Climate feedbacks in the Black Sea region

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Introduction and scope

The Black Sea is a large deep water basin on the border between European and Asian continents lying in the continental mid-latitude climate zone. It is an important climatic factor for all borderline countries (Bulgaria, Romania, Ukraine, Russia, Georgia and Turkey). The open plane in north direction enables the propagation of the Siberian High influence in winter. From the other side, the Mediterranean Sea influence is significant through the Mediterranean cyclones passing frequently the area.

Black Sea freezing is observed regularly in the northern part and near the Kerch Straits and occasionally spread during cold winters to south reaching Romanian coast (Simonov and Altman, 1991). Since 1972 rare freezing was observed, but the 2012 was extremely cold and the Black sea ice covered area reached Constanta in Romania. 2017 was also anomalously cold in this area.

The scope here is to study the interannual-to-decadal variability of the thermal regime and winter severity in the region and to seek a relation with the important climate action centers.

Romanian coast near Constanta in February 2012

Locations of the meteorological stations used in the study

Data used in the study

The analysis combines data for several sources:

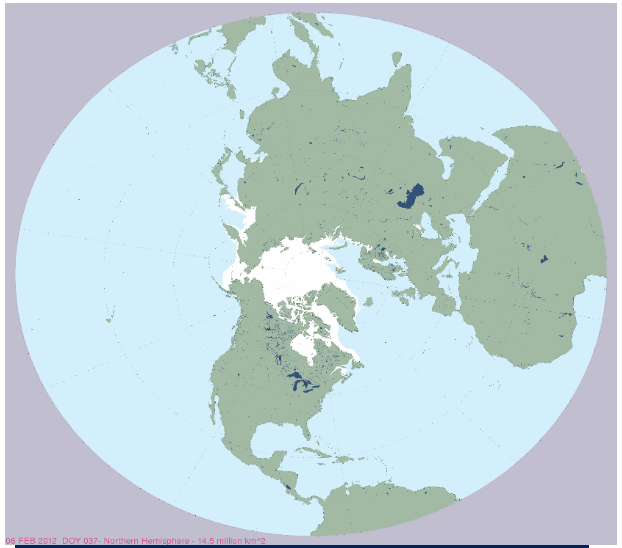
1) Historical publications for the temperatures and ice cover in the area (Simonov and Altman, 1991) for the period 1925-1985

2) Synoptic measurements for the period 1950-2020 in 9 meteorological stations along the Black Sea coast – Burgas, Varna, Odesa, Herson, Mariupol, Batumi, Trabzon, Sinop and Istanbul from the NOAA data set Global Surface Summary of the Day – GSOD (data.nodc.noaa.gov)

3) Ice cover data product Multisensor Analyzed Sea Ice Extent - Northern Hemisphere (MASIE-NH) of the US National Snow and Ice Data Center at 4 km spatial resolution, period 2006-2020 (www.nsidc.org)

4) ERA5 Monthly reanalysis data (climate.copernicus.eu)

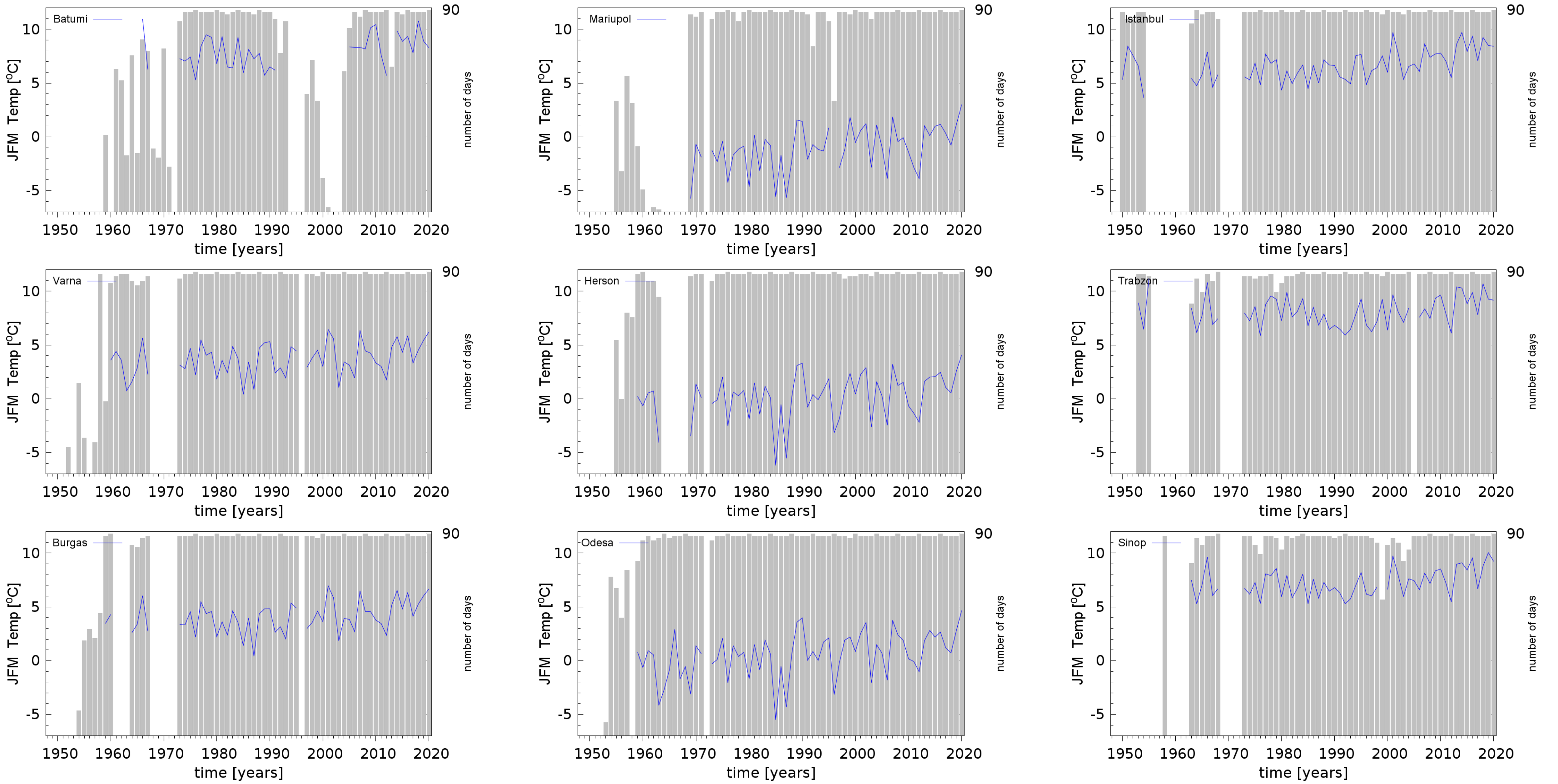
5) Combined weather maps of the 500 hPa geopotential height, sea level pressure and relative topography of the difference between 500 and 1000 hPa geopotential height, copied from www.wetter3.de as a representation of the synoptic conditions.



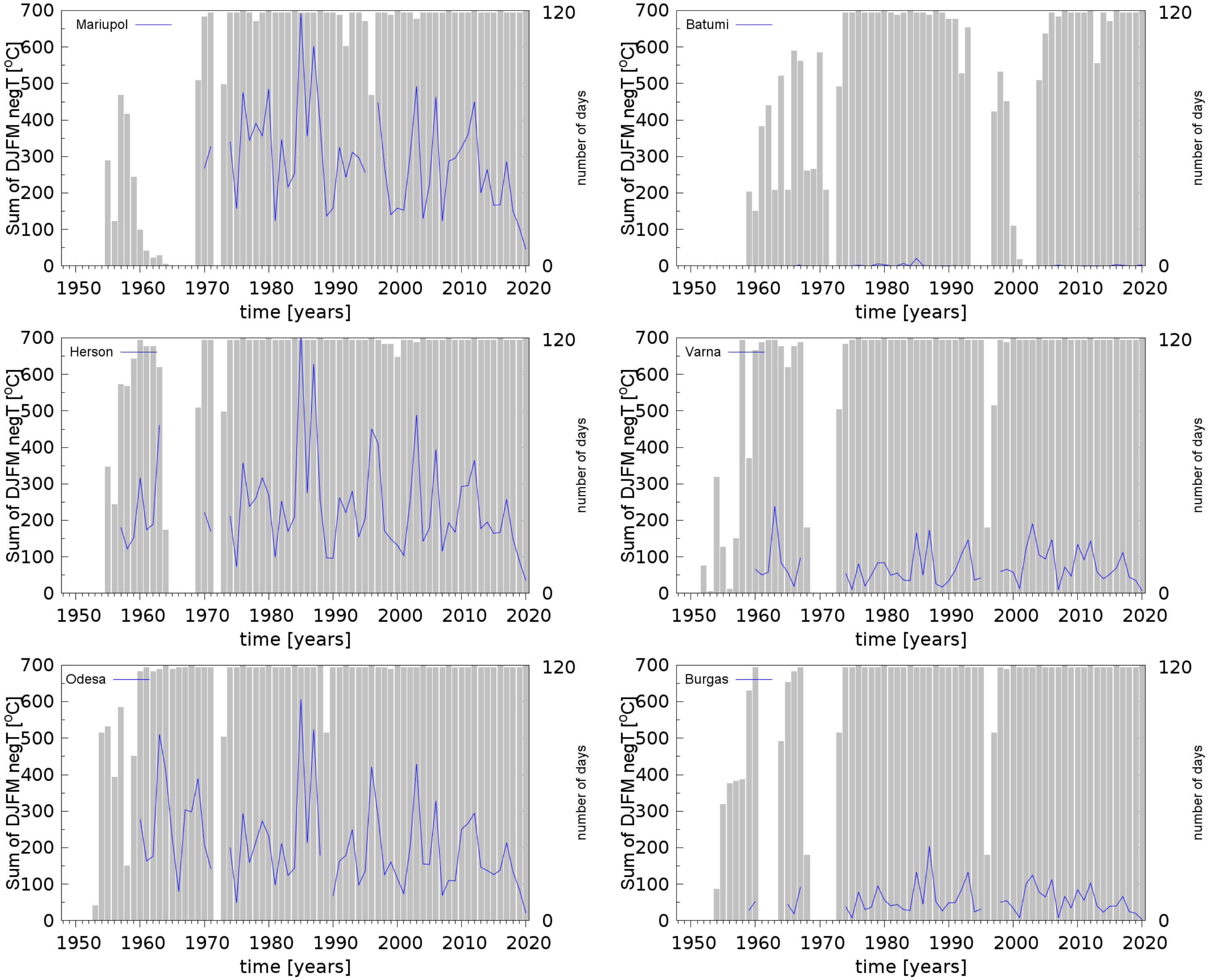
Region covered by MASIE-NH

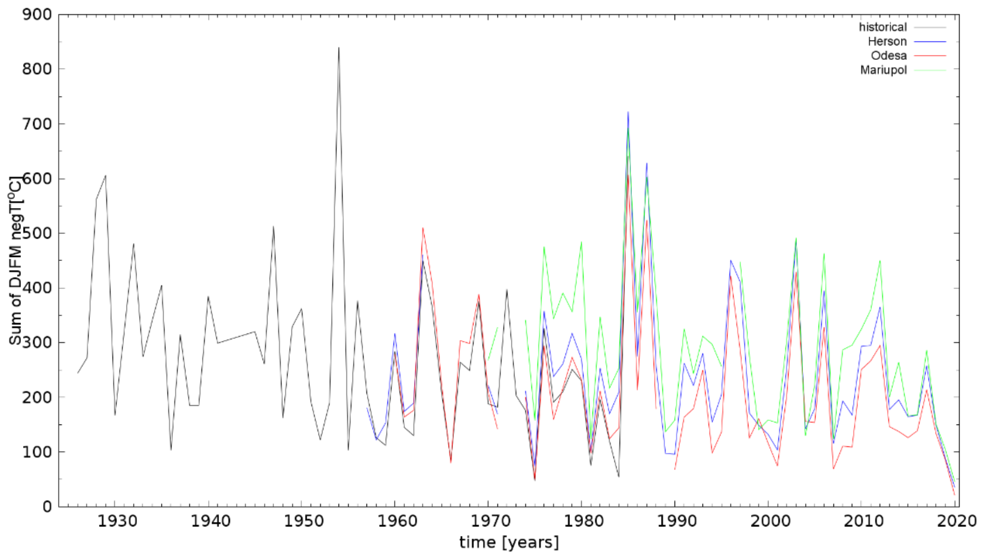
Analysis of the winter temperature (mean value for the months January, February and March) in the 9 meteorological stations

The graphs bellow show significant interannual variability. As expected the north-coast stations (Odesa, Herson and Mariupol) are much colder than the south ones (Istanbul, Sinop and Trabzon), and the one eastern (Batumi) is similar to the south ones. Burgas and Varna winter temperature on the west coast is in between. Overall, the variations in the 9 stations are very similar and in phase, suggesting that the winter conditions are uniform in the entire area. Interesting fact to notice also is the slight tendency for milder winter.



Winter intensity is estimated by the sum of the negative temperatures during the period December, January, February and March. In Odesa, Mariupol and Herson every winter the temperature falls bellow zero, on the contrary - in Istanbul, Sinop and Trabzon very rare (not shown here). Burgas and Varna on the west coast are similar to the north but Batumi on the east is like the southern stations.





Winter intensity (WI) in the period 1925-2020.

The graphs above combines the historical data for the northern coast of the Black Sea with the synoptic measurements in Odesa, Herson and Mariupol for the near past period. There is an overlapping period 1960-1985, where it is seen that the curves evolve very similar. The conclusion is that we can use the three chosen stations to represent long-term variations in the winter conditions in the area.

Only the severe winter cause negative temperatures in Istanbul, Sinop, Trabzon and Batumi. Such winter was for example the 1984/1985. In the past decade the relatively cold winters were the 2002/2003, 2005/2006, 2011/2012 and 2016/2017. An extremely cold winter was 1953/1954.

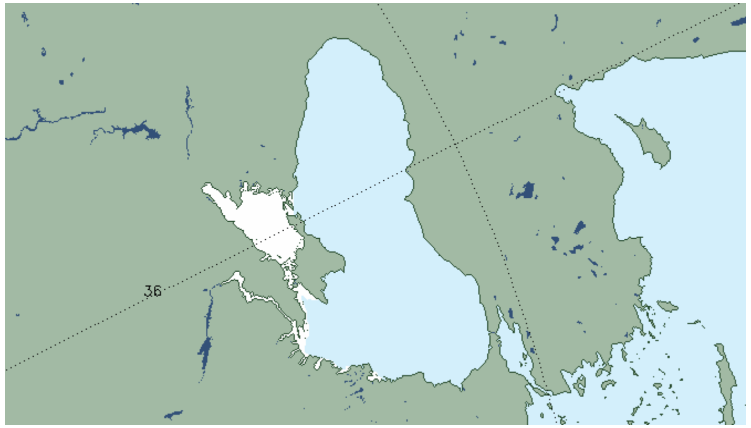
The analysis shows that the “cold” weather in winter decreases from north to south and from west to east: the freezing days are almost absent in the Trabzon station.

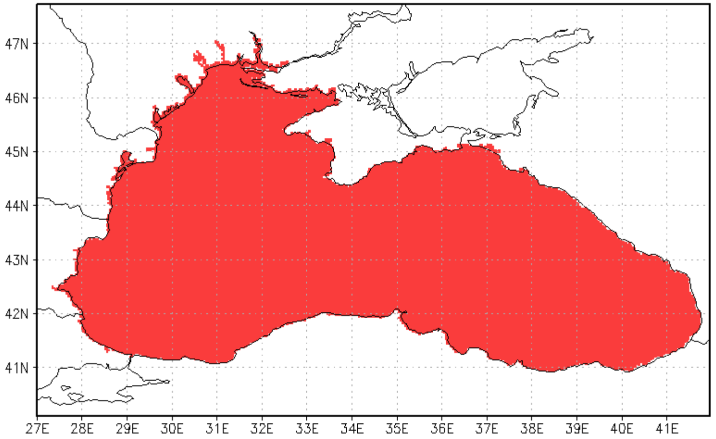
Another interesting observations is that the negative trend after 2000. Also, the peaks in the last three decades decrease in height. This definitively reflects the warming trend in the period.

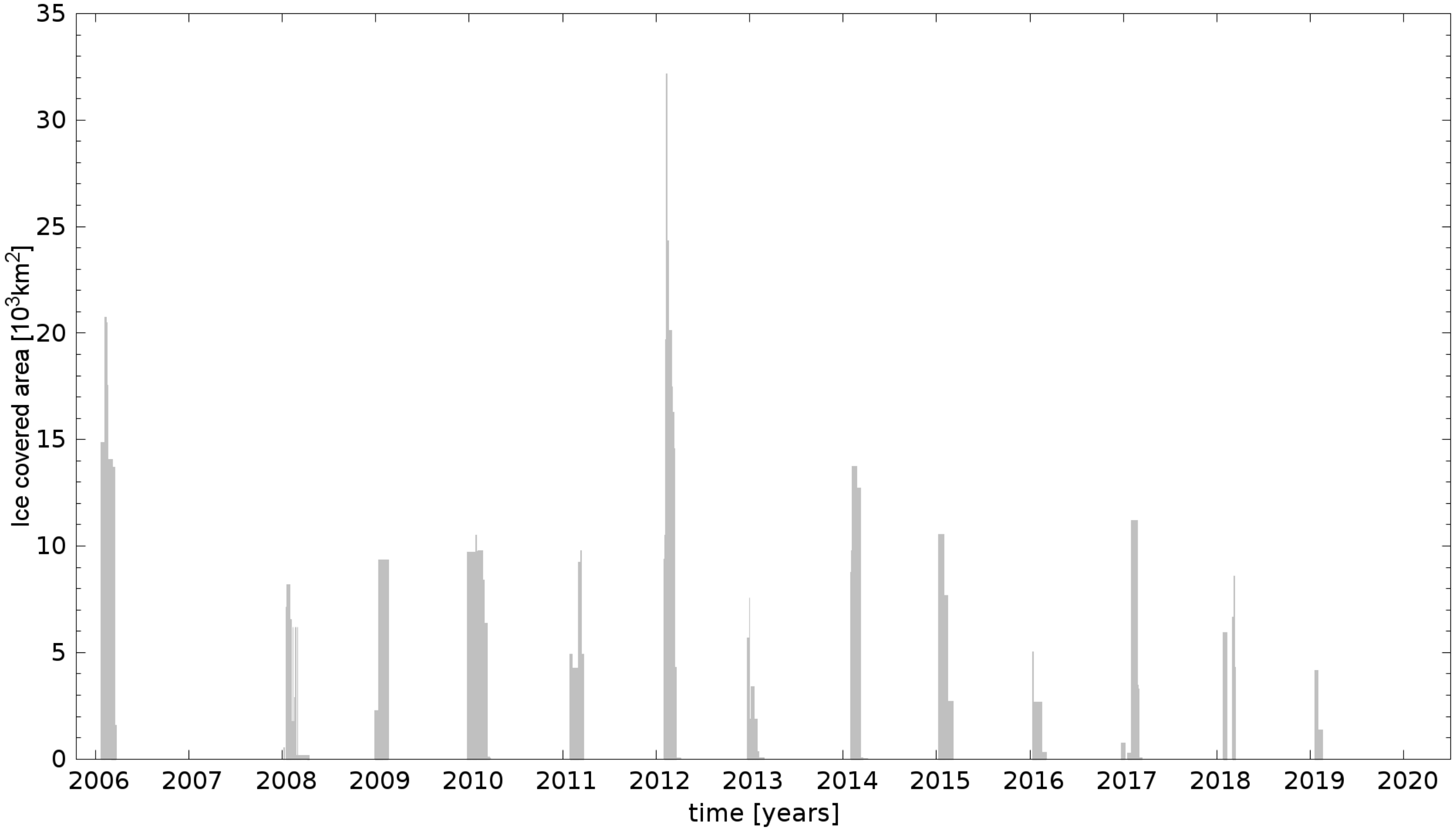
Analysis of the sea ice extent variability.

Data for the ice extent are taken from the US National Snow and Ice Data Center product Multi-sensor Analyzed Sea Ice Extent - Northern Hemisphere (MASIE-NH). This provides daily sea ice data from January 1st, 2006 to the present. The satellites used for this research are ALOS, AQUA, DMSP, ENVISAT, GOES, MSG, and RADARSAT-2. Parameters measured by these sensors include sea ice, ice edges, ice extent, and ice growth/melt. Spatial coverage in the study is the entire Northern Hemisphere specified as N 90° to N 0° and E 180° to W - 180°. Raster data pixels (grid cells) are 4 km x 4 km thus 16 km^2 each (MASIE, Technical References).

The available geotiff image in polar stereographic projection is processed to Mercator projection and using the mask for the Black Sea pixels, only the “sea” pixels with ice are counted. Thus the average and maximal sea ice extent for the four months in the winter season (December to March) are calculated. One can note that the mas contains also the lakes and the major rivers estuaries. The results are shown on the right graph for each daily image. In 2007 winter no ice was observed, and maximal area is reached in February 2012 but for relatively short period. The ice coverage in 2006 and 2010 for example is less than that in 2012, but stays for a longer period of time. The conclusion is that almost every year freezing in the north Black Sea occurs.







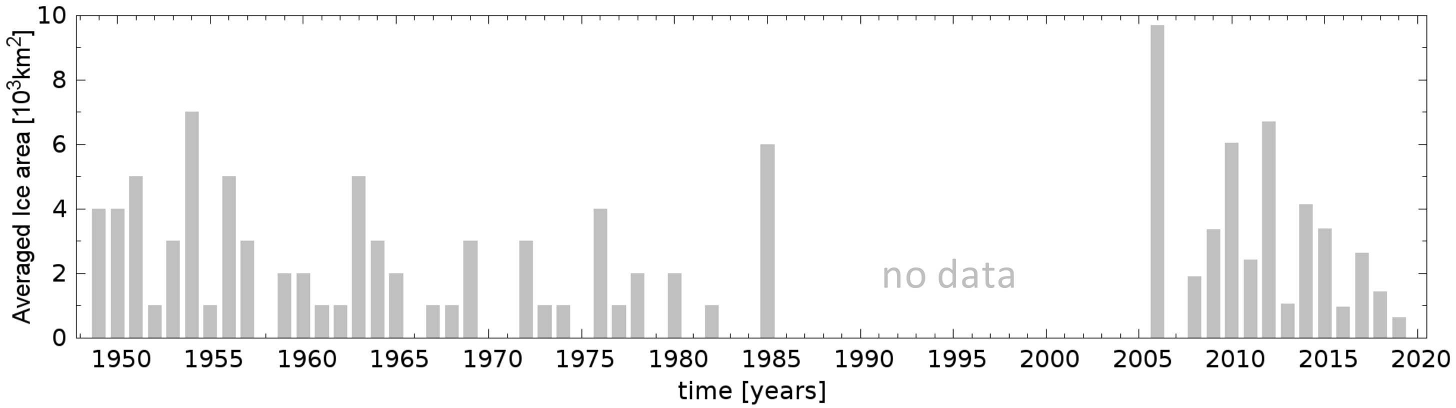
Averaged and maximal ice extent variability.

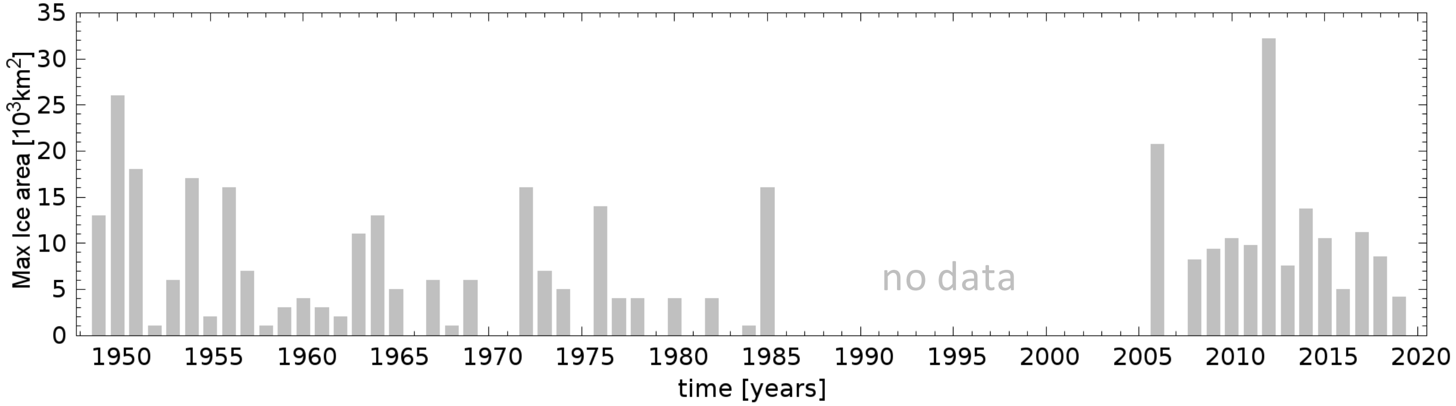
The plot bellow shows combined historical data from 1950-1985 for sea ice extend and data from MAISIE-NH in the period 2006-2020, processed as described in the previous slide. Nevertheless global warming trend, it is clear that the freezing occurs rather regularly which leads to the conclusion that it is result from synoptic situations rather than the seasonal averages.

The variation in the ice extent are in agreement with the variations of the winter intensity (the sum of the freezing days temperature with opposite sign). This allows us to make a classifications of the winter in the region using the extend of the ice and the threshold values for the winter intensity as in the table.

WI value	Winter type
[0, 200]	Mild
[200, 400]	Moderate
[400, -]	Cold

In the right the winter in the 1926 to 2020 are listed and the type according to the above classification is given. Note that since 2003 no “cold” winter conditions are observed, and the relative colder moderate winters are classified as Moderate*.





Year	Winter type	**1959**	Mild	**1990**	Mild
1926	Moderate	**1960**	Moderate	**1991**	Moderate
1927	Moderate	**1961**	Mild	**1992**	Moderate
1928	Cold	**1962**	Mild	**1993**	Moderate
1929	Cold	**1963**	Cold	**1994**	Mild
1930	Mild	**1964**	Moderate	**1995**	Moderate
1931	Moderate	**1965**	Moderate	**1996**	Cold
1932	Cold	**1966**	Mild	**1997**	Cold
1933	Moderate	**1967**	Moderate	**1998**	Mild
1934	Moderate	**1968**	Moderate	**1999**	Mild
1935	Cold	**1969**	Moderate	**2000**	Mild
1936	Mild	**1970**	Mild	**2001**	Mild
1937	Moderate	**1971**	Mild	**2002**	Moderate
1938	Mild	**1972**	Moderate	**2003**	Cold
1939	Mild	**1973**	Moderate	**2004**	Mild
1940	Moderate	**1974**	Mild	**2005**	Mild
1941	Moderate	**1975**	Mild	**2006**	Moderate*
1945	Moderate	**1976**	Moderate	**2007**	Mild
1946	Moderate	**1977**	Mild	**2008**	Mild
1947	Cold	**1978**	Moderate	**2009**	Mild
1948	Mild	**1979**	Moderate	**2010**	Moderate
1949	Moderate	**1980**	Moderate	**2011**	Moderate
1950	Moderate	**1981**	Mild	**2012**	Moderate*
1951	Mild	**1982**	Mild	**2013**	Mild
1952	Mild	**1983**	Mild	**2014**	Mild
1953	Mild	**1984**	Mild	**2015**	Mild
1954	Cold	**1985**	Cold	**2016**	Mild
1955	Mild	**1986**	Moderate	**2017**	Moderate
1956	Moderate	**1987**	Cold	**2018**	Mild
1957	Moderate	**1988**	Moderate	**2019**	Mild
1958	Mild	**1989**	Mild	**2020**	Mild

Sea surface temperature variation

The available data from synoptic daily measurements of the sea surface temperature (SST) in Burgas and Varna meteorological stations allow us to calculate the winter months mean SST for the period 2000-2020 (Figure 10). The winter months are taken from January to March. The two curves show rather similar in-phase behavior: in Varna the winter SST is generally lower but not always. The comparison of SST with the sea-ice cover together with the winter air temperature and WSI variation reveals that the different sources of data confirm the anomalous cold and warm years: the winters in 2003, 2012 and 2017 were especially cold and on the contrary, the winters in 2001, 2007 and 2020 were very warm.

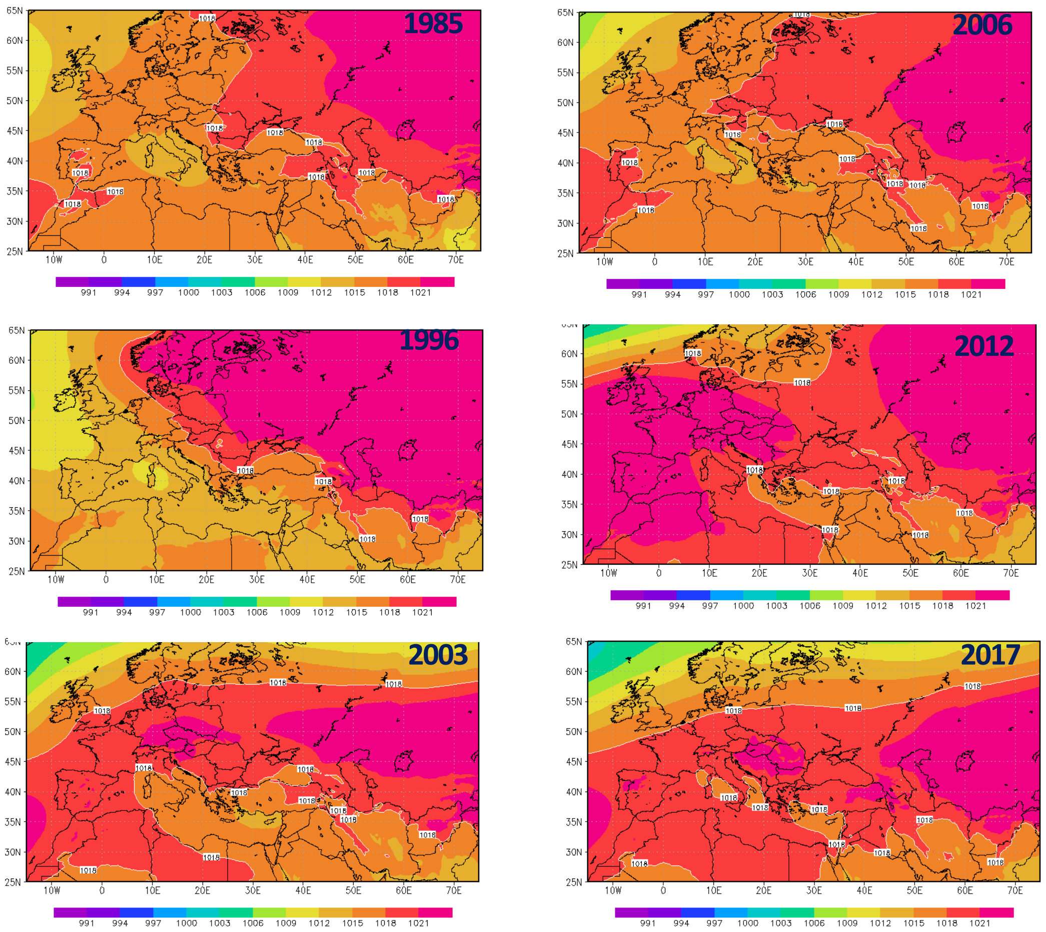
The influence of the Siberian High

From the winter classification it could be noted that “cold winter” conditions usually last only one season and the following winter is either mild or moderate. Rarely there are two cold winters in sequence. In this region the very cold synoptic situations are due to the Siberian High expanding to the west and reaching the Central Europe.

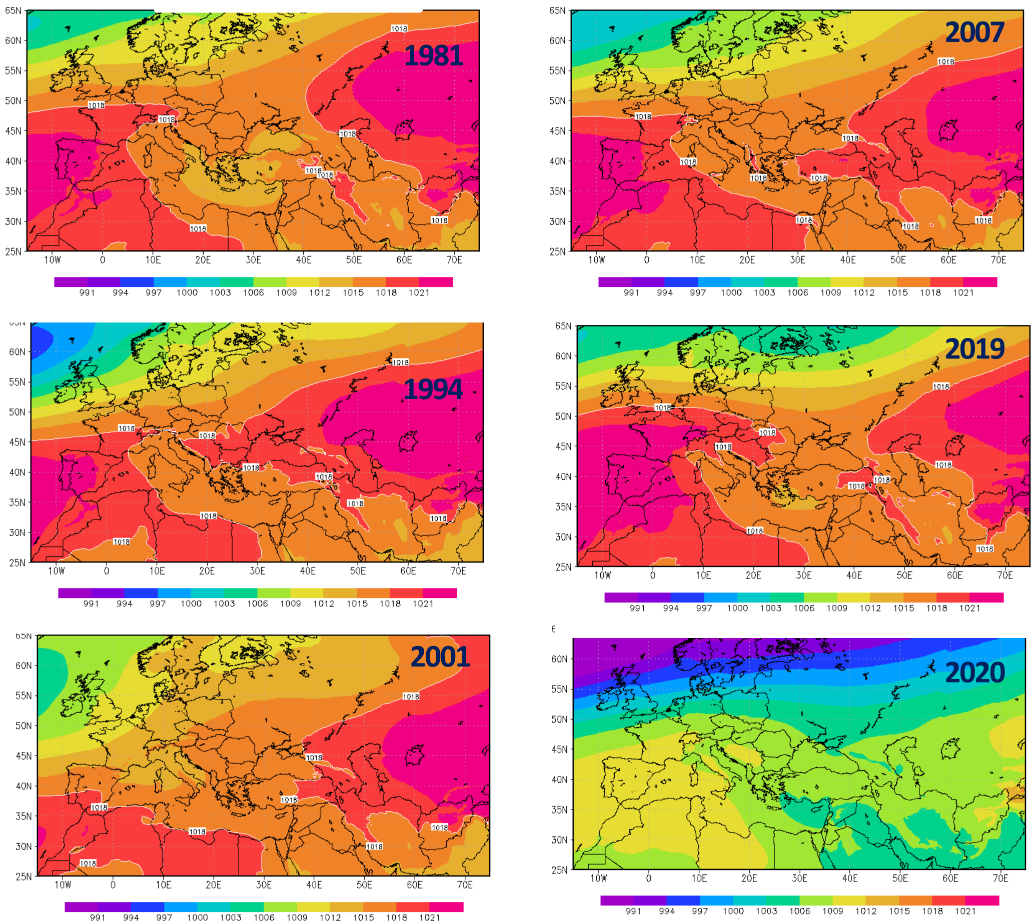
That is why we examined the seasonal mean sea level pressure for several years with anomalous cold and warm situation. It appears that in the “cold” winters the Siberian High expanded over the Black Sea region, and on the contrary in “mild” winter conditions the Siberian High is less intense. There is a mean difference of 3 HPa for the two different part and about 300 in the Winter Intensity. The position and intensity of the Siberian anticyclone is also shown as the 1018 isobar. One can conclude that the the “cold” winter are associated with intense Siberian High expanding over Northeastern Europe, and the “mild” winter – with less intense Siberian High and more intense Iceland and Arctic Low.

“Cold” Winter			“Mild” Winter		
year	$MSLP_{mean}$	WI	year	$MSLP_{mean}$	WI
1985	1018.52	641	1981	1015.9	75
1987	1018.09	524	1990	1021.53	70
1996	1019.83	423	1994	1018.81	98
2003	1019.42	436	2001	1017.53	74
2006	1017.92	328	2007	1017.46	69
2012	1019.27	295	2019	1016.91	85
2017	1020.15	215	2020	1006.31	20
mean	**1019.02**	**409**	**mean**	**1016.35**	**70**

“Cold” Winter

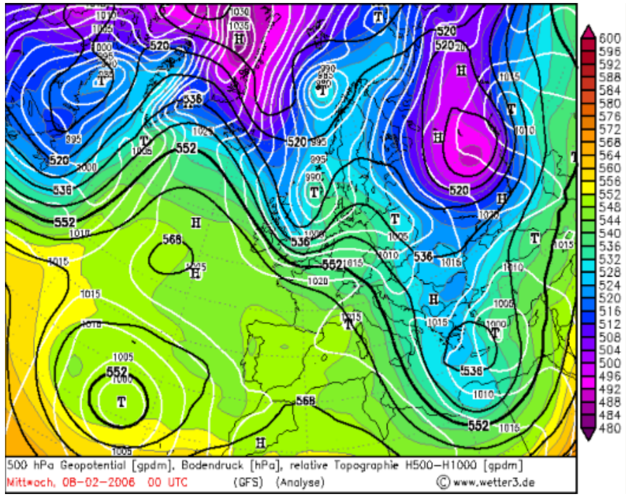


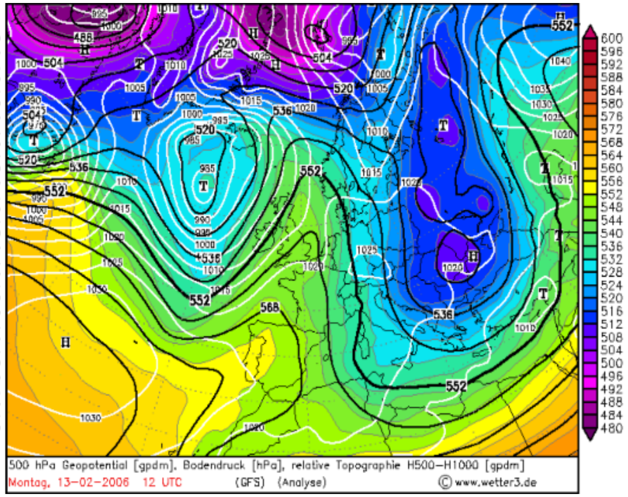
“Mild” Winter



Analysis of the synoptic conditions impact on the freezing.

The aim in our study is to try to evaluate the importance of the seasonal and synoptic conditions for the freezing occurrence in the Black Sea. Of course these processes are related as the season comprises several synoptic conditions. Here we analyze the “cold” synoptic conditions in the winter of 2006, 2010, 2012 and 2017 which were associated with intense penetration of cold air masses over the northern Black Sea area and as consequence the freezing occurs.



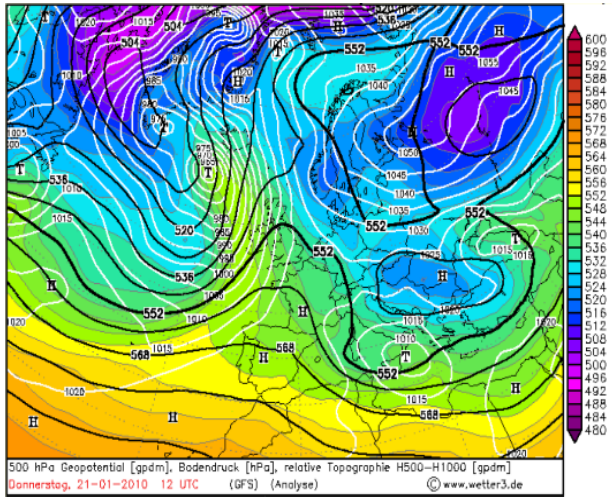


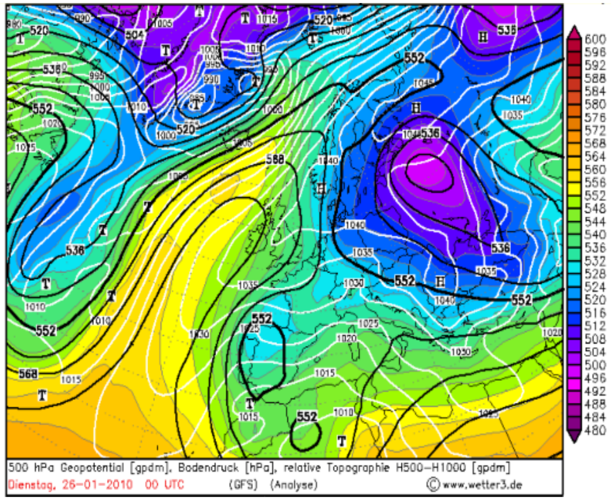
8-13 February 2006

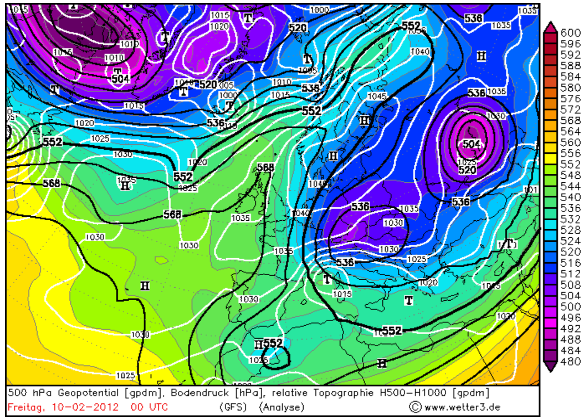
Weather maps in left figure are shown for the period of maximal sea ice extent 8-13 February 2006. In the beginning of February (left) a deep cyclone of North Atlantic origin is formed and stationary in Norther Europe. A trough of cold air penetrates in south direction forming a cold core which is further transformed to an anticyclone on February 13th. The anticyclone lingers for several days over the Black Sea and then moves north. Overall, this could be classified as penetration of a cold air mass of North Atlantic-Arctic origin.

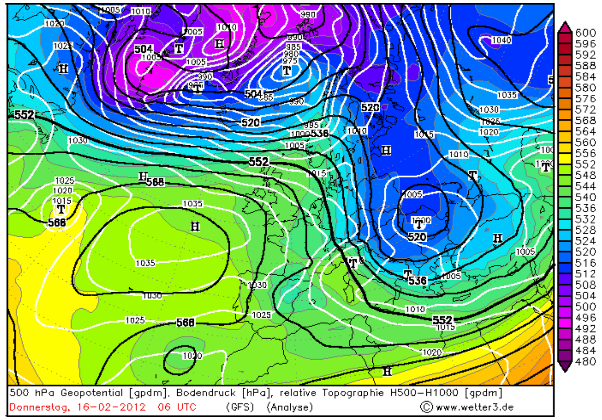
21-27 January 2010

In the winter of 2010 the freezing is observed for long period: starting in late December and staying till middle of March. The maximal extent was seen in the second half of January associated with the stable Siberian High with expansion over East Europe. The weather was very dynamic and a rapid cyclone of Scandinavian origin replaced the anticyclone. On January 21st (Right figure - left), one can see that the weather is dominated by the large anticyclone expanding over central Europe and Balkan Peninsula. In Tyrrenian Sea a Mediterranean cyclone is formed and propagated in eastern direction above the Black Sea in the next three days. This caused a rapid entrance of cold air along the north-west periphery of the cyclone enhancing the low temperature (Fig. 14, right). After January 27th series of cyclones of high latitude Atlantic origin enter Europe and destroy the Siberian High tongue. The prolonged freezing is related to consecutive penetrations of air masses from Siberian and Arctic origin.









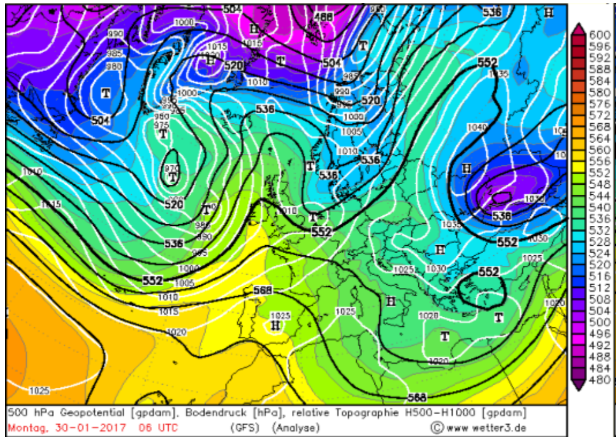
10-20 February 2012

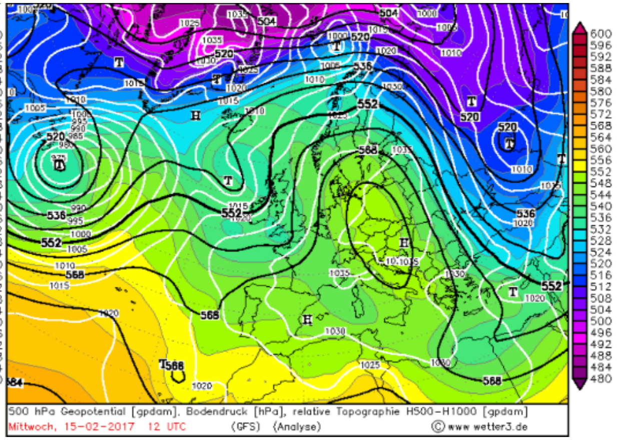
A maximum of the sea ice cover seen by the satellites for the period 2006-2020 is reached in 10-11 February 2012. The beginning of February was dominated by a stable Siberian High tongue which expanded over large part of Europe (Left figure - left).

This blocking ended with a cyclone of high latitude Atlantic and Arctic origin, which on 14th February passed through Scandinavian Peninsula, migrated in south direction to Northern and Central Europe, and on February 16th reached the Black Sea (Fig. 15, right). As a consequence the already cold weather conditions enhance even more due to the entrance of cold arctic air in the periphery of the cyclone. This freezing occurrence could be related to combined influence of Siberian and Arctic air masses.

30 January – 15 February 2017

The winter in 2017 is characterized by almost constant sea ice extent in February. The end of January 2017 is typically influenced by the Siberian High expansion over the Balkan Peninsula (Right figure - left). Then February 2017 is very dynamic with many cyclones of high latitude Atlantic origin, which pass over central Europe and north Balkan Peninsula. An interesting condition is formed in the middle of the month – a stable anticyclone over central Europe which brings cold air on its eastern periphery in the Black Sea region (Fig. 16, right).



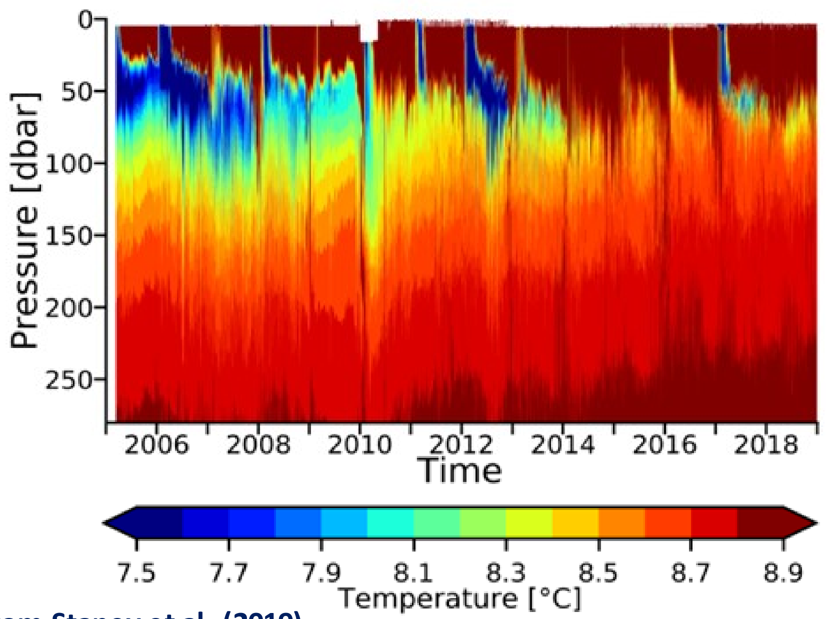


The analysis of the weather patterns during the periods of maximal sea extent lead to the conclusion that favorable for freezing in the northern Black Sea is the situation of a relatively long period under Siberian High influence followed by an Arctic air mass penetration on the periphery of a high latitude Atlantic cyclone.

Black Sea respond to atmospheric variations

The Black Sea has peculiar characteristics regarding the vertical stratification and it responds to the atmospheric thermal regime in a unique way: the winter cooling of surface water triggers the winter convection and the formation of the cold intermediate layer (CIL). The colder the winter, the thicker this layer. Stanev et al. (2019) showed that in the last 15 years the CIL constantly diffuses, fed only in the cold winters, 2006, 2012 and 2017. This is in accordance with the results from the previous slides.

Then the question is what is the feedback: the Black Sea “dumps” the seasonal signal amplitude and perhaps this is the reason to observe single “cold” winter conditions. This analysis requires further attention.



From Stanev et al, (2019)

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CONCLUSIONS AND FUTURE PLANS

- We have used synoptic observations from 9 coastal Black Sea meteorological stations in order to analyze the interannual-to decadal variations in the mean winter temperature . Our study shows that the variations are very similar and in phase, suggesting that the winter conditions are uniform in the entire area.
- There is a slight tendency for milder winter in the last 4 decades in all 9 stations.
- Along the north coast (Odesa, Mariupol and Herson) every winter the temperature falls bellow zero, and along the south coast (Istanbul, Sinop, Trabzon and Batumi) only the severe winter cause negative temperatures. For example - 1984/1985 was extremely cold and in the past two decades there are 4 very cold winters - 2002/2003, 2005/2006, 2011/2012 and 2016/2017.
- The sum of daily negative temperatures with opposite sign for the winter season is used to define the winter intensity (WI). It presents a negative trend after 2000 reflecting the global warming tendency.
- Satellite observations are used to estimate the sea ice cover area and it is found that in the north part freezing is observed rather regularly. In 2007 winter no ice was observed, and maximal area is reached in February 2012 but for relatively short period. The ice cover in 2006 and 2010 for example is less than that in 2012, but stays for a longer period of time. The conclusion is that the freesing results from extremely cold synoptic situations rather than seasonal extreme.
- The variation of the winter season ice extent are in agreement with the variations of the winter intensity estimated from the temperature. The two data time-series were used to classify the winters’ severity in the period 1925-2020 as cold, moderate and mild.
- Since 2003 no real “cold” winter conditions are observed, but 2006, 2012 and 2017 are cool.
- Analysis of the winter mean sea level pressure for the climate reanalysis ERA5 leads to the conclusion that the “cold” winter conditions are associated with intense Siberian High expanding over Northeastern Europe, and the “mild” – with less intense Siberian High and more intense Iceland and Arctic Low.
- The winter 2019/2020 is anomalous, the mildest from the analyzed period and the MSLP field shows unusual position of the climate centers of action. Future analysis is foreseen to investigate thorough the impact of the Siberian High, as well as the “buffer” role of the Black Sea.
- The analysis of the weather patterns during the periods of maximal sea ice extent lead to the conclusion that favorable for freezing in the northern Black Sea is the situation of a relatively long period under Siberian High influence followed by an Arctic air mass penetration on the periphery of a high latitude Atlantic cyclone.