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Characteristics of the September-December Teleconnection (SDT) in the current Atlantic Multidecadal Oscillation (AMO) phase

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Abstract— The atmospheric teleconnection presented in our former paper (*Babolcsai* and *Hirsch*, 2019) shows a particularly strong regularity between the Euro-Atlantic mean sea level pressure anomaly pattern in September and the pattern three months later, in December, in the current positive AMO (Atlantic Multidecadal Oscillation) phase lasting since 1995.

Euro-Atlantic mean sea level pressure anomaly patterns for September were divided into four clusters, whereas cases that could not be classified as any of these, were assigned to a fifth cluster.

Based on the clustering, the December macrosynoptic situation in Europe can be predicted in a significant number of cases, and hence the sign of the temperature anomaly in Central Europe.

In our paper, these regularities are described, as well as their connection to the polar vortex, which is the main factor in forming the mean sea level anomaly of the winter months of the northern hemisphere. In the last 29 years, clustering based on the mean sea level pressure anomaly for September has been able to divide significantly cold and mild December months even better than the state of the polar vortex in December (sign of the AO index).

In addition, a new phenomenon is presented, which might be a sign of climate change and has been interfering in the atmospheric processes since 2019.

Key-words: teleconnection, Arctic Oscillation (AO), polar vortex, temperature anomaly, mean sea level pressure (MSLP), Central Europe, climate change

1. Introduction

It is well known that a part of the inner variability of the climate system is not due to random fluctuations. Instead, these are caused by teleconnections, which are different anomalies mostly in a distance of thousands of kilometers but in a way connected to each other.

The best-known atmospheric oscillation phenomena are the El Niño-Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO), which are connected to anomalies of the sea surface temperature (SST) and the large-scale cyclic changes in mean sea level pressure (MSLP). NAO accounts for approximately one-third of the whole atmospheric variability (of temperature, precipitation, and so on) in the North Atlantic Region (*Marshall et al*., 2001).

A small part of long-distance connections has a prognostic value, i.e., in addition to spatial distance, temporal distance (lagged teleconnection) is also shown, so the connection can act as an anomaly predictor.

For example, the extent of the polar ice cover and the Eurasian snow cover can be predictors. The Eurasian snow cover anomaly in spring has been considered as one of the important factors affecting Asian summer monsoon variability. According to a study (*Liu* and *Yanai*, 2002), in the years of excessive Eurasian snow cover anomalies, cooling and a cyclonic circulation anomaly in the lower troposphere appear over the northern part of Eurasia, leading to a Rossby-wave-train-like circulation response, then to a weakened East Asian summer monsoon and deficient rainfall with an anticyclonic circulation anomaly south of Lake Baikal. Anomalies with opposite signs occur in the years of deficient snow cover. Another investigation (*Ye* and *Bao*, 2001) shows that winter snow depth over European Russia and central Siberia is associated with summer monsoon rainfall over southern and western India and eastern Pakistan, and sea-surface temperatures over the eastern and central tropical Pacific Ocean during the following winters. The connection is slightly stronger when snow depth over European Russia is above normal. The results of this study suggest that winter snow depth over the western rather than the eastern portion of Eurasia is critical to the Southeast Asian summer monsoon rainfall and eastern tropical Pacific SSTs during the following seasons.

Some of the teleconnections have a known physical explanation, while others have yet to be identified. According to a conceptual model (*Cohen et al*., 2007), when snow cover is above normal in the fall across Siberia, the diabatic cooling helps strengthen the Siberian high and leads to below normal temperatures. Snow-forced diabatic cooling in proximity to the high topography of Asia increases upward flux of wave activity from the troposphere, which is absorbed in the stratosphere. The strong convergence of wave activity flux leads to higher geopotential heights, a weakened polar vortex, and warmer temperatures in the stratosphere. Zonal mean geopotential height and wind anomalies propagate down from the stratosphere into the troposphere all the way to the surface. Finally, the dynamic pathway culminates with strong negative phase of the Arctic Oscillation (AO) at the surface.

The cold equatorial Pacific SST anomalies generate weakened tropical convection and Hadley circulation over the Pacific, resulting in a decelerated subtropical jet and accelerated polar front jet in the extratropics (*Kim* and *Ahn*, 2015). The intensified polar front jet implies a stronger stratospheric polar vortex relevant to the positive AO phase; hence, surface manifestations of the reflected positive AO phase were then induced through the downward propagation of the stratospheric polar vortex. The results suggest that properly assimilated initial ocean conditions might contribute to improve the predictability of global oscillations, such as the AO, through large-scale tropical ocean–atmosphere interactions.

In an another study (*Yang et al.,* 2016), the authors suggest a connection between the November sea ice extent in the Barents and Kara Seas and the following winter's atmospheric circulation in terms of the fast sea ice retreat and the subsequent modification of local air–sea heat fluxes. In particular, the dynamical processes that link the November sea ice in the Barents and Kara Seas with the development of AO anomalies in February is explored. In response to the lower-tropospheric warming associated with the initial thermal effect of the sea ice loss, the large-scale atmospheric circulation goes through a series of dynamical adjustment processes: the decelerated zonal-mean zonal wind anomalies propagate gradually from the subarctic to midlatitudes in about one month. The equivalent barotropic AO dipole pattern develops in January because of wave–mean flow interaction, and firmly establishes itself in February following the weakening and warming of the stratospheric polar vortex. This connection between the sea ice loss and the AO mode is robust on time scales ranging from interannual to decadal. Therefore, the recent winter AO weakening and the corresponding midlatitude climate change may be partly associated with the early winter sea ice loss in the Barents and Kara Seas.

The atmospheric teleconnection presented in this paper – and referred to as September-December Teleconnection, SDT – shows a particularly strong regularity between the Euro-Atlantic mean sea level pressure anomaly pattern in September and the pattern three months later, in December, in the current positive AMO phase lasting since 1995.

We have not found a description of a teleconnection similar to the clustering-based method for forecasting air pressure, temperature, and AO index presented in this paper, either for Central Europe or for other regions of the world.

2. Data and methods

All the data used for the research (mean sea level pressure and surface temperature fields as well as time series of the AO index) are based on the NCEP/NCAR reanalysis (https://psl.noaa.gov/data/reanalysis/reanalysis.shtml) developed as a joint project between the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR). A state-of-the-art data assimilation system is used with a wide variety of weather observations to provide analyses of atmospheric parameters from 1948 up to recently. For calculations and visualization of results, the web application tool provided by NOAA (https://psl.noaa.gov/cgi-bin/data/composites/printpage.pl) was used.

The reference period for mean sea level pressure anomaly is 1991 to 2020, whereas surface temperature anomaly refers to the average of the period 1995 to 2022. The mean Central European surface temperature anomaly for December is calculated as the average of the grid point values within the area of 10° to 27.5° E and 45° to 55° N. This surface temperature anomaly average is shown on the top right side of the December maps, whereas relevant AO index values are shown on the left side (*Figs. 1–5*).

The AO index is constructed by projecting the monthly 1000 hPa geopotential height anomalies between 20° N and 90° N onto the first leading mode from the EOF analysis of the same parameter (https://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/history/method.shtml). Monthly values of the AO index are calculated by NOAA and updated on a regular basis for a period from 1950 (https://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/monthly.ao.index.b50.current.ascii.table).

The research is based on our own clustering of Euro-Atlantic mean sea level pressure anomaly fields for September for the period 1995 to 2023. Due to the small number of cases (only 29 years) and the mostly clearly distinguishable anomaly patterns, subjective clustering was applied focusing on the areas of Greenland, Scandinavia, and the British Isles.

3. Results and discussion

The following clusters were identified for the Euro-Atlantic mean sea level pressure anomaly for September. In the figures below, the mean sea level pressure anomaly pattern for September is presented for each year that belongs to the given cluster. The anomaly pattern for the corresponding December months is also shown.

3.1. *Cluster H1*

- Strong positive mean sea level pressure anomaly can be seen to the east, southeast, and south of Greenland and negative anomaly south of this area (*Fig. 1*)
- Septembers prior to the 6 coldest Decembers in Central Europe are in this cluster.
- September of 2021 and 2022 also belong to this cluster, which will be discussed later together with the years 2019 and 2020 of the cluster H2. (2021 is a borderline case due to a small area with negative anomaly within the larger area of positive anomaly in and around Greenland, which was followed by a December with mean temperature around average.)

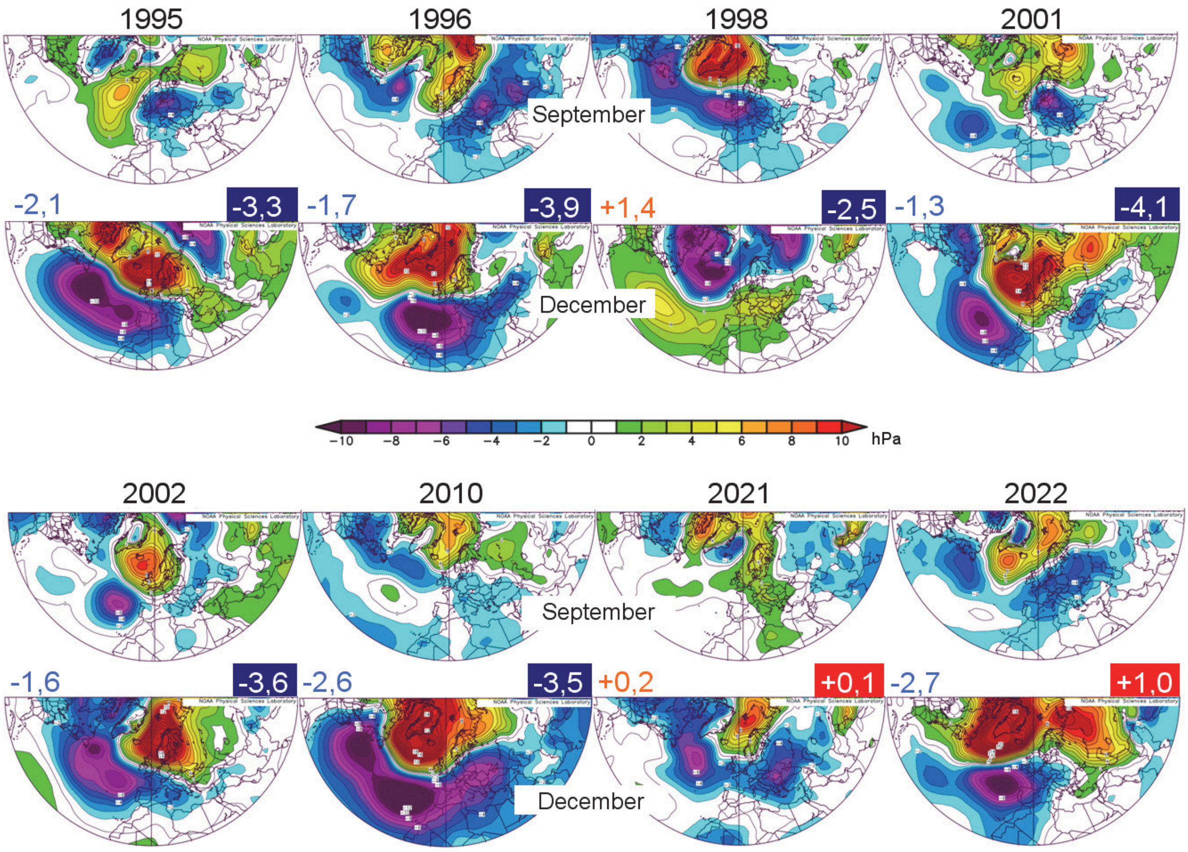

Fig. 1. Monthly mean sea level pressure anomaly of the years in cluster H1 for September and December (1995–2023), temperature anomaly in Central Europe in December compared to the average of the period 1995–2022 (°C, right), and AO index in December (left).

3.2. Cluster H2

- Strong negative anomaly can be seen in North Scandinavia, to the north of this area as well as between Scandinavia and Greenland, while significant positive anomaly occurs to the southwest and south (*Fig. 2*). (The year 2019 is a borderline case with the negative anomaly slightly more to the east and less significant positive anomaly. This September was followed by the mildest December of the cluster by far.)
- September months of the years with a negative temperature anomaly in December of less than 2 °C were all classified as members of this cluster.

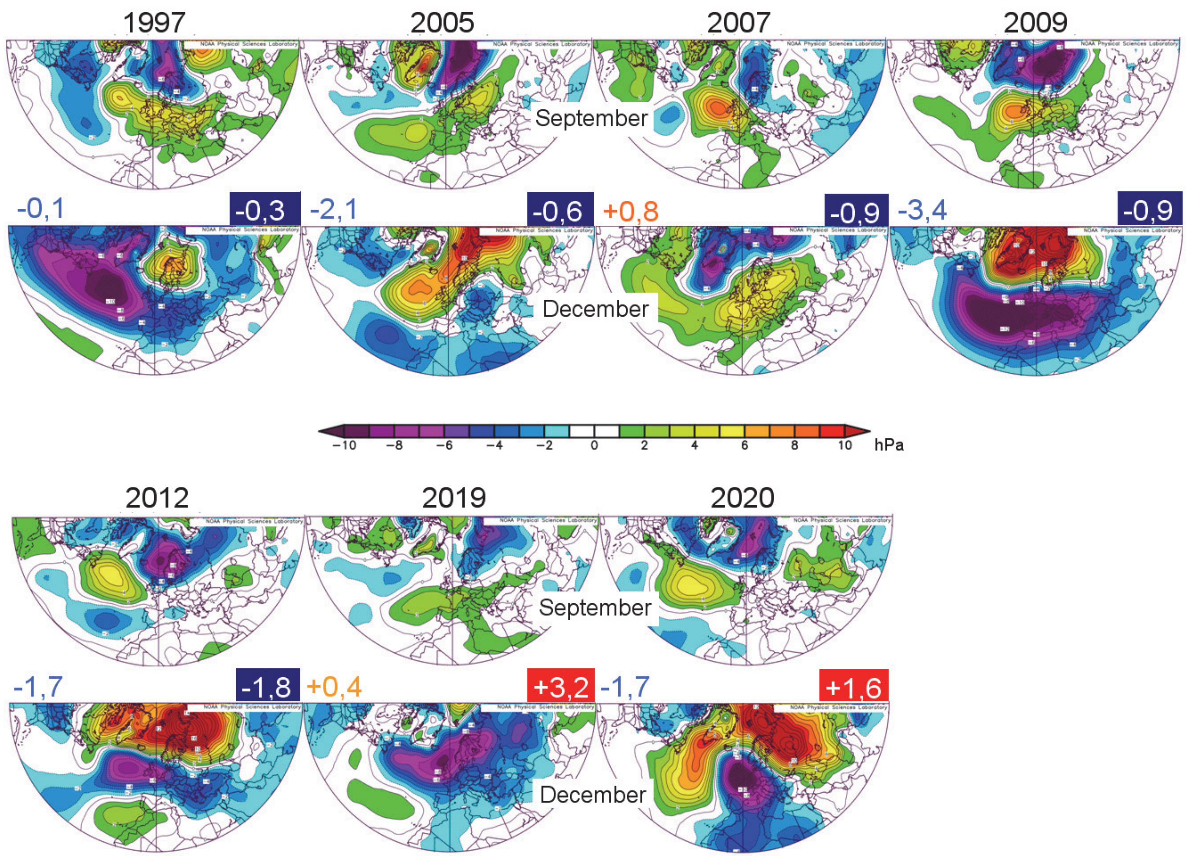

Fig. 2. Monthly mean sea level pressure anomaly of the years in cluster H2 for September and December (1995–2023), temperature anomaly in Central Europe in December compared to the average of the period 1995–2022 (°C, right), and AO index in December (left).

3.3. Cluster E1

- A ring-like band of positive anomaly is stretching from North America with an area of very strong negative anomaly over Greenland or to the east, southeast of that (*Fig. 3*).
- September months in this cluster were followed by moderately mild Decembers.

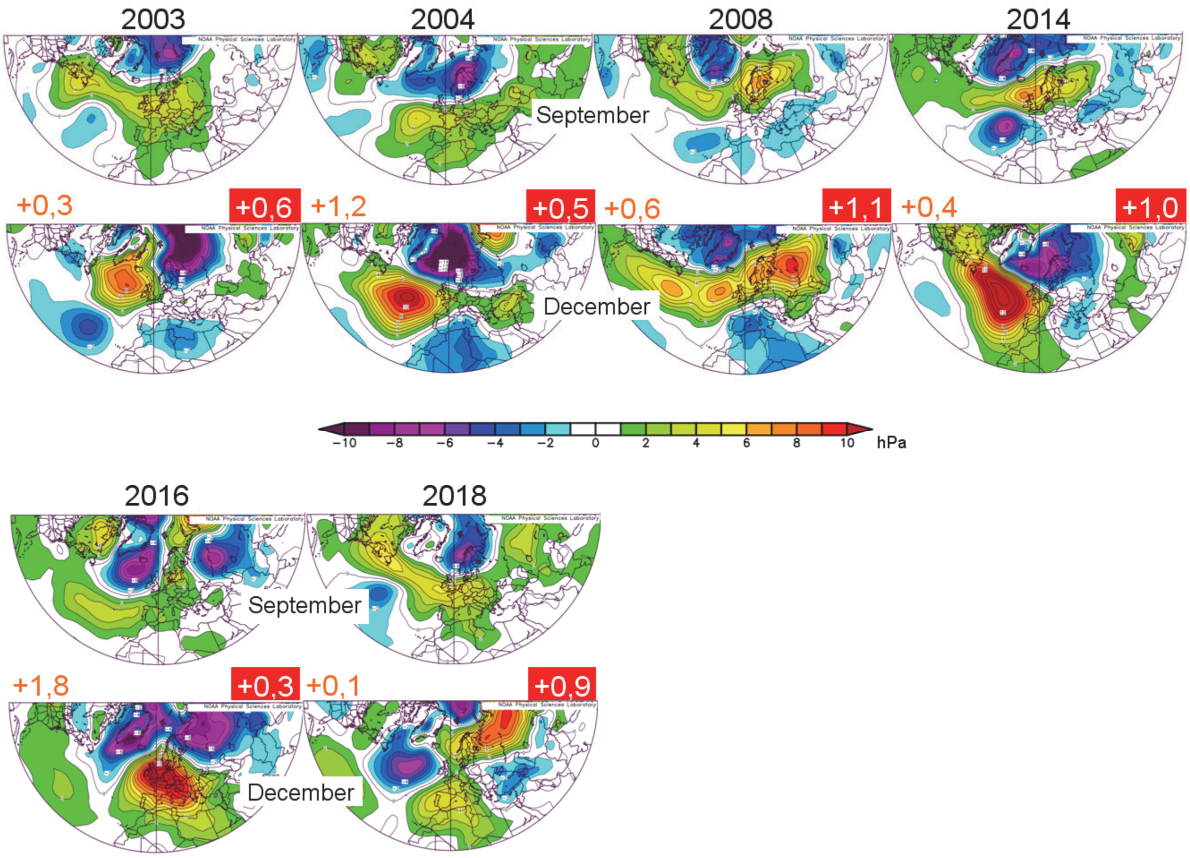

Fig. 3. Monthly mean sea level pressure anomaly of the years in cluster E1 for September and December (1995–2023), temperature anomaly in Central Europe in December compared to the average of the period 1995–2022 (°C, right), and AO index in December (left).

3.4. Cluster E2

- Positive anomaly is limited to Scandinavia and to the north of that region with negative areas to the south and near Greenland (*Fig. 4*).
- These are cases prior to December months with significantly positive temperature anomaly (over +1.5 °C).

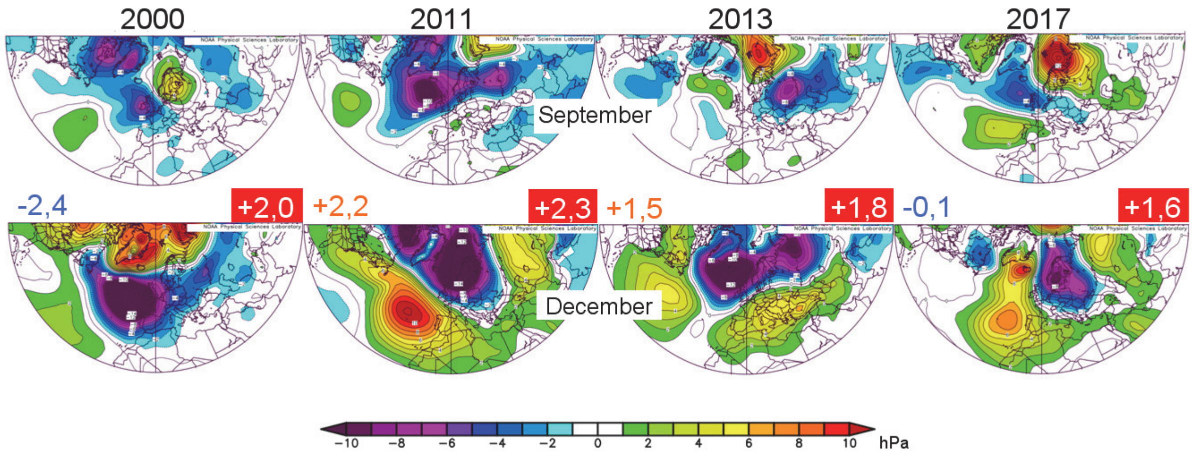

Fig. 4. Monthly mean sea level pressure anomaly of the years in cluster E2 for September and December (1995–2023), temperature anomaly in Central Europe in December compared to the average of the period 1995–2022 (°C, right), and AO index in December (left).

3.5. Cluster N

Four September months could not be classified as any of the 4 mentioned clusters (*Fig. 5*).

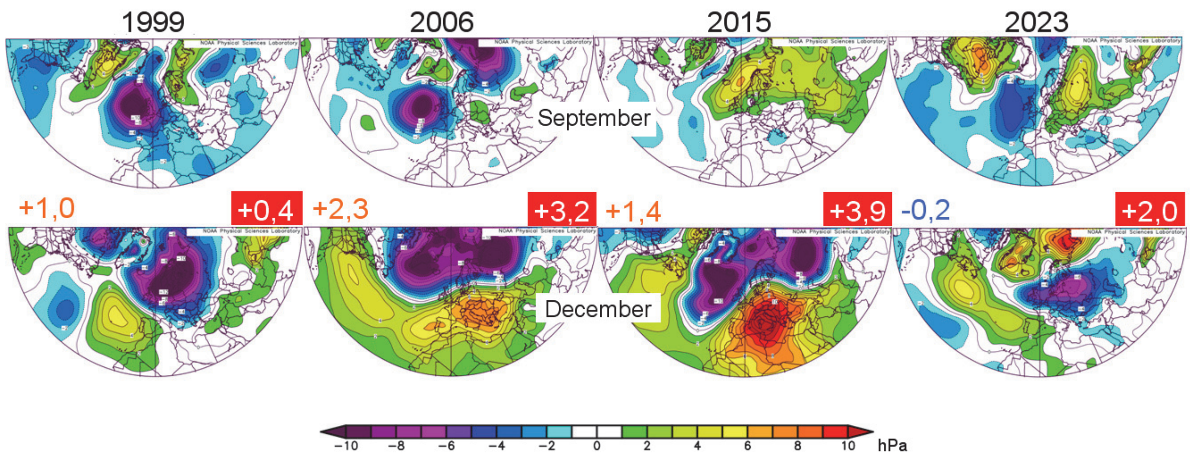

Fig. 5. Monthly mean sea level pressure anomaly of the years in cluster N for September and December (1995–2023), temperature anomaly in Central Europe in December compared to the average of the period 1995–2022 (°C, right), and AO index in December (left).

3.6. Similarity of the years 1996 and 2021 in cluster H1

In case of two years belonging to cluster H1, 1996 and 2021, the similarity of the mean sea level anomaly pattern between the two years lasted even for a period of a whole year starting in May, stretching to April next year (*Fig. 6*). Without the existence of teleconnections, such a similarity at half-hemispheric level for a whole year would not be possible.

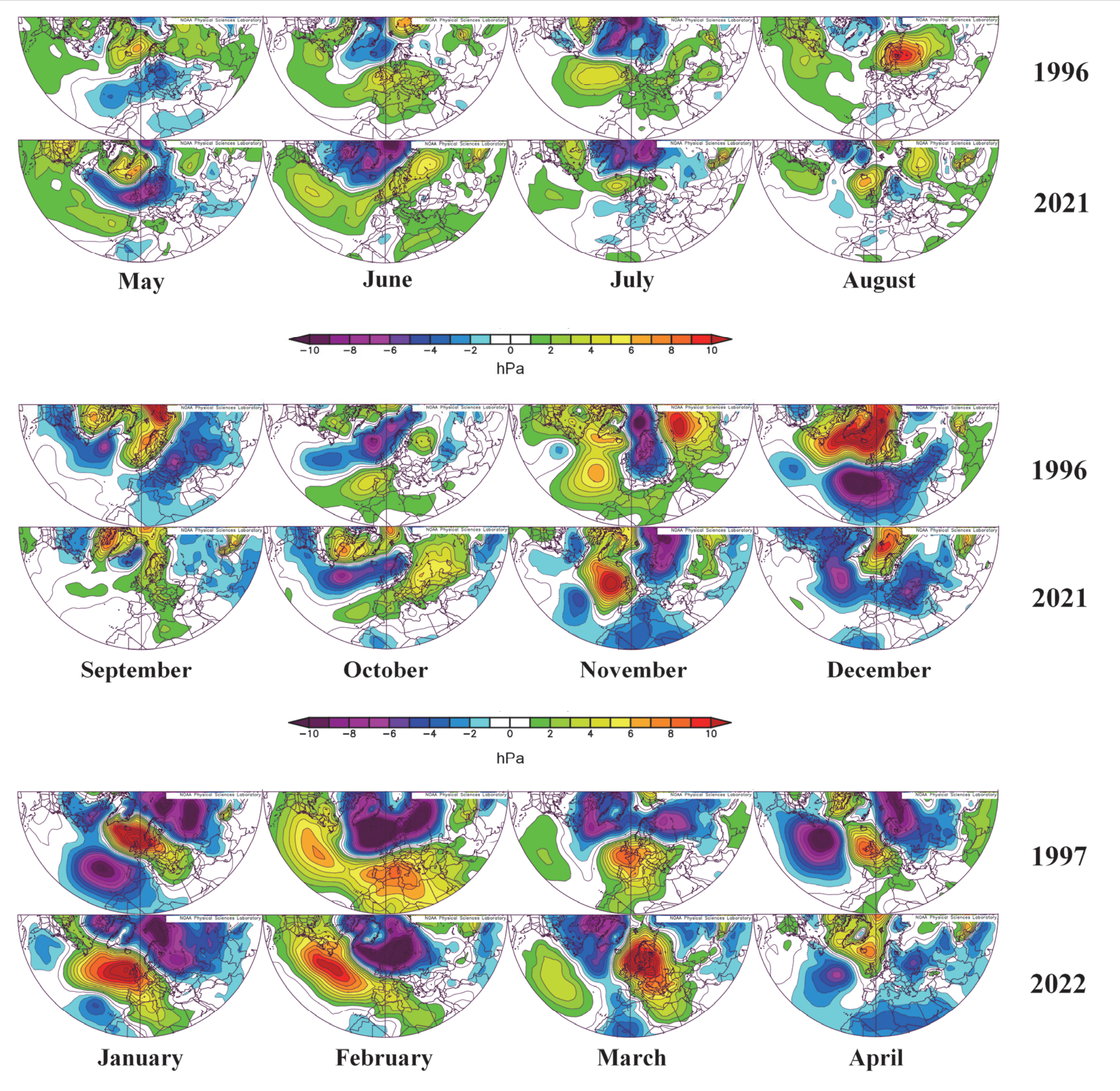

Fig. 6. Monthly mean sea level pressure anomaly in 1996/97 and 2021/2022 from May until April.

3.7. *Connection of SDT with the polar vortex and the AO index*

The AO index is an important measure of the state of the polar vortex, which is responsible for the winter temperature anomaly of the northern hemisphere to a high degree (*Cohen et al.*, 2007; *Kennedy* and *Lindsey,* 2014). In case of a strong polar vortex (significantly positive AO index), cold air is not able to frequently reach lower latitudes (also Central Europe) in larger quantity in the winter period, due to the fact that it is locked in the arctic region by the vortex. In this case, our region is also characterized by temperature conditions mostly above average. When the arctic low pressure is weak (significantly negative AO index), cold air can more often burst from the arctic region towards the south by the more frequent wave development on the polar jet stream, leading to longer lasting cold winter weather in Europe, North America, and also in Asia.

The clusters classified based on the mean sea level pressure anomaly in September in the Euro-Atlantic region predicted the state of the significantly weak or strong polar vortex with high accuracy (*Fig. 7*): 10 of the 11 Decembers with an AO index of under -1 belong to cluster H1 or H2, but only 1 of the 7 cases with an AO index of over +1 belongs to these clusters.

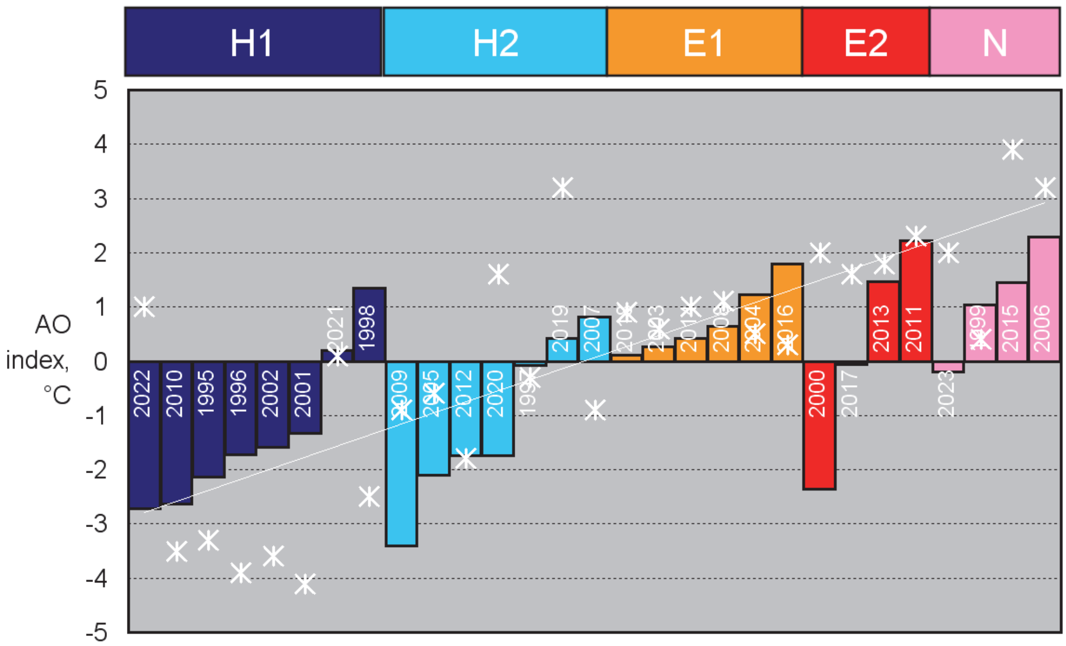

Fig. 7. Monthly AO index values (colored) and temperature anomalies (white) of the December months in Central Europe in each cluster (1995–2023)

Fig. 8 showing mean sea level pressure anomaly distribution averaged for September and December in each cluster provides an expressive explanation of the results presented above: in clusters H1 and H2, strongly positive mean sea level pressure anomaly can be found over the arctic in December, whereas clusters E1 and E2 show strongly negative anomalies over the mentioned region.

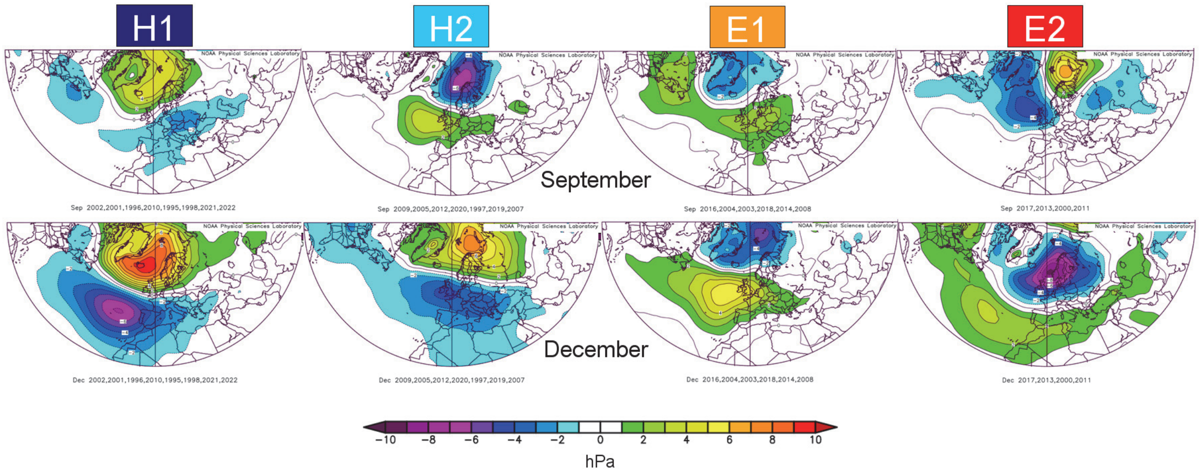

Fig. 8. Mean sea level pressure anomaly distribution averaged for September and December in each cluster (1995–2023).

Mean sea level pressure anomaly distribution averaged for all December months with a negative AO index (*Fig. 9*) strongly resembles to that of the clusters H1 and H2 (*Fig. 8*).

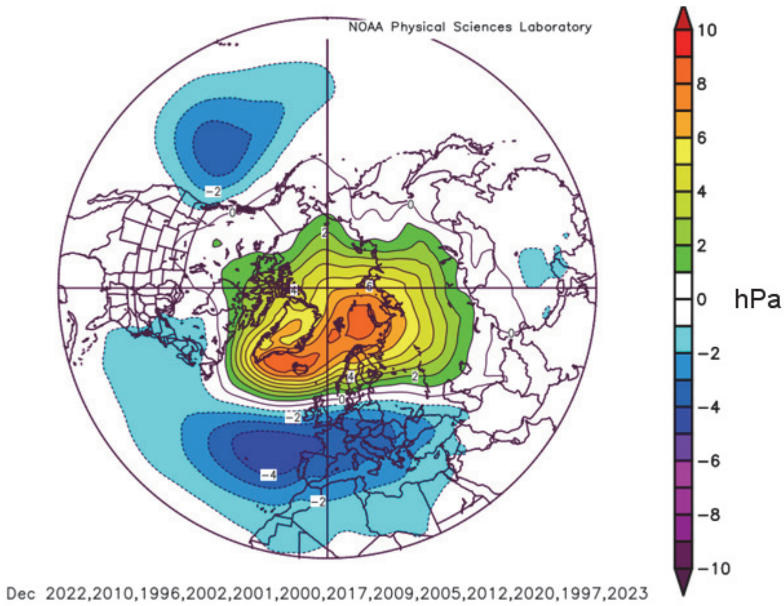

Fig. 9. Mean sea level pressure anomaly distribution averaged for all December months with a negative AO index (1995–2023).

Since 1995, 6 of the 7 December months with a negative temperature anomaly exceeding 1 °C in Central Europe have been accompanied with a negative AO index. Meanwhile, 4 of the 9 December months with a positive temperature anomaly exceeding 1 °C were also characterized by a negative AO index. Consequently, a weaker than average polar vortex is, apart from some exceptional cases, a necessary but not at all sufficient condition for a cold December in our region. The explanation for that is that cold bursts from the arctic might not hit Central Europe (mostly affecting North America or the Atlantic in these cases), leading to a mild December in our region. **In the last 29 years, clustering based on the mean sea level pressure anomaly for September has been able to divide significantly cold and mild December months even better than the state of the polar vortex in December (sign of the AO index) with 7 of 7 months and 5 of 7 months in the right cluster (not regarding cluster N), respectively.**

3.8. A new phenomenon: mysterious depression in December over the British Isles and Scandinavia

An unpleasant experience of recent years was that although the clustering provided a good prediction of the large scale mean sea level pressure anomaly, the December was mild in Central Europe instead of the cold expectations between 2019 and 2022. An appropriate mean sea level pressure anomaly forecast on global scale with a relatively good prediction of the location of positive and negative anomalies might of course lead to regional effects in temperature conditions contrary to expectations, however, in 4 consecutive years?

The explanation can be found in *Fig. 10*. Since 2019 there has been a new phenomenon over the British Isles and Scandinavia in December: significantly negative mean sea level pressure anomaly for 4 years compared to the average of their respective clusters. This led, contrary to expectations, to mild December months between 2019 and 2022 in Central Europe and also in most parts of the continent by modifying the mean sea level pressure pattern in a sensitive area. In 2023, the relation to the cluster average could not be investigated since this September was unclassifiable (Cluster N), but mean sea level pressure was again well below average, and the area of negative anomaly over the continent seems to have merged with that over the British Isles (*Fig. 5*).

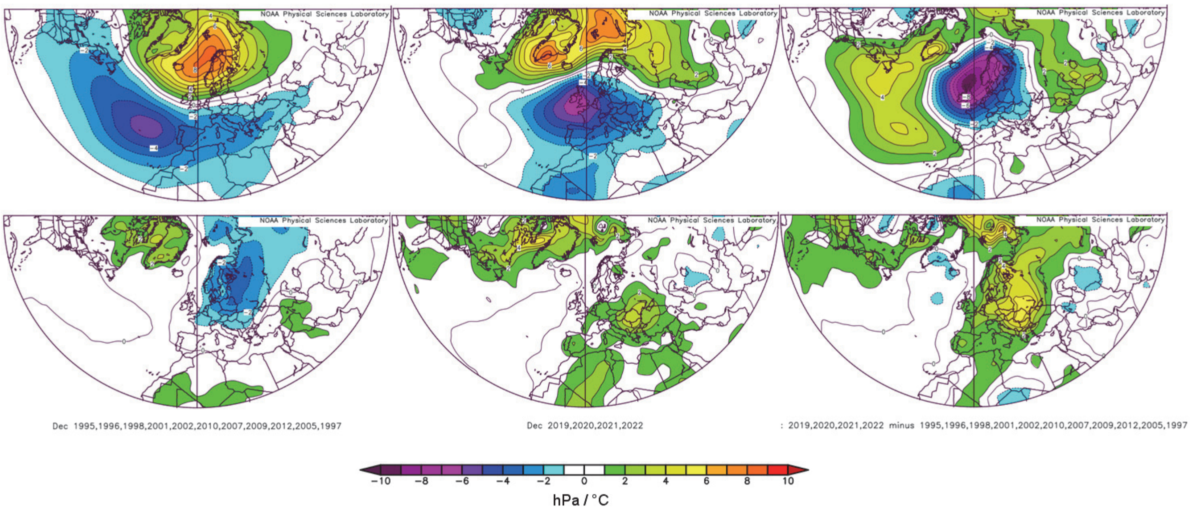

Fig. 10. Mean sea level pressure anomaly averaged for December of the cases in cluster H1 or H2 before 2018 (11 cases, left above), after 2018 (4 cases, in the middle above), their difference (right above), and relevant temperature anomalies (below).

Increase in the strength and the number of low-pressure systems, modification of their tracks in the region of the British Isles and Scandinavia might be another consequence of climate change, which is excellently illustrated by *Fig. 11*. A new climate regime seems to have started in 2019 in Central Europe regarding temperature anomaly for December. Before 2019, there was no overlapping in temperature anomaly values of December months following September months in different clusters: cases of cluster H1 were in the range of -2 to -4 °C, in 0 to -2 °C for cluster H2, in 0 to +1 °C for cluster E1, and in +1.5 to + 2.5 °C for cluster E2. These bands seem to have been increased by 3 to 4 °C after 2018.

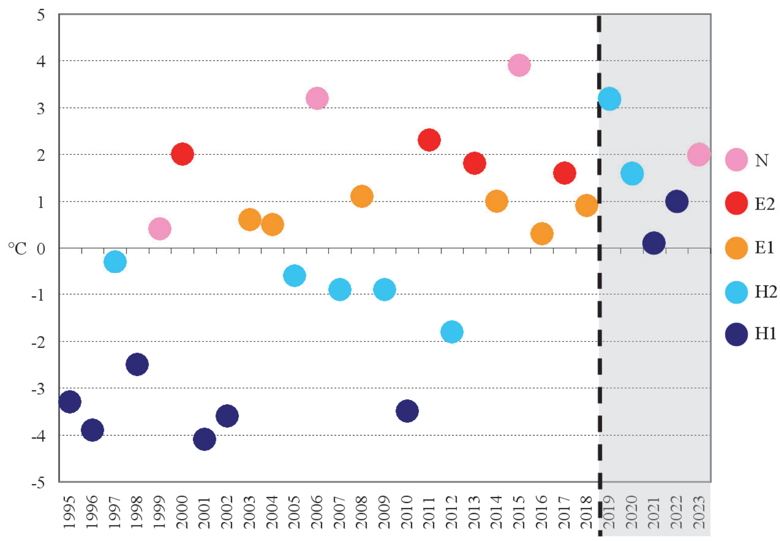

Fig. 11. Temperature anomaly for December in Central Europe between 1995 and 2023 colored as a function of the clusters

4. Summary and conclusions

The September-December Teleconnection (SDT) shows particularly strong regularities in the current positive AMO phase lasting since 1995, which makes it possible to divide years into clusters.

With the help of the clustering based on the mean sea level pressure anomaly in September in the Euro-Atlantic region, the state of the polar vortex in December can be predicted. September months in clusters of the type H are followed by December months with a negative AO index, those in clusters of the type E by December months with a positive AO index with an accuracy of nearly 90% for the significant cases. On the other hand, a forecast for the sign and strength of the temperature anomaly in Central Europe can be provided in most cases.

However, a new phenomenon has turned up, possibly connected to climate change. Since 2019, a strong negative mean sea level pressure anomaly can be found over the British Isles and Scandinavia for the cases in clusters H1 and H2 compared to their former cluster average. This could make our prime goal, forecasting the temperature for December in Central Europe, more difficult or in other cases, paradoxically even easier.

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