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THE FROZEN BOSPHORUS AND ITS PALEOCLIMATIC IMPLICATIONS BASED ON A SUMMARY OF THE HISTORICAL DATA

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Abstract:

Historically, the first evidence of a frozen Bosphorus was noted during the time of Herodotus. Analysis of the historical data about freezing events in the Bosphorus (at Istanbul) reveals the existence of four main cold periods since 1 AD. The first occurred around the 1st century. Although the temperature was close to, or perhaps a little lower than, that of the present, three successive freezing events are indicated between 7–17 AD. The second cold period was in the 4th century, when another freezing event was reported in 401 AD. After a slight temperature increase up to the beginning of the 8th century, the third cold period extended from the mid-8th to the 13th century, during which the Bosphorus and even parts of the Black Sea were repeatedly frozen, and floating ice masses entered the Sea of Marmara. Winters were markedly mild for 400 years starting from the mid-13th century. The fourth cold period began early in the mid-17th century and has lasted to the present day; it has been characterized by severe winters, however, the intensity of the winter cold has gradually diminished during this interval. Our aim is to evaluate existing historical data on these modern cold periods, to analyze instrumental meteorological data, and to provide suitable data for future correlations with the amplitude and frequency of paleoglacier advances both in the Alps and in Anatolia. These four periods are more or less coeval with the phases of glacial advance in the Northern Hemisphere. As the accuracy of the historical data increases with time, evidence is more detailed for the fourth period. During this interlude, which coincides with the Little Ice Age, freezing events were not all coeval with reliable central European evidence. This can be explained by the low index of the North Atlantic Oscillation that resulted in higher precipitation ratios.

Keywords:

climate change, Istanbul, Little Ice Age, Anatolia, paleoclimate, Bosphorus freezing

1. INTRODUCTION

Istanbul is a huge metropolis connecting continents, cultures, and religions, a home to approximately 15 million people (Figure 1). Its history begins with the foundation of Byzantium in Hellenistic times and continues through the Roman, Byzantine, and Ottoman periods to today. Most of the accounts dealing with the establishment of Istanbul focus on the year 2700 BP, though it is evident that people had already settled around Istanbul before this date. In the region, archaeological surveys have revealed the presence of continuous settlement, the earliest sites of which appeared 300,000 years ago.

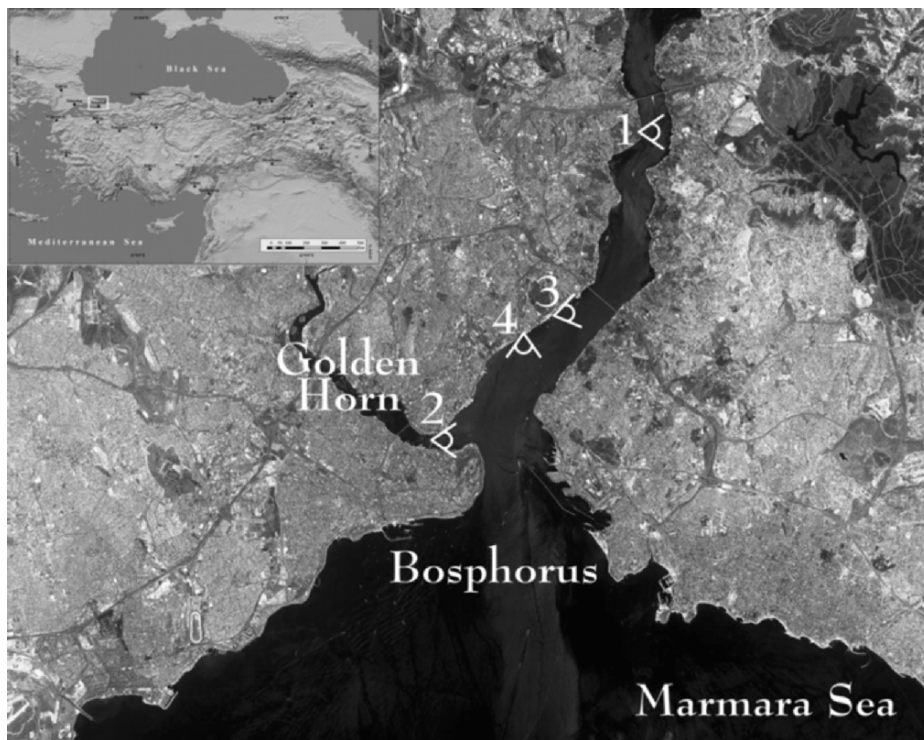


Figure 1. Satellite image of Istanbul with approximate orientations of the photographs in the following figures: Figure 2 = 1; Figure 3 = 2; Figure 4 = 4; Figure 5 = 3.

At around the Last Glacial Maximum, Anatolia (including Istanbul) experienced a substantial expansion of cold steppe vegetation at the expense of forest and woodland. Closed lakes were far more extensive than at present, which is best explained by a reduction in evaporation together with evapotranspiration losses, accompanied by higher catchment runoff coefficients (Kuzucuoğlu and Roberts 1997). Meanwhile, the Black Sea was a large lake to

the north, and Marmara Sea was a lake without any connection to the Aegean and Black Seas. During the Late Glacial period, this region experienced several climatic oscillations until the present-day environment was established, approximately 3000 years ago (Özdoğan 1997).

Herodotus, the Greek historian of the 5th century BC, supplied important information about Istanbul, notably that there were originally two cities (2002). The former was Kalkhedon, situated on the Asian coast of the Bosphorus. The latter was Byzantion, located on the “Historical Peninsula” on the European side. Also, there was a third city, Selymbria, but this was situated on the northern Marmara coast, far away from the two cities that formed the nucleus of today’s Istanbul. Herodotus stated that Kalkhedon was founded 17 years before Byzantion. The Greek geographer Strabo (1st century BC to 1st century AD) recorded similar data in his famous work, *Geography* (2000). Byzantion, a well-protected harbor city, was established in 663 BC by colonists from cities in the Peloponnese. Due to its position dominating the Bosphorus Strait, it grew rich in little time, becoming the key point for trade between the Black and Marmara Seas. It then started to control both the Bosphorus traffic and passages between Asia and Europe.

In this study, the aim is to evaluate existing historical data on the recorded cold periods, to analyze instrumental meteorological data, and to provide a suitable synthesis for further studies.

2. FREEZING EVENTS IN THE BOSPHORUS AND BLACK SEA REGION IN HISTORICAL RECORDS

Herodotus provided the first information about freezing in the Bosphorus. In addition to this event which occurred during the Cimmerian historic time, Herodotus reported another freezing occurrence in the Kerch Strait of the Azov Sea. Subsequently, there is no indication of a freezing event in the Bosphorus until the time of Augustus. In *Epistulae Ex Ponto* (Letters from Black Sea) and *Tristia* (Songs of Madness), Ovid (1977) mentioned three successive freezing episodes in the Black Sea region between 7 and 17 AD.

Between the time of Ovid until the 4th century AD, there is no information on freezing of surface waters in the Bosphorus and Black Sea region, although freezing of several rivers, especially the Danube, was reported. The Roman historian, Ammianus Marcellinus (1808), reported not only the freezing of rivers that flow into Black Sea but also that parts of Black Sea open to northerly winds were covered by thick ice.

Scaliger, in his quotation from *Chronicon Pachale* (Paschal Chronicle), mentioned that the Black Sea was completely frozen in 401 AD, at the time of

Emperor Arcadius (395–408 AD) (Chikhachef 1864). Freezing was so intense that ice masses floated into the Marmara Sea continuously even a month into spring (March?). According to another source, winter in Istanbul was so severe in the same year that the Bosphorus and Golden Horn were completely frozen. The inhabitants of Istanbul believed that this was the “Wrath of God” (Pamukciyan 2002).

Around 600 AD, Jordanes (1882) mentioned that the Azov Sea was frozen but reported that the Don River was not affected by the cold event. After the cold spell documented by Scaliger, no freezing in the Bosphorus or Black Sea basin was reported for 300–350 years. On the other hand, the winters of 401, 418, and 441 AD (Schnurrer 1823–25) were harsh in Western Europe. Also, the winters of 660 AD—data from Theophanes (1997)—and 760 AD—data from Nicephorus, Patriarch of Constantinople (1990)—in Istanbul were dominated by extensive, abnormal cold, and the region was under snow for several months.

The Bosphorus was reportedly frozen again in 739 AD (Hammer-Purgstall 1827–35). Byzantine Emperor Leo III (717–741 AD) was against praying in front of icons, and ordered that the fresco of Jesus be removed from the gate of the Palace. During his reign, the winter of 739 AD was so violent that the Bosphorus was completely frozen. Inhabitants and priests related this extraordinary phenomenon to the struggle against the saints (Pamukciyan 2002).

At the time of the Emperor Konstantinos V Kopronymos, freezing events with harmful consequences were reported throughout his reign (741–775 AD). The first one occurred in 753 AD, during the winter of which, ice masses were dragged by the force of the elements from the Black Sea to the Marmara Sea (Pamukciyan 2002). This occurred again in 756 and 763 AD. Byzantine chronographers recorded these events in detail, and several historians made different observations, descriptions, and interpretations relating to this decade (753–763 AD). Later, at the beginning of 12th century, the historian Zonaras described the 8th century:

In this interim (Emperor Kopronymos), there was a harsh winter. Not only rivers, also the Black Sea is frozen partially. Because of the frozen Bosphorus, sea passage from Byzantium to Chrysopolis (Üsküdar) on the Asian side is hardened. The inhabitants who could walk to Üsküdar, and loads could be carried with animals and two-wheeled ox-carts. It is known that similar phenomena occurred in other seas. With spring warming, the ice was broken into pieces and these pieces started to flow and were dragged by strong winds. Many domestic and wild animals were killed by the collision of island like ice masses. Some of these masses were dragged quickly and hit the city walls, with the intensity of the strike not only the walls but also buildings nearby were damaged (Indjidjian 2000).

The Byzantine chronographer Glykas (1836) described the same event. The freezing that occurred several times when Emperor Kopronymos was in power was also described by Theophanes the Confessor (1997), who lived in this

time. Theophanes mentioned the freezing of a broad stretch of 100 miles along the coast of the Black Sea, first to a depth of 30 and later to 50 fathoms, and the occupation of the Bosphorus and Hellespontus by a thick ice cover:

In the same year (762 AD), starting in early October, there was very bitter cold, not only in our land, but even more so to the east, the north, and the west, so that on the north coast of the Pontos to a distance of 100 miles the sea froze from the cold to a depth of thirty cubits. The same happened from Zigchia to the Danube, including the river Kouphis, the Danastris, the Danapris, and Nekropelai, and the rest of the coast as far as Mesembria and Medeia. All this ice was snowed upon and grew by another twenty cubits, so that the sea became indistinguishable from land: upon this ice wild men and tame animals could walk from the direction of Chazaria, Bulgaria, and other adjoining countries. In the month of February (763 AD) of the same 2nd indiction this ice was, by God's command, split up into many different mountain-like sections which were carried down by the force of the winds to Daphnousia and Hieron and, by way of the straits, reached the City and filled the whole coast as far as the Propontis, the islands, and Abydos. Of this I was myself an eyewitness, for I climbed on one of those [icebergs] and played on it together with some thirty boys of the same age. Some of my wild and tame animals also died. Anyone who so wished could walk without hindrance as on dry land from Sophianai to the City and from Chrysopolis to St Mamas and to Galata. One of the icebergs struck the jetty of the Acropolis and crushed it. Another huge one struck the wall and shook it greatly so that the houses on the inside partook of the quake. It then broke into three pieces and ringed the City from the Mangana to the Bosphorus, rising in height above the walls. All the inhabitants of the City, men, women, and children, ceaselessly watched these things and would return home with lamentation and tears, not knowing what to say. (Theophanes the Confessor 1997)

According to Byzantine historians, this cold period was one of the most significant events in history. Patriarch Nicephorus supplied important information on winter 763 AD in Istanbul:

In the beginning of autumn (762 AD) winter has come with abnormal colds; all, also saline waters are frozen which affected inhabitants of the city severely. 100 miles stretch of the sea [1 Roman mile is approximately 1.5 km] is covered by ice like in the regions north of Black Sea. Ice invaded most of the rivers; the coasts of Mesembria and Medeia were a solid mass as ice was 30 coudée thick [old unit of length, being the distance from elbow to fingertips; 30 coudee = about 13–14 m]. Also snowfall was so heavy that this ice is enclosed by 20 coudée [about 9–10 m] of snow and all morphological differences between sea and coast disappeared. Now a white cover unified sea and land. All parts of Black Sea facing north were solidified [= frozen]. Especially the areas of Hazars and around the Scythian's Lands were inaccessible and unsuitable for human and animal life. After a while (according to Georgios Kedrenos in February) this significant crystal crust broke into several pieces and these were uplifted in the middle of the sea like Pyramids. Most of them, dragged by winds, were smashed and sunk in the opening of the Bosphorus to the Black Sea near Daphnousia, which was a powerful castle. Most of them entered into the Bosphorus. They filled up all the curls of the water way and connected Asia and Europe. They

formed a land bridge between two continents and it was easier to pass the strait by walking instead of using boats. Accumulated ice masses in the Bosphorus without any delay were dragged into Propontis [Marmara Sea] and even reached Abydos. There they accumulated again in a perfect way to form a structure like a monolith and Propontis lost its sea characteristics. One of these huge icebergs was grounded in the bottom of Constantinopolis Fortress, and shook the city walls so that inhabitants were excited. Icebergs accumulated in front of the Fortress, then invaded all waterways. They accumulated to the same height as the city walls. As a result inhabitants of the city were able to go out of the city from the harbor by crossing these icebergs and they can walk to the Galata Castle on the other side from Constantinopolis Fortress (Chikhachef 1864).

There is no evidence of cold winters in Western Europe during this decade (753–763 AD), however, a period of intense cold after December, 770 AD, was mentioned. This cold period was extensively felt in almost all of Europe (Schnurrer 1823–25). In 787 AD, European authors reported an abnormal cold pulse in Italy (Schnurrer 1823–25) that went unmentioned in Byzance.

Freezing in the Black Sea occurred again at the start of 9th century. In 800 AD, it was frozen to a considerable depth (Schnurrer 1823–25). The winter of 801/802 was also noted in Europe for cold temperatures. As a whole, the 9th century is accepted as one of the coldest periods in Europe. In 820 AD, the Danube, Elbe, and Rhine Rivers were frozen for a month. Furthermore, the winters of 832, 855, 859, 864, 874, and 880 AD were so harsh, especially in 859, that the Adriatic Sea was frozen, and Italy was under snow for 100 days (Schnurrer 1823–25). Despite these climatic events, Byzantine chronographers documented no severe winters or freezing events for the Bosphorus.

Glykas and Symeon Logotheta revealed four freezing events in the following century. At the time of Emperor Romanus I Lecapenus (919–944 AD), winters were cold in 928 and 934 (Hammer-Purgstall 1827–35). In the time of Emperor Nicephorus II Focas (963–969 AD), temperatures fell again (data from Glykas). Also the winter of 993 AD, at the time of Basileus II (976–1025 AD), was reported as severe by Byzantine chronographers (data from Glykas). Leo Grammaticus, who lived in the time of Emperor Romanus, reported severe cold and stated that one of these periods lasted for 120 days, with severe frost occurring (Indjidjian 1794).

Europe experienced harsh winters in the 10th century. They occurred either before the two freezing events in the time of Emperor Romanus or between the reigns of Emperors Romanus and Nicephorus Focas, in the years of 912, 927, 940, and 943 AD. Freezing of the Bosphorus and the Black Sea was reported by several authors in 1011 during the period of Basileus II (Schnurrer 1823–25). A severe winter was also reported in Europe. Ice was floating on the Nile River (Michaud 1825–29).

After the severe winter 1011, there is no evidence for freezing of coastal waters in the Black Sea region for 210 years, with the exception of the freezing of the Kerch Strait that connects the Azov and the Black Seas. This period is

known as the “Little Climatic Optimum,” or the Medieval Warm Period (Telelis 2000). In 1221, during the time of Emperor Robert I (1219–1228), a very severe winter struck Byzance such that the Bosphorus and Golden Horn were completely frozen (Pamukciyan 2002). This recurred in 1232 (Hammer-Purgstall 1827–35).

Both Europe and the East witnessed several harsh winters, whereas in Istanbul and in the Black Sea, a period of 221 years passed without any freezing. The summer of 1043 was recognized in Europe as “A year with snowfall, which covered both the German farmers and their yield” (Chikhachef 1864). In the winter of 1076, Rennes was frozen, and in 1113, following a severe winter in France, there was a very hot and dry summer when dead trees caught fire under “the burning sun” (Chikhachef 1864). As a consequence of heavy snowfall in Baghdad in 1117, snow cover reached the height of a man and remained for 14 days (Hammer-Purgstall 1842–43). Several locations in Europe had to experience very low temperature during the winters of 1124, 1126, 1127, 1129, 1179, and 1210 (data from Chikhachef 1864).

In winter of 1232, after a very hot summer in 1231, the Bosphorus was frozen again, and this event does not coincide with severe winters in Europe. In 1234, the Adriatic Sea was also frozen as a result of a severe winter in Italy, and it was possible to walk across (Indjidjian 1794). During a 385-year period, the Adriatic Sea was frozen only once, yet this event was not duplicated in the Black Sea region. Similarly, the 1232 freezing event in the Bosphorus was not felt in the Adriatic Sea.

After the 1232 Bosphorus freezing, a 250-year warm interval ensued. Petrus Gyllius (1489–1555) cited (1561, 1562) two severe winters during his time, writing that even the sea surface from Kağıthane to Galata, on the harbor side of Istanbul, was frozen, so that boats could advance only by breaking the ice. Unfortunately, the author did not provide the years. These events probably took place between 1520 and 1550 (Hammer-Purgstall 1827–35).

According to Hammer-Purgstall (1827–35), thick ice covered the Bosphorus and connected the two continents in 1620, at the time of Sultan Osman II (1618–1622). Demetrius Cantemir, in his *History of the Ottoman Empire*, reported frost and freezing of the Bosphorus due to severe cold, and that the inhabitants of Istanbul were walking from Istanbul to Üsküdar in the winter of 1621 (Pamukciyan 2002). This event was mentioned by Hammer-Purgstall and Cantemir with one year difference (but we conclude that it is the same event). According to Nicephorus (1829–55), there was first a heavy snowfall and then dry cold so that the Bosphorus was frozen. People were able to walk from Galata to Üsküdar and from Üsküdar to Istanbul in January of 1621.

During the 339 years from 1232 to 1621, there were several harsh winters in Europe. Those of 1292, 1322, 1323, 1341, 1342, 1358, 1363, 1399, 1042, 1407, 1408, 1421, 1433, 1434, 1457, 1491, 1506, 1513, 1514, 1534, and 1607 were recognized especially as “difficult years with severe winters”

(Chikhachef 1864). Such severe winters were not experienced in the Bosphorus and Black Sea region. Only the winters of 1341, 1342, and 1343 brought unusual cold to Istanbul (Schnurrer 1823–25). In 1513, the Rhine and Danube Rivers were frozen when cold conditions dominated Europe, but Ottoman chronographers recorded no freezing events in the Bosphorus (Pamukciyan 2002).

But in 1669, the Bosphorus was again frozen, at least partially, with floating ice masses on the waterway (Schnurrer 1823–25). Between 1621 and 1669, severe cold periods from Europe and even from America are known. The cold winters of 1642, 1658, 1667, and 1669 were especially significant. Hailstones of 1 kg reportedly fell in Egypt on July 28, 1667. Until 1755, cold winters were more common in Europe, Asia, and America. The winters of 1670, 1673, 1695, 1697, 1705, 1709, and 1716 witnessed partial freezing along the coasts of Denmark. During the winter of 1729, the Danube froze over three times. The winter of 1740 affected all of Europe, while the winters of 1741, 1744, and 1750 were extreme in America (Hammer-Purgstall 1827–35). Even though there was no freezing reported for the Bosphorus, the 1750 winter was difficult in Istanbul.

In 1755, during the time of Sultan Osman III (1754–1757), when severe winters were absent, Turkish chronographers noticed an ice cover on the Bosphorus that enabled one to walk from Ortaköy to Sütluçe on February 16th (Pamukciyan 2002). In January or February of 1779, the Bosphorus was once again frozen due to cold weather conditions (Indjidjian 1794).

During the 68-year interval from 1779 to 1823, central and northern Europe experienced a series of long and very cold winters. Considering their continuity, duration, and intensity, it is very difficult to find a cold period of equal severity. Europe endured 20 harsh winters between 1668 and 1816, i.e., the winters of 1768, 1775, 1776, 1778, 1779, 1780, 1784, 1785, 1786, 1789, 1793, 1796, 1799, 1800, 1802, 1808, 1810, 1812, 1813, and 1816 (data from Chikhachef 1864). This represented an almost continuously cold period, with only two-year breaks. This period marks the maximum of the Little Ice Age in Europe (Grove 1990). Was the Little Ice Age a global or a regional European phenomenon? In this context, data from the Bosphorus region are crucial. Some of the significant parameters of this cold period are outlined below.

On January 27, 1776, temperature was measured at -28.7°C in Leipzig, -22.5°C in Montdidier, -21.5°C in Nancy, -20°C in Paris, and -21.5°C in Vienna (Schnurrer 1823–25). Nearly all the rivers of Europe were frozen from the beginning of December, 1784, to the end of February, 1785. On February 27, 1785, temperature was -29.2°C in Waldheim, Germany. Cold weather reached abnormally low levels in Paris, Naples, and several cities of Spain in the same month of that year (Schnurrer 1823–25). In most of Europe, temperatures were lower than -25°C in the winter of 1789 (Schnurrer 1823–25). From the end of summer, 1801, harsh, cold conditions dominated all of Europe. Temperatures were measured at -48°C in Bialystok, Poland, on January 1, 1802, -27.3°C in

St. Petersburg on March 12, -24° C in Yekaterinburg on May 11. The sea in Livorno was frozen the same year (Schnurrer 1823–25). England and Germany were under heavy snowfall in 1802; temperature was measured at -29.2° C in Stuttgart. After the severe winter of 1802, tropical weather conditions dominated the whole summer, and temperatures as high as 37.5° C were recorded in Vienna, for example (Schnurrer 1823–25). In 1808, a severe winter dominated southern Europe, especially Italy. On February 27, Naples was under heavy snowfall, and the Rhone River in southern France was frozen (Schnurrer 1823–25). The 1809 winter followed the same pattern, with temperatures of -9.7° C in Naples, -35° C in Lithuania, -42.2° C in St. Petersburg, and the mercury froze in Moscow (Schnurrer 1823–25). The winter of 1812 was the last in the series of severe winter weather, but with an “inverse” temperature pattern, e.g., the thermometer registered -6.2° C in Stuttgart and -11.2° C in Naples (Schnurrer 1823–25). Although the severe winters in Europe had an important geographical extension and were felt in Hungary and/or Thrace, which are relatively closer to the Black Sea basin, there is no evidence of freezing in the Bosphorus and Black Sea region in historical records for that time period.

The Black Sea and Bosphorus witnessed another severe winter in 1823, however. The northern coasts of the Black Sea froze completely, and ice masses were dragged into the Bosphorus. Also, the Golden Horn was partially frozen (Pamukciyan 2002). For this year, the cold event recorded in the Bosphorus and Black Sea seems to correlate with difficult conditions dominating Europe. For instance, temperatures were measured at -30° C in Hamburg between February 21 and 26. Mean temperature in Berlin was around -23° C (peak -35° C), in Bucharest -23° C to -25° C, -37° C in Sweden, and -11° C in St. Petersburg. Meanwhile, Spain and Portugal were under snow (Schnurrer 1823–25).

The Golden Horn froze on February 6, 1849 (Chikhachef 1864). From January 9 to 10, 1862, the Bosphorus was again frozen (Pamukciyan 2002). During this winter, temperatures dropped abruptly north of the Black Sea (-30° C in Moscow on December 9, 1862), whereas this winter was almost unfelt in France, England, and even Vienna.

When the Golden Horn froze in 1857, inhabitants could drive from Halicioğlu to Eyüp (from the Archives of the Kandilli Observatory). The Golden Horn and Bosphorus froze again in 1878 during the Russian-Ottoman Wars (Pamukciyan 2002). The same event occurred again in 1893 (from the Archives of the Kandilli Observatory).

The most severe winter after that time occurred in 1928. The Golden Horn was partially frozen, and icebergs were observed in the Bosphorus. Again in 1929, a part of the sea froze, and ice masses were dragged from the Black Sea and accumulated in the Bosphorus (Figures 1, 2, and 3).

The last freezing event in the Bosphorus was during the second harsh winter of the young Turkish Republic in 1954. Ice masses accumulated in the Bosphorus and prevented marine traffic for several days (Figures 1, 4, 5, and 6).



Figure 2. Partially frozen Bosphorus in the winter of 1929; position 1 in Figure 1 (from Üster 2000).



Figure 3. Frozen Golden Horn and Bosphorus in the winter of 1929; position 2 in Figure 1 (from Üster 2000).



Figure 4. Ice masses in the Bosphorus in the winter of 1954; position 4 in Figure 1 (from Üster 2000).



Figure 5. Ice masses accumulated in the Bosphorus in the winter of 1954; position 3 in Figure 1 (from Üster 2000).

3. DISCUSSION

According to the historical records, over the last 2000 years, there have been 40 severe winters in Istanbul accompanied by (1) freezing of the Bosphorus and the Golden Horn and (2) ice masses dragged in from the Black Sea. During these two millennia, 14 freezing events have been reported in the Black Sea only. The Bosphorus has been totally frozen 12 times and partially frozen 6 times. The Golden Horn has been totally frozen 15 times and partially frozen 6 times.

Most descriptions in the historical records show that freezing occurs, and



Figure 6. Iceberg floating on the Bosphorus in early spring of 1954 (from Üster 2000).

ice masses are dragged in from the Black Sea, due to strong easterly winds that blow during severe winters. For instance, the descriptions of Zanos, Theophanes, and Nicephorus for the winters of 753, 756, and 763 mention cold and strong winds. Historians also recorded that dry, cold conditions subsequent to heavy snowfall brought about freezing in the Bosphorus during the 1621 winter. In order to freeze saline water and transport ice masses from the Black Sea, through the Bosphorus, and across the Marmara Sea as far as the Dardanelles, strong winds and cold, dry air masses are required. Within the general atmospheric circulation patterns affecting the Eastern Mediterranean region (Figure 7), such winds are driven by the strong thermal high pressure system that covers a large part of the Asian continent and affects the region substantially in winter. This Siberian High Pressure System causes dry and cold continental polar air masses to move in a southwesterly direction. It is logical to conclude that extension and intensification of the Siberian High occurred during winters when the Bosphorus froze.

The effect on these events of the North Atlantic Oscillation (NAO), which dominates atmospheric variability in the subtropical northern hemisphere during winter, is unclear (Figure 8). The longest precipitation record for Turkey is from Istanbul (Erinç and Bener 1961), but the relationship between total winter precipitation and freezing events remains, unfortunately, poorly understood. Causes of this inconsistency could be the absence of long-term meteorological measurements and inconsistencies in the historical data for older events.

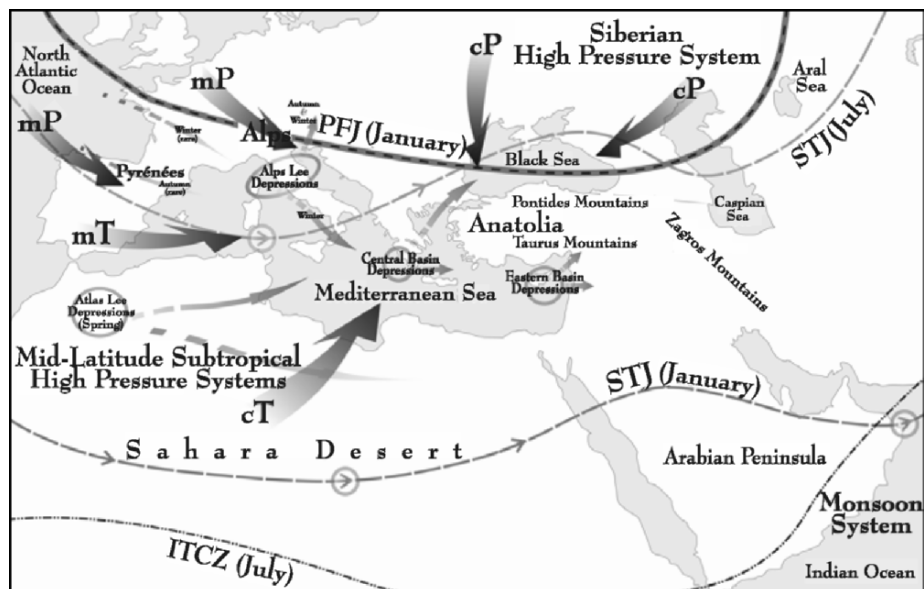


Figure 7. Mean positions of the Polar Front Jet (PFJ), Subtropical Jet (STJ), and Intertropical Convergence Zone (ITCZ) in winter and summer in the Mediterranean Region, and schematically located low pressure and high pressure systems that influence the climate of the Eastern Mediterranean: cP = Continental Polar Air Mass; mP = Marine Polar Air Mass; cT = Continental Tropical Air Mass; mT = Marine Tropical Air Mass (from Akçar and Schlüchter 2005).

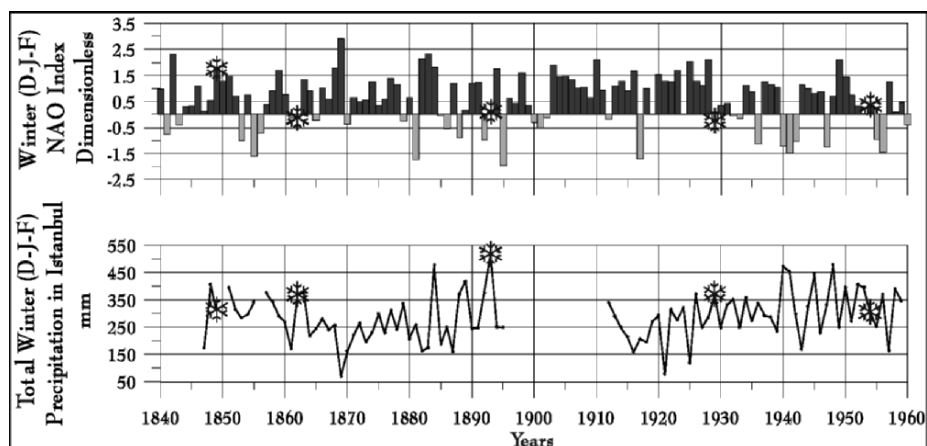


Figure 8. Total winter precipitation in Istanbul (data from Erinç and Bener 1961); Winter North Atlantic Oscillation Index (<http://www.cru.uea.ac.uk/cru/data/nao.htm>) and Freezing Events in Bosphorus between 1840 and 1960 (modified from Yavuz *et al.* 2003).

The historical data on freezing events in the Black Sea and Bosphorus show four main cold periods since 1 AD (Figure 9). The first period was around the 1st century. Although the temperature was close to or perhaps a little lower than at present, three successive freezing events were indicated on the Black Sea coast between 7–17 AD. The second cold period occurred in the 4th century, when parts of the Black Sea were frozen, and floating icebergs reached the Marmara Sea in 401 AD. The third cold period extended from the mid-8th to the 13th century, when the Bosphorus and parts of the Black Sea were repeatedly frozen, and floating icebergs were present in the Marmara Sea in the winters of 739, 753, 756, 763, 928, 934, 1011, 1221, and 1232. The fourth cold period began in the early mid-17th century and lasted to the present day. It has been characterized by severe winters (with freezing of the Bosphorus, the Golden Horn, and parts of the Black Sea in 1621, 1669, 1755, 1779, 1823, 1849, 1862, 1857, 1878, 1893, 1928, 1929, and 1954), however, the intensity of the winter cold has gradually diminished during this interval.

The four episodes are more or less contemporaneous with the phases of glacial advance in the Northern Hemisphere (Grove 1990). As the accuracy of the historical data increases with time, evidences for events are more frequent and more reliable for the fourth period. During this time interval that coincides with the Little Ice Age, freezing events are not always contemporaneous with the central European evidence.

5. CONCLUSIONS

Over the last 2000 years, 40 severe winters occurred, which were accompanied by freezing of the Bosphorus and the Golden Horn and by the dragging of ice masses from the Black Sea. Fourteen freezing events are reported for the Black Sea. The Bosphorus has been totally frozen 12 times and partially 6 times. The Golden Horn has been totally frozen over 15 times and partially 6 times (Figure 9).

The effect of the NAO Index on the precipitation pattern and on the freezing events in the Bosphorus is not clear. The climate of the region is strongly influenced by the Siberian High Pressure System during winter. The frozen Bosphorus during the most recent cold periods (from 1621 to 1954) can be explained by the interaction of the North Atlantic Oscillation and the Siberian High Pressure Systems (Figures 7 and 8).

The four cold episodes are more or less coeval with phases of glacial advance in the Northern Hemisphere (Grove 1990). As the accuracy of the historical data increases with time, evidence for freezing events is more frequent and reliable in the fourth period. At this time, which coincides with the Little Ice Age, freezing events were not always coeval with the central European evidence.

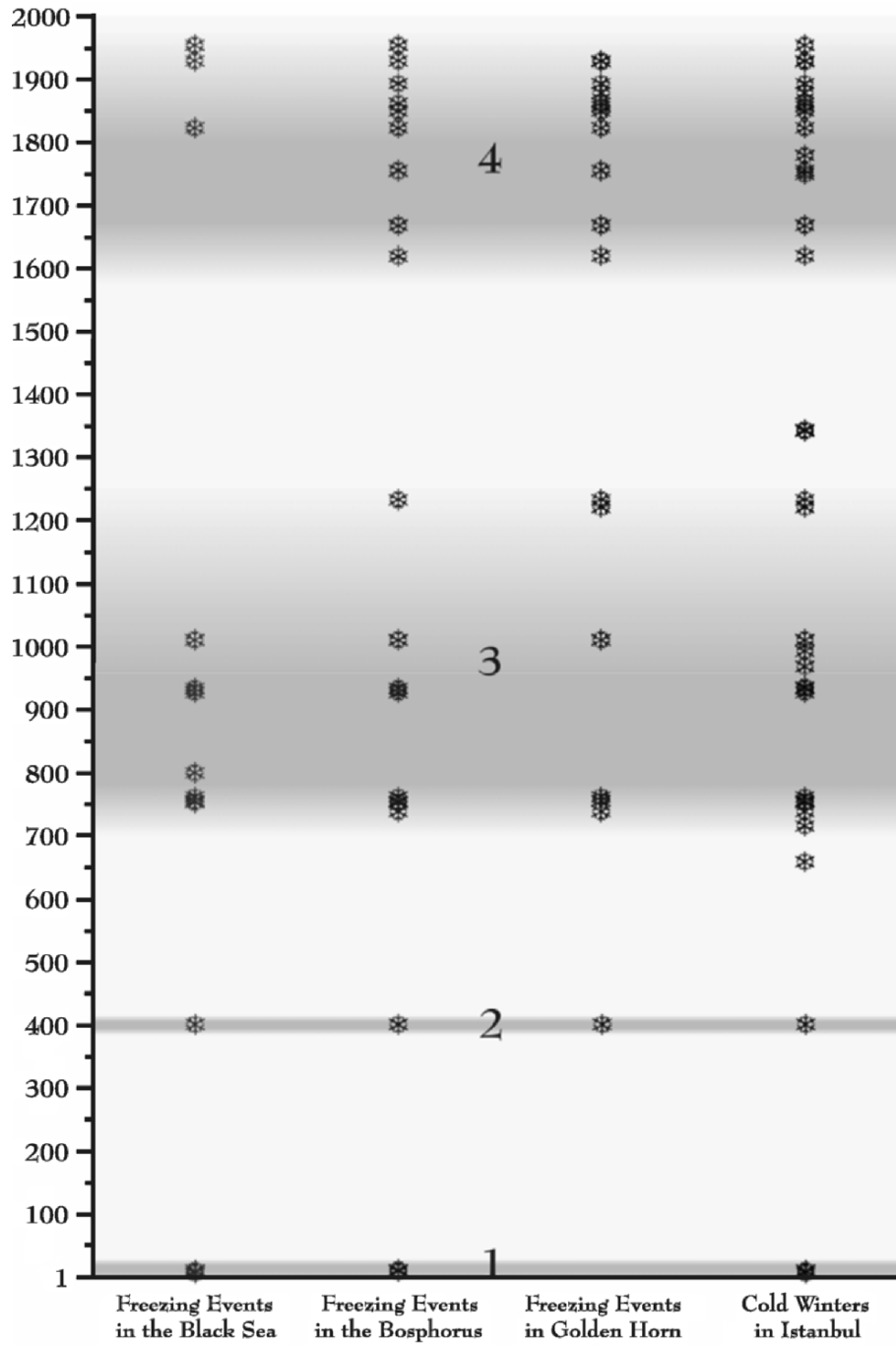


Figure 9. Distribution of historically recorded cold events since 1 AD with four main cold phases.

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