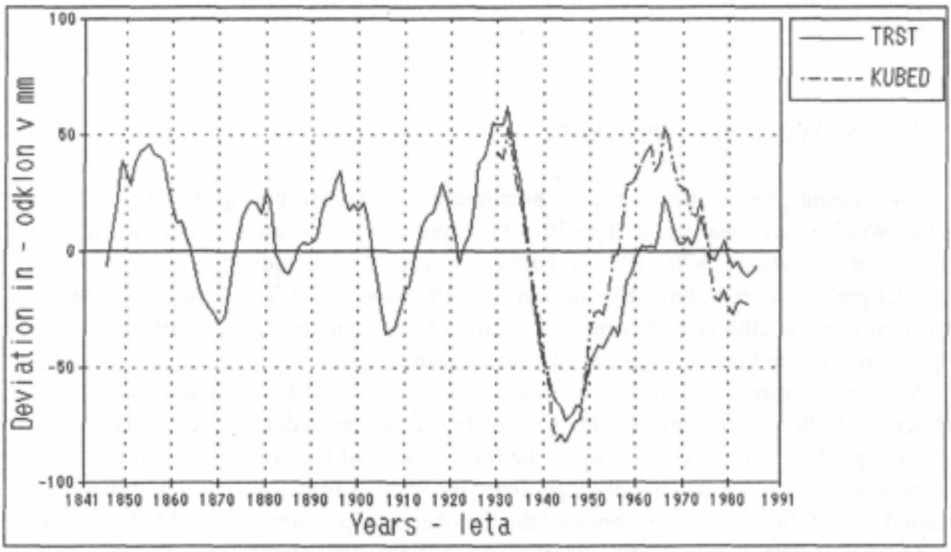


Fig.25: Varying spring precipitation in Trieste (1841-1991) and at Kubed (1925-1990) 10-year running means.

Sl.25: Variiranje spomladanskih padavin v Trstu (1841-1991) in v Kubedu (1925-1990) 10 letne drseče sredine.

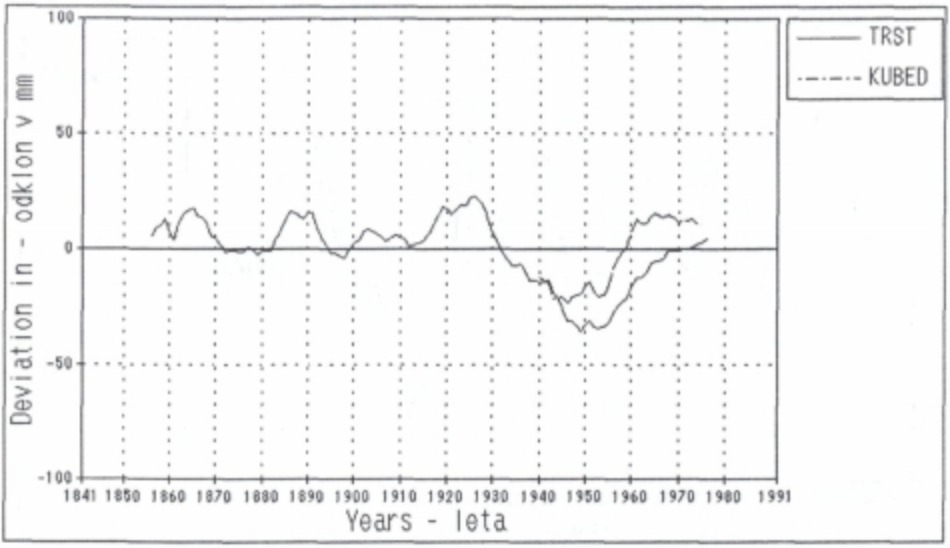


Fig.26: Varying spring precipitation in Trieste (1841-1991) and at Kubed (1925-1990) 30-year running means.

Sl.26: Variiranje spomladanskih padavin v Trstu (1841-1991) in v Kubedu (1925-1990) 30 letne drseče sredine.

4.2.3 SUMMER PRECIPITATION

Like spring precipitation, summer precipitation in Trieste during the last 150 years varies without any clear trend. The 30-year running means show two periods of above average precipitation (1870 - 1925 and after 1960) and two periods of lower than average summer precipitation (before 1870 and between 1925 and 1960). The most outstanding dry period was in the 20th century when for almost 25 years the total amount of summer precipitation was one third or even one half lower than normal.

Similar variations in summer precipitation were also observed in Ljubljana (I. Gams, M. Krevs, 1990). In comparison with those of Trieste, the most distinctive trend in increasing precipitation was observed only in the third quarter of the last century. In the case of Ljubljana, there was a statistically significant increase in June precipitation which in the second half of this century has replaced the October precipitation peak and led to the widening of area with a continental precipitation pattern from northeastern Slovenia to the center of the Ljubljana Basin (I. Gams, 1988).

Compared with the frequently named northern Italian stations, differences in summer precipitation are greater, both for short-term fluctuations and long-term trends. In the latter case a decreasing trend in summer precipitation was established, for example, in Turin and Vallombrosa. This trend is even more distinctive for stations in southern Italy, particularly in the second half of this century.

According to the 10-year running means, the long period of above average summer precipitation in Trieste (1875-1925) may be divided into three subperiods: two periods of more precipitation (1870 - 1895 and 1905-1925) and one period of less precipitation (1895-1905) when precipitation figures fluctuated around the average. Summer precipitation reached its highest values during the peak periods of high precipitation in the second half of the 1880's and around 1915.

After the high peak in the first half of the 1960's, the trend in variations in summer precipitation shows a steady fall until the beginning of the 1980's followed by a slight increase.

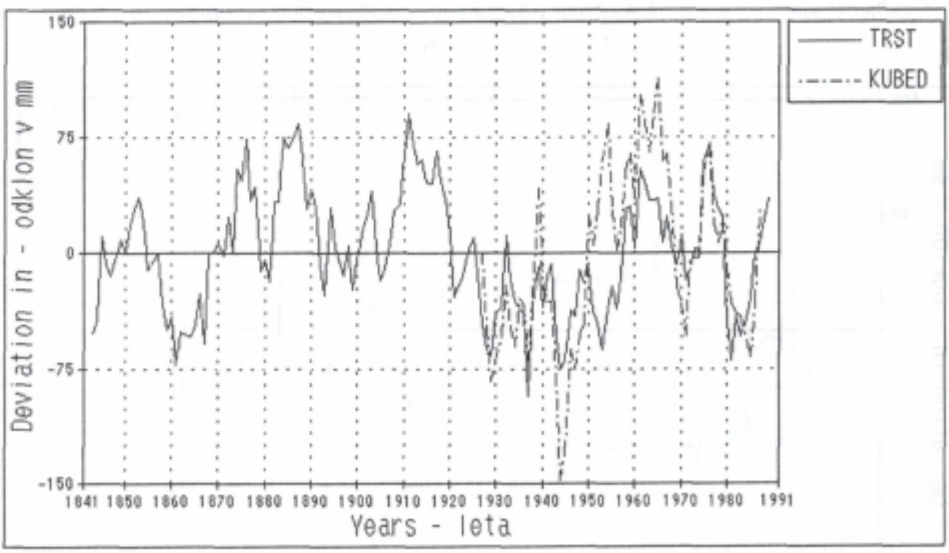


Fig.27: Varying summer precipitation in Trieste (1841-1991) and at Kubed (1925-1990) 5-year running means.
Sl.27: Variiranje poletnih padavin v Trstu (1841-1991) in v Kubedu (1925-1990) 5 letne drseče sredine.

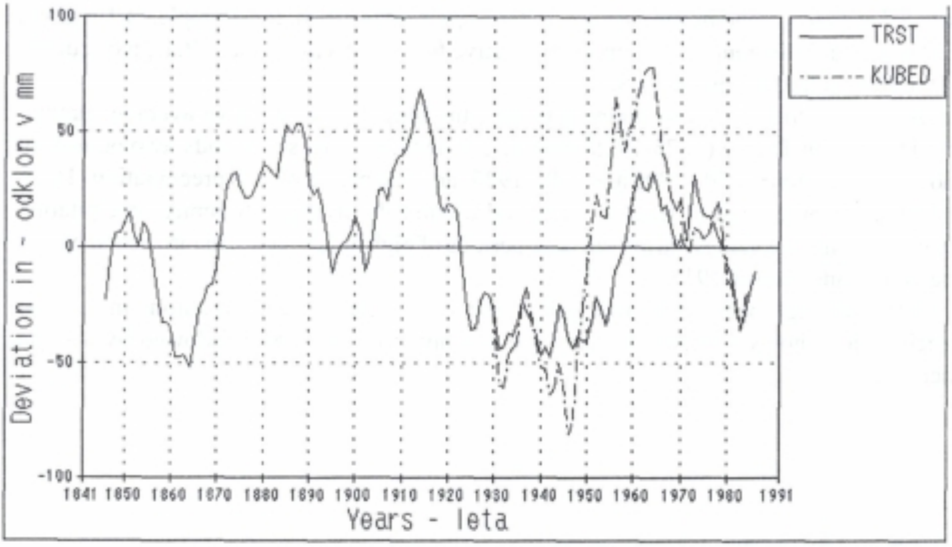


Fig.28: Varying summer precipitation in Trieste (1841-1991) and at Kubed (1925-1990) 10-year running means.

Sl.28: Variiranje poletnih padavin v Trstu (1841-1991) in v Kubedu (1925-1990) 10 letne drseče sredine.

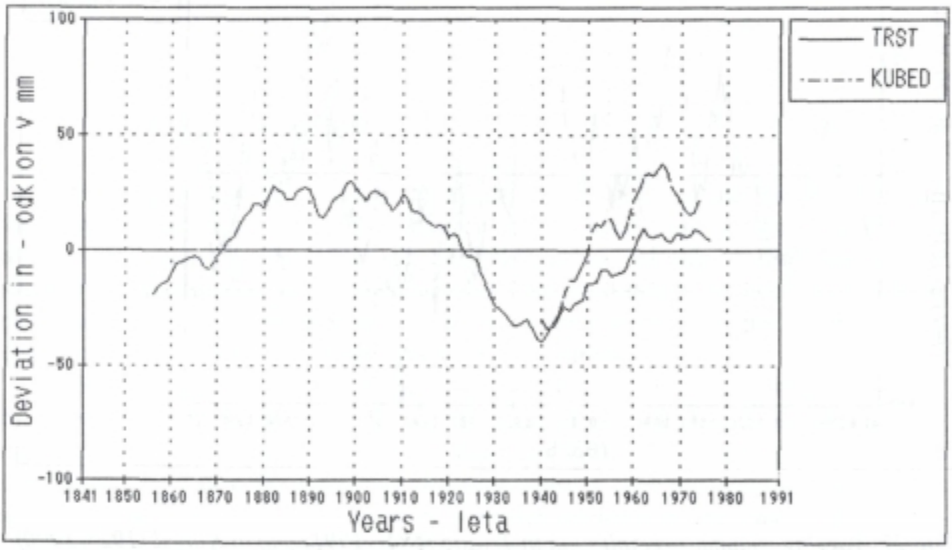


Fig.29: Varying summer precipitation in Trieste (1841-1991) and at Kubed (1925-1990) 30-year running means.

Sl.29: Variiranje poletnih padavin v Trstu (1841-1991) in v Kubedu (1925-1990) 30 letne drseče sredine.

4.2.4 AUTUMN PRECIPITATION

According to the linear trend from the middle of the last century, autumn precipitation has decreased constantly (Figures 30, 31, and 32). Until the end of the last century, it was mostly above average, varied around the average in the first half of this century, and fell below average after 1930. During the 1940's it fell by about 50 mm below the long-term average and maintained this level through the 1980's. The reduction tendency amounts to 98 mm/100 years. The trend is statistically significant but within the limits of standard deviation for autumn precipitation in Trieste which amounts to 133 mm.

Autumn precipitation, particularly for October, is also decreasing in Ljubljana (M. Krevs, 1986), Turin (A. Biancotti, L. Mercalli, 1991) and Tuscany (C. Gandolfo, M. Sulli, 1991).

A comparison between autumn precipitation in Kubed and Trieste reveals a high level of synchronism between oscillations at the two stations although there are many more distinctive peaks in Kubed than in Trieste, especially at the beginning of the 1960's. Levels of precipitation are similar at the two stations. The result of this situation is a greater divergence in the curves for both stations. This is particularly obvious for the 30-year running means, where it could even be possible to make conclusions about a trend toward an increase in autumn precipitation in the case of Kubed, which we were not able to prove statistically. The trend is illusory and mainly the result of a distinctive peak during the 1960's when relative to the 10-year running means precipitation exceeded usual amounts by about 100 mm.

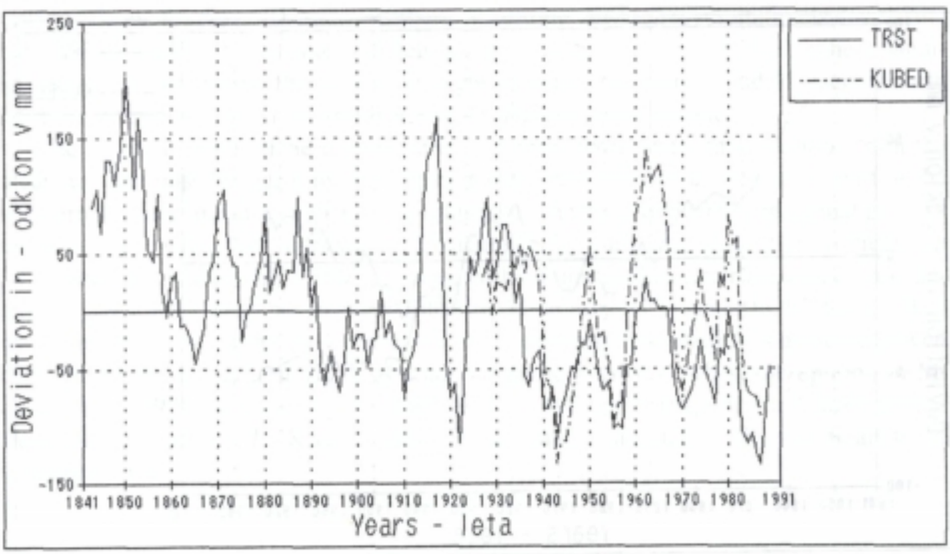


Fig.30: Varying autumn precipitation in Trieste (1841-1991) and at Kubed (1925-1990) 5-year running means.

Sl.30: Variiranje jesenskih padavin v Trstu (1841-1991) in v Kubedu (1925-1990) 5 letne drseče sredine.

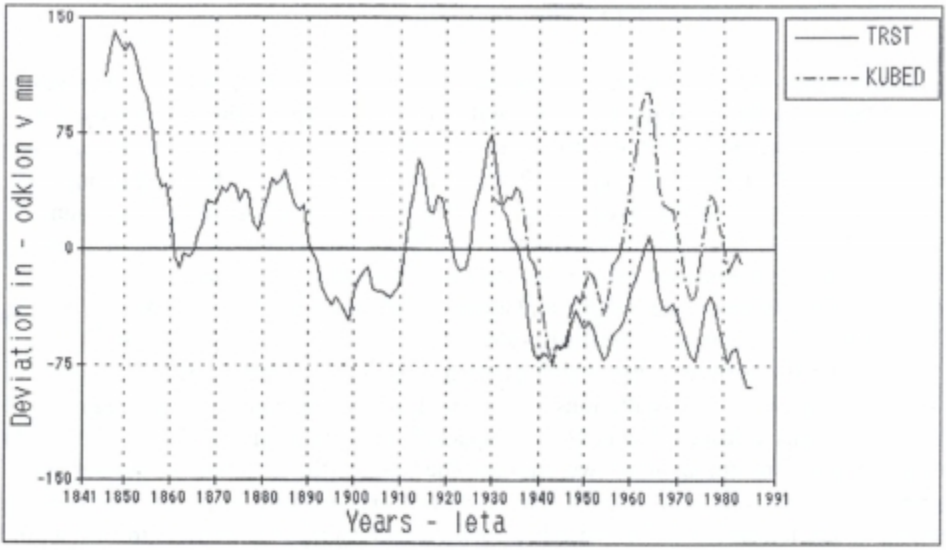


Fig.31: Varying autumn precipitation in Trieste (1841-1991) and at Kubed (1925-1990) 10-year running means.
Sl.31: Variiranje jesenskih padavin v Trstu (1841-1991) in v Kubedu (1925-1990) 10 letne drseče sredine.

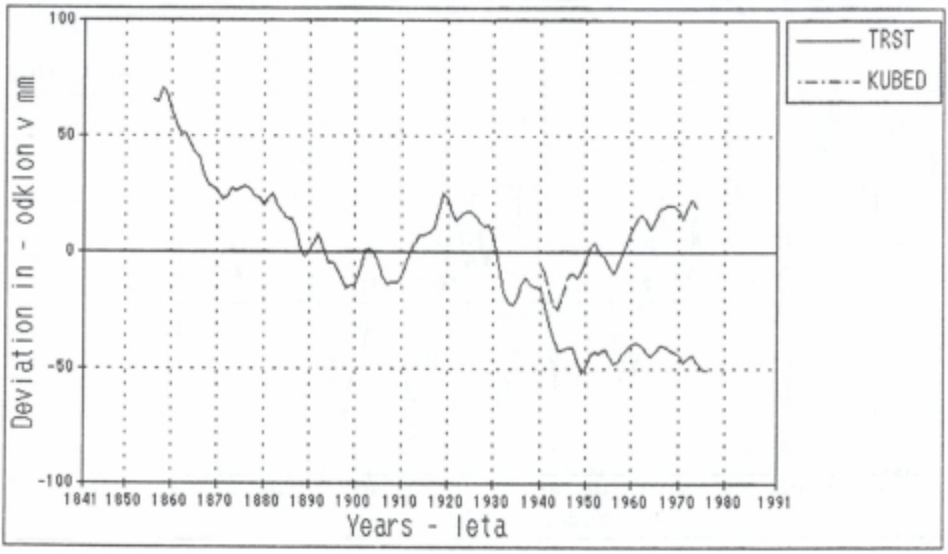


Fig.32: Varying autumn precipitation in Trieste (1841-1991) and at Kubed (1925-1990) 30-year running means.
Sl.32: Variiranje jesenskih padavin v Trstu (1841-1991) in v Kubedu (1925-1990) 30 letne drseče sredine.

4.2.5 ANNUAL PRECIPITATION

Variations in annual precipitation in Trieste and Kubed are very similar to those of autumn. In Trieste, annual precipitation has been constantly decreasing since the middle of the last century. Until 1930 it was mostly above average, and then decreased considerably, from the mid-1920's to the mid-1930's by about 130 mm. It was lowest during the 1940's when it was around 180 mm below average, rising to average level during the 1960's and 1970's. During the last decade there has again been a decreasing trend.

The decreasing trend for the whole 1841-1991 period is very similar to the autumn precipitation trend and amounts to 98 mm/100 years. This represents less than one half the standard deviation, so that we may calculate that this long-term tendency is still within the normal variation for annual precipitation in Trieste.

As in the case of autumn precipitation, the tendency for annual precipitation in Kubed to increase is an illusory trend. Here too, the trend is primarily the result of unusually rainy autumns at the beginning of the 1960's and is not statistically significant.

If we were to spread the trends in the variations of annual precipitation in Trieste over a wider area, we may discover that Trieste belongs to the group of stations in the Mediterranean Basin where a continuous decrease in precipitation has been recorded during the last 150 years. We should not also ignore the fact that decreases in annual precipitation for Trieste are mainly the result of decreases in autumn precipitation or a reduction in the primary peaks, while precipitation in the remaining seasons does not show any trend.

The trend in annual precipitation for Trieste deviates slightly from C.D. Schoenwiese's (1991) scheme for the northern hemisphere, according to which precipitation is decreasing between the Tropic of Cancer and 40 degrees north latitude, i.e. mainly the southern Mediterranean, remains nearly the same with slight increases between 40 and 45 degrees north latitudes, and increases considerably above 45 degrees north latitude.

The fact that this scheme represents only a framework and that deviations from the mean are also possible are proven by some trends from stations in the central part of the northern Mediterranean as well as from Ljubljana. The trend of decreasing annual precipitation during the last 200 years was also calculated for Turin and Moncalieri in Piedmont (A. Biancotti, L. Mercalli, 1991). In Turin, both autumn and summer precipitation is decreasing. A similar trend has been recorded in Vallombrosa (C. Gandolfo, M. Sulli, 1991) where precipitation figures have decreased for all seasons. Precipitation is decreasing even more markedly in southern Italy (Sardinia, northeast Sicily) which in the opinion of M. Conte et al. (1991) is primarily the result of the growing influence of the Azores anticyclone. As for Ljubljana, M. Krevs (1986) did not establish any statistically significant trend in precipitation.

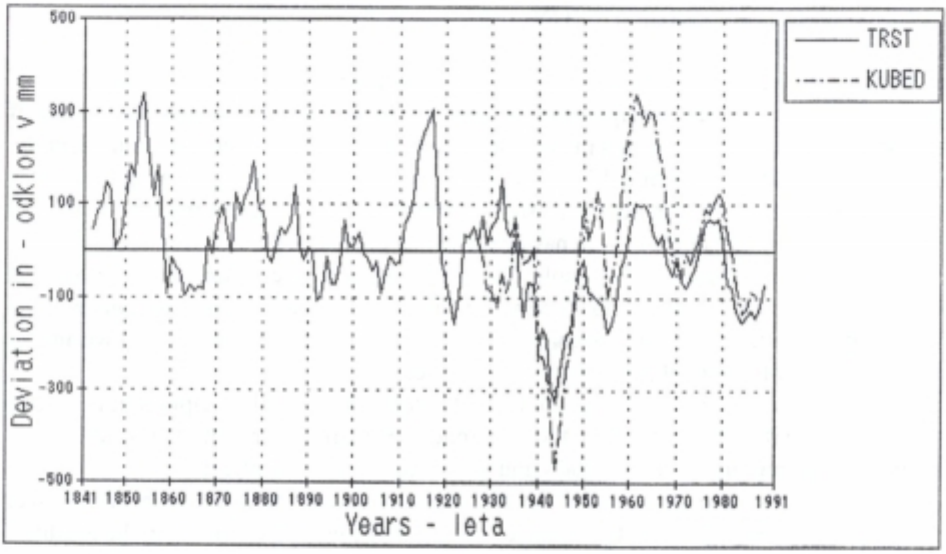


Fig.33: Varying annual ty of precipitation in Trieste (1841-1991) and at Kubed (1925-1990) 5- year running means.
Sl.33: Variiranje letne količine padavin v Trstu (1841-1991) in v Kubedu (1925-1990) 5 letne drseče sredine.

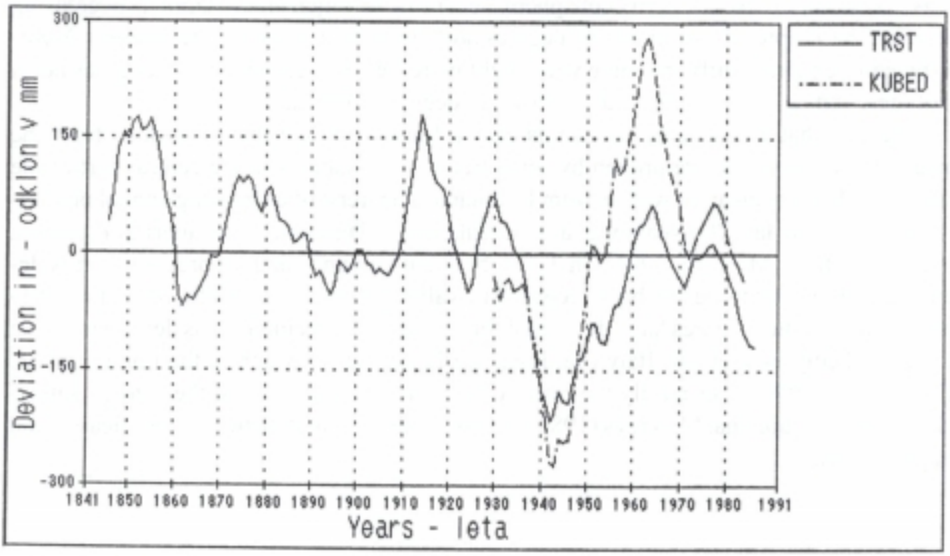


Fig.34: Varying annual precipitation in Trieste (1841-1991) and at Kubed (1925-1990) 10-year running means.
Sl.34: Variiranje letne količine padavin v Trstu (1841-1991) in v Kubedu (1925-1990) 10 letne drseče sredine.

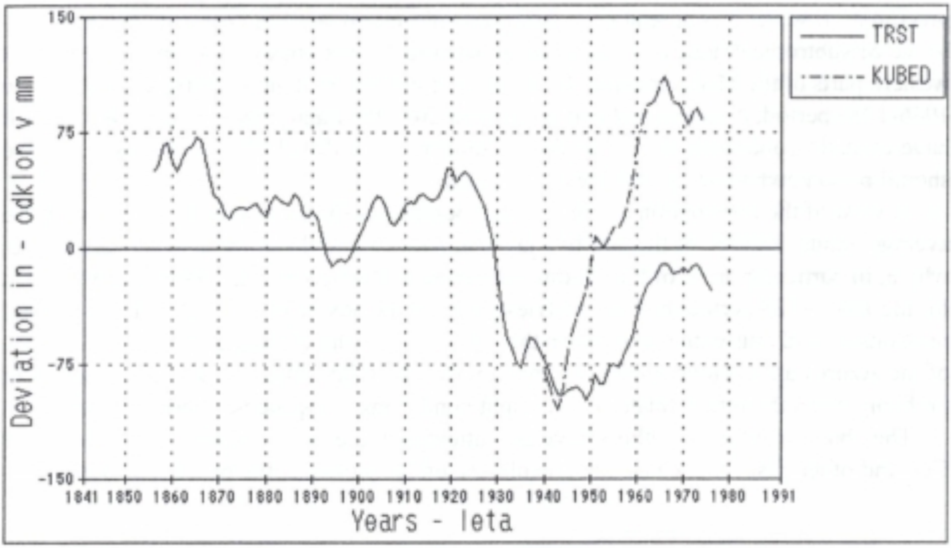


Fig.35: Varying annual precipitation in Trieste (1841-1991) and at Kubed (1925-1990) 30-year running means.

Sl.35: Variiranje letne količine padavin v Trstu (1841-1991) in v Kubedu (1925-1990) 30 letne drseče sredine.

* * *

The temperature variations which we have described in our discussion contradict to a certain extent suppositions regarding the greenhouse effect according to which temperatures were expected to rise particularly rapidly after 1970 when the amount of CO_2 in the atmosphere began to increase sharply. After this year temperatures actually fell in Trieste and Kubed. According to the 10-year running means, temperatures in Trieste began to rise only at the beginning of the 1980's.

In the case of Trieste and the trends in average annual temperature for some regions in Italy which are under the maritime influence and lie between 42 and 46 degrees north latitude (Friulia, Veneto, eastern Tuscany, Abruzzi; M. Pinna, 1991), we may conclude that natural causes of climatic fluctuations are at this point more important than possible anthropological causes since temperatures in the listed regions were not as high during the 1980's as the peaks reached during the middle of this century. As at the majority of continental meteorological stations of central Europe, however, there is a very distinct trend in rising temperatures for southern regions of Italy (Sardinia and especially for Sicily where average annual temperatures have increased sharply since the beginning of the 1960's).

Researchers of the so-called "Mediterranean oscillation" (M. Conte, A. Giuffrida, S. Tedesco, 1991) are of the opinion that the process of temperature rises and the decrease in precipitation which has spread over southern Italy is probably the result of the slow advance of subtropical anticyclones, in particular the Azores anticyclone, over central and western parts of the Mediterranean. If this process continues at the same pace as during the 1946-1988 period, it is expected that by the year 2030 the Lazio region in central Italy will have climatic conditions similar to those Tunisia had in the 1950's. At the moment, we should be somewhere in the middle of this process.

In view of the distribution of correlation coefficients for the relationships between the average annual altitude of the 500 hPa layer in Algeria and the altitude of this layer elsewhere, in particular areas of the central and western Mediterranean, according to the data for the 1946-1988 period the Gulf of Trieste lies on the border of a statistically significant relationship and thus with variations in the Azores anticyclone (Figure 36). If the influence of the Azores anticyclone grows, we may expect the relationship to increase which will probably mean the intensification of drought conditions along the northern Adriatic.

The above-mentioned authors have also attempted to discover whether the increase of CO_2 and other gases that cause the greenhouse effect influence the process of Mediterra-

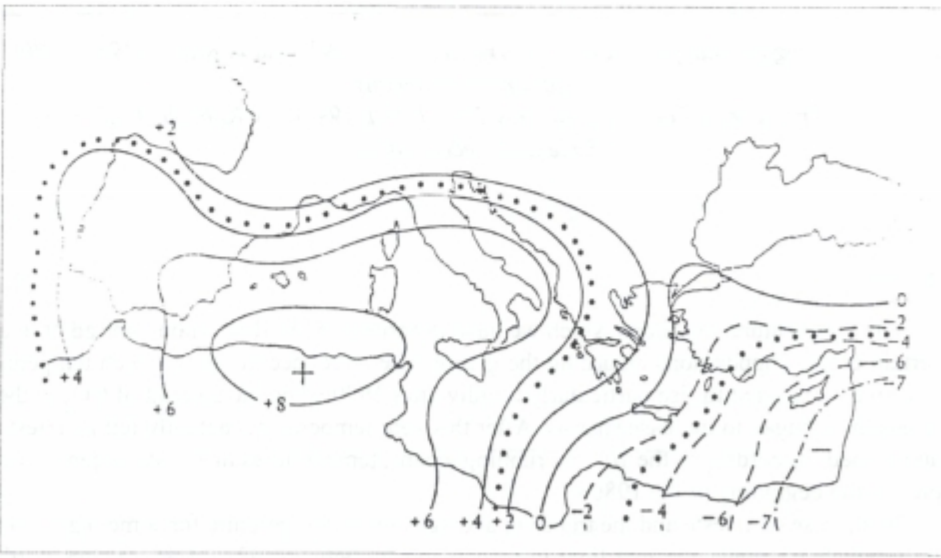


Fig. 36: Distribution of correlation coefficients for the average annual altitude of 500 hPa layer in Alger and the altitude of this layer elsewhere in the Mediterranean (correlation coefficients are multiplied by 10). Statistically significant correlation coefficients within the dotted line area are on the 5 % level. Data for the 1946-1988 period. (M. Conte et al., 1991).

Sl. 36: Porazdelitev korelacijskih koeficientov za povprečno letno višino 500 hPa ploskve v Alžiru in višino te ploskve drugje v Sredozemlju (korelacijski koeficienti so pomnoženi z 10). V območju znotraj pikčaste črte so korelacijski koeficienti statistično pomembni na ravni 5 %. Podatki so za obdobje 1946-1988. (M. Conte et al., 1991).

nean oscillation and the increase in influence of the Azores anticyclone. According to some models (J.F. Mitchell, 1987; J. Hansen et al., 1988; M. Conte et al., 1991), increased amounts of these gases ought to cause a lowering of the thermal gradient at a particular meridian between tropical and polar regions and bring about the expansion of subtropical anticyclones, increases in tropospheric temperatures, and reductions in stratospheric temperatures. Results have shown that it is not probable, or at least for the moment it has not been clearly proven, that the gases that cause the greenhouse effect have any effect on Mediterranean oscillation. They warn, however, that it is necessary to take the findings of some developers of climatic models into consideration. According to these findings, indicators of the changes which occur as a result of the greenhouse effect should begin to appear only during the 1990's or at the beginning of the next century.

5. CONCLUSIONS

Using secondary and tertiary sources, we compiled a chronicle for the period from the 7th century to the middle of the 19th century when regular meteorological observations began in Trieste. In order to achieve more accuracy in the chronicle and climatic similarities we also included data from to the Koper region augmented by data from neighbouring regions along the northern Adriatic.

The collected data is not enough to allow a more thorough reconstruction of past climate along the northern Adriatic with the use of historical sources. In particular, there is a lack of data for the period before the 16th century when the data is also less reliable. On the basis of the collected material and the frequency of occurrence of particular events during individual periods, we could only draw conclusions regarding some tendencies in climatic variations.

The chronicle consists mainly of data about severe winters and their consequences. After condensing the data, we may conclude that winters were somewhat colder between 800 and 865, between 1300 and 1570 (reaching peaks between 1400 and 1450 and 1475 and 1570), and between 1680 and 1865 (reaching the peak in the first half of the 18th century). "Warmer periods" without such reports occurred between 875 and 1300 and 1570 and 1675.

Based on comparisons of historical data with modern measurements, we made a more detailed reconstruction of two shorter periods: 1475-1491 (about the time of the first cold peak in the Little Ice Age) and 1700-1765, the period for which data about severe winters is most abundant. According to our calculations, winters were 0.8°C cooler than present-day temperatures during the first period and 0.5°C cooler in the first half of the 18th century.

Records on other events include mostly data on droughts. The majority of this data refers to droughts during the vegetation period and is mainly concentrated in three periods: 1540-1660, the first half of the 18th century, and 1820-1848. Compared to temperature, precipitation is a more variable phenomenon and we could therefore not make any conclusions directly about lower than average precipitation during these periods on the basis of periods with the most frequent records of drought.

In the process of reconstructing past climate with the help of historical sources, we had high expectations from data from the Piran archives on salt production at the Piran saltworks. Since the beginning in the 10th century to the present day, salt production has remained strongly dependent on the weather during the salt season. In addition, we were aware that due to its economic and political significance, there was a wealth of documentary material on the saltworks. Regrettably, data on salt production in the otherwise abundant literature on the subject is fragmented, and due to difficulties with the Venetian paleography, we were only able to analyze archive materials from the 19th century on.

The reconstruction that we have done for the first half of the 19th century therefore has a largely methodological value. Its purpose is to present the possibilities and problems which may arise when using such material. A more thorough investigation carried out with the help of this method would certainly require an understanding of medieval writing and a more detailed consideration of data from the Piran and Venetian saltworks archives.

The reconstruction of summer precipitation during the first half of the 19th century was made on the basis of statistical relationships we established between salt production and some climatic elements of the 20th century. In the process, we partially eliminated the influence of social conditions which were quite unstable during the 20th century by calculating production per unit of active surface. We did the same for the reconstruction of the first half of the 19th century.

Salt production, which at the Piran saltworks lasts from April until September, depends on conditions for the evaporation of sea-water which are directly proportional to the number of clear days and inversely proportional to the number of precipitation days, the amount of precipitation, and the number of cloudy days. The correlation coefficients calculated for these relationships were high and statistically significant. They presented a sound basis for the reconstruction of precipitation during the salt production season. Because of the strength of the relationships, we were able to conclude that in periods when salt production was below average, precipitation figures were higher than average and vice versa.

Using the described methodology we were able to reconstruct precipitation conditions in the salt seasons only for the 1791-1824 period when there were no limits on production. After 1824 when the government placed limits on production, we drew less reliable conclusions about probable weather conditions from data on the achievement or non-achievement of the limit and from the dates when the limit was achieved.

In 1841 the Trieste station began making regular meteorological observations. Although the station was moved several times in its more than 150-year history, always within the city boundaries, the researchers who analyzed its measurements maintain that it presents a homogeneous series of data on temperatures and precipitation for the whole period. With the help of data from the Trieste station and the rural station in Kubed which began taking precipitation measurements in 1925 and temperatures in 1951, we investigated short-term and long-term variations and trends in seasonal and annual temperatures and precipitation. It is characteristic of both precipitation and temperatures that they varied considerably over the whole period. Variations were synchronous at the two stations, except that the peaks in precipitation were more accentuated at Kubed.

We have calculated a statistically significantly trend in rising winter temperatures for Trieste during the last 150 years (0.52°C / 100 years) and a similar trend in falling summer temperatures (0.54°C / 100 years). The trend in rising winter temperatures is a common characteristic of stations in central and southern Europe while summer temperatures do not indicate any uniform trend at these stations. Both calculated trends are still within the limits of the standard deviations for variations in winter and summer temperatures although summers in Kubed have become cooler by more than one standard deviation (by 0.76°C) during the last 40 years.

We did not establish any statistically significant trends for average annual temperatures or the remaining seasons in Trieste. It is evident from the long-term annual temperature variations that there was a noticeable trend in rising temperatures between 1880 and 1960, in falling temperatures from 1960 until the beginning of the 1980's, and rising temperatures again during the last decade. If we analyze the period after the Second World War as a single period, the annual temperatures in both Trieste and Kubed have fallen by 0.7°C. This trend is statistically significant.

Winter, spring, and summer precipitation in Trieste during the last 150 years have varied without any trend. A statistically significant trend is shown by winter precipitation in Kubed which increased after 1925 at the rate of 180 mm/100 years or by 117 mm during the period the station has been in operation.

There was a statistically significant reduction in autumn precipitation in Trieste which also had an effect on annual precipitation. The reduction trend is the same in both cases and amounts to 98 mm/100 years. The variations in both are still within the limits of standard deviations so we may still consider this tendency as a variation within the normal oscillatory limits of autumn and annual precipitation levels.

The gradual reduction in annual precipitation in Trieste can be placed in a wider range of climatic variations which characterize the Mediterranean region. It must be remembered here that this reduction is in essence due to weakening primary peaks of autumn precipitation. Similarly, we must not forget that the amount of precipitation in the Mediterranean region, particularly in the south, has been decreasing for all seasons while at the same time temperatures have been rising (in Trieste mainly winter temperatures as summer temperatures are even falling), causing climatic aridity. In view of the established characteristics of climatic changes in Trieste and some regions in the northern Mediterranean, these regions belong more to the edge or transitional belt of Mediterranean climatic changes. In the opinion of some researchers, these are primarily the result of the so-called "Mediterranean oscillation" or of the slow advance of subtropical anticyclones (the Azores) above the central and western Mediterranean in recent times. At present we are in the middle of this process and we may therefore expect that the weather will become more arid if the influence of subtropical anticyclones on climate in the northern Adriatic increases.

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NOVOVEŠKE SPREMEMBE KLIME NA OBMOČJU TRŽAŠKEGA ZALIVA

Povzetek

Razprava je vsebinsko razdeljena na dva dela. V prvem so prikazani nekateri vidiki spremenljivosti klime v predinstrumentalnem obdobju. Za analizo smo uporabili zapise o izrednih vremenskih in klimatskih dogodkih ob Severnem Jadranu iz raznih zgodovinskih kronik, ki segajo v čas od 7. do srede 19. stoletja in podatke o proizvodnji soli v Piranskih solinah v prvi polovici 19. stoletja. V drugem delu analiziramo kratke in dolgoročne trende spreminjanja letnih in sezonskih temperatur ter padavin v Trstu (1841 - 1991) in Kubedu (temperature: 1951 - 1990; padavine: 1925 - 1990).

Kronologijo vremenskih in klimatskih dogodkov smo sestavili večinoma na podlagi sekundarnih (terciarnih) zgodovinskih virov. Izhodišče nam je bila kronika vremenskih dogodkov, ki jo je za Trst, Istro in Vzhodno Furlanijo sestavil G.Braun (1934). Braunovo kroniko smo dopolnili še z anali A.Schiavuzzija (1889) in D.V.Scusse (1863), s kroniko dogodkov "Fasti Istriani", ki je izhajala v časopisu "L'Istria" (1846 - 1852) in z Dolničarjevo

Ljubljansko kroniko (J.Pučnik, 1980). Podatke o zaledenitvah Beneške lagune smo povzeli po D.Camuffu (1990).

V kronologiji so zbrani predvsem podatki o hidroloških učinkih vremena (poplave, presihanje studencev in vodnjakov), o posledicah za kmetijstvo (dobre in slabe letine, zgodnje - zapoznelo cvetenje in zorenje), o ekonomskih učinkih (pomanjkanja, spreminjanja cen, lakote) in o direktnih vremenskih učinkih (zmrzali, suše, viharji ipd.).

Tabela 11: Pregled nekaterih vremenskih in klimatskih dogodkov ob Severnem Jadranu od 7.st. do leta 1850.

Ostre zime:
603, 763, 811, 853* 858, 859,
860*, 864, 1118*, 1122, 1123*,
1224, 1234, 1238, 1304, 1310,
1312, 1339, 1368, 1408, 1432*,
1441, 1443*, 1475*, 1476*, 1487*,
1491*, 1503, 1515, 1548, 1549*,
1561, 1569, 1595, 1603, 1648,
1660, 1684, 1685, 1704, 1709*,
1711, 1713, 1716*, 1726, 1729,
1762, 1763, 1782, 1788, 1789*,
1795, 1813, 1814/15, 1818/19,
1820, 1829, 1830, 1832, 1838,
1840, 1846, 1850,

Mile zime:
1186, 1628, 1682, 1686, 1702,
1772, 1794, 1817, 1822, 1834,
1843

Suše v vegetacijski dobi:
1324, 1540, 1546, 1548, 1559,
1561, 1562, 1616, 1644, 1660,
1691, 1704, 1717, 1718, 1735,
1747, 1748, 1784, 1788, 1794,
1802, 1817, 1820, 1822, 1828,
1830, 1832, 1833, 1834, 1835,
1839, 1841, 1842,

Moče v vegetacijski dobi:
1644, 1703, 1706, 1711, 1715,
1795, 1815,

Neurja s točo in močnim vetrom:
1309, 1480, 1488, 1489, 1563,
1617, 1622, 1644, 1645, 1646,
1660, 1677, 1683, 1687, 1688,
1690, 1691, 1706, 1710, 1734,
1735, 1739, 1748, 1756, 1770,
1802, 1834, 1847,

Lakote, pomanjkanja, draginje:
793, 1276, 1339, 1348, 1349,
1350, 1352, 1355, 1356, 1442,
1475, 1488, 1489, 1510, 1528,
1546, 1559, 1560, 1563, 1581,
1582, 1590, 1629, 1649, 1650,
1686, 1704, 1706, 1710, 1718,
1741, 1749, 1752, 1764, 1795,
1817,

Opomba: Z * so označene zelo ostre zime.

Zbranih podatkov je bilo premalo, da bi lahko izvedli temeljitejšo rekonstrukcijo pretekle klime ob severnem Jadranu s pomočjo zgodovinskih virov. Še zlasti primanjkuje podatkov za čas pred 16. stoletjem, ko so tudi sicer manj zanesljivi. Iz zbranega gradiva oz. pogostosti določenih dogodkov v posameznih obdobjih smo lahko torej le sklepali o nekaterih tendencah spreminjanja klime.

V kronikah je največ podatkov o hudih zimah in njihovih posledicah (Sl.37). Po zgostitvi teh podatkov sklepamo, da so bile zime nekoliko hladnejše med leti 800 in 865, med 1300 in 1570 (z viškoma med 1400 in 1450 ter 1475 in 1570) ter med 1680 in 1865, z viškom hudih zim v prvi polovici 18. stoletja. "Toplejši obdobji", brez tovrstnih poročil, sta bili med 875 in 1300 ter med 1570 in 1675.

Za dve krajši obdobji, 1475-1491, to je za čas okoli prvega viška ohladitve v mali ledeni dobi, in 1700-1765, ko je bilo podatkov o hudih zimah največ, smo na podlagi primerjave zgodovinskih podatkov s sodobnimi meritvami naredili tudi podrobnejšo rekonstrukcijo. V prvem obdobju so bile zime po naših izračunih za 0,8°C hladnejše od današnjih, v prvi polovici 18. stoletja pa za 0,5°C.

Zapisov, ki poročajo o milih zimah, je zelo malo. Primanjkuje jih zlasti za obdobje pred letom 1700. Še največ jih je po letu 1770, to je v obdobju, v katerem imamo tudi pogosta poročila o ostrih zimah, kar kaže na verjetnost, da so bile zime v tem času zelo spremenljive.

Med zapisi o ostalih dogodkih je še največ podatkov o sušah. Večina se jih nanaša na suše v vegetacijski dobi, zgoščeni pa so v treh obdobjih: 1540-1660, prva polovica 18. stoletja in 1820-1848. V primerjavi s temperaturami so padavine bolj variabilen pojav, zato na podlagi obdobij s pogostejšimi zabeležbami o sušah ne moremo neposredno sklepati o podpovprečni namočenosti teh obdobij.

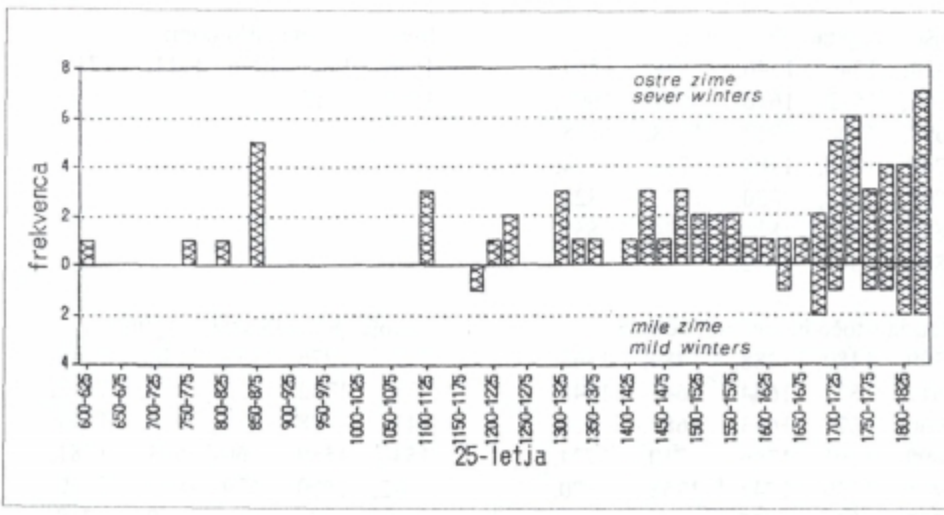

Fig. 37: 25-years frequency of sever and mild winters in the North Adriatic.
Sl. 37: 25 letna pogostnost ostrih zim ob Severnem Jadranu.

O neugodnih vremenskih in klimatskih razmerah v posameznih obdobjih lahko sklepamo tudi iz poročil o lakotah, pomanjkanjih in draginjah. Iz kronik je sicer razvidno, da so bile te nevšečnosti lahko tudi posledica vojn, turških vpadov, kug in invazij kobilic, večina pa jih le ima vzroke v neugodnih vremenskih razmerah. Če zanemarimo vesti o slabih vinskih letinah sredi 14.stoletja, potem se skoraj polovica vseh tovrstnih novic nanaša na 16. stoletje. Vzroki zanje so tako v neugodnih podnebnih razmerah (7 hudih zim, 6 velikih suš), kot tudi v političnih dogodkih (beneško-avstrijske vojne, turški vpadi) in kugah (6 kužnih let).

Pri rekonstrukciji pretekle klime s pomočjo zgodovinskih virov smo si veliko obetali od podatkov piranskega arhiva o proizvodnji soli v Piranskih solinah. Proizvodnja soli je namreč od svojih začetkov v 10. stoletju do današnjih dni ostala močno odvisna od vremena v času solne sezone, poleg tega pa smo vedeli, da je zaradi njenega gospodarskega in političnega pomena ohranjeno tudi bogato dokumentarno gradivo. Toda žal so v sicer bogati literaturi podatki o proizvodnji soli fragmentarni, arhivsko gradivo pa smo zaradi težav z beneško paleografijo lahko analizirali šele od 19. stoletja naprej.

Rekonstrukcija, ki smo jo naredili za prvo polovico 19. stoletja, ima torej bolj metodološko vrednost. Njen namen je predstaviti možnosti in težave, do katerih lahko pride pri uporabi tovrstnega gradiva. Podrobnejše proučevanje s pomočjo te metode vsekakor terja poznavanje srednjeveških pisav in podrobnejšo obdelavo piranskih in beneških arhivskih solnih fondov.

Rekonstrukcijo padavin v poletnem času v prvi polovici 19. stoletja smo opravili na podlagi statističnih zvez, ki smo jih ugotovili med proizvodnjo soli in nekaterimi vremenskimi elementi v 20. stoletju. Pri tem smo vpliv družbenih pogojev, ki so bili v 20. stoletju precej nestabilni, deloma odstranili tako, da smo proizvodnjo preračunali na enoto aktivnih površin. Enako smo naredili pri rekonstrukciji za prvo polovico 19. stoletja.

Proizvodnja soli, ki v Piranskih solinah traja od aprila do septembra, je odvisna od pogojev za izhlapevanje morske vode, ti pa so premosorazmerni s številom jasnih dni in obratnosorazmerni s številom padavinskih dni, količino padavin in številom oblačnih dni. Izračunani korelacijski koeficienti za te zveze so bili v različnih obdobjih 20. st., z različnimi družbenimi pogoji proizvodnje, visoki in statistično pomembni. Za zvezo s količino padavin v solni sezoni se je Pearsonov koeficient korelacije gibal med -0,62 in -0,92, za zvezo s številom padavinskih dni med -0,72 in -0,76, s številom oblačnih dni je znašal -0,52, s številom jasnih dni pa +0,49.

Izračunani korelacijski koeficienti so nam bili dovolj trdna osnova za rekonstrukcijo padavin v času trajanja solne sezone. Zaradi čvrstosti zvez smo lahko sklepali, da je bilo vreme v obdobjih, ko je bil pridelek soli podpovprečen, nadpovprečno deževno, in obratno.

Z opisano metodologijo smo lahko rekonstruirali padavinske razmere v solni sezoni le za obdobje 1791-1824, ko je bila proizvodnja soli brez omejitev. Po letu 1824 je država omejila proizvodnjo, zato smo o možnih vremenskih razmerah sklepali iz podatkov o (ne)doseganju limita in datumih, ko je bil limit dosežen, kar pa je manj zanesljivo.

V obdobju 1791 - 1824 so bile ugodne razmere za izparevanje morske vode med leti 1808 in 1811 ter med 1818 in 1822, neugodne pa med 1794 in 1796, med 1798 in 1800 ter med 1812 in 1817.

V drugem obdobju (1824 - 1841) predpisani limit zaradi deževnega poletja ni bil dosežen leta 1831 in 1837. Zelo pozno, septembra ali celo oktobra, je bil limit dosežen leta 1824, 1825, 1827, 1829, 1831, 1834 in 1838, iz česar lahko sklepamo, da je bila solna sezona nadpovprečno namočena. Zelo zgodaj, julija, so limit dosegli leta 1828, 1830, 1835, 1836 in 1841, kar kaže na sušnost dotedanje sezone.

Leta 1841 je začela z rednimi meteorološkimi opazovanji postaja v Trstu. Čeprav se je postaja v svoji več kot 150-letni zgodovini nekajkrat selila, toda vedno znotraj mesta, ima po mnenju avtorjev, ki so analizirali njene meritve (S.Polli, 1942, 1946; F.Stravissi, 1976), homogene nize podatkov o temperaturah in padavinah za celotno obdobje. S pomočjo podatkov tržaške postaje in podeželske postaje Kubed, ki je začela s padavinskimi meritvami leta 1925 in s temperaturnimi 1951, smo raziskali kratkoročne in dolgoročne variacije ter trende sezonskih in letnih temperatur in padavin. Spremembe smo ugotavljali s pomočjo 5, 10 in 30 letnih drsečih sredin in z linearnim trendom. Za tržaško postajo smo analizirali obdobje 1841 - 1991, za Kubed pa obdobji 1925 - 1990 (padavine) in 1951 - 1990 (temperature).

Tako za padavine kot za temperature je značilno, da so skozi celotno obdobje zelo variirale. Na obeh postajah so bile variacije sinhrone, z razliko, da so bili viški padavin pri Kubedu bolj poudarjeni.

Pri temperaturah smo za Trst v obdobju 1841 - 1991 izračunali statistično pomemben trend naraščanja zimskih temperatur (0,52°C/100 let) in podoben trend upadanja poletnih temperatur (0,54°C/100 let). Trend zvišanja zimskih temperatur je splošna značilnost postaj v Srednji in Južni Evropi, medtem ko pri poletnih temperaturah postaje nimajo enotnih trendov. Oba izračunana trenda sta še vedno v okviru standardnih deviacij variiranja zimskih in poletnih temperatur, pač pa so se za več kot eno standardno deviacijo (za 0,76°C) ohladila poletja v zadnjih 40. letih v Kubedu.

V ostalih letnih časih in pri povprečnih letnih temperaturah v Trstu nismo izračunali statistično pomembnih trendov. Iz dolgoročnega gibanja letnih temperatur je razvidno, da je bila opazna tendenca ogrevanja v obdobju od 1880 do 1960, po tem letu so se temperature do začetka 80-tih let nižale, v zadnjem desetletju pa ponovno naraščajo. Če obdobje po drugi svetovni vojni analiziramo kot enotno obdobje, potem so se letne temperature tako v Trstu kot v Kubedu znižale za 0,7°C; trend je statistično pomemben.

Zimske temperature so bile večino druge polovice prejšnjega stoletja pod 150 letnim povprečjem. Najnižje so bile okoli leta 1860 in 1890, ko so se glede na 10 letne drseče sredine spustile pod povprečje za nekaj več kot 1°C. V 20. stoletju je opazen trend ogrevanja. Zime so bile najtoplejše v desetletju 1970 - 1980 in v obdobju 1910 - 1925, podpovprečno hladne pa v drugi polovici 30-tih in v prvi polovici 40-tih let.

Za spomladanske temperature je značilno močno variiranje brez trenda - v razmeroma kratkih obdobjih tudi za več kot 2°C. Daljša obdobja z nadpovprečno toplimi pomladmi so bila: 1857 - 1870, 1913 - 1925 in 1943 - 1953, ko so bile pomladi najtoplejše doslej. Od začetka 50-tih let naprej je opazen trend ohlajevanja. Podpovprečno tople pomladi so bile zlasti med 1870 in 1910 (z najnižjimi temperaturami med 1875 in 1880), v 20. stoletju pa med 1925 in 1943 in v 50-tih letih.

Statistično pomemben trend ohlajevanja poletij se je začel po desetletju 1850 - 1860, ko so bile poletne temperature najvišje v zgodovini tržaške postaje. Pod dolgoletno povprečje so se poletja ohladila ob prelomu stoletja in taka ostala do srede 20-tih let 20. stoletja. Sledilo je "toplo obdobje" z viškom v drugi polovici 40-tih let, in nato izrazit trend ohlajevanja do leta 1980. V desetletju 1980 - 1990 so se poletja ponovno ogrevala, kar se nadaljuje tudi v prvi polovici 90-tih let.

Glede na 30 letne drseče sredine imajo spremembe jesenskih temperatur obliko vala s periodo okoli 110 let. Od leta 1860 do začetka 20. stoletja so bile jeseni podpovprečno tople, v 20. stoletju pa večinoma nadpovprečne. Najtoplejše so bile na prehodu 30-tih v 40. leta.

Padavine so v primerjavi s temperaturami bolj variabilen klimatski element, zato so odkloni sezonskih padavin od dolgoletnega povprečja večji - tudi za več kot 100%.

Za variiranje zimskih padavin je značilno, da so bile glede na 30 letne drseče sredine večino prejšnjega stoletja, razen druge polovice 60-tih let, podpovprečne, v 20. stoletju pa, razen obdobja 1930 - 1945, nadpovprečne. Za obdobje po letu 1935 je opazen izrazit trend naraščanja, z viškom sredi 60-tih let.

Pri spomladanskih padavinah so se do začetka 20-tih let 20. stoletja relativno enakomerno izmenjevala obdobja z nad in podpovprečno količino padavin. Obdobja z nadpovprečnimi padavinami so glede na 10 letne drseče sredine trajala 10 do 15 let, s podpovprečnimi pa do 10 let. V 20-tih letih tega stoletja je najprej prišlo do povečanja spomladanskih padavin nad do tedaj najvišje vrednosti in nato do močnega upada, z minimumom v 40-tih letih. Minimumu je sledil dvig spomladanskih padavin na raven povprečnih.

Podobno kot spomladanske, so tudi poletne padavine variirale brez jasnega trenda. Glede na 30 letne drseče sredine sta se izmenjali dve obdobji z nadpovprečno namočenimi (1870 - 1925, po letu 1960) in dve obdobji s podpovprečno namočenimi poletji (pred letom 1870, 1925 - 1960). Po sušnosti je prednjačilo obdobje v 20. stoletju, ko je bila skoraj 25 let vsota poletnih padavin za tretjino ali celo polovico manjša od običajne.

Spreminjanje padavin v jeseni, ko imajo ob Tržaškem zalivu svoj primarni višek, in variiranje letne količine padavin, si je zelo podobno. Do konca prejšnjega stoletja so bile večinoma nadpovprečne, nato so v prvih desetletjih tega stoletja nihale okoli povprečja, po letu 1930 pa so se padavine spustile globoko pod povprečje. V 40-tih letih 20. stoletja so bile jesenske padavine nižje od dolgoletnega povprečja za okoli 40 mm, letna količina padavin pa za okoli 180 mm. Podpovprečne so ostale jesenske padavine tudi v zadnjih desetletjih, letne padavine pa kažejo težnjo dvigovanja proti povprečju.

V Trstu so zimske, spomladanske in poletne padavine v celotnem 150 letnem obdobju variirale brez trenda. Statistično pomemben dvig imajo zimske padavine v Kubedu, ki so v obdobju 1925 - 1990 naraščale s stopnjo 180 mm/100 let oz. 117 mm v času delovanja postaje.

Za statistično pomembno stopnjo so se v Trstu znižale jesenske padavine in pod njihovim vplivom tudi letna količina padavin. Težnja zniževanja je pri obeh ena in znaša 98 mm/100 let. Spremembi sta še v okviru standardnih deviacij, zato lahko to tendenco še vedno štejemo kot spremembo v običajnih okvirih nihanj jesenske in letne količine padavin.

Postopno zmanjševanje letne količine padavin v Trstu lahko umestimo v širši sklop klimatskih sprememb, ki so značilne za Sredozemlje. Pri tem pa ne smemo prezreti, da gre pri tem zmanjševanju v bistvu predvsem za slabljenje primarnega viška padavin v jeseni.

Prav tako pa ne smemo pozabiti, da se v Sredozemlju, zlasti še južnem, količina padavin zmanjšuje v vseh letnih časih, medtem ko istočasno naraščajo temperature (v Trstu predvsem zimske, poletne se celo znižujejo), kar povzroča aridizacijo klime. Glede na ugotovljene značilnosti klimatskih sprememb v Trstu in v nekaterih pokrajinah v severnem Sredozemlju, sodijo te pokrajine bolj na rob oz. v prehodni pas mediteranskih klimatskih sprememb. Te naj bi bile po mnenju nekaterih raziskovalcev (M. Conte et al., 1991) povsem posledica t.i. "mediteranske oscilacije" oziroma počasnega napredovanja subtropskih anticiklonov (Azorskega) nad osrednje in zahodno Sredozemlje v novejšem času. Trenutno naj bi bili na sredi tega procesa, zato lahko pričakujemo, da se bo podnebje še bolj aridiziralo, če se bo vpliv subtropskih anticiklonov na podnebje v severnem Jadranu še povečal.