ASSESING HISTORICAL (1926-1996) NEAR-SURFACE WIND SPEED VARIABILITY ACROSS SWEDEN

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Abstract

Homogenized near-surface wind speed (NSWS) series of 7 stations from rescued observational journals have been analyzed for the 70-years time-period 1926-1996 to investigate past changes and variations across Sweden. During the whole period, there has been a statistically significant (at $p < 0.05$) decreasing trend of -0.11 m s^{-1} $decades^{-1}$. In particular, there has been a steep slowdown in wind (-0.27 m s^{-1} $decades^{-1}$) for 1945-1960, followed by a long period of stabilization until 1990. Complementary data from 1956-2013 and 1997-2019 also reveal a stilling period between 1990-2005, followed by a reversal which is in line with previous studies from Scandinavia. Summer and fall are the season which show the largest decreasing trends (-0.11 and -0.12 m s^{-1} $decades^{-1}$). Winter shows a greater interannual variation, and reports the same, smaller decreasing trend as spring (-0.7 m s^{-1} $decades^{-1}$). In addition, wind speed series have been correlated with 4 different large-scale circulation, namely North Atlantic Oscillation (NAO), Artic Oscillation (AO), Scandinavian Pattern (SCA) and East Atlantic Pattern (EA). Correlation with circulation patterns has wide seasonal differences. Correlation with NAO generally shows a positive correlation, which is highest during winter (0.5); AO shows the largest positive correlation in spring and winter (0.45 and 0.5 respectively); and EA has the highest positive correlation with wind speed during spring (0.45). SCA is the only teleconnection system which displays statistically significant ($p < 0.05$) negative correlation, largest in summer (-0.27). A possible cause for the seasonal variation in wind speed trends is the tendency to a positive phase in NAO, AO and EA during winter and spring, which increases the westerly winds strength; during summer, when large-scale circulation has less tendency for positive phase (i.e., less pressure difference), smaller more-regional and local patterns may affect, for example, the uneven warming in the high latitudes, causing less pressure gradient and leading to decreased wind speeds.

Keyword: Near-surface wind speed, teleconnection patterns, Sweden, stilling, reversal

Acknowledgements

This master thesis is a part of a project called WINDGUST (Ref. ***2019-00509)*** which is a collaboration between the Swedish Meteorological and Hydrological Institution (SMHI) and the Regional Climate Group at Gothenburg University (RCG-GU). The project aims to obtain high quality, centennial near-surface wind speed series from rescued wind speed data and to assess long term trends and variations of wind speed in Sweden. The project was divided into three work packages:

WP1 - Data rescue of observed long-term wind speed series.
WP2 - Quality control and homogenization of wind speed series rescued.
WP3 - Assessment and attribution of wind speed changes over centennial timescales in Sweden.

WP1 was performed by staff at SMHI from winter 2020 through summer 2021, WP2 was performed mainly by researchers at RCG-GU during autumn and winter of 2021 and WP3 is presented in this thesis.

I want to express my gratitude towards the staff at SMHI, especially Erik Engström, Lennart Wern and Sverker Hellström for providing data from the rescued data journals and for being a part of the WINDGUST project. I also want to thank Chunlüe Zhou for providing me with high-quality homogenized wind speed series and offering constructive advice for the thesis and Cesar Azorin-Molina for the feedback and the introduction to this subject. Of course, I also want to thank Deliang Chen for introducing me to this work and during his courses made me open up my interest for this type of climate study. Last, but definitely not least, I want to express my appreciation towards Lorenzo Minola, who even from afar have manage to help me understand new aspects in the subject through discussion and learning and who have always found time to help, even in stressful periods, and been an exceptional supervisor who always cheers for me and calmed me down during hard, stressful and grieving periods, thank you.

Thank you also, to my wonderful partner Alfred, for keeping me sane during an unusual period of isolation and for making sure I had everything I needed, for being my rock and shoulder to lean on in stressful situation and for taking care of me when I forgot.

I want to finish by dedicate a few words to my recently lost best friend, my rescue dog Sara, thank you for teaching me the meaning of joy and for giving me the strength to move forward from hard situations, you are deeply missed, and I will never forget you. Rest in Peace.

Contents

Abbreviation

AA - Anthropogenic Aerosols
AO - Artic Oscillation
EA - East Atlantic Pattern
LLJ - Low-level Jets
NAO - North-Atlantic Oscillation
NOAA - National Oceanic and Atmospheric Administration
NSWS - Near-surface wind speed
PGF - Pressure gradient force
PMF - Penalized Maximal F-test
SAT - Surface Air Temperature
SCA - Scandinavian Pattern
SLP - Sea Level Pressure
SMHI - Swedish Meteorological and Hydrological Institute
SNAO - Summer North Atlantic Oscillation
WMO - World Meteorological Organization

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1. Introduction

The understanding of wind speed variability is of high importance. Changes in NSWS can cause changes in natural processes such as evaporation (McVicar et al., 2012), it can regulate the concentration of air pollutants in urban cities (Liu et al., 2020) and contribute to cooling in urban heat island (Bing et al., 2020). Another important socio-economic aspect, which has come to great meaning the past years in terms of reduction of GHG, is the wind energy sector (Li et al., 2020). Energy produced by wind turbines is an important source towards exchanging fossil fuels for renewable energy and a lot of countries have already taken a vast leap towards this exchange. In Sweden, the wind energy stood for about 16% of the overall energy production in 2020 and at the end of the same year, the increase in produced wind energy was over 5000 GWh compared to the year 2019, which was an >25% increase (Energimyndigheten, 2021). In Denmark, more than a third of the energy produced comes from wind sources (DEA, n.d.), proving that wind power is an important energy source in Scandinavia. Zeng et al. (2019) stated that the amount of energy produced by winds would be halved at the end of this century if the declining trend from 1980-2010 would have continued, excluding winds as a significant source of energy in the future. In order to evaluate the potential in wind energy, and other factors affected by winds, it is important to understand past wind variations and the cause of the variations to estimate future wind scenarios.

In the last few decades, multiple studies have found that there has been a decrease in mean near-surface wind speed (hereafter NSWS) in areas such as China (Fu et al., 2011; Zang et al., 2021), North America (Wan et al., 2010; Pryor et al., 2009), South Europe (Azorin-Molina et al., 2014) and Scandinavia (Minola et al., 2016; Laapas and Venäläinen, 2017), among other areas across the globe. This phenomenon has been called "stilling" and was first adapted by Roderick et al. (2007) in a study to evaluate potential causes for a decrease in pan evaporation. Several studies also found that, while NSWS has been decreasing over most land area, there has been an increasing trend over the oceans (Zheng et al., 2016). Therefore, the term "stilling" refers to the global terrestrial stilling, as stilling trends has been observed in most studies made over land (Wu et al., 2018). The observing trends in NSWS are often expressed in meters per second per decade ($m\ s^{-1}\ decade^{-1}$) and varies depending on the studied region. Between 1981-2011 the magnitude of the slowdown varied from smallest decrease found in in Australia (-0.062 $m\ s^{-1}\ decade^{-1}$) to largest decrease found in North America (-0.105 $m\ s^{-1}\ decade^{-1}$), while the global terrestrial stilling observed for the same period was estimated to -0.078 $m\ s^{-1}\ decade^{-1}$ (summarized by Wu et al., 2018).

Recent studies have found that the stilling stopped and shifted towards an increasing trend in the 21th century in several regions (Azorin-Molina et al., 2018a; Zeng et al., 2019; Zha et al., 2021), a phenomenon which has been named the "reversal". The global average wind speed anomaly (excluding Australia) in 2020, compared to the period 1981-2010, amounted to +0.052 $m\ s^{-1}$, even with spatial variations from the largest negative anomaly of -0.0084 $m\ s^{-1}$ in North America to the largest positive anomaly of +0.178 $m\ s^{-1}$ in central Asia (Azorin-Molina et al., 2021a). In 2019 the global anomaly was reported to be +0.033 $m\ s^{-1}$ (Azorin-Molina et al.,

2020) and in 2018 the anomaly was +0.017 m s^{-1} (Azorin-Molina et al., 2019), all pointing towards a reversed, increasing trend.

Since wind speed is regulated by several geophysical, metrological, and in some cases anthropogenic factors, it is hard to estimate the exact reasons behind wind changes. Winds arise due to the uneven warming between two locations which cause differences in surface pressure: this pressure difference, called the pressure gradient force (PGF) together with the Coriolis force and earth friction are the main factors which drive and control winds (Rohli & Li, 2021). Therefore, several studies have explored the possible relations between changes in semi-permanent pressure systems and wind speed, such as those of the North-Atlantic Oscillation (NAO) (Minola et al., 2016; Philips et al., 2013; Zhou et al., 2022). Other factors such as changes in land surface (Minola et al., 2021a, Vautard et al., 2010, Zeng et al., 2018), aging equipment (Azorin-Molina et al., 2018b) and anthropogenic aerosols (AA) (Bichet et al., 2012; Jacobson & Kaufman, 2006) have also been suggested as potential cause of wind speed changes.

Previous studies about NSWS in Sweden have been conducted during shorter time periods. One of the first studies made with wind observations across Sweden was performed by Aschberger et al. (2005) who mapped the mean NSWS statistics using wind speed measurements from 1999-2000. At that time, studies on NSWS changes in Sweden and Scandinavia were sparse but in the latest decade more attention has been given to this study area. The work of Minola et al. (2016) was the first work to analyze and assess long-term wind speed changes in Sweden, during a period of 1956-2013, where not only the overall stilling was in focus but also the seasonal variations. This study proved that the stilling phenomenon was more pronounced in summer and less during winter. Since then, studies have been made to assess possible cause for the wind variation in Sweden which has shown a strong correlation with the NAO as well as correlations with land-use changes (Minola et al., 2021a).

Fewer studies have been done on a centennial scale, in some case, reanalysis sets have been used to reconstruct wind speed variability during the 20^{th} century (Shen et al., 2021; Wholand et al., 2019). But studies made from observational data during early 20^{th} century are sparse. Observational data on centennial scale is important to cover the full cycle of atmospheric modes, which can last between 60-80 years (Hurell et al., 2003), but also to increase the reliability in historical wind speed data by extending its period (IPCC, 2021). This will be the first study which will evaluate centennial NSWS changes from observational data in Sweden.

2. Aim

This research intends to (i) investigate centennial trends and variations in NSWS in Sweden, with a focus on the 70-year long period 1926-1996, and (ii) assess the correlation with four different large-scale circulations.

To lead this research, three main research questions has been put forward:

(i) How has the near-surface wind speed changed in Sweden since 1920s?
(ii) What are the possible causes for the NSWS variation in Sweden?
(iii) How does large scale circulations correlate with wind speed trends in Sweden?

This thesis is divided into several sections to provide the reader with necessary understandings about NSWS variability and analysis of wind speed data. The geological and climatological qualifications for Sweden are represented in section 3 to get a deeper understanding of what factors affecting wind variations in Sweden. The data rescue and homogenization process is briefly explained in section 5 and 6, since these steps are crucial for implements of this research and laid the foundation for the analysis, which is presented in the result (8). The study will end in a discussion (9) and conclusion (10), where also possible future research will be brought to attention.

3. Study area

3.1 Geography of Sweden

Sweden, with its 450.000 km², extends from 55°N (at Smygehuk) to 69°N (at the Three-Country Cairn in Kiruna). Its oblong form and few land borders mean that Sweden has one of Europe's longest coastlines, and several of Sweden's biggest cities are located along the coast. The long coastal line can cause development of coastal fronts and low-level jets (LLJ), due to the difference in temperature and roughness between land and sea. These weather phenomena usually only last around 12 hours and stretches about 100km, making them more of a local mesoscale weather system than regional wind patterns, and is common in cold seas such as the Baltic Sea outside Sweden's east coast (Malda et al., 2007, Svensson et al., 2018). The development of local land and sea breezes at coastal sites is more persistence when the geostrophic winds are weak (Källstrand et al., 1999) and when the thermal difference between land and sea is large such as during summer days (sea breeze) and nights (land breeze) (Azorin-Molina et al., 2011; El-Geziry et al., 2021; Fredrico et al., 2010).

Sweden is also rich in lakes and rivers: roughly 9% of the land area consists of lakes and covers in total about 40.000 km² (SMHI, 2008). The total length of all of Sweden's rivers are estimated to be about 500.000 km (SLU, 2020a). Due to the presence of the Scandes in the northwest of Sweden and east of Norway, numerous river valleys flow from northwest to southeast, largely affecting the direction of the winds in this area (Achberger et al., 2006). Lakes can cause local wind patterns in the same way that oceans do due to the thermal difference between land and water and are just like sea breezes, more common during the afternoon in spring and summer (Zengmao, 1986). Figure 1 presents the topography of Sweden where in the northwest, the Scandes can be seen ranging along the Norwegian border in a north-south direction, with its highest (Swedish) point at Kebnekaise about 2000 meters above sea level. The Scandes act as a barrier from winds originated from the west, sheltering the north of Sweden and may be leading to reduced wind speed in this area (Achberger, 2006). In the southernmost Sweden and along the west coast, the land is flatter and consists of large agricultural areas, exposing this region to westerly winds. The land use of Sweden is dominated by forest areas with about 70% of the total land use counting as forest land (SCB, 2019). Figure 2 shows the land use across Sweden. Forest cover increase the surface roughness which in turn decreases the speed of near-surface winds. Deforestation of an area will lead to an increase in wind speed, while afforestation will lead to a decrease in wind speed (Minola et al., 2021a; Nikitin et al., 2019). Due to the effective forest management among other factors, such as climate change (which favor the growing conditions in Sweden), forest lands have continuously increased since the early 20th century (Skogsstyrelsen, 2020; SLU, 2020b).

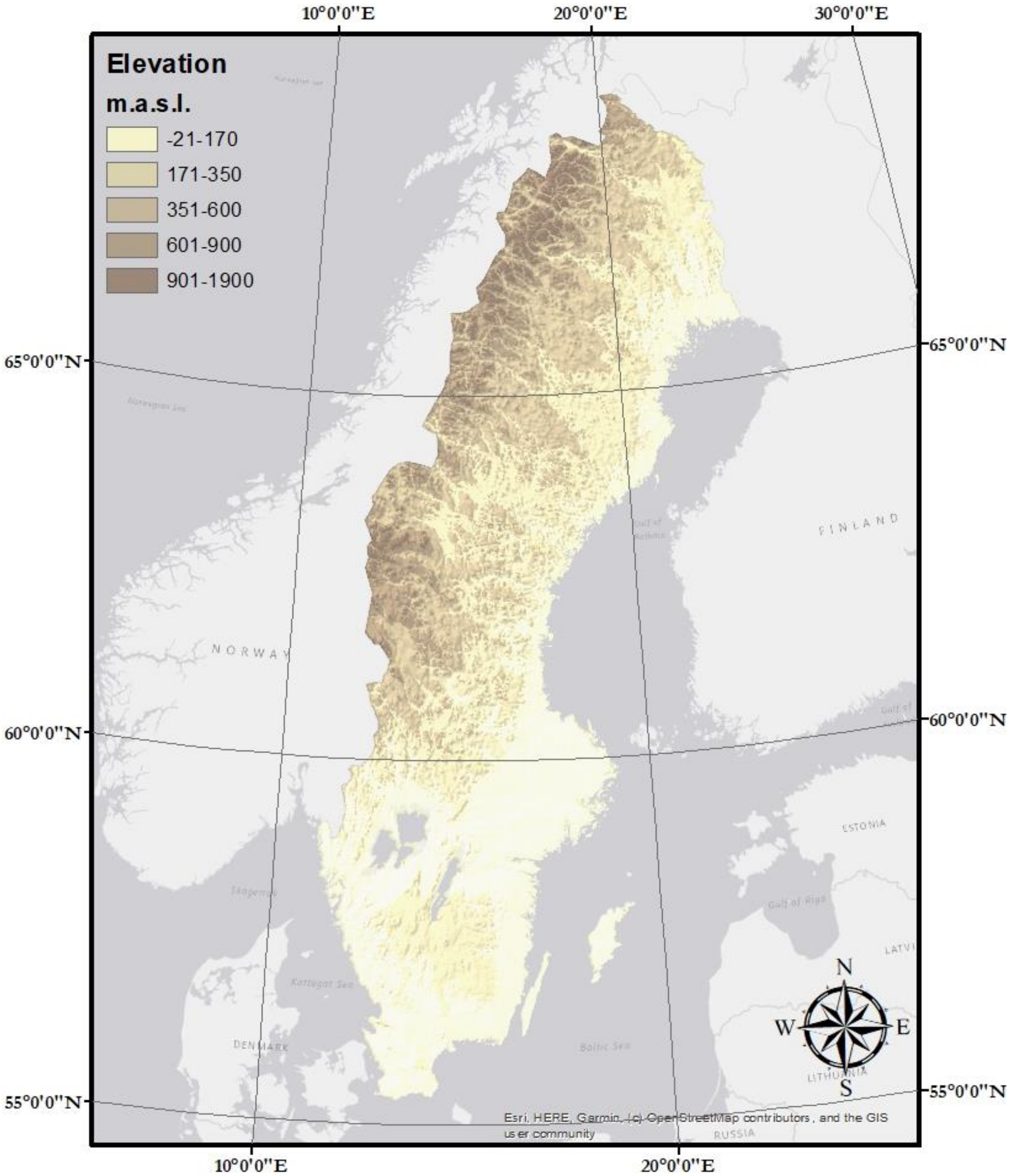


Figure 1. *Topography of Sweden (ArcGIS, Lantmäteriet)*

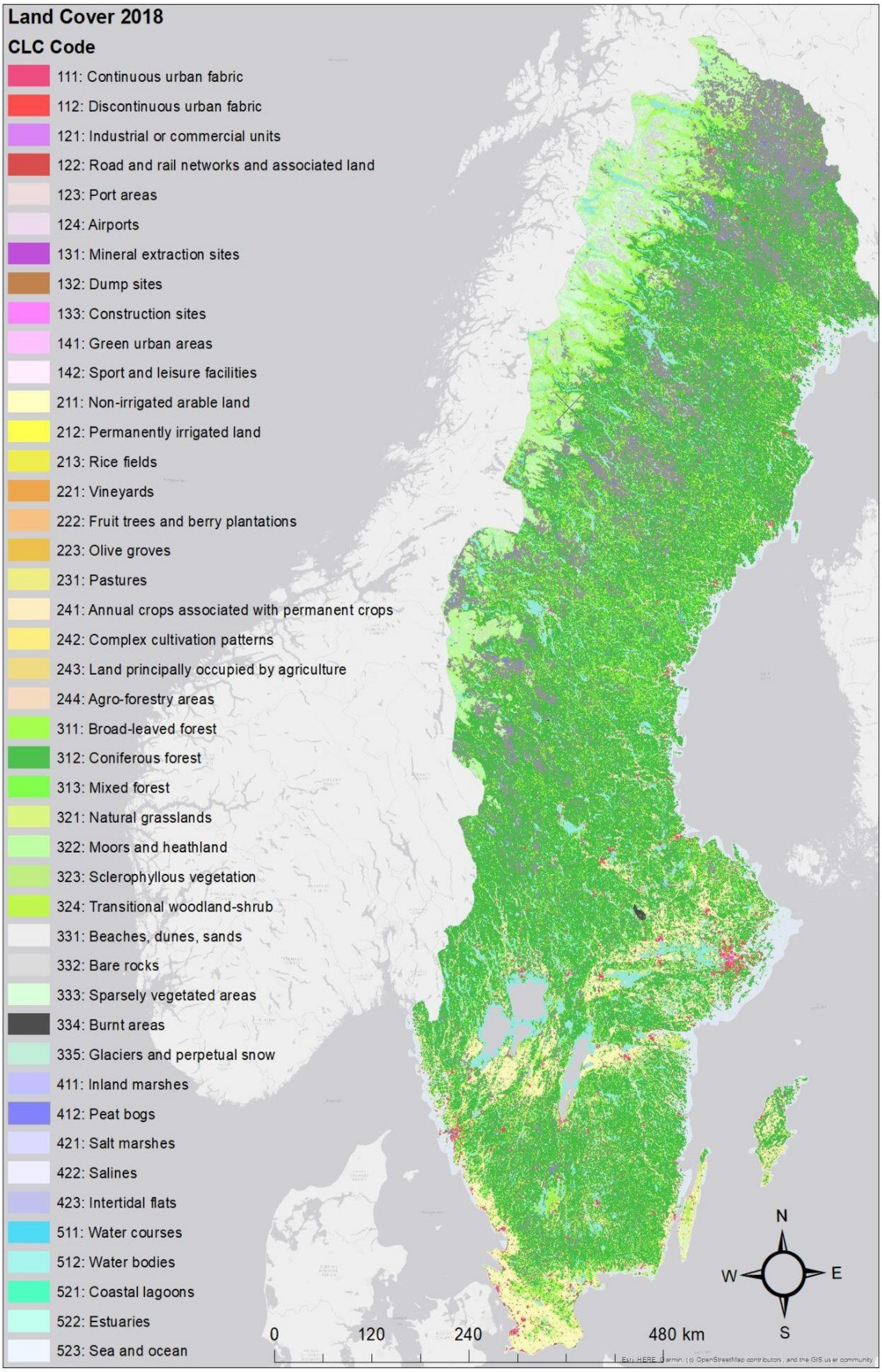


Figure 2. *Land Cover of 2018 in Sweden (ArcGIS, Copernicus, CLC 2018).*

3.2 Climatology of Sweden

3.2.1 Temperature

Since Sweden stretches between 55°N and 69°N, the climate between southern and northern Sweden varies. According to Köppen-Heiger Climate classification, the coast of southern Sweden is classified as an C (warm/mild temperate zone) with mean temperatures above -3°C during the coldest month and above 10°C during the warmest month, while the rest of Sweden is classified as D (continental zone) with temperatures below -3°C during the coldest month but above 10°C during the warmest month. Some regions in the northern Scandes even experience polar climate (Figure 3; Kottek et al., 2006). Thanks to the Gulf Stream, Sweden experience warmer temperatures than other places at the same latitude. However, the temperature can sometimes drop below -20°C in some parts and the temperature difference between winter and summers are large, more so in northern Sweden. The abundance of precipitation, especially in summer and autumn, can also help altering the temperatures (SMHI, 2021). Temperatures can range between -30°C to above 0°C in winters while most of Sweden experiences temperatures above 20°C in summer (Visit Sweden, 2022).

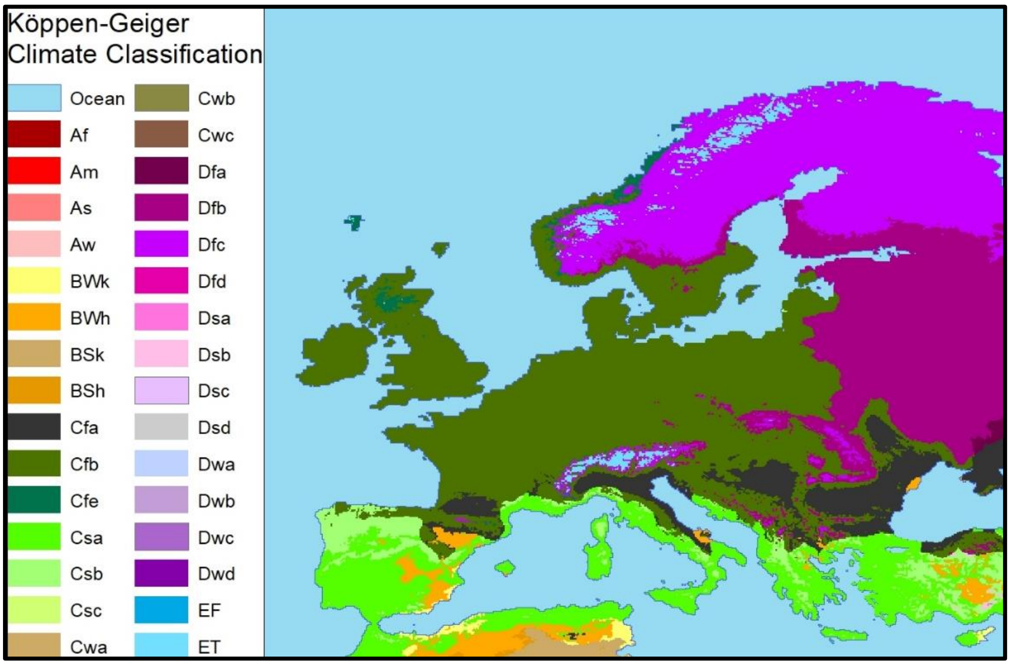


Figure 3. *Color coded Köppen-Geiger climate classification over Europe (ArcGIS, Kottek et al, 2006).*

3.2.2 Precipitation

The annual precipitation is usually higher than the evapotranspiration in most of Sweden, which is one of the causes for the richness in lakes and rivers (SLU, 2020). Precipitation has steadily increased over several decades, mostly due to increased winter precipitation (Grusson et al., 2021; Bengtsson & Rana, 2013). According to future model projections, climate change will increase precipitation in all seasons in Sweden (SMHI, 2019). Most of the increase will be experienced in northern Sweden during winters.

3.2.3 Winds

There are several mechanisms driving surface winds, from local winds and large-scale circulations to thermodynamic component such as lapse rate and phase transition. Generally, wind is generated by pressure differences between two locations which are mostly caused by the uneven warming of the earth surface (Rohli & Li, 2021). The heat is more concentrated in the area around the equator and less at the poles, causing warm, moist air to rise, leaving a low-pressure area at the equator. The air moves towards the pole and becomes cooler and eventually descends again, creating a cooler high-pressure area. Air always moves from high to low pressure and this movement of air is ultimately what creates winds. Since the earth is spinning around its own axis, the winds will not blow directly from lower to higher latitudes, but the Coriolis force will force the wind to the east in the northern hemisphere and west in the southern hemisphere (Rohli & Li, 2021). This will eventually affect the air trade, which will not occur in a single transportation from equator to poles. Instead, the circulation is divided into three cells: the Polar cells, the Ferrel cell, and the Hadley cells. In these cells, air circulation between high-pressure areas and low-pressure areas between the cells will occur and create three global wind patterns: the polar easterlies, the westerlies and the trade winds which ultimately helps control much of the earth climate (Turgeon & Morse, 2012). Sweden is located in the westerlies belt where low pressure zones move in the polar front, causing Sweden to experience winds mainly from the southwest, which origin from the horse latitude in the south (SMHI, 2009). When westerlies are weak, cold winds which origins from the poles can also strike over the country (Hurell et al., 2003a).

Since the earth do not have a homogeneous sectioning between land and earth and due to the fact that land warms and cools much faster than the ocean, semi-permanent pressure system can form over some regions, creating large-scale circulation patterns (Rohli & Li, 2021). Some of the patterns affecting Sweden, and the rest of Europe, is explained below and will be a part of the correlation analysis later.

North Atlantic Oscillation

The North Atlantic Oscillation (NAO) is a large-scale atmospheric circulation mode, caused by the pressure differences between the Icelandic low and Azore high (NAO, 2021b). NAO is measured as the difference of the pressure between these two pressure systems and is expressed as an index. When there is a large difference between the pressure, the NAO has a positive phase which will lead to stronger westerly winds and will cause warmer temperatures over most of Europe. It will also cause a northeast shift of the Atlantic storm tracks leading to stormier winter weather in the north and a slightly calmer winter weather in the southernmost parts of Europe (Hurell et al., 2003a). On the opposite, when the pressure difference is small, the NAO is said to have a negative phase and the westerlies are weaker, leading to higher chance of cold easterly wind from the pole to sweep over northern Europe, causing colder and drier winters (Hurell et al., 2003a). The effect of the NAO in Europe varies between seasons because of the seasonal variations of the jet streams and are most notable during winter (Hurrel et al., 2003b), hence, most climate studies have been focusing on the correlations with the winter NAO. Although, summer NAO has recently been brought to attention. Parallel NAO patterns during summer called summer NAO (SNAO) have been lifted, and in a study by Folland et al. (2008) this pattern is shown to have high correlation with rain, cloudiness and temperatures in northern Europe. The SNAO is located more north and in a smaller scale, which may be the reason why we more often speak of winter NAO than SNAO (Folland et al., 2008).

NAO is often mentioned as one of the main causes for wind changes in the North Atlantic area, with high correlation is during winter and lower during summer (Azorin-Molina et al.,2014; Minola et al., 2016; Montreuil and Chen., 2018).

Arctic Oscillation

Similar to the NAO, the Arctic Oscillation (AO) is a large-scale atmospheric circulation mode caused by pressure difference between different locations in the arctic and the mid-latitudes (NOAA, 2021a)**.** The AO measures the pressure over the Arctic and the mid latitude of the North Pacific/North Atlantic (Thompson et al, 2000). The AO and NAO have both differences and resemblances. Just like the NAO, the AO affects the Jet Stream, altering the weather and climate in the mid-latitude, especially in the winter. But, unlike NAO, the AO also has a center in the pacific and a broader center over the arctic, causing it to affect a larger area (Thompson et al., 2000).

When the pressure over the Arctic is lower than average, the AO has a positive phase which generally causes the jets to be more north and cause a shifting towards northwards movement of storms, meaning a reduced risk in cold air sweeping over NH. The negative phase is characterized by a higher-than-average pressure over the Arctic and will cause the jets to shift toward the equator and cause higher risk of cold and dry winter climate from the Arctic to reach the mid-latitudes (NOAA, 2009). The AO has shown strong positive correlations with East Asian Moonsoon (Li et al., 2014; He et al., 2017), sea ice and snow melting in the NH (Schaefer et al., 2004; Yang et al., 2016) and wind patterns, both in the Atlantic area and in the Pacific area (Freitas et al., 2022; Zhang et al., 2020).

Scandinavian Pattern

The Scandinavian Pattern (SCA) is a smaller oscillation that mainly affects Europe. Even though the pressure centers may shift, the pattern is driven by pressure differences between Scandinavia and western Europe/eastern Russia (NOAA, 2012a). This Pattern was first classified and identified by Barnston and Livezey (1986) and was then called Eurasia Type 1. The positive phase of SCA occurs when western Europe/eastern Russia experiences low pressure and Scandinavia experiences high pressure which will lead to cooler, drier(wetter) winters and warmer (cooler), drier (wetter) summers in northern (southern) Europe. The negative phase is the opposite phase with low pressure center over Scandinavia and a high-pressure center over central Europe/Eastern Russia, which will lead to warmer (cooler), wetter (drier) winters and cooler (warmer), wetter (drier) summers in Northern Europe (Dutton, 2021). During the positive phase, the westerlies are weakened over Scandinavia and the Jet streams are slightly extended to the east. This generally leads to fewer storm-tracks over Scandinavia and the sub-polar Eurasia area (Bueh and Nakamura, 2007).

East Atlantic Pattern

The East Atlantic Pattern (EA) is much like the NAO and has a north-to-south pressure center dipole southeast of the NAO pressure poles. This pattern was also identified by Barnston and

Livezey (1987), although the first time this pattern was mentioned was by Wallace and Gutzler (1981) but their interpretation was slightly different. Barnstone and Livezey identification is similar to the one used by the National Oceanic and Atmospheric Administration (NOAA) today (NOAA, 2012b).

The positive phase of the EA experience large pressure difference between the two pressure-centers which generally leads to warm and wet weather in Europe, while the negative phase brings cool and dry weather to Europe (NOAA, 2012). Because of its similar location to the NAO, the combined effect of these two patterns have been studied. Rodrigo (2021) found that, if the EA is in the opposite (same) phase as that of the NAO in the winter, the influence on precipitation and temperature in the Iberian Peninsula will be strengthened (weakened). Furthermore Mellado-Cano et al. (2019) found that, when in the same phase, NAO and EA have the same effect on the jet stream speed but opposite effect in the latitude of the jets.

4. Data and methods

4.1 Data

4.1.1 Digitization and Data Rescue

During the last decades our society has undergone a huge development towards a more mobile and digital environment. This has contributed to more accessible data and has been a huge improvement for climate research since climate data now is easily accessed from all around the world (WMO, 2016). There are still valuable climate journals which are being stored on aging papers in a single archive, exposing them to risks such as oxidation and fire and water damages. It is important to save old climate journals as it can contribute to a better understanding of our climate and enhance the climate records we have today. Old climate data also contribute to the development of more accurate climate projections in climate models (WMO, 2016).

Data rescue and digitization was the first step in the WINDGUST project and was executed by staff at SMHI during 2020. The data was rescued from the archive at SMHI in Norrköping by scanning old weather journals between the years of 1920-1940. The "Guidelines on Best Practices for Climate Data Rescue" from the World Meteorological Organization (WMO 2016) was followed during the whole process (Engström et al., n.p.). Only the stations which had recorded wind speed in m s^{-1} were rescued since the data then was considered to be from an anemometer. In some cases, wind speed was recorded in Beaufort (i.e., a 12 level detection unit), but then wind changes considered to be detected through signs in the surrounding rather than measured from an anemometer. The stations had daily records with data from every sixth hour and recorded both wind speed and wind direction (Engström et al., n.p.). The rescue project resulted in digitized data from 13 stations with most of the stations located in the south of Sweden or along the coast. Table 1 summarizes the rescued data.

Station	First year of rescue	Last year of rescue
Bjuröklubb	1926	1938
Haparanda	1925	1938
Hoburg	1926	1938
Holmögadd	1926	1938
Härnösand	1925	1938
Kalmar	1927	1942
Landsort	1926	1938
Malmslätt	1928	1936
Torslanda	1932	1938
Vinga	1926	1938
Visby	1925	1938
Väderöbod	1926	1948
Ölands Norra Udde	1926	1938

Table 1. *Station name and the years which where digitization of the 13 stations with rescued data.*

4.1.2 Quality control and homogenization

To have data of high quality is of great importance when performing a climate study. Knowing your metadata is a crucial part when discussing the outcome of the results and when drawing conclusions about it (WMO, 2003). Data recording varies between stations in terms of the different equipment and the surroundings, which can affect the outcome of the data. For example, a station with decreased surrounding land roughness over time is more likely to record increased wind speeds (Minola et al., 2021a) and station which use older equipment is more likely to record decreased wind speed (Azorin-Molina et al., 2018). If the station relocates to a new site (i.e. from an airport to a research base or from higher to lower altitude), it can alter the exposure the equipment have to winds, affecting the outcome (Mayor Salgado et al., 2013; Safaei Pirooz et al., 2018). These are some examples which can lead to misinterpretations of the result, homogenization and quality control of climate data aims to detect and correct these non-climatic signals in a series. WMO (2003) lists four steps that are commonly used in assessing a homogeneous time series: (1) Metadata Analysis and quality control, (2) Creating a reference series, (3) Detecting breakpoints and (4) Data adjustment. The homogenization of the data used in this study followed these steps. During the quality control, suspicious and missing values were flagged and checked, and the extremely high or low outliers were usually removed. There can be several reasons behind these extreme values, for example misreading in the scanning process, then an adjustment could be made instead of treating the value as missing data (Engström et al., n.p.).

A good reference series is essential for the homogenization process for all climate studies because it helps to find and correct small discontinuities in the time series which might otherwise be hard to detect (WMO, 2020). There are several different types of reference series that can be used, such as geostrophic winds (Minola et al., 2016; Wan et al., 2010), nearby-station (Coll et al., 2020) or climate reanalysis (Azorin-Molina et al., 2014). Depending on the type of the study and availability of data, the different approaches vary, a correlation test can determine which type of reference series is of best use. After comparing several reference series (figure 4), the CERA-20C reanalysis dataset was used to represent the reference series between 1925-2010 and the ERA5 model was used to extend the series from 2011-2021 in the homogenization process of the data used in this study (Zhou et al., 2022).

Before the homogenization, the data was converted from hourly or daily values into monthly averages for the month which contained 10 or more daily values. Month with less values were excluded, which was only about 0.7% of the total data (Zhou et al., 2022). By converting to monthly averages, daily variation is removed and instead of focusing on day-to-day weather, the long-term climate is studied.

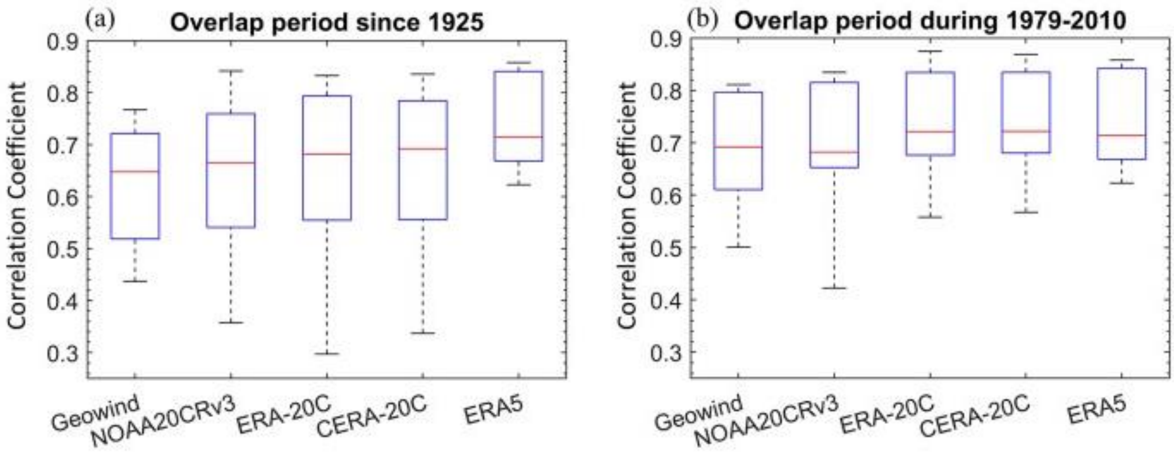


Figure 4. *Correlation coefficients between different reference series and the data of the 13 stations (Zhou et al, 2022) from the overlap period since 1925 (a) and the period 1979-2012 (b).*

There are several statistical tests that can be used in the homogenization process to detect break point (i.e. points in time when the values suddenly increase/decrease). For these series, the Penalised Maximal F-test (PMF) (Wang, 2008) was used for detection. In total 71 brake points were detected and changed in the 13 stations (Zhou et al., 2022). In figure 5 the number of brake points at different years is represented in a histogram.

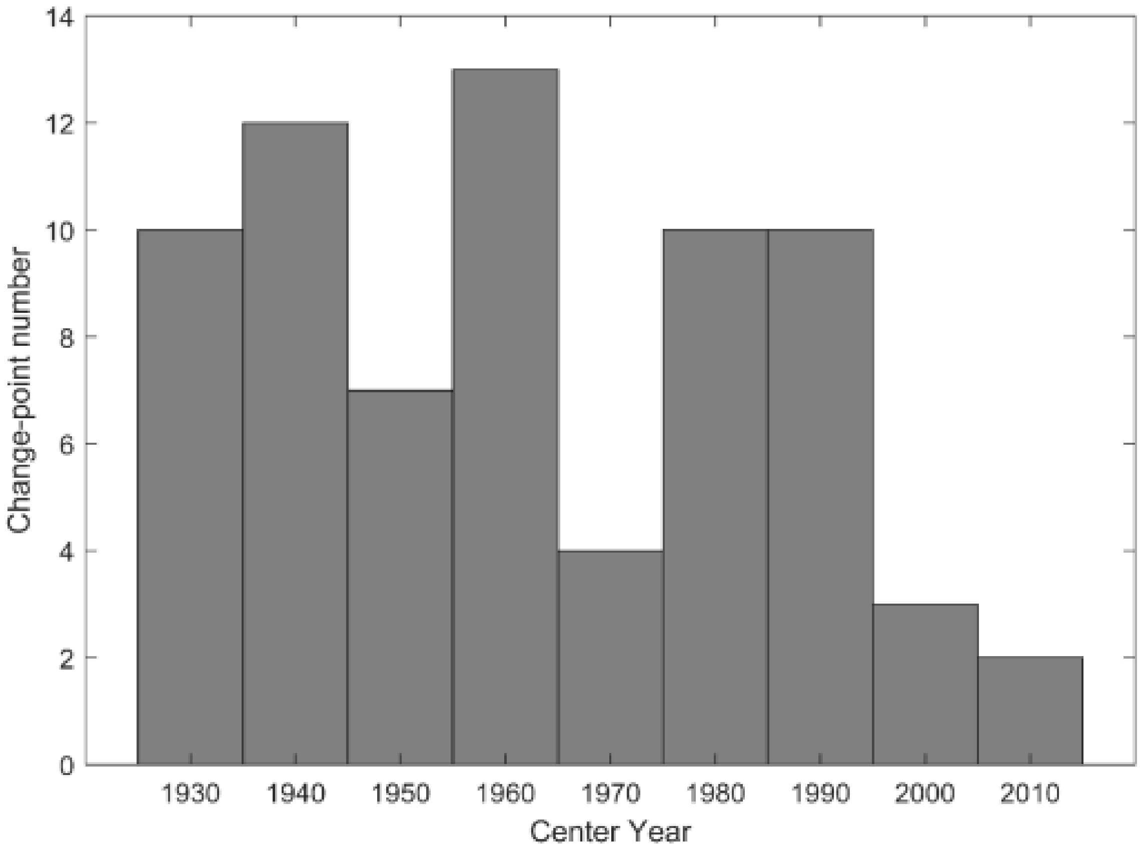


Figure 5. *Number of detected change points in each decade between 1925-2021 for all 13 stations with rescued data (Zhou et al., 2022).*

The result before and after the homogenization is shown in figure 6 for the station Bjuröklubb. Large breakpoints, which in this case where detected in the 1950, is adjust and as seen the result generate a series without sudden changes which may have been caused by several reasons.

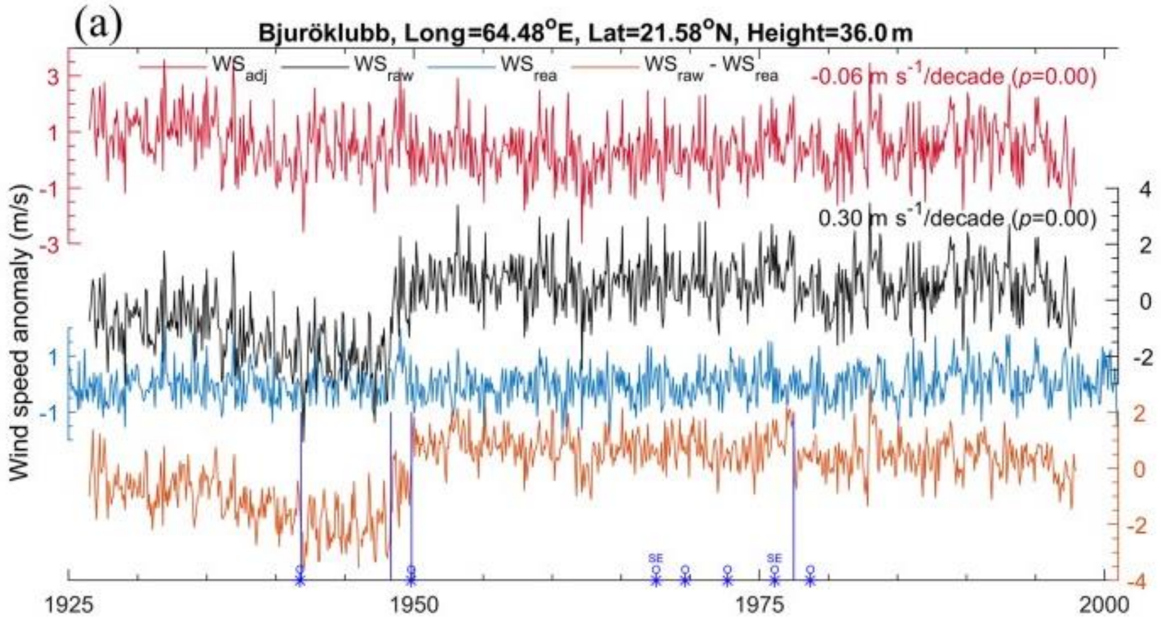


Figure 6. *Result before and after the homogenization process at the station Bjuröklubb. Raw data series (WSraw) are shown in black, reanalysis (WSrea) in blue, and and adjusted (WSadj) in red l). The orange line is the residual (raw series minus reanalysis series: WSraw–WSrea, calculated by linear regression) used for removing the natural climate variability from the raw series, which then amplifies spurious discontinuities during the homogenization (Zhou et al., 2022).*

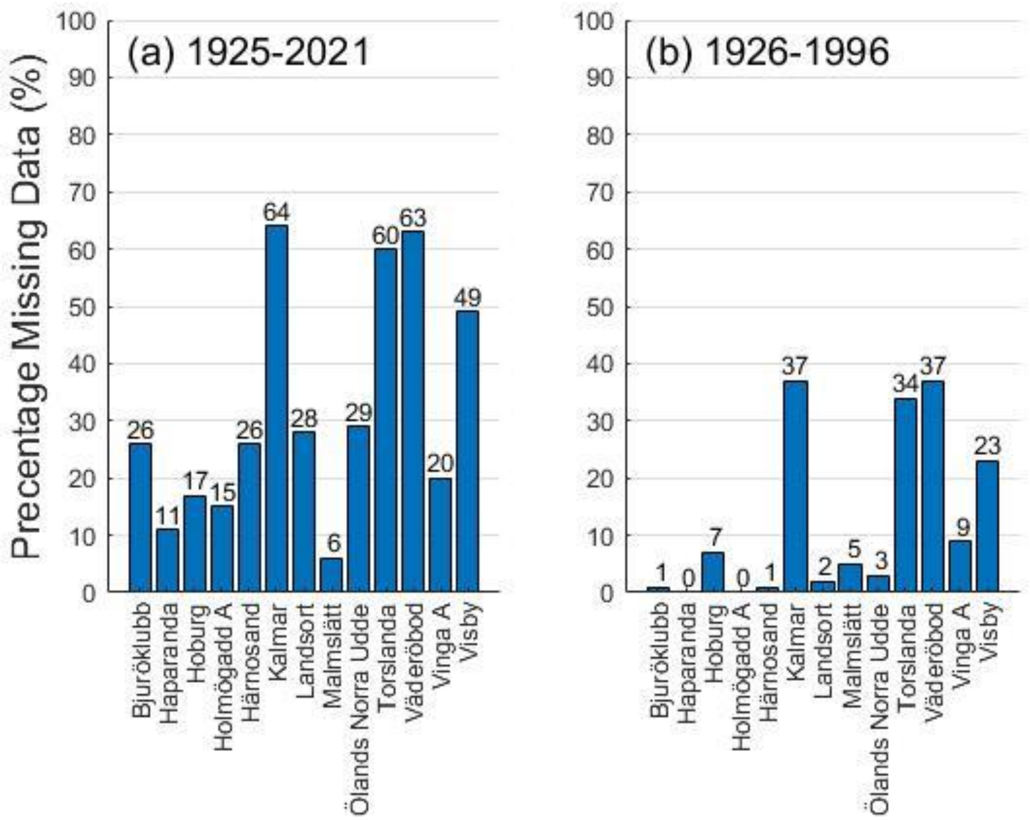
4.1.3 Wind observations for 1926-1996

Rescued and homogenized data from the 13 stations were meant to represent and cover mean wind speed in all of Sweden from 1925 up until today. However, all stations did not have the same length and availability of the data for all years and some stations had a lot of missing values. In table 2 the starting and the ending year of each stations series is shown. A lot of the stations only have data until the 90's, some even shorter, and only two stations are still active today, covering the recent years.

To avoid that only one or two stations will represent data from Sweden as a region, a shorter time period was selected when stations had a reduced amount of missing data. The longest period which measures the best with the least amount of missing data was between 1926-1996, covering a 70-year period. Figure 6 compares the percentage of missing data from 1925-2021 (a) and 1926-1996 (b) respectively.

Station	Start Year	End Year
Bjuröklubb	1926	1997
Haparanda	1925	2010
Hoburg	1926	2012
Holmögadd	1926	2008
Härnösand	1925	1996
Kalmar	1927	1996
Landsort	1926	1996
Malmslätt	1928	2021
Ölands Norra Udde	1926	1995
Torslanda	1939	1977
Väderöbod	1926	1965
Vinga A	1926	2021
Visby	1925	1986

Table 2. *Station names and the year at which the series begin and end for all the station with rescued data.*



Figur 7. *The percentage of missing monthly values in each station between 1925-2021 (a) and 1926-1996 (b).*

To have as little missing data as possible to get a better representation, a threshold was set to 5% missing data: stations still included would then have 3.5 years (42 month) of missing data at the most. Consequently, the stations Hoburg, Kalmar, Torslanda, Vinga and Väderöbod were discarded. Figure 7 shows the location of all the stations and unfortunately (because of high percentage missing data during long period of time; fig. 8) the stations at the west coast of Sweden where all discarded, thus no representation from the west coast is presented in this study.

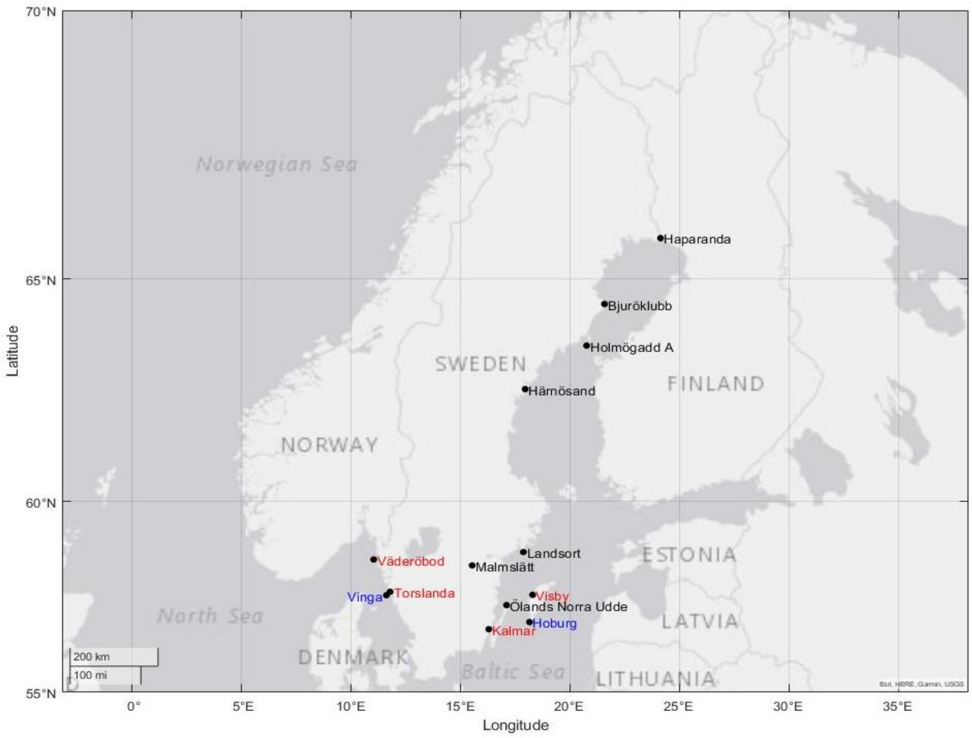


Figure 8. *Station location. Black stations has <5% missing data between 1926-1996, blue stations have <10% missing data and the red stations have >10% missing data.*

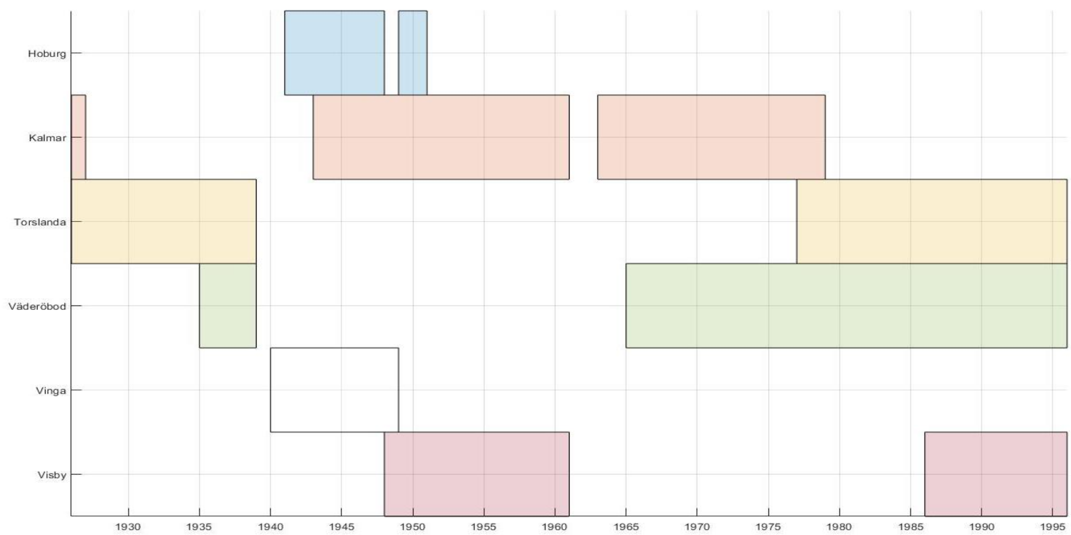


Figure 9. *Time periods for which the stations with <5% missing data had invalid data. The colored zone is where data is missing from the station.*

4.1.4 Wind observations after 1997

Because 23 years were removed due to lack of data from most stations, these years have been complemented with data from two different studies made with daily and monthly mean wind speed data in Sweden. The first dataset covers a time-period between 1956-2013 (Minola et al., 2016) and the second covers a more recent time-period between 1997-2019 (Minola et al., 2021a). These compliments are to assess if the trends follow the same pattern and will only be used to analyze a longer time period and will not be a part of the correlation analysis.

To make an accurate analysis with common data, the nearest stations from the study of Minola et al. (2016) and of Minola et al. (2021a) were used in place of the stations from the period 1926-1996. Table 3 summarizes the stations used for each period and figure 9 shows the location of the supplement stations. Holmögadd lacked a nearby station in the period 1956-2013 (Minola et al., 2016) and this period thus only have seven stations representing the regional mean. But since Holmögadd lays between two other stations used in the study, no radical loss was made in means of regional representation.

Station 1926–1996	Station 1956–2013 (Minola et al., 2016)	Station 1997–2019 (Minola et al., 2021a)
Bjuröklubb	Bjuröklubb	Bjuröklubb
Haparanda	Haparanda	Storön A
Holmögadd A	-	Järnäsklubb
Landsort	Stockholm/Bromma	Landsort
Härnösand	Sundsvalls Flygplats	Lungö
Malmslätt	Malmslätt	Malexander A
Ölands Norra Udde	Ölands Norra Udde	Ölands Norra Udde

Table 3. *Stations used for replacement (nearest station) during the time period 1956-2013 (Minola et al., 2016) and 1997-2019 (Minola et al., 2021a).*

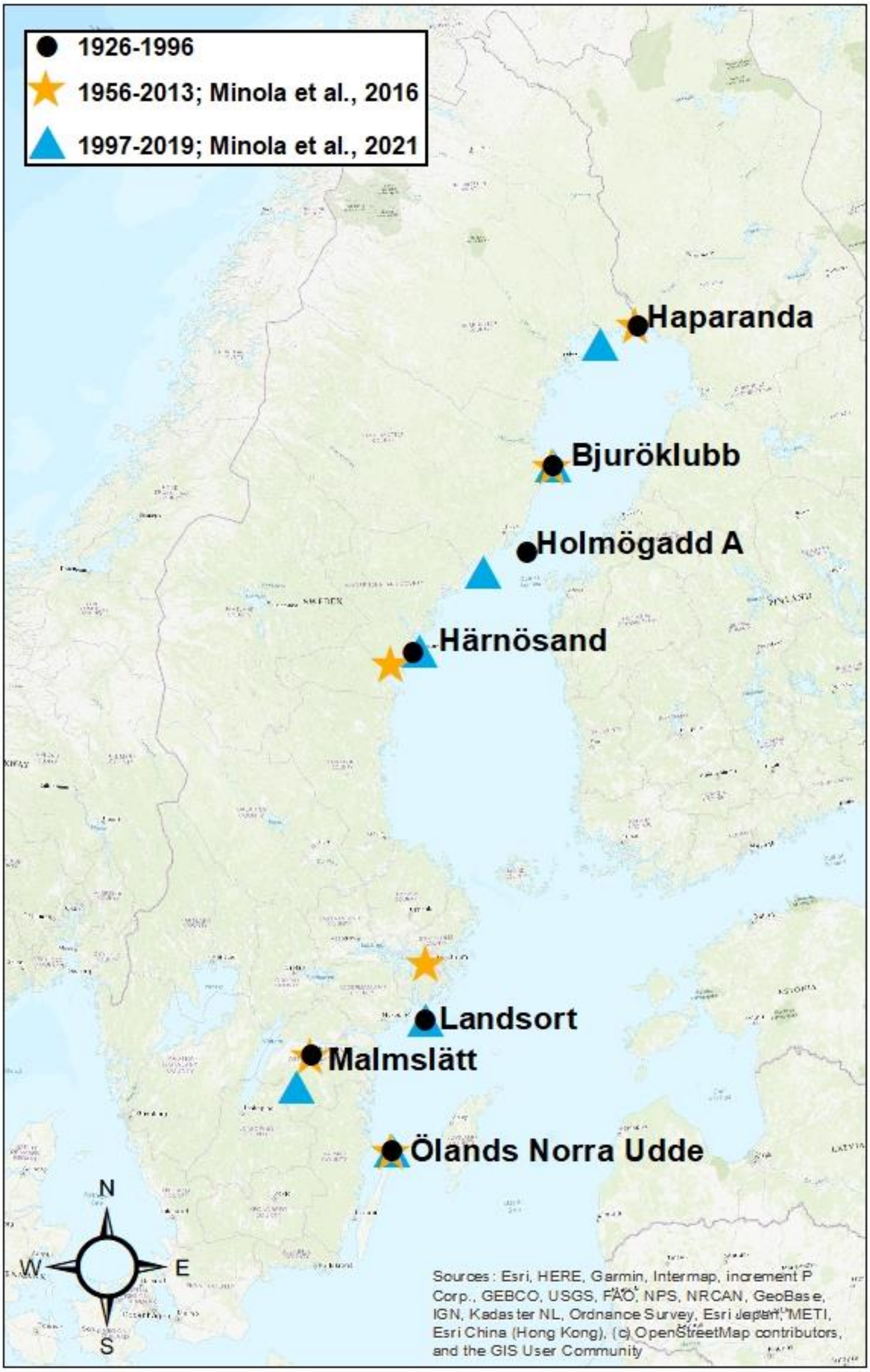


Figure 10. *Geographic location of the stations from this study (black dot) and the nearby stations from Minola et al., 2016 (yellow star) and Minola et al., 2021a (blue triangle) used to extend the timeline.*

4.1.5 Indexes of teleconnection patterns

All pressure data, which represent the teleconnection patterns, is obtained as indexes which present the pressure differences (indexes described in section 4).

NAO series was obtained via the Climate Research Unit homepage (available online at https://crudata.uea.ac.uk/cru/data/nao/index.htm; last accessed 9 March 2022) as monthly indices. Data was available from 1891 up until today but only the years used for the main wind speed series (1926-1997) were extracted and used in the correlation analysis. When comparing against the extended series (fig 24), the years between 1997-2019 was also treated. The published series is mainly based on Jones and Wheelers (1998) extended, homogenized series with instrumental sea level pressure measurements from Gibraltar, Spain and Reykjavik, Iceland (fig. 10). These station locations are based close to where the pressure centers of the NAO are located in the winter and differs from some NAO series which handles data from the station based on Ponta Delgada, Azores (Cropper et al., 2015) or Lisbon, Portugal (Hurell, 1995).

Figure 11. *Station location for the two stations used to measure low-pressure center (Reykavik, Iceland; L) and high-pressure center (Gibraltar, Spain; H) for construction of the NAO index.*

AO series was obtained from the Cooperative Institution for Climate, Ocean & Ecosystem Studies (available online at http://research.jisao.washington.edu/ao/#monthly; last accessed 9 March 2022). The index is projected from SLP anomalies provided from Trenberth & Paolino Jr (1980) up until 1957 and from NCEP/NCAR Reanalysis from 1958 and onwards, both are defined as sea level pressure poleward of 20N°

Both the SCA and the EA series were obtained from Data Published for Earth and Environmental Science (avalible online at: https://doi.pangaea.de/10.1594/PANGAEA.892768?format=html#download; last accessed 9 March, 2022) from Comas-Bru & Hernandez (2018) reconstructed series. Since instrumental indices data is only available from 1950 for these two modes of variability, Comas-Bru & Hernandez used sea level pressure from Valentia, Ireland and Bergen, Norway to reconstruct EA and SCA respectively using five different reanalysis datasets (ERA-40, ERA-Interim, ERA-20C, 20CRv2c and NCEP/NCAR) in an Empirical orthogonal function (EOF) analysis. The data was sorted by season and reconstructed to monthly indices. All data is summarized in table 4.

Weather Pattern	Available Years	Method	Reference
NAO	1891-2022	Observation Data	Jones et al., 1997
AO	1899-2002	Reanalysis (NCEP/NCAR)	Thompson et al., 1998 Hodge, 2000
SCA	1925-2016	Reanalysis (EOF)	Comas-Bru & Hernández, 2018
EA	1851-2016	Reanalysis (EOF)	Comas-Bru & Hernández, 2018

Table 4. *Summary of the data for teleconnection patterns used in this study.*

4.2 Trend analysis

Regional wind speed series were obtained by calculating the average wind speed of all the 7 stations each month, all series were then converted into annual mean wind speed series to reduce the noise from the annual variation. Seasonal wind speed series were calculated into annual average using the original, homogenized, monthly wind speed series. The seasons used are: March-April-May (Spring), June-July-August (Summer), September-October-November (Fall) and December-January-February (Winter). Following Azorin-Molina et al., 2014, all series were calculated as anomalies relative to each series 1926-1996 mean and are represented as deviations in m s^{-1} relative to the mean. This was done to avoid that more windy series would dominate the regional series. A new regional wind speed series was calculated for the 1956-2013 and for the 1997-2019 series using only the nearby-stations from this study. These series were also calculated as annual and seasonal wind speed series.

The trends have been calculated using a regression analysis where the relationship between the date and the wind speed series has been examined and is expressed as m s^{-1} $decade^{-1}$. This was done by applying Mann-Kendall Tau with Sen's method, as suggested by Burkey (2006). In MatLab, the function is available online at http://www.mathworks.com/matlabcentral/fileexchange/authors/23983; (last accessed 2022-03-10). Sen's slope were developed to better fit data that does not follow a linear trend and which is also less sensitive to outliers (Sen, 1968). Sen's slope is defined as followed, where x_i and x_j are the data at time i and j, for when j is bigger than i:

$$Sen's\ Slope = Median\left\{\frac{x_j - x_i}{j - i}\right\} : i < j$$

The statistical significance was calculated using a modified Mann-Kendall test at 3 different significances: significant at < 0.05, significant at < 0.1 and non-significant at > 0.1. This has been done previously in wind studies to not exclude significant wind speed trends by only looking at one statistical significance level (Azorin-Molina et el., 2015; Lorenzo et al., 2016). The modification was developed by Hamed and Rao (1998) from the original Mann-Kendall test (Mann, 1945; Kendall, 1975, Gilbert; 1987) and is available online at: https://www.mathworks.com/matlabcentral/fileexchange/25533-mann-kendall-modified-test (last accessed 2022-03-10).

4.3 Correlation Analysis

Correlation between wind speed series and atmospheric circulation series was calculated using the *corr* function in MatLab which determines the linear correlation between two variables. Pearson's correlation was used as a coefficient and is defined as followed, where n is the length of each column:

$$rho(a,b) = \frac{\sum_{i=1}^{n}\left(X_{a,i} - \overline{X_a}\right)\left(Y_{b,i} - \overline{Y_b}\right)}{\left\{\sum_{i=1}^{n}\left(X_{a,i} - \overline{X_a}\right)^2 \sum_{j=1}^{n}\left(Y_{b,j} - \overline{Y_b}\right)^2\right\}^{1/2'}}$$

This returns two values: the correlation coefficient (r) and the statistical significance (p). The coefficient of determination (R^2) has been calculated separately as the correlation coefficient in a square.

5. Results

5.1 Seasonal Cycle

The regional seasonal cycle reports higher wind speed during fall and winter and lower during spring and winter. The lowest average wind speed is experienced in July (4.53 m s^{-1}) and highest in December (5.94 m s^{-1}), which has a difference of 1.41 m s^{-1} between the two seasons. In figure 12 we can see the average monthly variation for the regional series.

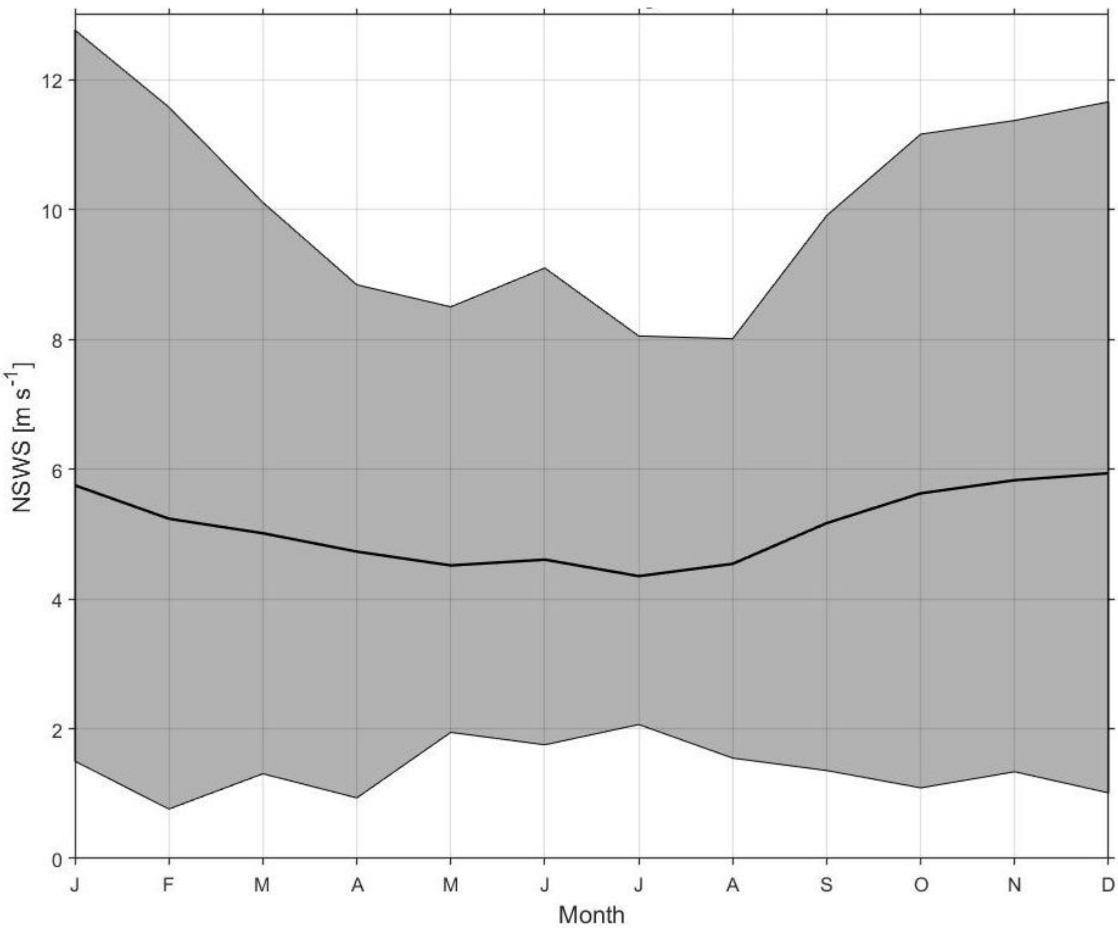


Figure 12. *Mean regional (i.e., average of all stations across Sweden) seasonal cycle of wind speed for during the period 1926-1996. The shaded grey area is the range of minimum and maximum wind speed values each month.*

Figure 13 shows the seasonal cycle for each station. Most of the stations experience common cycle but some have next to no variation month to month. Härnösand is the only station which has opposite seasonal cycle compared with the regional average, with highest wind speed during summer and lowest during winter. Holmögadd is the station which experiences most variation in wind speed from month to month. Haparanda and Malmslätt experience almost no variation between seasons.

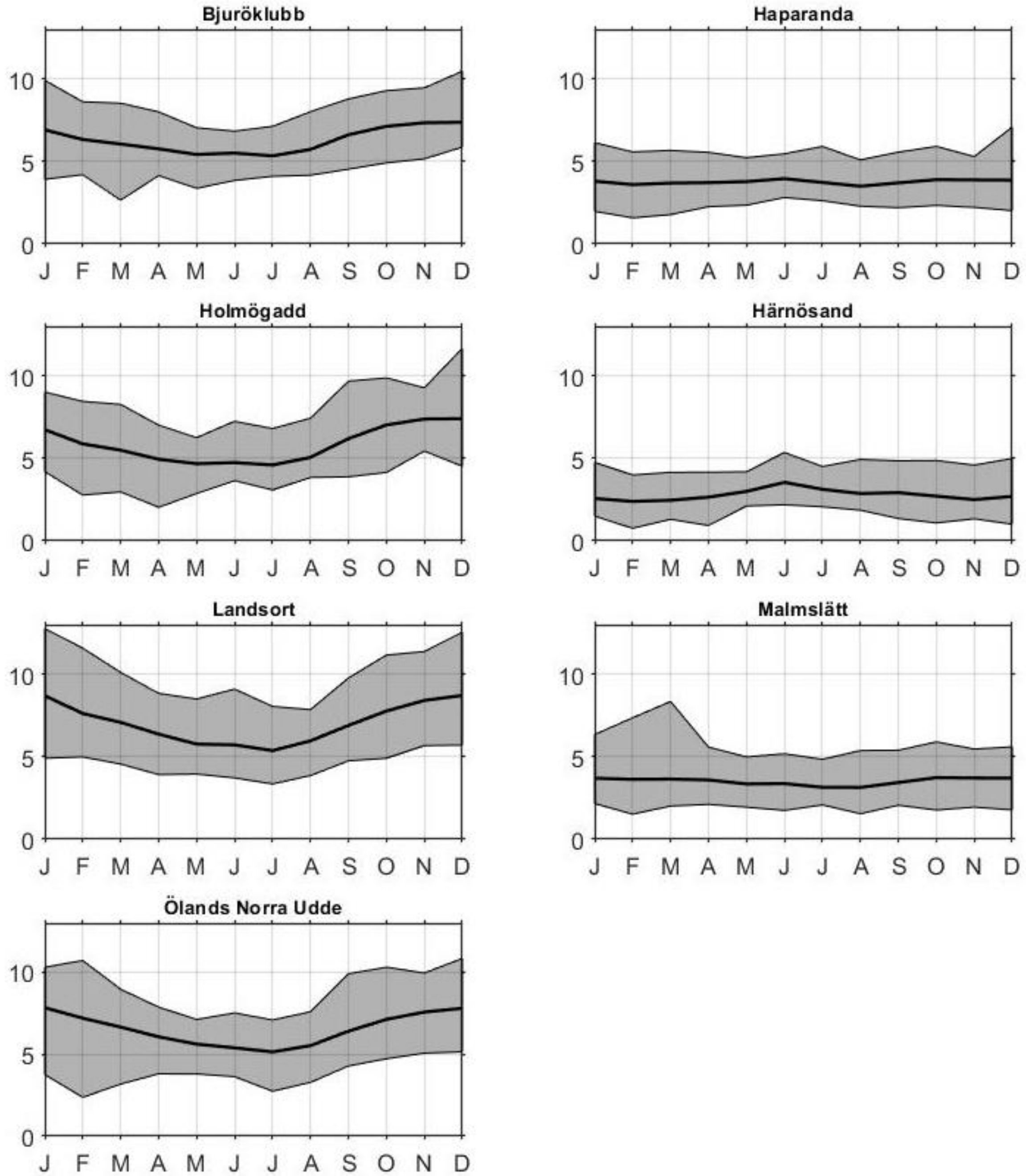


Figure 13. *Seasonal cycle of wind speed for each station during the period 1926-1996. The shaded grey area is the range of minimum and maximum values each month for that station.*

5.2 Annual wind speed trends

Homogenized wind speed series from 7 stations across Sweden have been used to examined NSWS trends for the whole region. Figure 14 shows the regional anomaly annual series for the whole period between 1926-1996, with an applied Gaussian-weighted average filter to reduce the interannual noise. There has been an overall slowdown in NSWS for the whole period 1926-1996, and the decadal trend has found to be -0.11 m s^{-1} $decades^{-1}$ (statistically significant at $p < 0.05$). From 1926-1940 the first stilling period is revealed and can be seen in figure 14, this is followed by a small stabilization between 1940-1945. The period 1945-1960 experienced a long stilling period (-0.27m s^{-1} $decades^{-1}$, significant at $p < 0.05$) followed by a long period of stabilization until 1990. The series end in a new stilling starting 1990. Table 5 reports the trends and the statistical significance for these sub-periods to strengthen the trends seen in figure 14.

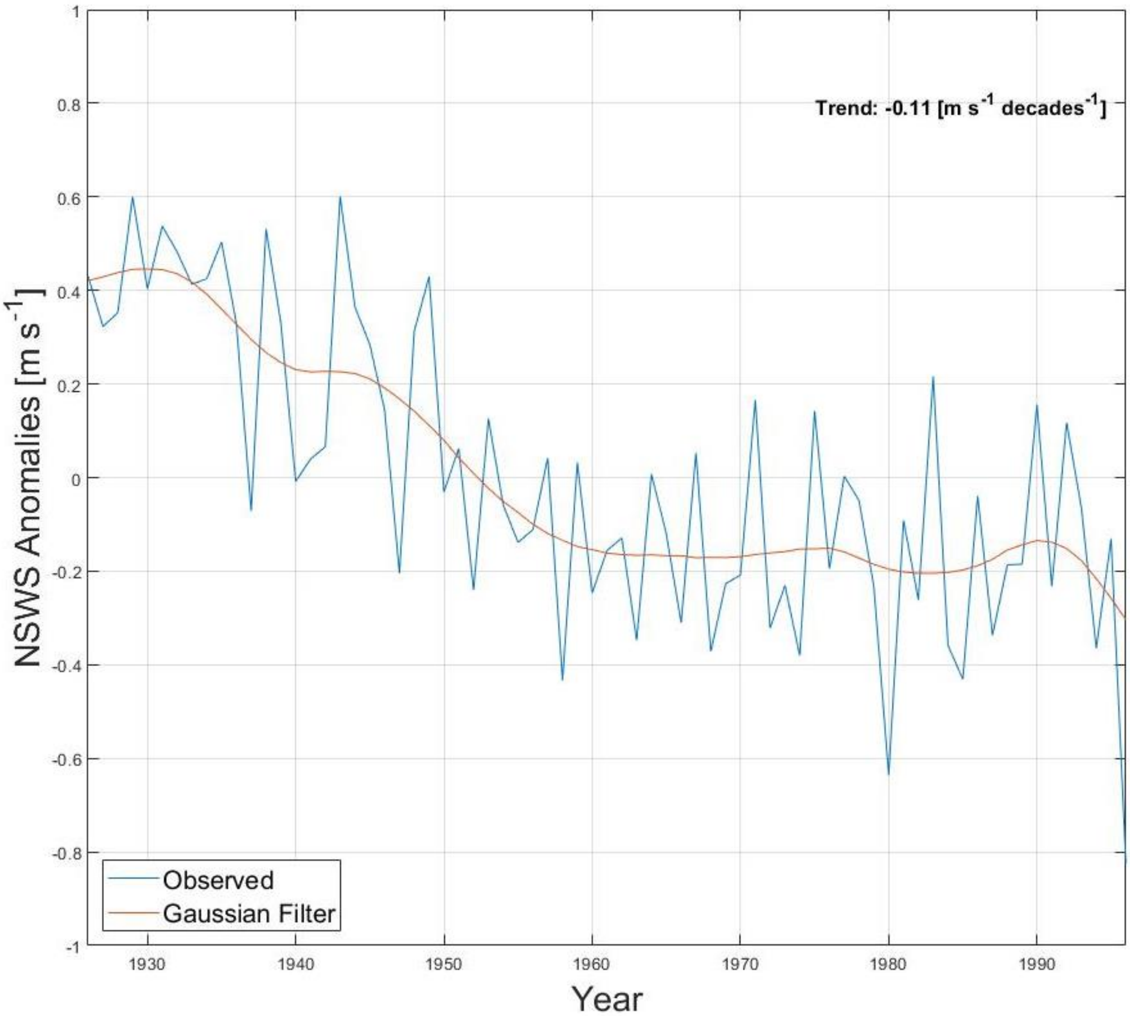


Figure 14. *Series of mean (i.e., average of all stations across Sweden) annual wind speed anomaly (blue line) during 1926-1996. The low-frequency variability is with the applied Gaussian-weighted average filter (15-year window; red line). Wind speed anomalies are relative to the regional mean for the same period. The reported 1926-1996 trend -0.11 m* s^{-1} *$decades^{-1}$ is statistically significant at* $p < 0.05$.

PERIOD	1926-1996	1926-1945	1945-1960	1960-1990	1990-1996
ANNUAL	**-0.11**	*-0.08*	**-0.27**	*+0.01*	-1.19

Table 5. *Annual and seasonal trends, expressed as m s^{-1} $decades^{-1}$ for the whole period, and 4 subperiods. Statistical significance at $p < 0.05$ is showed in bold, significance at $p < 0.1$ is showed as normal font and non-significant trends at $p > 0.1$ is showed in cursive.*

Figure 15 displays trends for different time windows during the whole period 1926-1996. Mainly decreasing trends are reported but for several shorter time-windows in the later years there is a positive trend. The 30-year period between 1960-1990 shows, just as table 5, a small positive trend, while the 19-years period between 1926-1945 shows a large negative trend.

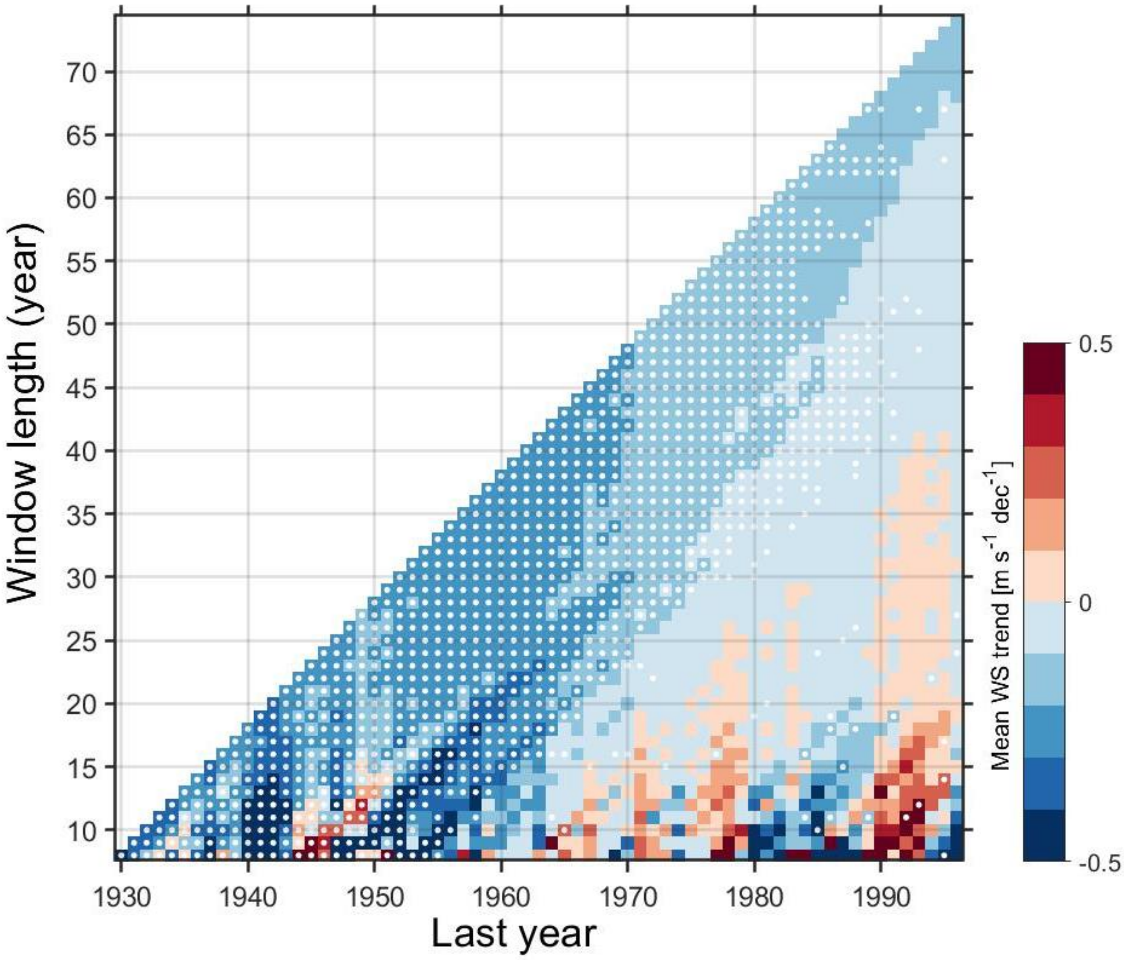


Figure 15. *Running trends of mean (i.e., average of all stations across Sweden) annual wind speed anomaly during 1926-1996. Statistical significance (at $p < 0.1$) is represented with a with circle for each time period.*

To extend the series, datasets from Minola et al. (2016) and Minola et al. (2021a), were added to evaluate the trends following the 1926-1996 period. Figure 16 shows the series for the period 1926-1996, series for the period 1956-2013 (Minola et al., 2016) and series for the period 1997-2019 (Minola et al., 2021a). As seen in figure 16, the 1926-1996 series and the 1956-2013 series go along each other very well between the common period 1956-1996: Pearson's correlation coefficient show a high value of 0.85 (statistically significant at $p < 0.05$) for the common period. The 1956-2013 and 1997-2019 series also show a high correlation of 0.72 (statistically significant at $p < 0.05$) between the common period 1997-2013. These high correlation values are an indication that the series are a good supplement for extending the timeline. As expected, the stilling from 1990 continues up until 2005 and is then followed by a reversal. A start of a small stilling trend can also be seen at the end in the 1997-2019 series. Table 6 reports the trends and the statistically significance for each of the series, both annually and seasonally and the reported trend from the three series show an overall negative annual trend of -0.11 m s^{-1} $decades^{-1}$ (1926-1997), -0.12 m s^{-1} $decades^{-1}$ (1956-2013) and -0.09 m s^{-1} $decades^{-1}$ (1997-2019), all statistically significant at $p < 0.05$.

As for the stations, they present a variety of trends, from an overall positive trend of +0.05 (not significant at $p > 0.1$) at Malmslätt to a negative trend of -0.21 in Landsort (significant at $p < 0.05$) and Öland (not significant at $p > 0.1$). Figure 17a-g shows the series for each station and figure 22a present a visualization of the magnitude of the trends and its significance for each station. The largest negative trends are experienced at the southeastern coast while the only positive trend is found at the only inland station. Malmslätt only reports positive trends for the recent decades (fig. 17f), while Landsort reports an opposite, negative, trend during the recent decades. Öland is the station showing most interannual variation (fig 17g), while Härnösand displays a small interannual variation (fig 17d). Figure 18 introduces the extended series for each station and as seen, some stations correlate better than others. In table 7, the correlation with the series from 1956-2013 and the correlation between the 1956-2013 and 1997-2019 series are presented. Landsort reveals the lowest correlation of 0,03 (not significant at $p > 0.1$) for the period 1956-1996, and Öland the lowest correlation of 0,16 (not significant at $p > 0.1$) for 1997-2013. Bjuröklubb has both the highest correlation of 0,83 (significant at $p < 0.5$) for the period of 1956-1997 and 0,67 (significant at $p < 0.5$) for the period 1997-2013.

Figure 19 shows the regional series highlighted, together with the station series as background noise to analyze the variation between stations. The stations show a relative similar pattern between 1940-1960. The early years show a wider variety between stations, as do the years from 1960 and onwards.

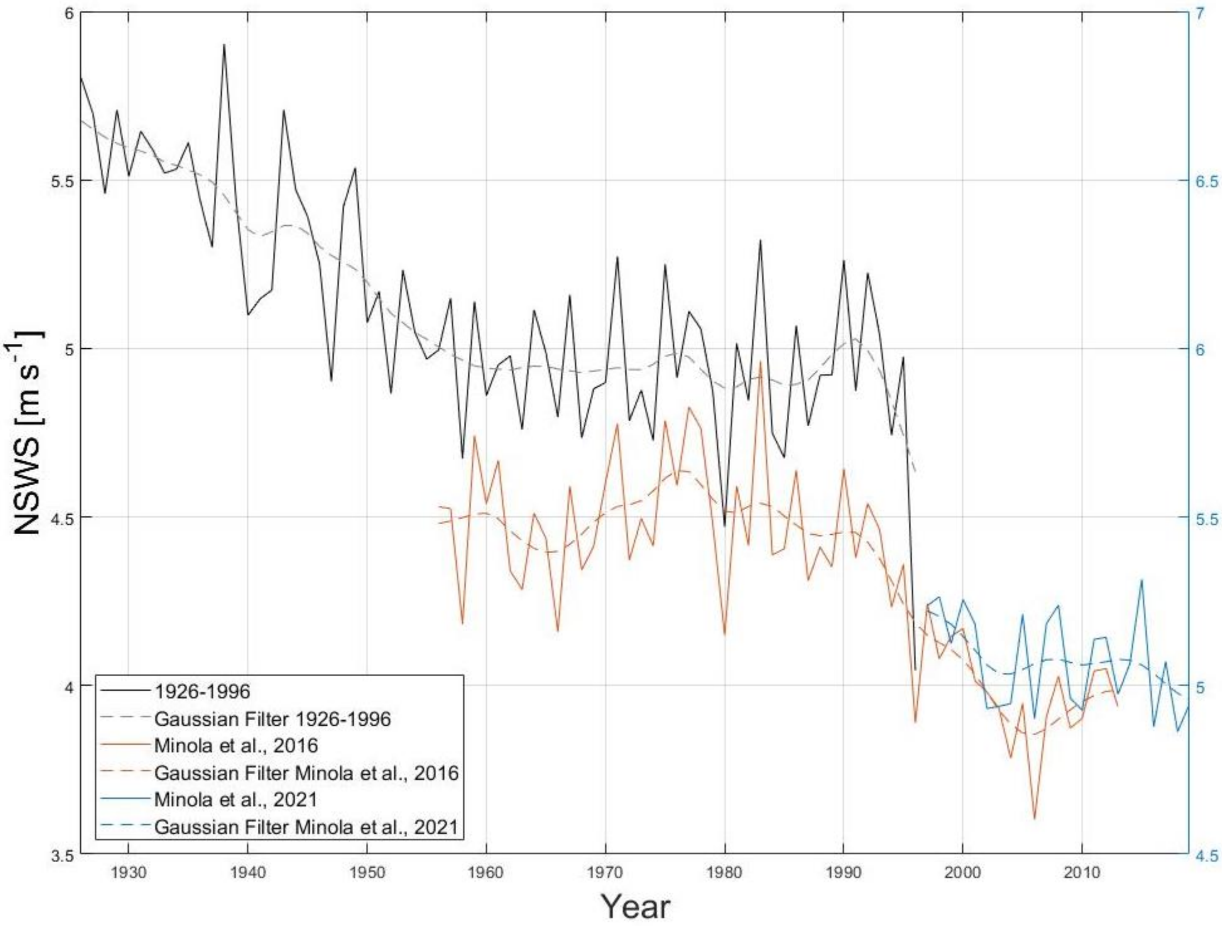


Figure 16. *Series of mean annual wind speed during 1926-1996 (black line), during 1956-2013 (Minola et al. 2016; orange line) and 1997-2019 (Minola et al. 2021a; blue line). The low-filter variability is shown with the dashed lines of the applied Gaussian-weighted average filter (15-year window).*

PERIOD	1926-1996	1956-2013	1997-2019
ANNUAL	**-0.11**	**-0.12**	**-0.09**
SPRING	**-0.07**	**-0.12**	*-0.05*
SUMMER	**-0.11**	**-0.16**	*-0.02*
FALL	**-0.12**	**-0.16**	*-0.14*
WINTER	-0.07	*-0.07*	*-0.04*

Table 6. *Annual and seasonal trends, expressed as m s^{-1} $decades^{-1}$ for the period from 1926-1996 from this study, 1956-2013 from the study Minola et al. (2016), and 1997-2019 from the study Minola et al. (2019). Statistical significance at $p < 0.05$ is showed in bold, significance at $p < 0.1$ is showed as normal font and non-significant correlations at $p > 0.1$ is showed in cursive.*

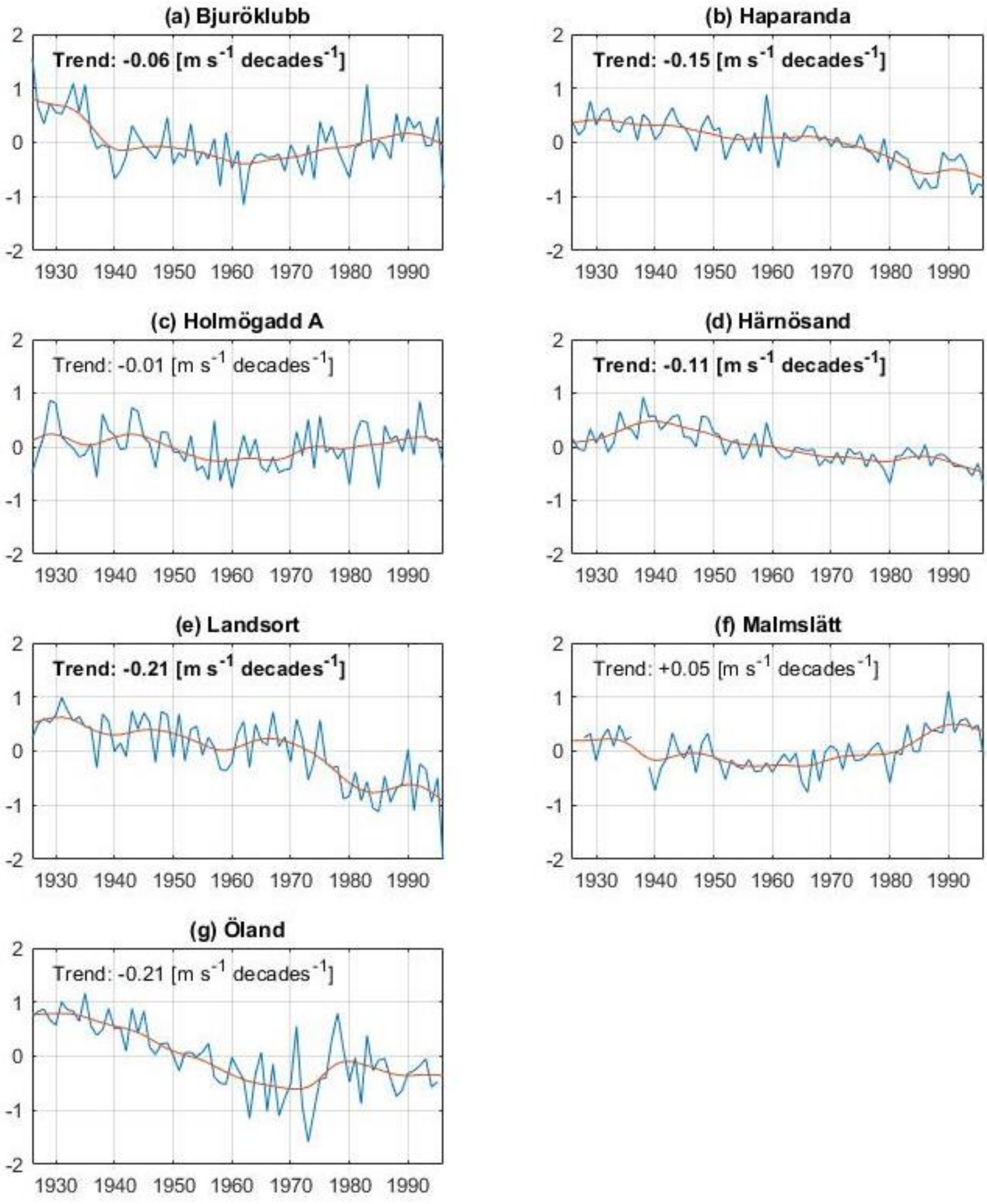


Figure 17. *Series of annual wind speed anomalies (blue line) during 1926-1996 for all the 7 stations used in this study. The low frequency variability is with the applied Gaussian-weighted average filter (15-year window; red line). Wind speed anomalies are calculated relative to the station mean for the 1926-1996 period. Trends are represented in bold for statistically significant at $p < 0.05$ and normal for non-statistically significant at $p > 0.1$, none of the stations reported a statistically significance at $p < 0.1$.*

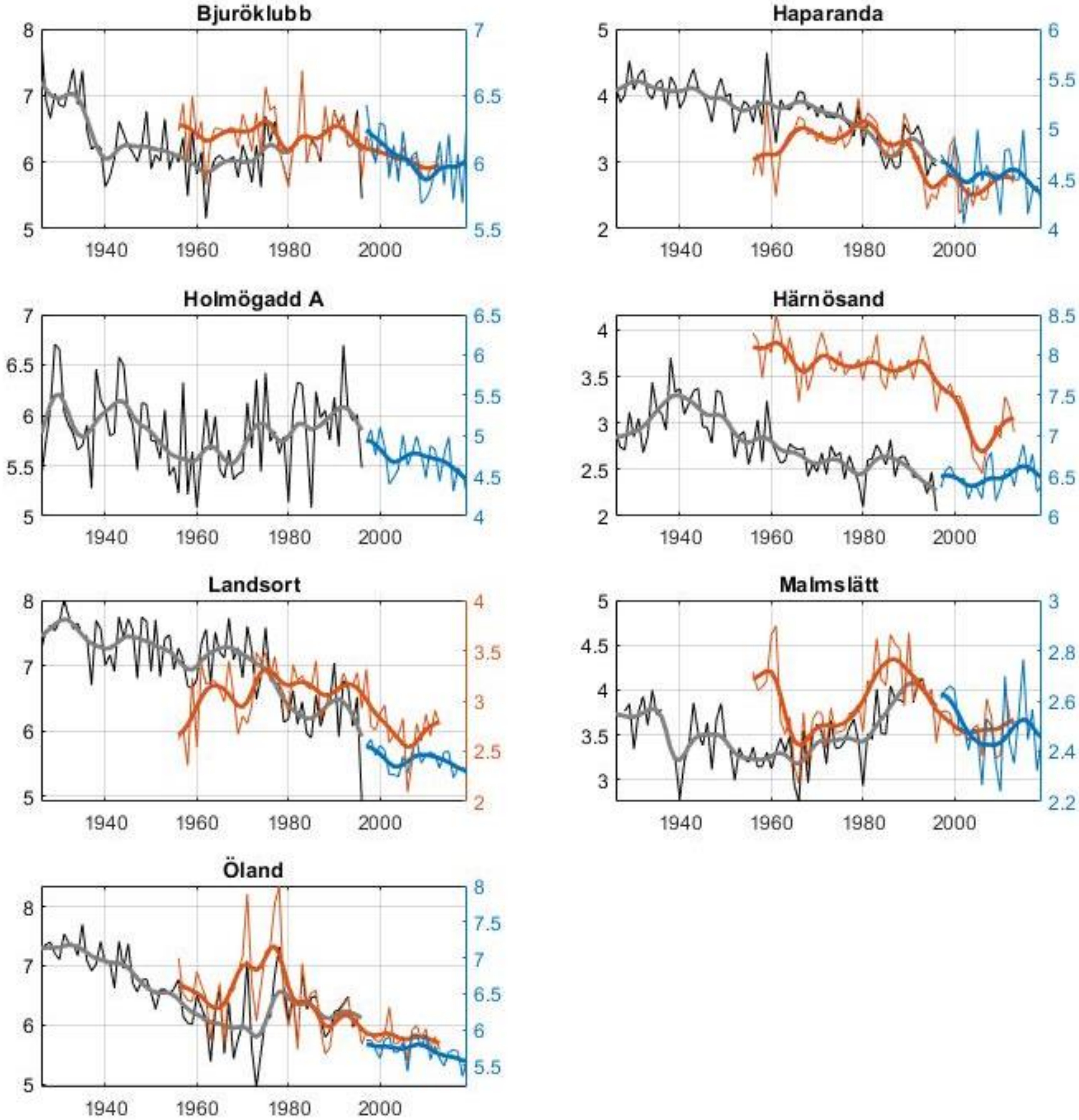


Figure 18. *Series of mean annual wind speed during 1926-1996 (black line), during 1956-2013 (Minola et al. 2016; orange line) and 1997-2019 (Minola et al. 2021a; blue line) for all stations used in this study. The low-filter variability is shown with the dashed lines of the applied Gaussian-weighted average filter (15-year window).*

	1956-1997	1997-2013
REGIONAL	**0,85**	**0,72**
BJURÖKLUBB	**0,83**	**0,67**
HAPARANDA	***0,61***	*0,33*
HOLMÖGADD	**-**	**-**
HÄRNÖSAND	**0,43**	*0,40*
LANDSORT	*0,03*	**0,50**
MALMSLÄTT	**0,59**	**0,63**
ÖLAND	**0,65**	*0,16*

Table 7. *Annual Pearson's correlation coefficient between the two wind speed series 1926-1996 and 1956-2013 for the common period 1956-1997 and correlation between 1956-2013 and 1997-2019 series for the common period 1997-2013. Statistical significance at $p < 0.05$ is showed in bold, non-significant correlations at $p > 0.1$ is showed in cursive, no station shows a significance at $p < 0.1$.*

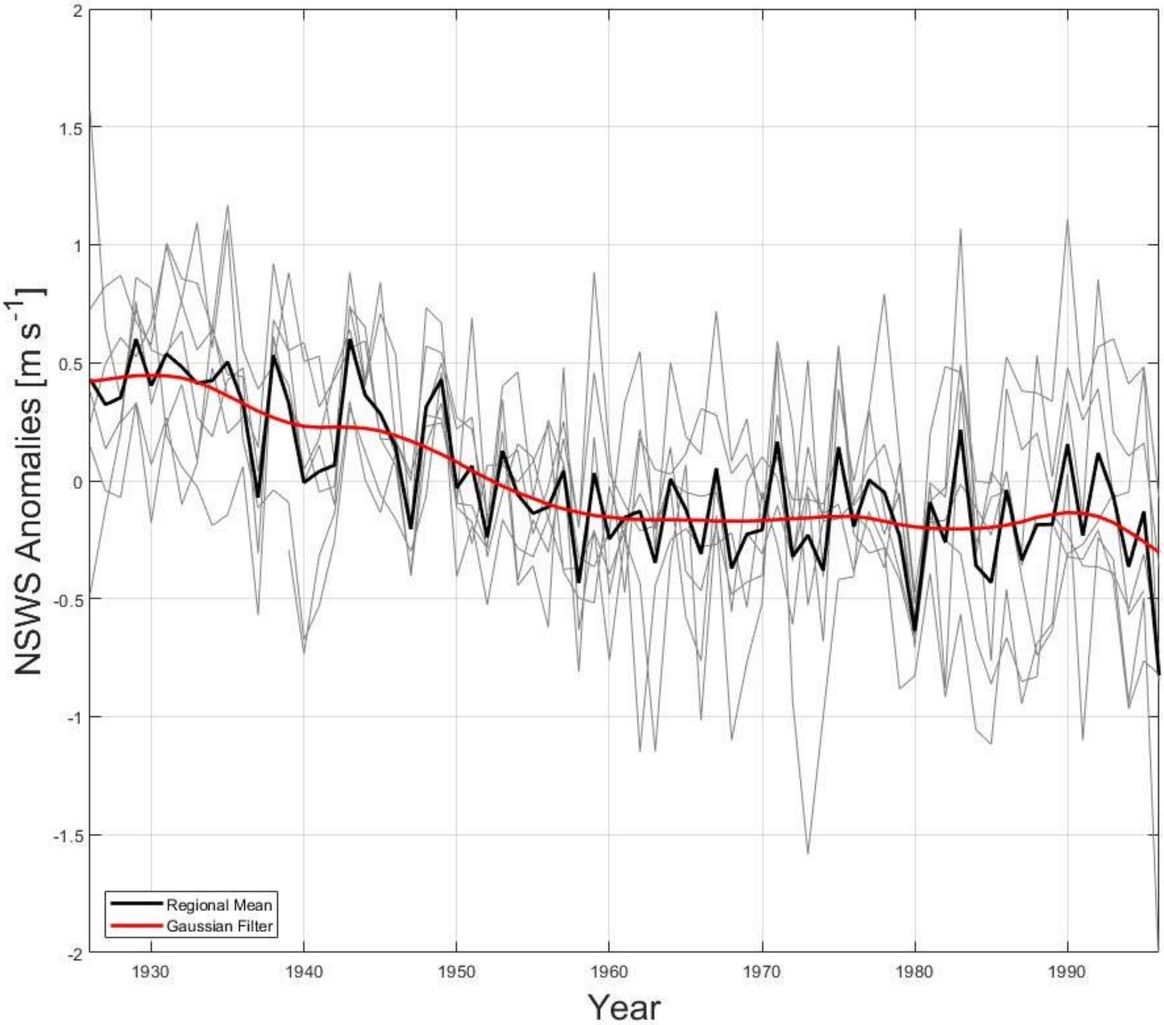


Figure 19. *Series of regional mean (i.e., average of all stations across Sweden) annual wind speed anomaly (black line) during 1926-1996. The low-frequency variability is with the applied Gaussian-weighted average filter (15-year window; red line). Series of wind speed anomalies for each station are also shown as grey lines. The wind speed anomaly of each station is calculated relative to the station 1926-1996 mean.*

5.3 Seasonal trends

The seasonal trends of the NSWS anomaly series and their significance are reported in table 8 for all stations. All seasons show a statistically significant trend (at $p < 0.1$). When looking at individual stations, spring is the season which experiences least statistically significant trends (only for Haparanda and Härnösand) while winter is the season with most statistically significant trends (for the stations Haparanda, Holmögadd, Härnösand and Landsort). The largest regional trend is experienced during fall, with a decreasing trend of -0.12 m s^{-1} $decade^{-1}$ (statistically significant at $p < 0.05$). The strongest negative trend (statistically significant at $p < 0.05$) is experienced in spring at Haparanda (-0.21 m s^{-1} decade-[1]). No statistically significant positive trend is reported. Only Malmslätt and Öland experience zero statistically significant trend in neither of the seasons and only Haparanda experienced statistically significant trends in all seasons. Malmslätt is the only stations which report positive trends in all four seasons.

Figure 20 shows the interannual variations for the regional mean for each of the seasons. Winter is the season with the largest interannual variation while summer has the smallest interannual variation. For summer, no distinctive period of increasing wind speed can be seen. Both spring and fall show a period of increasing wind speed after 1960, while winter shows the same trend a few years later. In spring it also appears a period of increasing wind speed in the 40's, and for winter for both the early and the recent years. As for the annual, each season's series has been extended using Minola et al. (2016) and Minola et al. (2021a), which is shown in figure 21. As expected, all seasons experience a downward trend post 1996 and like the annual trend, a small reversal in the mid 00's.

Figure 22 visualizes the magnitude of the trends for each station in each season and the significant trends are all experienced in the northern stations, while the strongest (both positive and negative; not statistically significant at $p > 0.1$) trends are experienced at the southeast stations in all seasons. The northernmost station (Haparanda) also experiences some of the strongest negative trends, especially in spring. The only inland station (Malmslätt) experiences the weakest (positive) trend which is also not statistically significant at $p > 0.1$. It is also clear that spring experience most positive trends, although not that strong.

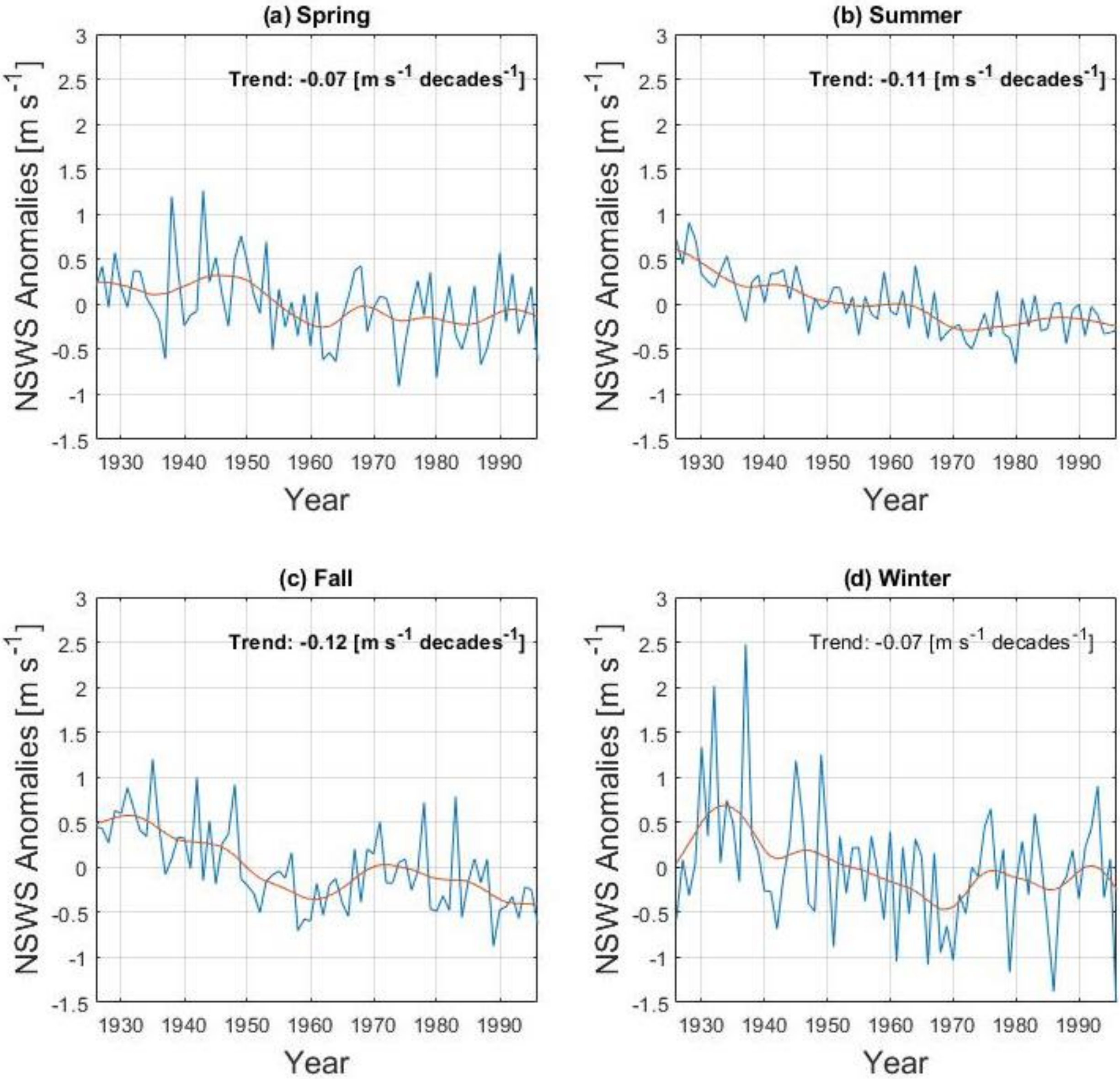


Figure 20. *Series of mean (i.e., average of all stations across Sweden) annual wind speed anomaly (blue line) during 1926-1996 for the seasons Spring (March, April, May (a)), Summer (June, July, August (b)), Fall (September, October, November(c)) and Winter (December, January, February (d)). The low-frequency variability is with the applied Gaussian-weighted average filter (15-year window; red line). Wind speed anomalies are relative to the regional mean for each season. The 1926-1996 trend is reported in bold font if statistically significant at $p < 0.05$ and normal font if statistically significant at $p < 0.1$.*

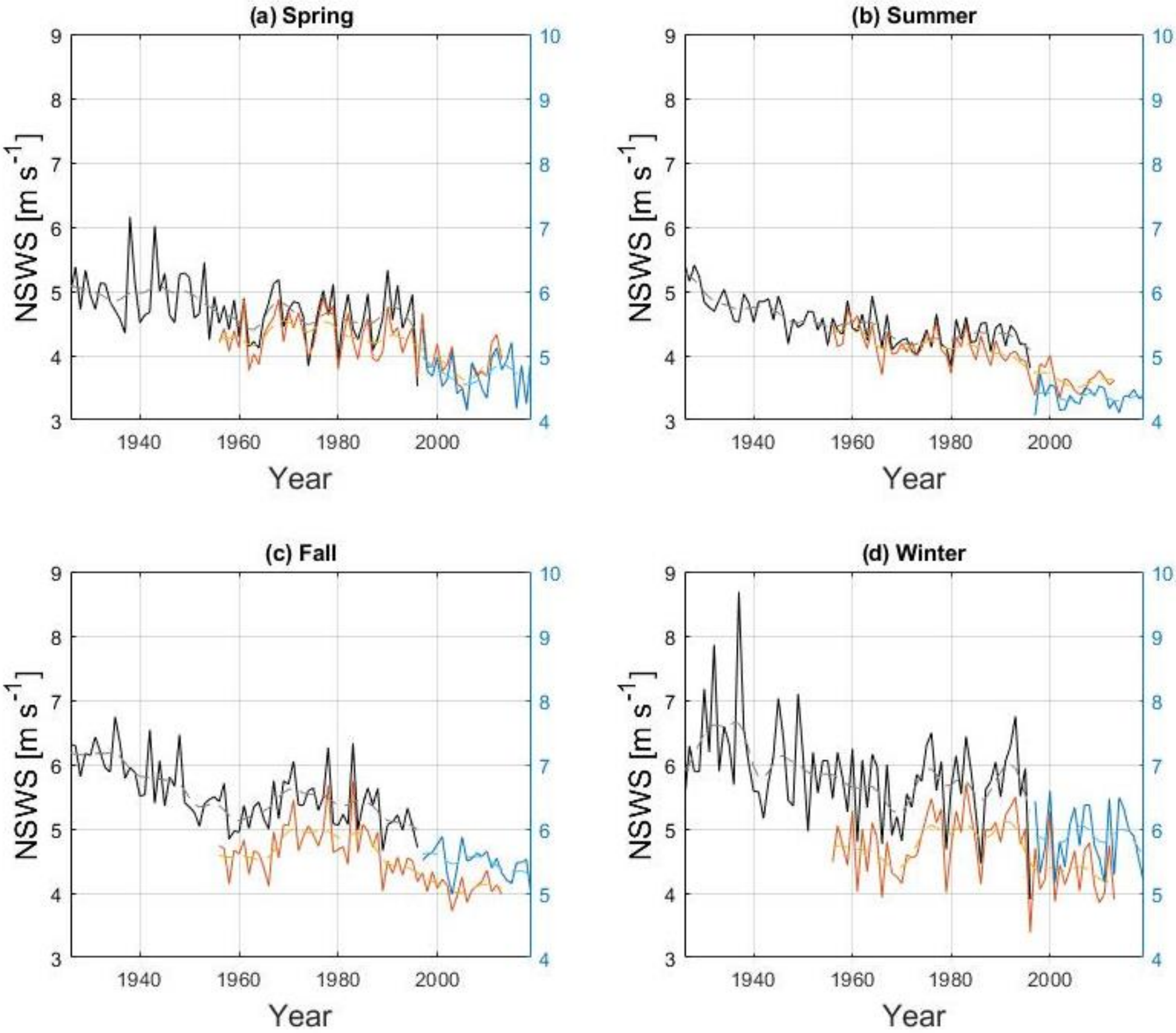


Figure 21. *Series of mean annual wind speed during 1926-1996 (black line), during 1956-2013 (Minola et al. 2016; orange line) and 1997-2019 (Minola et al. 2021a; blue line) for the seasons Spring (March, April, May (a)), Summer (June, July, August (b)), Fall (September, October, November(c)) and Winter (December, January, February (d)). The low-filter variability is shown with the dashed lines of the applied Gaussian-weighted average filter (15-year window).*

	ANNUAL	SPRING	SUMMER	FALL	WINTER
REGIONAL	**-0.11**	**-0.07**	**-0.11**	**-0.12**	-0.07
BJURÖKLUBB	**-0.06**	*0.01*	**-0.10**	**-0.14**	*-0.04*
HAPARANDA	**-0.15**	**-0.21**	**-0.07**	**-0.16**	**-0.17**
HOLMÖGADD	*-0.01*	*0.05*	*0.00*	**-0.10**	**0.01**
HÄRNÖSAND	**-0.11**	**-0.09**	**-0.12**	*-0.10*	**-0.11**
LANDSORT	**-0.21**	*-0.14*	*-0.24*	*-0.22*	**-0.16**
MALMSLÄTT	*0.05*	*0.06*	*0.02*	*0.05*	*0.15*
ÖLAND	*-0.21*	*-0.15*	*-0.18*	*-0.20*	*-0.20*

Table 8. *Trends for each station, and the regional, for each season and annual series. The trend is expressed as m s^{-1} $decade^{-1}$. The bold numbers have a significance of $p < 0.05$, normal font have a significance of $p < 0.1$, and cursive font is non-significant at $p > 0.1$.*

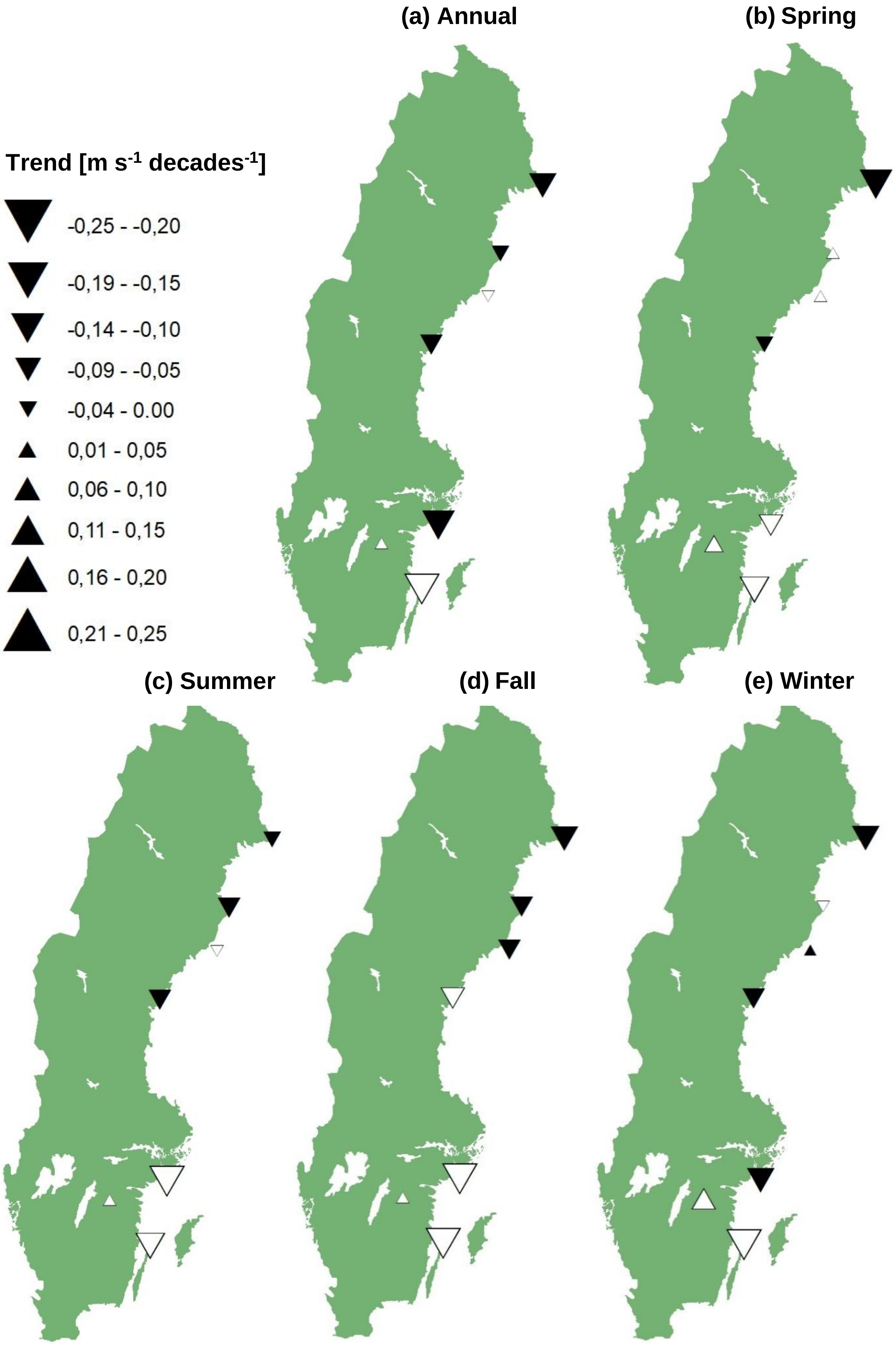


Figure 22. *Annual and seasonal magnitude of trend, expressed as m s^{-1} $decades^{-1}$, for all 7 stations in the period 1926-1996. Statistical significance is expressed as black filled for statistically significant at p < 0,05 and white for non-statistically significant at p > 0.1.*

5.4 Correlation with teleconnection patterns

Correlation between NSWS and 4 different teleconnection patterns (NAO, AO, SCA, EA) has been analyzed for all seasons and for all 12 months. Correlation with each of the pattern is presented in an individual chapter following this one. Figure 23 shows the correlation between annual NSWS and annual NAO (blue), AO (red), SCA (yellow) and EA (purple) for each months. The only negative correlation is found with SCA during almost all of the year and with AO and EA during the summer. Highest positive correlation is experienced in March for the NAO (0,48), AO (0,51) and EA (0,53), all statistically significant at $p < 0.05$. SCA experiences statistical significance only from July to November, while NAO, AO and EA experience statistical significance in all months except during summer months (and December for EA). Correlation with NAO and AO is similar in all months. Only a few months have a large difference in correlation, like August and September, otherwise AO experiences a marginally higher correlation than NAO does.

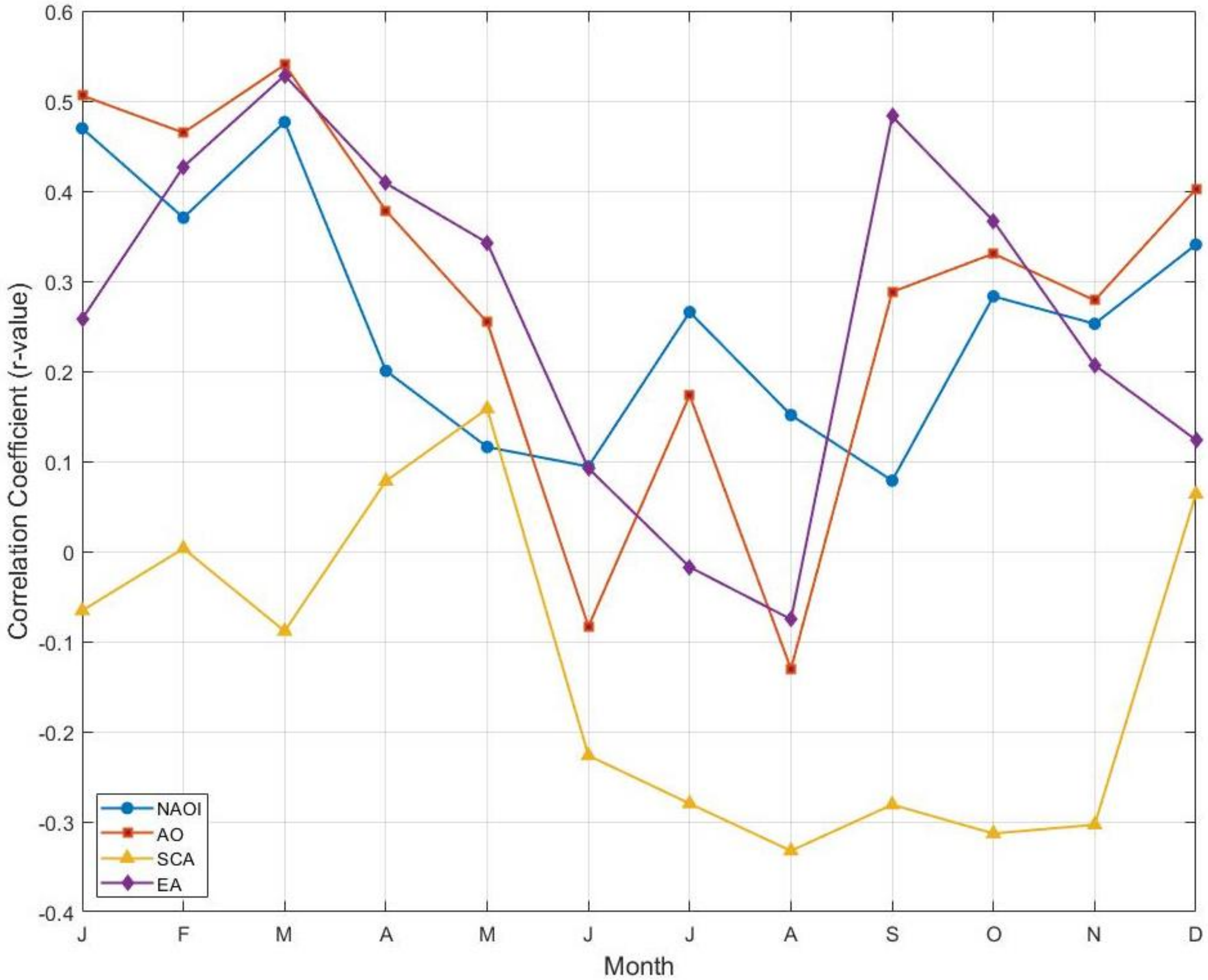


Figure 23. *Monthly correlation between the regional annual (i.e., average of all stations across Sweden) anomalies series and NAO (blue), AO (red), SCA (yellow) and EA (purple).*

Table 9 shows an overview of the annual correlation as well as the seasonal correlation. Both NAO and AO experience a statistically significant annual correlation (at $p < 0.05$) of 0,30 and 0,31 respectively, while neither SCA nor EA experience any annual correlation. Highest positive correlation is experienced with NAO and AO in winter, highest negative correlation is experienced in summer with SCA.

PERIOD	NAO	AO	SCA	EA
ANNUAL	**0,30**	**0,31**	*0,01*	*0,05*
SPRING	**0,28**	**0,45**	*0,08*	**0,45**
SUMMER	*-0,04*	-0,20	**-0,27**	*-0,06*
FALL	0,20	**0,31**	-0,20	**0,31**
WINTER	**0,50**	**0,50**	*0,03*	0,20

Table 9. *Annual and seasonal Pearson's correlation coefficient between regional wind speed anomalies series and NAO, AO, SCA and EA. Statistical significance at p < 0.05 is showed in bold, significance at p < 0.1 is showed as normal font and non-significant correlations at p > 0.1 is showed in cursive.*

5.4.1 North Atlantic Oscillation

Figure 25 displays a visual overview of the magnitude of annual and seasonal correlation between stations and NAO. Most stations experience highest correlation during winter (fig. 25e). The correlation during winter varies from highest in Malmslätt (0,56) to lowest in Öland (0,12), with all station statistically significant at $p < 0.05$, except Öland. The only negative correlation is reported in summer, when half of the stations experience a small negative non-significant correlation, and the others a small, non-significant, positive correlation. Öland has experienced no statistical significant correlation in any of the seasons, while Härnösand experiences statistically significant (at $p < 0.05$) in all seasons except summer. Largest positive correlation is found in Malmslätt for all the season except fall, where Härnösand experiences a 0,05 higher correlation.

Figure 24 shows winter NSWS for all three period (1926-1996, 1956-2013 and 1997-2019) alongside with the winter NAO index where the similarity of the annual variability comes forward.

Annual and seasonal correlation between all station and the NAO index can be viewed in the supplementary tables S1-5.

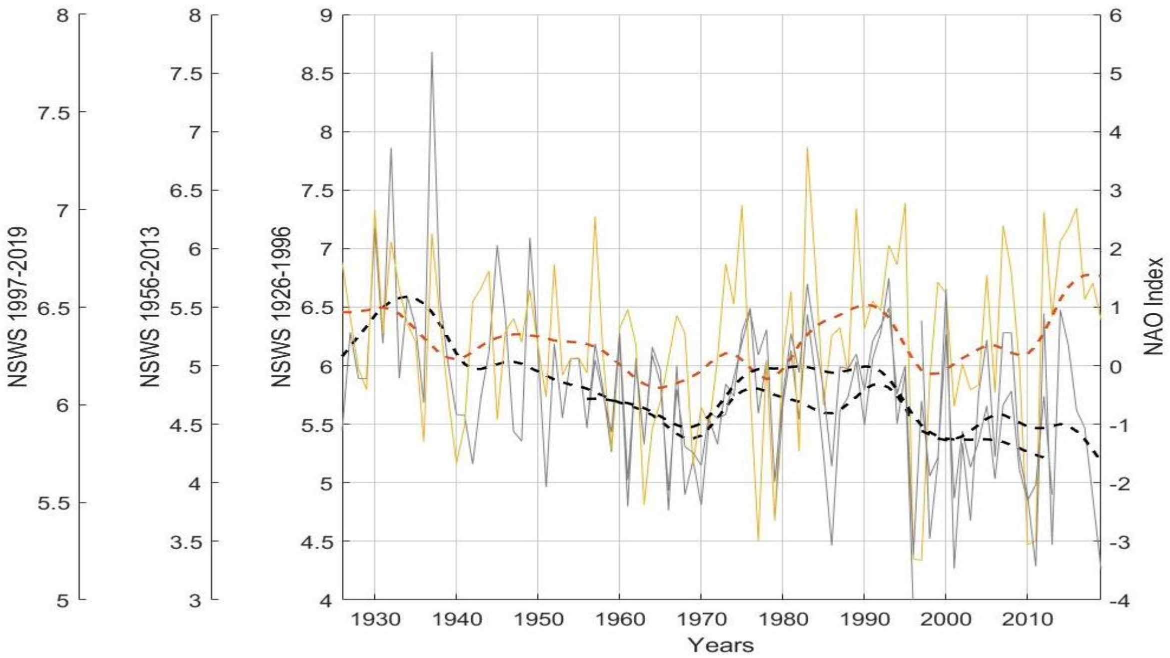


Figure 24. *Winter NSWS for the periods 1926-1996, 1956-2013 (Minola et al., 2016) and 1997-2019 (Minola et al., 2021a) all shown in gray (with an applied gaussian filter, 15-year window, as black) to avoid to many colors and noises. The yellow (with an applied gaussian filter, 15-year window, as orange) line follows annual winter NAO index between the years 1926-2019. The y-axis has been modified for each series to show the similarities in each series.*

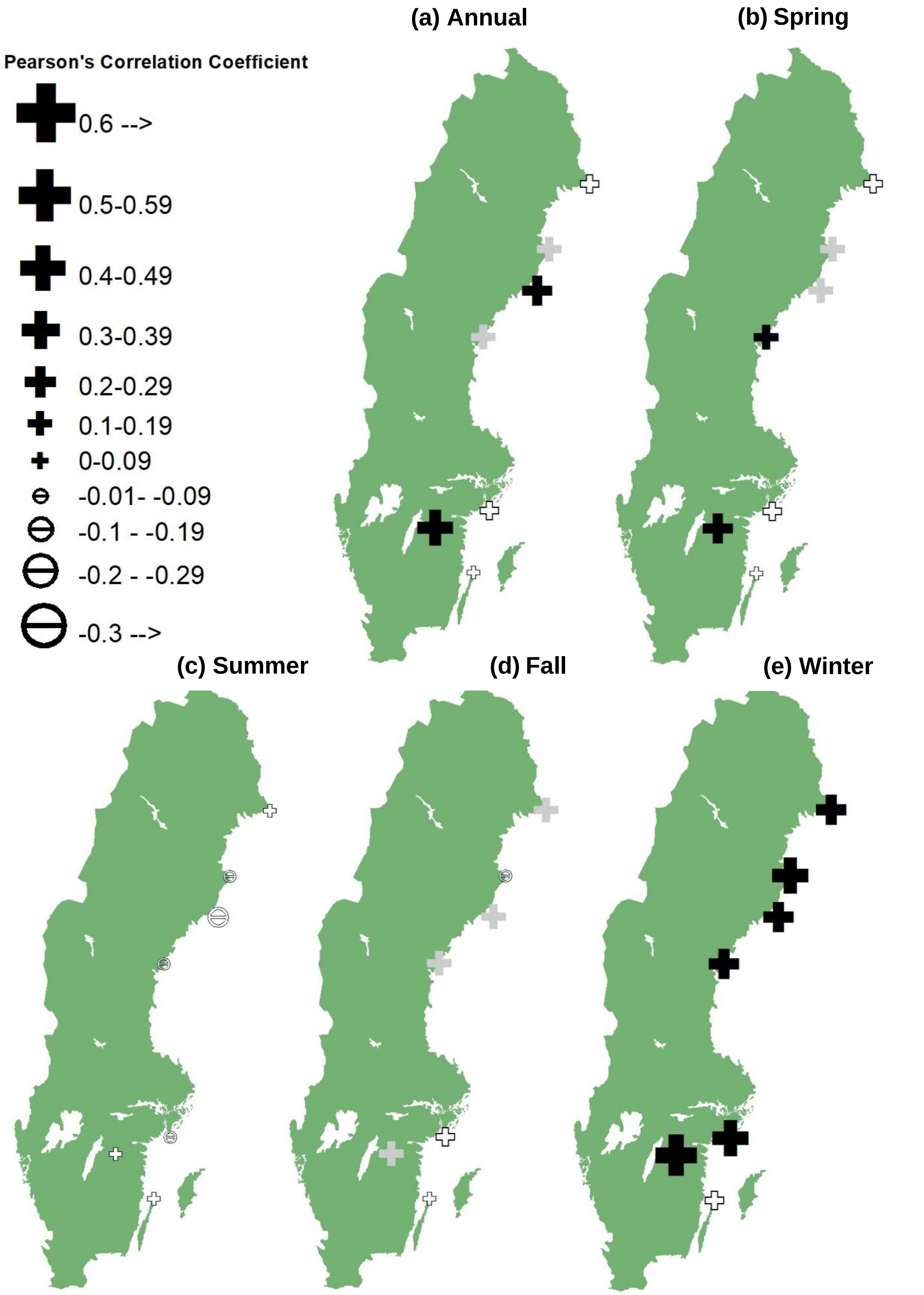


Figure 25. *Annual and seasonal magnitude of Pearson's correlation coefficient between annual NSWS and NAOI for all 7 stations in the period 1926-1996. Statistical significance is expressed as black for statistically significant at p < 0,05, grey for statistical significance at p < 0.1 and white for non-statistically significant at p > 0.1*

5.4.2 Artic Oscillation

Just like the NAO, AO experience the strongest correlations with most of the stations in winter (fig 28e). Winter also have significant high correlation in all stations, except Öland. The winter correlation range between 0,71 in Malmslätt to 0,23 in Haparanda (see supplementary table S5). Unlike the NAO, AO also experience high significant correlation in spring (fig 28b) for all station except Haparanda and Öland. The annual correlation is also higher than the correlation with NAO for many of the stations, and there is no significant annual correlation with Öland and Haparanda. Fall is the season which experience the widest variation of correlation: Malmslätt experiences a negative, statistically significant correlation (at $p < 0.05$), of -0,32 while Holmögadd experiences a positive, statistically significant correlation (at $p < 0.05$), of 0,40 (see supplementary table S4), the rest of the station experience no statistically significant correlation. Summer report no significant correlations with any of the stations.

Figures 26 and 27 show the resemblances between regional NSWS and AO during spring and winter respectively up until 2002 (with NSWS series until 2019). In spring a common increasing trend from 1940 is revealed, while there is a decreasing period in winter for the same period. In both figures AO seems to have more interannual variation than the NSWS series, with stronger decreasing and increasing trends, but in general, they follow the same pattern.

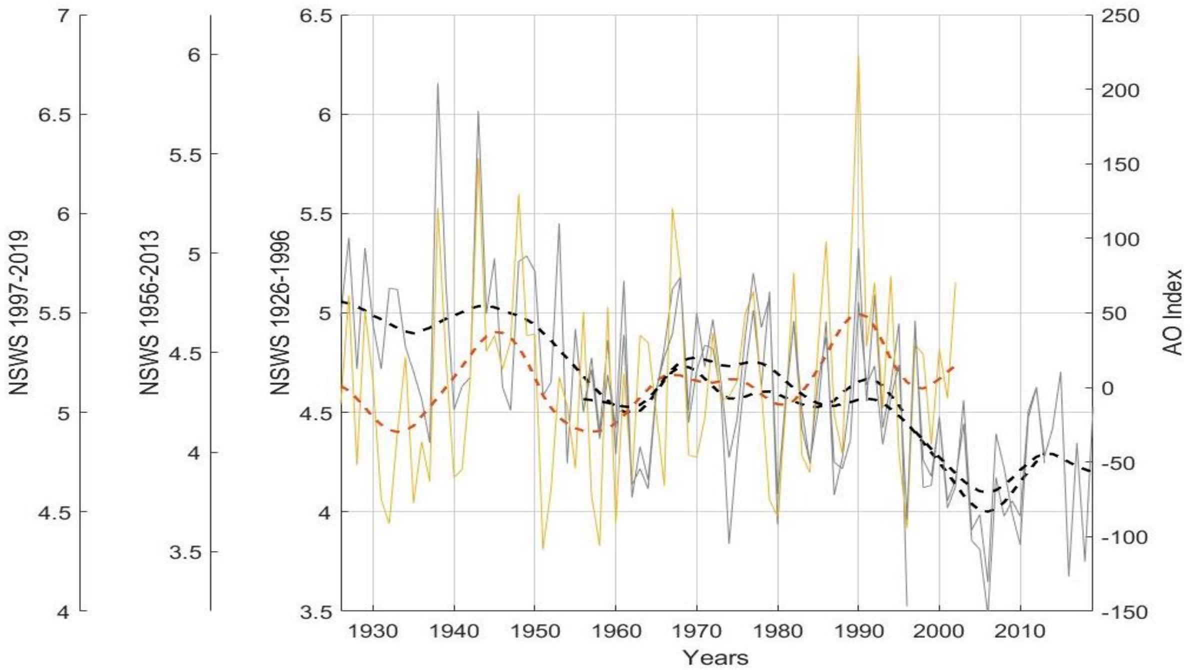


Figure 26. *Spring NSWS for the periods 1926-1996, 1956-2013 (Minola et al., 2016) and 1997-2019 (Minola et al., 2021a) all shown in gray (with an applied gaussian filter, 15-year window, as black) to avoid to many colors and noises. The yellow (with an applied gaussian filter, 15-year window, as orange) line follows annual spring AO index between the years 1926-2002. The y-axis has been modified for each series to show the similarities between AO and NSWS variations.*

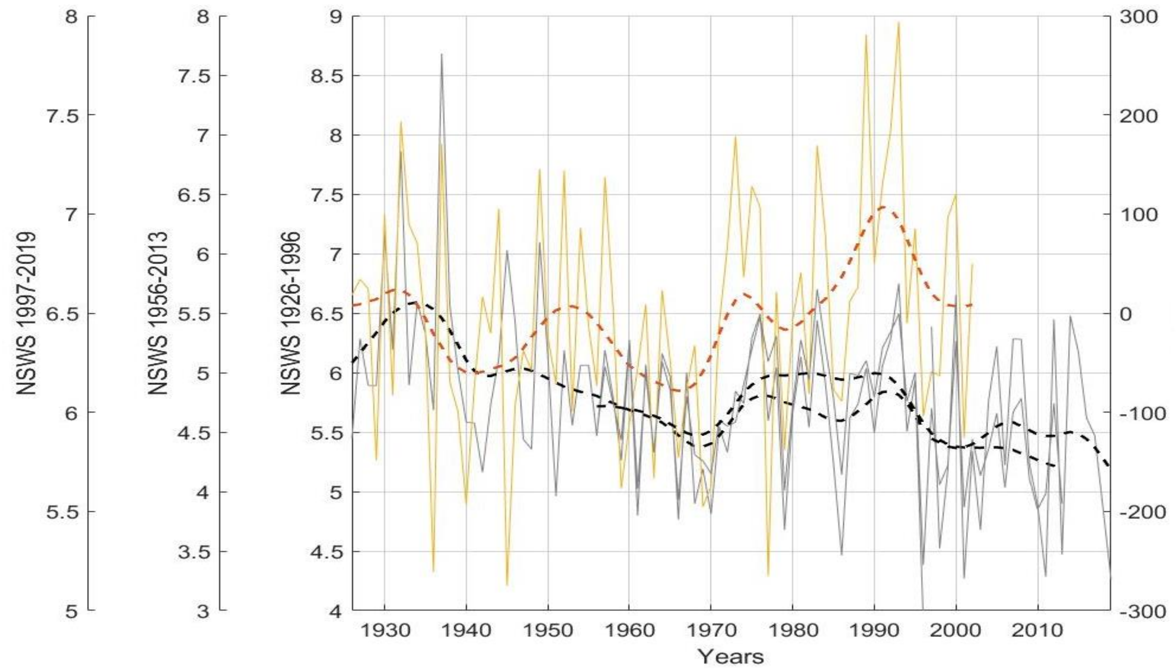


Figure 27. *Winter NSWS for the periods 1926-1996, 1956-2013 (Minola et al., 2016) and 1997-2019 (Minola et al., 2021a) all shown in gray (with an applied gaussian filter, 15-year window, as black) to avoid to many colors and noises. The yellow (with an applied gaussian filter, 15-year window, as orange) line follows annual winter AO index between the years 1926-2002. The y-axis has been modified for each series to show the similarities between AO and NSWS variations.*

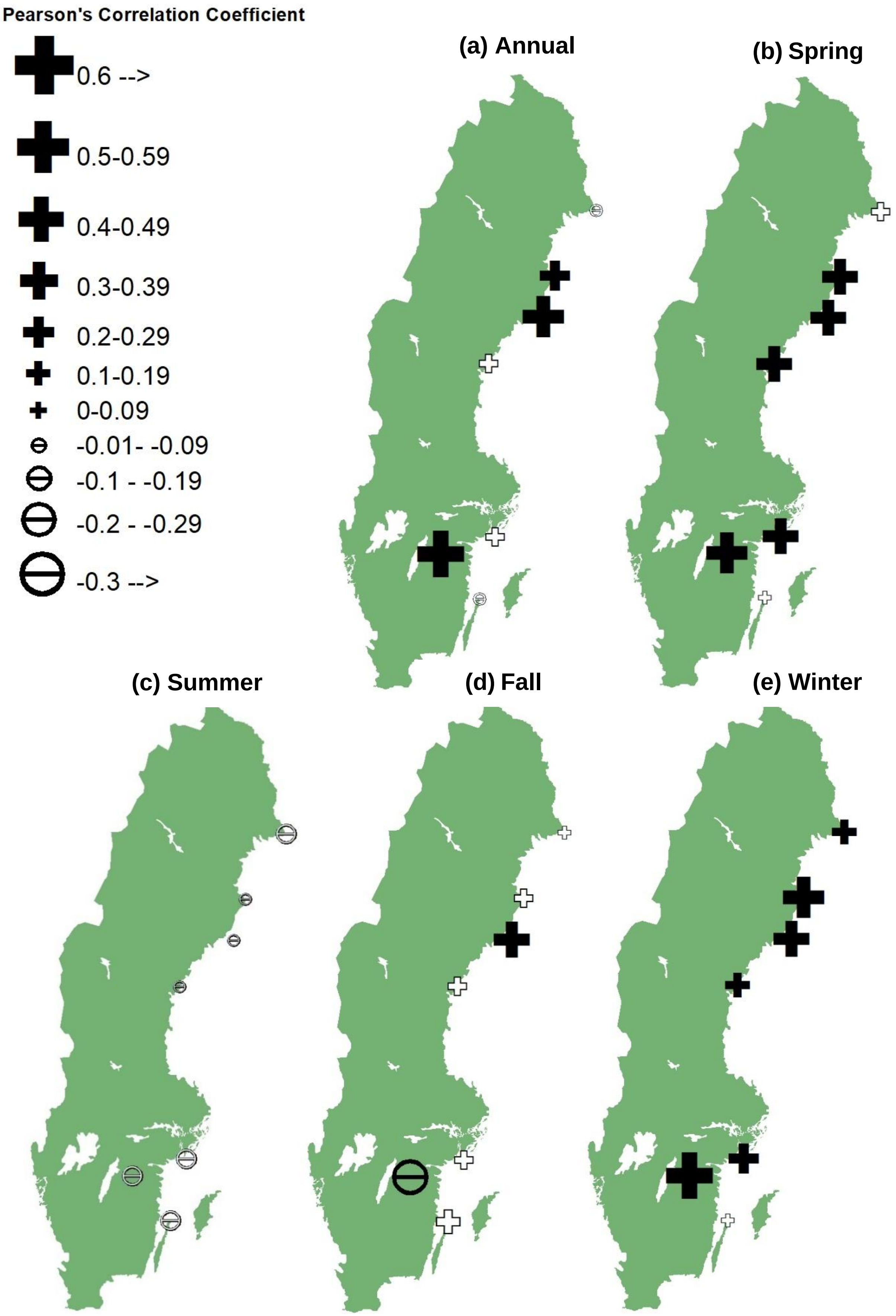


Figure 28. *Annual and seasonal magnitude of Pearson's correlation coefficient between annual NSWS and AO index for all 7 stations in the period 1926-1996. Statistical significance is expressed as black for statistically significant at p < 0,05, grey for statistical significance at p < 0.1 and white for non-statistically significant at p > 0.1.*

5.4.3 Scandinavian Pattern

SCA differs from the other teleconnection patterns as it is the only pattern which show predominantly negative correlation during almost all seasons. Figure 29 reveals that summer and fall is the only two seasons which have a statistically significant (negative) correlation with some stations, while spring and winter show now statistical significant correlation. The strongest correlations are reported in summer but only two stations (Landsort and Öland) report a significant correlation. Even if few stations experience low or no correlation, the regional correlation is found to be -0,27 (statistically significant at $p < 0.05$, see supplementary table S3), but for all other periods there is no statistically significant correlation for the regional mean.

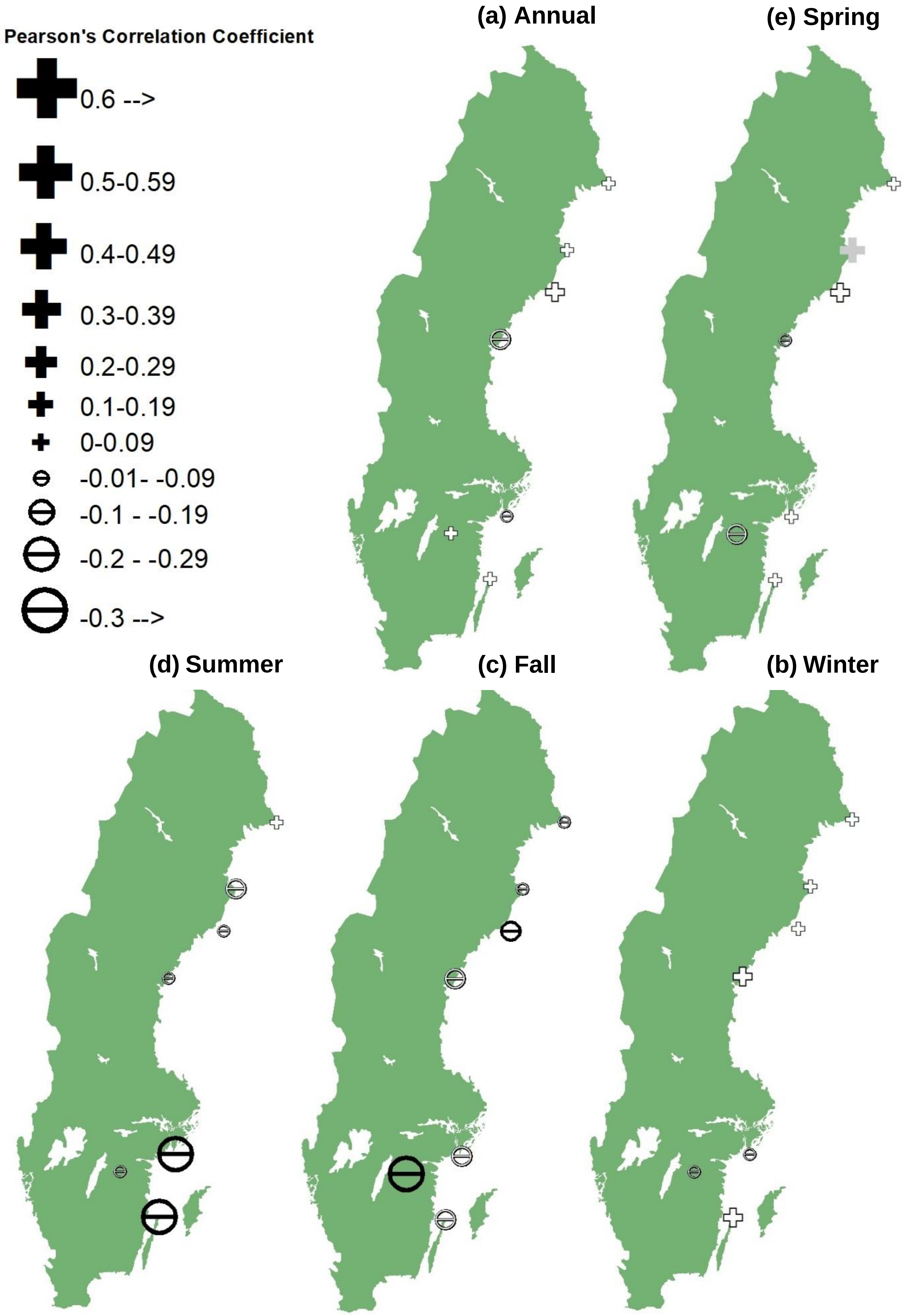


Figure 29. *Annual and seasonal magnitude of Pearson's correlation coefficient between annual NSWS and SCA index for all 7 stations in the period 1926-1996. Statistical significance is expressed as black for statistically significant at p < 0,05, grey for statistical significance at p < 0.1 and white for non-statistically significant at p > 0.1.*

5.4.4 East Atlantic Pattern

Correlation between NSWS and EA are most pronounced in spring (figure 31b). All stations apart from Öland and Haparanda experience a statistically significant positive correlation in spring. The highest spring correlation during is reported in Malmslätt (0,57), the other stations correlations vary between 0,40 to 0,48 (see supplementary table S2). In summer and annually, no stations (except Holmögadd annually) report a statistically significant correlation. In fall and winter only 3 of the 7 stations reports a significant correlation (at $p < 0.1$). Figure 30 shows the annual variation between the spring mean EA for the period 1926-2016 and spring mean regional average between 1926-2019. Between 1950 to 1960 both the NSWS and the EA experience a stilling followed by a reversal until the 70's. The interannual variation relates overall well with each other. After 1990 the stilling is more pronounced for the NSWS than for the EA.

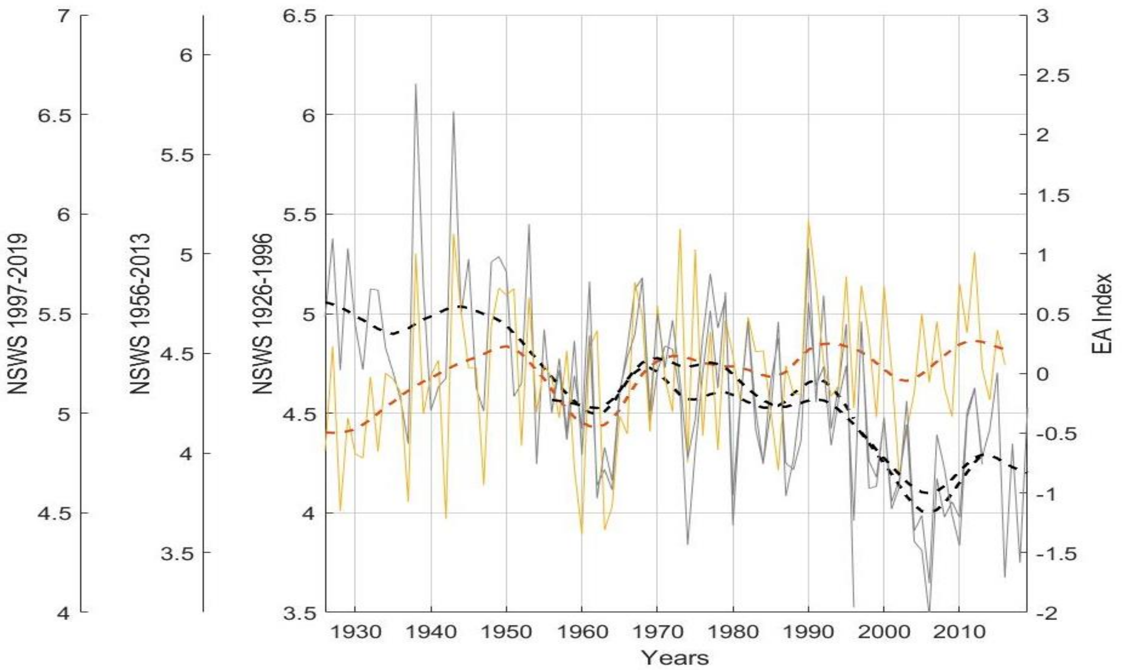


Figure 30. *Spring NSWS for the periods 1926-1996, 1956-2013 (Minola et al., 2016) and 1997-2019 (Minola et al., 2021a) all shown in gray (with an applied gaussian filter, 15-year window, as black) to avoid to many colors and noises. The yellow (with an applied gaussian filter, 15-year window, as orange) line follows annual spring EA index between the years 1926-2016. The y-axis has been modified for each series to show the similarities between EA and NSWS variations.*

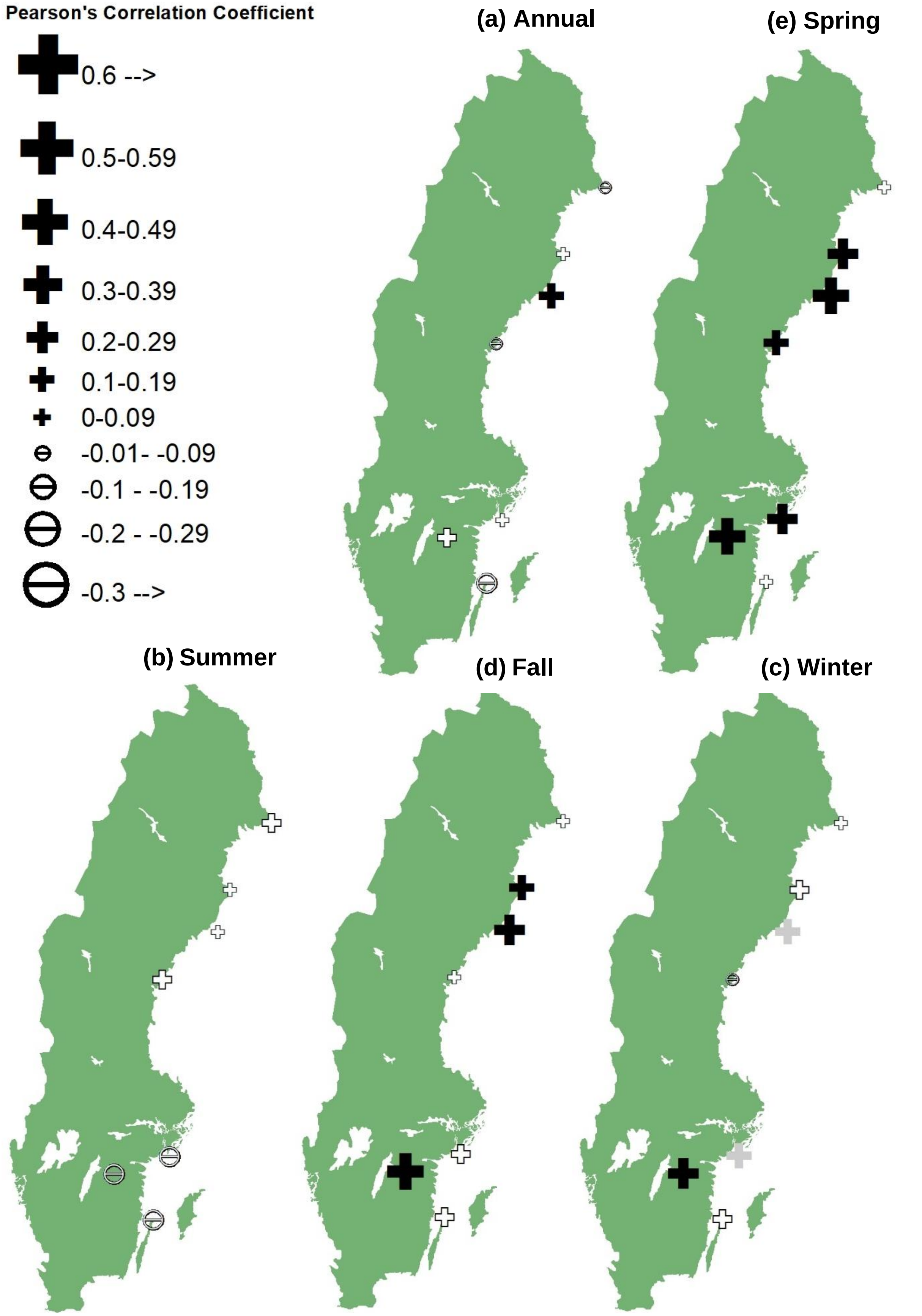


Figure 31. *Annual and seasonal magnitude of Pearson's correlation coefficient between annual NSWS and EA index for all 7 stations in the period 1926-1996. Statistical significance is expressed as black for statistically significant at $p < 0,05$, grey for statistical significance at $p < 0.1$ and white for non-statistically significant at $p > 0.1$.*

6. Discussion

This study has shown a 70-years decreasing trend in NSWS across Sweden between the years 1926-1996. The magnitude of the detected stilling is -0.11m s^{-1} $decade^{-1}$. Since few studies with homogenized observational data is available it is hard to compare the trends found in this study with others which have used similar methods. Although there are some centennial trends reported from reanalysis datasets. For example, Kirchner-Bossi et al. (2013) reported a centennial trend from reconstructed data from Spain. This trend was found for 1871–2009 and reported a – 0.1 m s^{-1} $centuary^{-1}$ decrease, which is 10 times lower than the decadal trend reported in this study. In the study of Kirchner-Bossi et al. (2013) there is a large increasing trend before the period starting 1920 which can explain this big difference in reported trend. Unfortunately, trends from other time periods where not reported by Kirchner-Bossi. Wholand et al. (2019), who used several reanalysis set (including ERA20CM, ERA20C and ERA20C) to reconstruct wind speed during the 20^{th} century. Whereas ERA20C and CERA20C seem to report a small increasing trend of 0.00-0.08 m s^{-1} $decade^{-1}$ over Sweden for 1900-2010. 20CR seems to have an even smaller, or vaguely negative trend. Neither of these trends agree well with the negative trend reported in this study. Wholand mentioned in his conclusion that reanalysis from the 20^{th} century may be "*boldly misleading*" when using only one reanalysis set and suggest that his result may not comprehend well with actual trends. The lack of studies using observational data can neither confirm nor reject the magnitude of trend and its sign shown in reanalyses. This adds to the importance of wind speed data rescue of old observational journals. This result also proves that the reported trend is highly dependent both on which time-period and the length of the period which is being studied (McVicar et al., 2012).

The trends reported during shorter time periods in this study can be used for comparison with other reported trends. This study reports a trend of -0.12 m s^{-1} $decades^{-1}$ in the period 1956-2013. These trends are calculated using homogenized series from Minola et al. (2016), but only for the same stations used in this study (1926-1996). Minola himself reported a trend for the same period of -0.06 m s^{-1} $decades^{-1}$ in his own study, using data from 24 stations across Sweden rather than only the 7 used in this study. The trend reported in this study, for the recent period 1997-2019, is -0.09 m s^{-1} $decades^{-1}$ while Minola reports a trend between 0 to -0.1 m s^{-1} $decades^{-1}$ (shown as colored time windows; Minola et al., 2021), where he used 100 stations across Sweden. This trend is more in line with the result found in this study for the same period. Since this study only uses 7 stations, it can be hard to determine a regional trend. The stations used here are mainly from the east coast of Sweden (only one which are more inland), with no stations left to represent the west coast or the inland, while Minola uses stations from all across Sweden, many which are inland: this can explain the large difference in reported trend. Minola et al. (2016) also shows that the trends for the costal stations are stronger than those inlands which may lead to a stronger regional trend reported in this study since only costal stations are used, and may also explain the large gap between other, weaker trends reported in Sweden. The seasonal cycles for the for stations Bjuröklubb, Holmögadd, Landsort and Öland resembles very much that of a costal station (Minola et al., 2021b; Coeling et al., 1998), while Härnösand resembled more that of an inland station (Minola et al,.m 2021b) and Haparanda and Malmslätt barely show any differences during the year. The over-representation of coastal stations has led to a regional seasonal cycle which has also taken form of a "coastal station", making the result found in this study more representative for coastal location rather than a regional representation. The lack of stations from the west coast can also affect the result as the flat land and lack of sheltering mountains make the west coast more susceptible to winds coming in from the coast. Laapas and Venäläinen (2017), used 33 stations all over Finland (close to Sweden east coast) and reported a trend for the period 1959-2015 -0.09 m s^{-1} $decades^{-1}$ which is closer to the 1956-2012 trend reported here than Minolas study. This add to the fact that the trends reported in this study might be more accurate for the east of Sweden rather than the for the whole region.

The two additional datasets from Minola et al. (2016) and Minola et al. (2021a) which have been used to extend the timeline to look at trends and interannual variations during more recent time, correlate well with the series between 1926-1996. During the period 1956-1997 the correlation with the original regional mean series was as high as 0,85, and the correlation between the two additional series from Minola is reported as 0,72 during the time period 1997-2013. If we look at the correlation between only the stations, it varies. Most have a high, significant correlation over 0,5 but some shows barely any correlation at all. Landsort shows no correlation during 1956-1997 but a correlation of 0,5 during 1997-2013. If we look at the map in figure 9, we can see that the location of the station which was used as a nearby station to Landsort during 1956-1997 is far more north than the original station. The same goes for Haparanda, which shows no significant correlation between the period 1997-2013 and this may be related to the fact that the nearby station from Minola et al. (2021a) is located much further south than the two others. Even though Malmslätt had to be replaced by a station much further south during 1997-2013, the stations show a significant correlation with each other. This method (to use other data from same or nearby station to recreate longer series of interannual variation) is shown in this study to work very well. It also agrees well with the fact that NSWS series can be greatly affected if the station relocate and that homogenization of data is important (Safai Pirooz et al., 2018; Zahradnícek et al., 2017). Even if all these series already were homogenized, the series can't be merged to create one whole series because of differences in homogenization methods (one method used reanalyzes while one uses geostrophic winds etc) which also explain why one series is windier than another. So, this method is not used to create long coherent series of NSWS, it is rather used to see the variations for the complement years after 1996, where we here see that the stilling trends from the 80's ends around 2005, the same pattern can also be seen in Laapas and Venäläinen (2017) and Minola et al. (2016).

The regional seasonal trends reported for the whole period are all significant (spring, summer and fall at $p < 0.05$ and winter at $p < 0.1$) and vary from -0.07 m s^{-1} $decades^{-1}$ in spring and winter to -0.11 m s^{-1} $decades^{-1}$ and -0.12 m s^{-1} $decades^{-1}$ in summer and fall, respectively. The overall stilling is more pronounced in summer and fall than it is during spring and winter, which is in line with the result from Minola et al. (2016) and Laapas and Venäläinen (2017). Although not statistically significant, the stilling seems more evident at the southern costal stations (Landsort and Öland) for all seasons than for the northern ones. This also seems to be the case in Minola et al. (2016), with a few exceptions. The only inland station (Malmslätt) shows no significant trend in any of the seasons, but it is the only station which shows (non-significant) positive trends in all seasons, which is not the case in Minola et al. (2016). This may be due to land-use changes (Minola et al., 2021a) or the fact that the wind speed is generally lower inland and therefore has less interannual variation (Minola et al., 2021b). The latitudinal differences of magnitude of trend has been noticed in several studies. For example, McVicar et al. (2012) reports an increase in wind speed in tropics and midlatitude while locations above 70° experience a slight increase of wind speed. Minola et al. (2016) mention the poleward expansion of the Hadley cell as one of the reasons for the latitudinal differences of trends reported in his study. As the Hadley cell moves closer to the poles, the storm track in the midlatitudes will also shift poleward and affect the NAO index. More regional explanation for the latitudinal differences is the reforestation which is mainly experienced in the northern of Sweden (where forest dominates the land use) or the fact that the urbanization is more pronounced in the south, which cause higher emissions of GHG and AA which can ultimately decrease the wind-speed (Bichet et al., 2013).

The interannual variation is much larger in winter than during any other season but has the overall weakest decreasing trend. Summer shows least interannual variation but also reports the strongest stilling, with scarcely any periods of recovering during the whole period. This agrees well with Minola et al. (2016), Minola et al. (2021a) and Laapas and Venäläinen. (2017) which all report a stronger, more pronounced stilling in summer and multiple periods with both stilling and recovering in winter. Although, the result disagrees with other studies made outside of Scandinavia, at lower latitudes. In the Iberien Peninsula (Azorin-Molina et al., 2014), Saudi Arabia (Azorin-Molina et al., 2018a) and China (Zhang et al., 2021), all report the weakest negative trend (in some case positive) in summer and strongest during spring or winter. The correlation between NSWS and NAO/AO has shown strongest during winter in several studies (Minola et al., 2016; Azorin-Molina et al., 2014), including this one. This may be explained by the more positive tendency NAO have during boreal winter (Dec-March) where the pressure anomalies are high and generate strong westerly winds (Visbeck et al., 2001). During summer on the other hand, the tendency for positive phase NAO is lower which give rise to the possibility of other sources of winds, such as more regional or local conditions (Clifton & Lundqvist). Zeng et al. (2021) found that the uneven heating was one of the causes for declining wind speed trends in northern China. Faster warming has occurred in higher latitudes and caused weaker pressure gradient (Zeng et al., 2021) which have led to a decline in wind speed. This could also explain why Scandinavia has experienced a more rapid decline in summer, when local pressure systems play a bigger role (i.e., sea breezes). The weak correlation with NAO and AO during summer also give room for smaller pressure systems to become prominent. One example being the SCA that in this study showed a significant negative correlation of -0.27. Few studies have been made analyzing the impact of only SCA on NSWS, but Zubiate et al. (2017) studied the combined effect of NAO and SCA/EA on winter NSWS and found that the combined effect was actually higher correlated to NSWS than the correlation with only NAO.

In this study EA shows correlation during spring and fall. Even though the modes of EA are similar to that of NAO the seasonal differences show that there are some differences. In spring, EA shows a much higher correlation than NAO and in winter EA shows a much lower correlation than NAO. Summer and autumn show a similar correlation. These differences may be due to the slightly more southwards location of the EA modes (NOAA, 2012a), which causes less temperature gradient than that of the NAO during the winter and higher during the spring. This again shows how uneven heating (and thus larger pressure differences) effect the NSWS.

For future studies it is important to preserve and rescue old weather data so that longer observational series can be assessed and so that multiple studies can be compared. It is also important to compare the trends with the shorter trends so the confidence level for historical wind speed could improve, and also top compare with the cycles of the atmospheric circulation such as those implemented in this study.

7. Conclusion

In times when renewable energies are more important than ever, wind speed studies have been more and more common. This study evaluates the long-term trends of NSWS in Sweden from observational data in the period 1926-1996, with additional series from 1956-2013 and 1997-2019, and examine the possible connection to four teleconnection patterns. The data has been rescued from old weather journals according to recommendations from WMO, and then undergone a quality control and homogenization protocol, also according to recommendation from WMO.

The 1926-1996 trend of -0.11 m s^{-1} $decades^{-1}$ indicates an overall stilling, which is in line with most results from the Northern Hemisphere. The largest stilling was experienced in the early years between 1930-1960. This was then followed by a period with relatively unchanged wind speed pattern up until 1990 when a new stilling period began. The complementary data used for the period 1956-2013 shows the same patterns and with an ending of the stilling in mid-00's. Results from data in the period 1997-2019 confirm this reverse in stilling in early 2000 and even show a beginning of a possible new stilling period starting 2015. The 1956-2013 trends of -0.12 m s^{-1} $decades^{-1}$ is in line with studies made in Finland, but not with other studies made in Sweden. This disagreement of regional trends in Sweden is probably caused by the low number of stations used in this study, the lack of stations from the west coast and the overrepresentation of costal stations, causing the regional mean in this study to represent only the east coast.

This study also concludes that there are seasonal differences in the stilling trend, which agree well with the seasonal differences found in previous studies made in Finland and Sweden. While the interannual variation is greater in winter, the stilling trend is more pronounced in summer and fall. The high correlation with the large-scale circulations NAO, AO and EA in spring and winter indicates that these are highly likely to influence wind speed during these periods. In summer and autumn, more regional or local pattern may be the explanation for wind variations. The pronounced stilling in summer can therefore be affected by the uneven warming and the more pronounced heating at higher latitudes. This also explain why the seasonal trends in this study match more with location at higher latitudes rather than location at lower latitudes such as Spain and Saudi Arabia. The SCA has shown a small correlation only during summer which also agree well with smaller teleconnection patterns having greater impacts when the large-scale patterns do not.

Wind speed variations is in need of assessment on how the combined effect implies on NSWS changes; therefore, it is important for future research (i) to investigate the joint influence by several large, small, regional and local circulation; (ii) to further investigate the seasonal connection between different factors have on NSWS as an annual correlation might not represent the connection well between seasons (iii) to investigate the possible effect the intense warming at the poles might have on wind speed at locations in higher latitudes. Lastly, it is important for assessing centennial trends to rescue old wind speed journals and make them available for other researcher so more studies on centennial scale can be implemented.

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Supplementary Materials

ANNUAL	**NAO**	**AO**	**SCA**	**EA**
REGIONAL	**0,30**	**0,31**	*0,01*	*0,05*
BJURÖKLUBB	0,21	**0,31**	*0,00*	*0,09*
HAPARANDA	*0,10*	*-0,02*	*0,04*	*-0,06*
HOLMÖGADD	**0,32**	**0,55**	*0,10*	**0,29**
HÄRNÖSAND	0,22	*0,11*	*-0,10*	*-0,05*
LANDSORT	*0,19*	*0,11*	*-0,01*	*0,02*
MALMSLÄTT	**0,44**	**0,62**	*0,03*	*0,18*
ÖLAND	*0,01*	*-0,02*	*0,04*	*-0,11*

Table S1. *Correlation with annual wind speed series and the North Atlantic Oscillation, Artic Oscillation, Scandinavian Pattern and East Atlantic Pattern. The bold numbers have a significance of $p < 0.05$, normal have a significance of $p < 0.1$, and cursive is non-significant at $p > 0.1$.*

SPRING	**NAO**	**AO**	**SCA**	**EA**
REGIONAL	**0,28**	**0,45**	*0,08*	**0,45**
BJURÖKLUBB	0,21	**0,40**	0,20	**0,39**
HAPARANDA	*0,10*	*0,19*	*0,02*	*0,08*
HOLMÖGADD	0,23	**0,48**	*0,11*	**0,44**
HÄRNÖSAND	**0,25**	**0,41**	*-0,07*	**0,28**
LANDSORT	*0,16*	**0,41**	*0,06*	**0,37**
MALMSLÄTT	**0,35**	**0,57**	*-0,11*	**0,43**
ÖLAND	*0,06*	*0,06*	*0,09*	*0,08*

Table S2. *Correlation with spring wind speed series and the North Atlantic Oscillation, Artic Oscillation, Scandinavian Pattern and East Atlantic Pattern. The bold numbers have a significance of $p < 0.05$, normal have a significance of $p < 0.1$, and cursive is non-significant at $p > 0.1$.*

SUMMER	**NAO**	**AO**	**SCA**	**EA**
REGIONAL	*-0,04*	-0,20	**-0,27**	*-0,06*
BJURÖKLUBB	*-0,03*	*-0,03*	*-0,11*	*0,04*
HAPARANDA	*0,02*	*-0,16*	*0,08*	*0,15*
HOLMÖGADD	*-0,10*	*-0,06*	*-0,02*	*0,02*
HÄRNÖSAND	*-0,07*	*-0,09*	*-0,07*	*0,10*
LANDSORT	*-0,06*	*-0,17*	**-0,39**	*-0,13*
MALMSLÄTT	*0,08*	*-0,10*	*-0,09*	*-0,18*
ÖLAND	*0,02*	*-0,18*	**-0,34**	*-0,13*

Table S3. *Correlation with summer wind speed series and the North Atlantic Oscillation, Artic Oscillation, Scandinavian Pattern and East Atlantic Pattern. The bold numbers have a significance of $p < 0.05$, normal have a significance of $p < 0.1$, and cursive is non-significant at $p > 0.1$.*

FALL	NAO	AO	SCA	EA
REGIONAL	0,20	**0,31**	-0,20	**0,31**
BJURÖKLUBB	*-0,01*	*0,11*	*-0,04*	**0,29**
HAPARANDA	0,21	*0,04*	*-0,03*	*0,06*
HOLMÖGADD	0,22	**0,40**	**-0,26**	**0,37**
HÄRNÖSAND	**0,26**	*0,16*	*-0,12*	*0,04*
LANDSORT	*0,15*	*0,16*	*-0,12*	*0,17*
MALMSLÄTT	0,21	**-0,32**	**-0,32**	**0,46**
ÖLAND	*0,06*	*0,20*	*-0,12*	*0,13*

Table S4. *Correlation with fall wind speed series and the North Atlantic Oscillation, Artic Oscillation, Scandinavian Pattern and East Atlantic Pattern. The bold numbers have a significance of p < 0.05, normal have a significance of p < 0.1, and cursive is non-significant at p > 0.1.*

WINTER	NAO	AO	SCA	EA
REGIONAL	**0,50**	**0,50**	*0,03*	0,20
BJURÖKLUBB	**0,42**	**0,53**	*0,04*	*0,16*
HAPARANDA	**0,32**	**0,23**	*0,06*	*0,02*
HOLMÖGADD	**0,35**	**0,46**	*0,05*	0,22
HÄRNÖSAND	**0,38**	**0,25**	*0,10*	*-0,05*
LANDSORT	**0,48**	**0,38**	*-0,07*	0,20
MALMSLÄTT	**0,56**	**0,71**	*-0,08*	**0,31**
ÖLAND	*0,12*	*0,08*	*0,15*	*0,10*

Table S5. *Correlation with winter wind speed series and the North Atlantic Oscillation, Artic Oscillation, Scandinavian Pattern and East Atlantic Pattern. The bold numbers have a significance of p < 0.05, normal have a significance of p < 0.1, and cursive is non-significant at p > 0.1.*

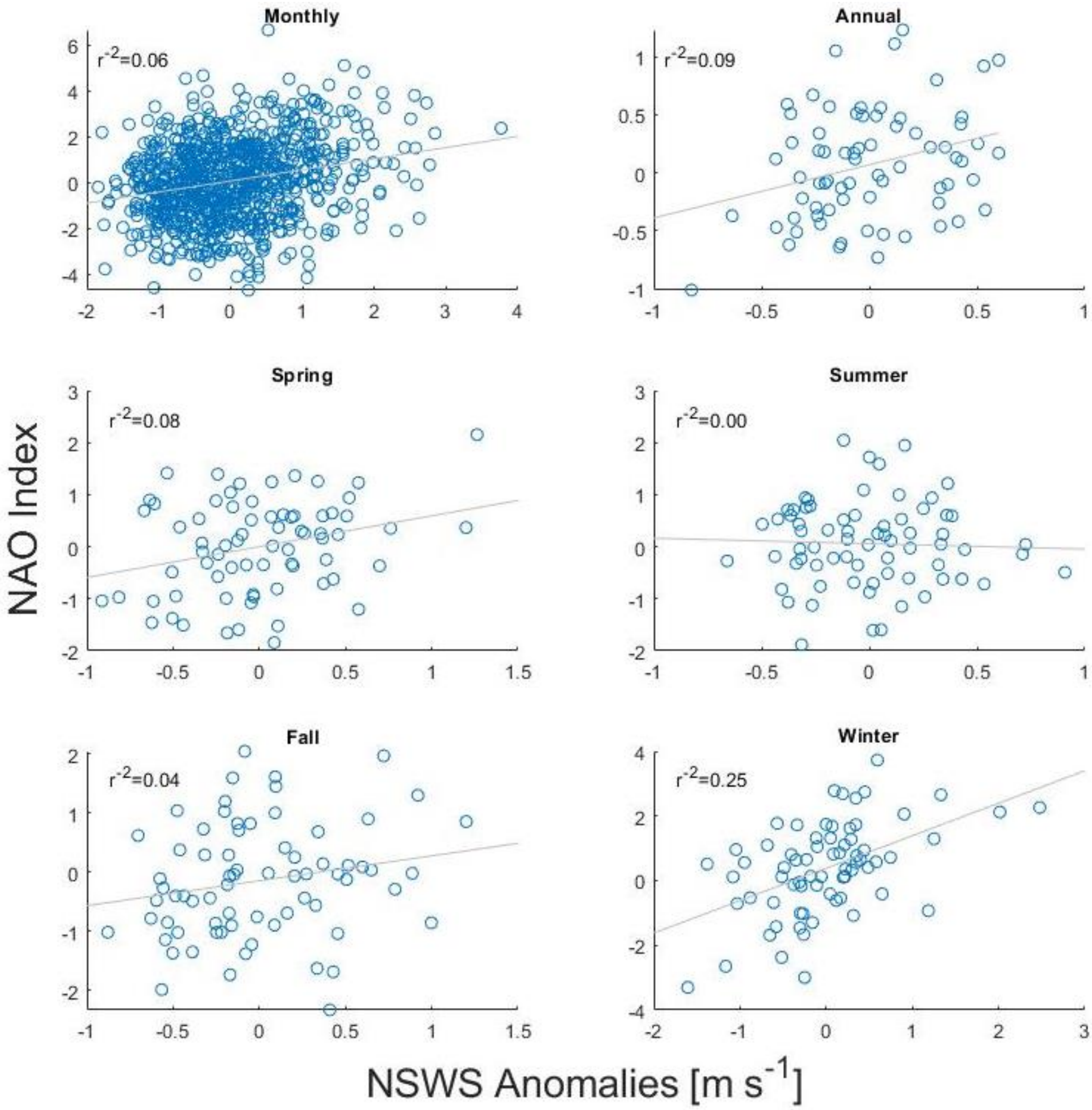

Figure S1. *Monthly (a), annual (b) and seasonal (c-f) correlation between the regional annual wind speed anomalies series and the NAO index between the years 1926-1996.*

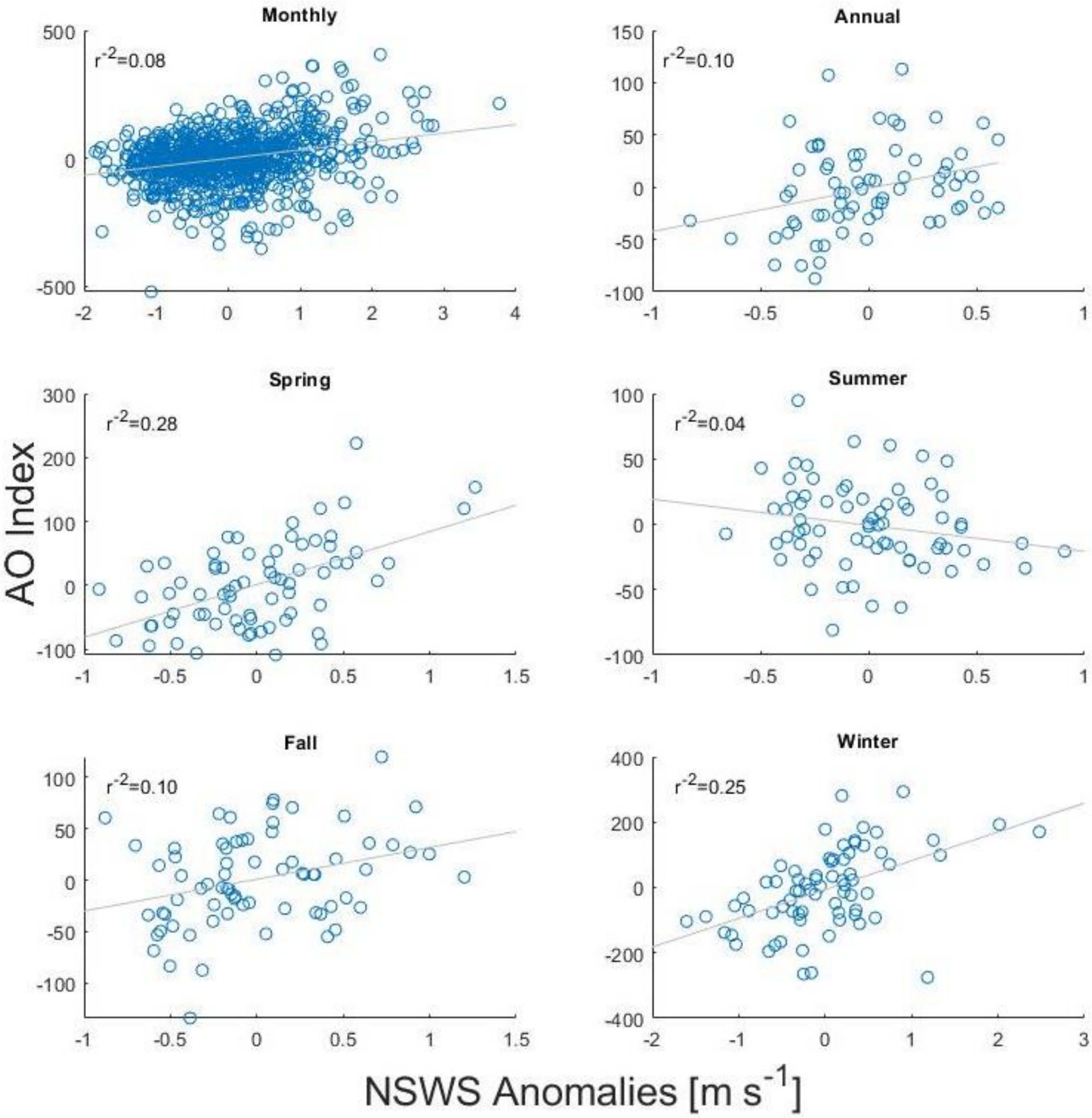

Figure S2. *Monthly (a), annual (b) and seasonal (c-f) correlation between the regional annual wind speed anomalies series and the AO index between the years 1926-1996.*

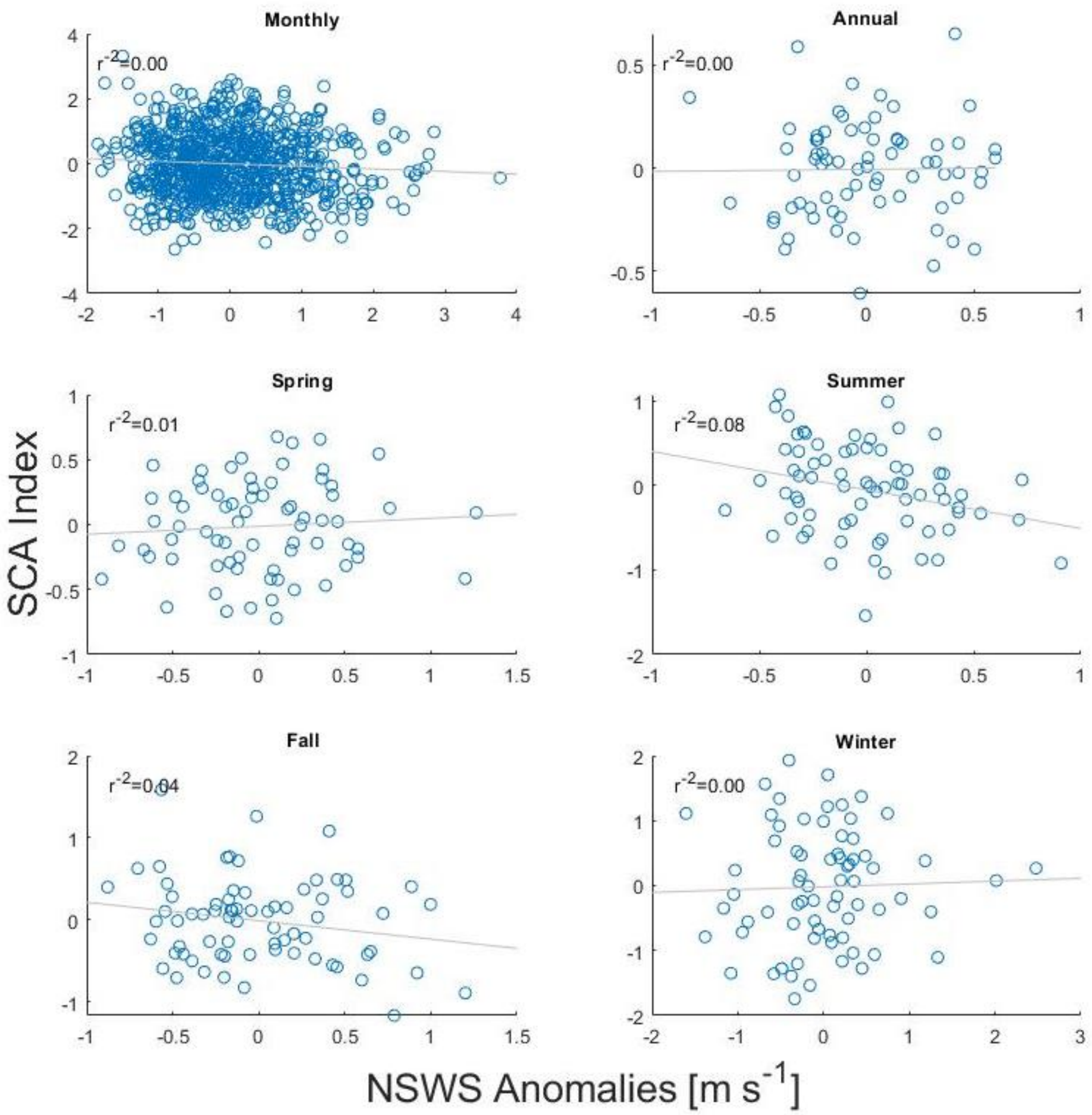

Figure S3. *Monthly (a), annual (b) and seasonal (c-f) correlation between the regional annual wind speed anomalies series and the SCA index between the years 1926-1996.*

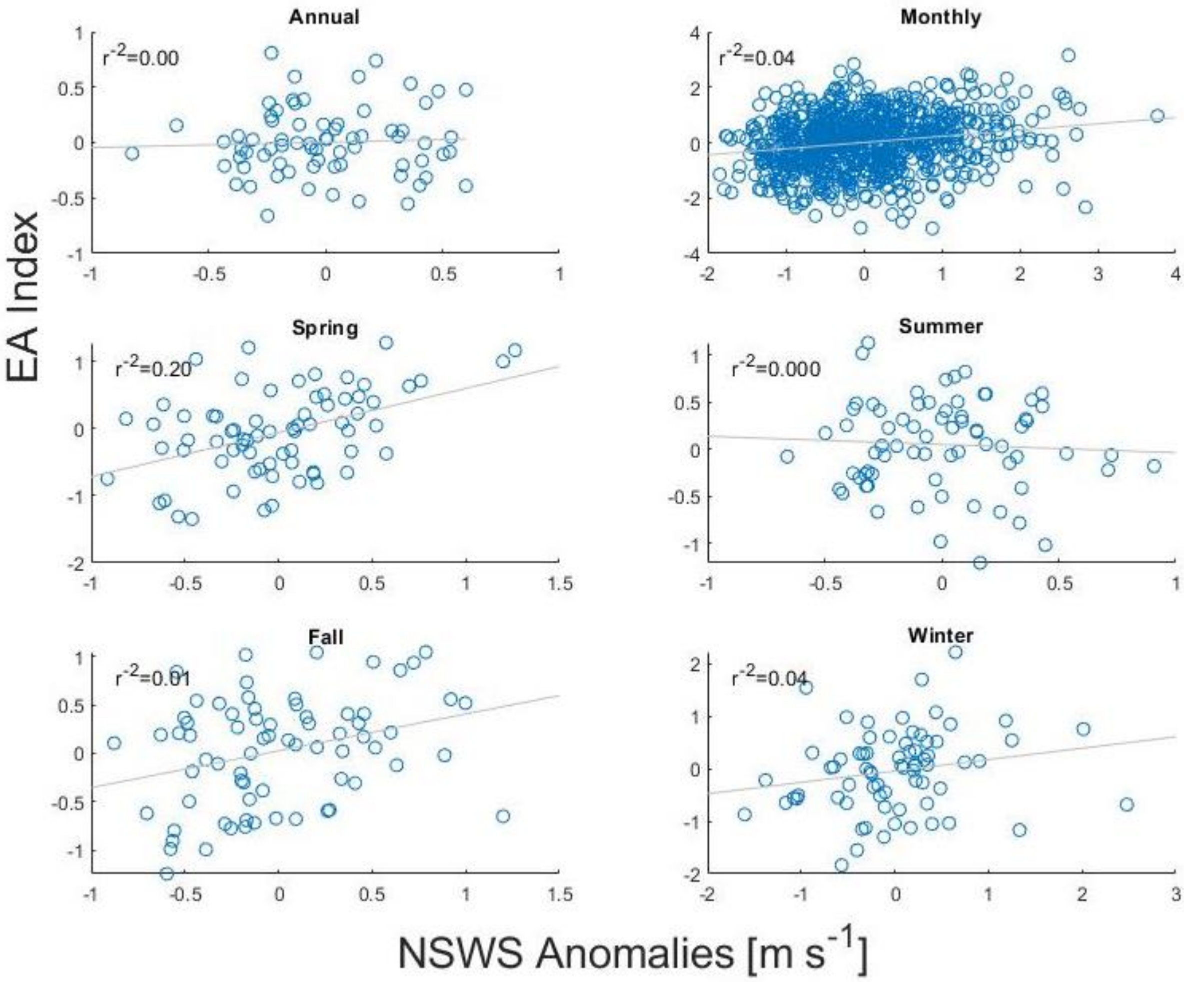

Figure S4. *Monthly (a), annual (b) and seasonal (c-f) correlation between the regional annual wind speed anomalies series and the EA index between the years 1926-1996.*

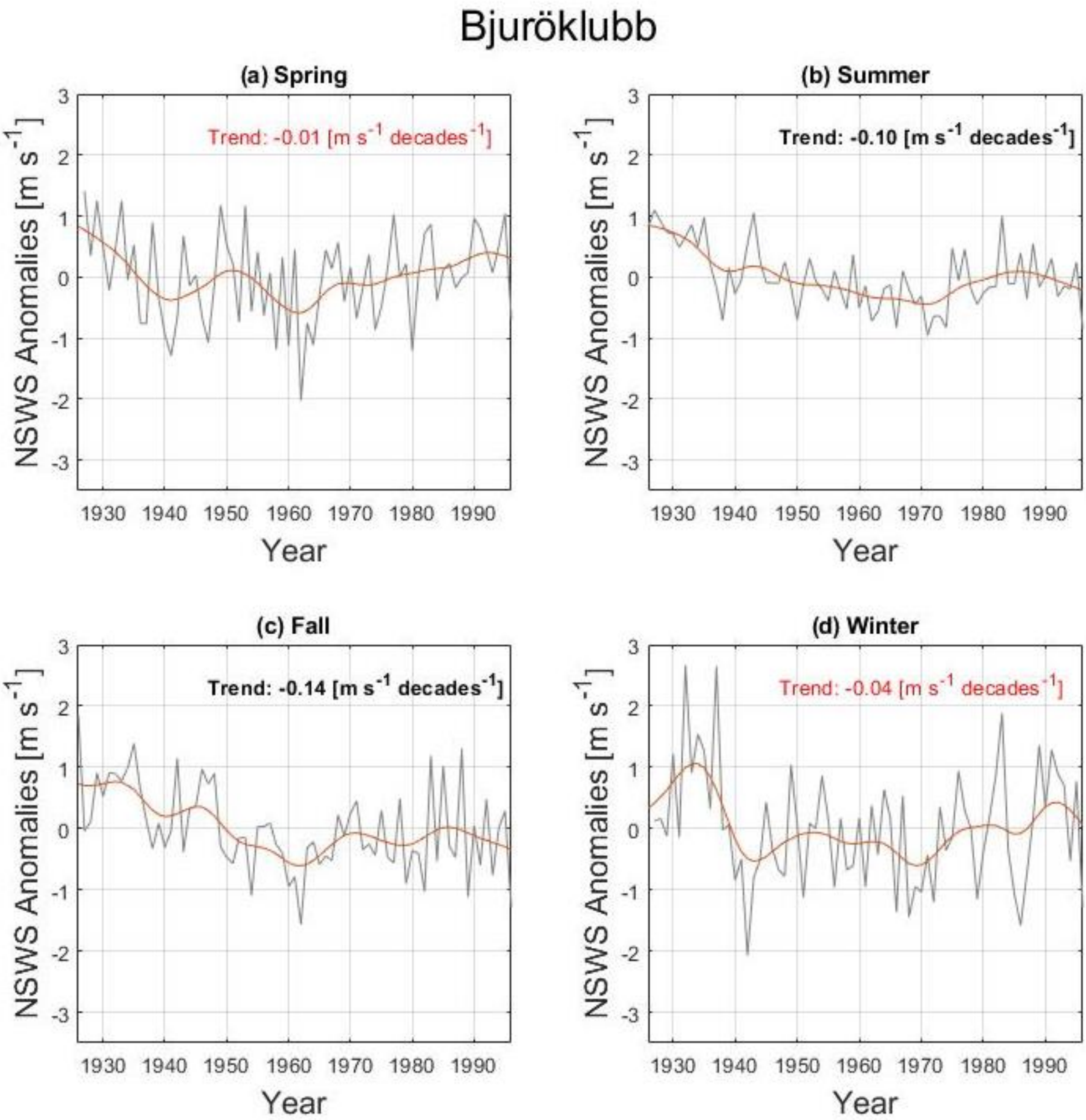

Figure S5. *Series of Bjuröklubb station (black line) during 1926-1996 for the seasons Spring (March, April, May (a)), Summer (June, July, August (b)), Fall (September, October, November(c)) and Winter (December, January, February (d)). The low-frequency variability is with the applied Gaussian-weighted average filter (15-year window; red line). Wind speed anomalies are relative to the station mean for the each season. The 1926-1996 trend is reported in bold black font if statistically significant at $p < 0.05$, normal black font if statistically significant at $p < 0.1$ and normal red font if non-statistical significant at $p > 0.1$.*

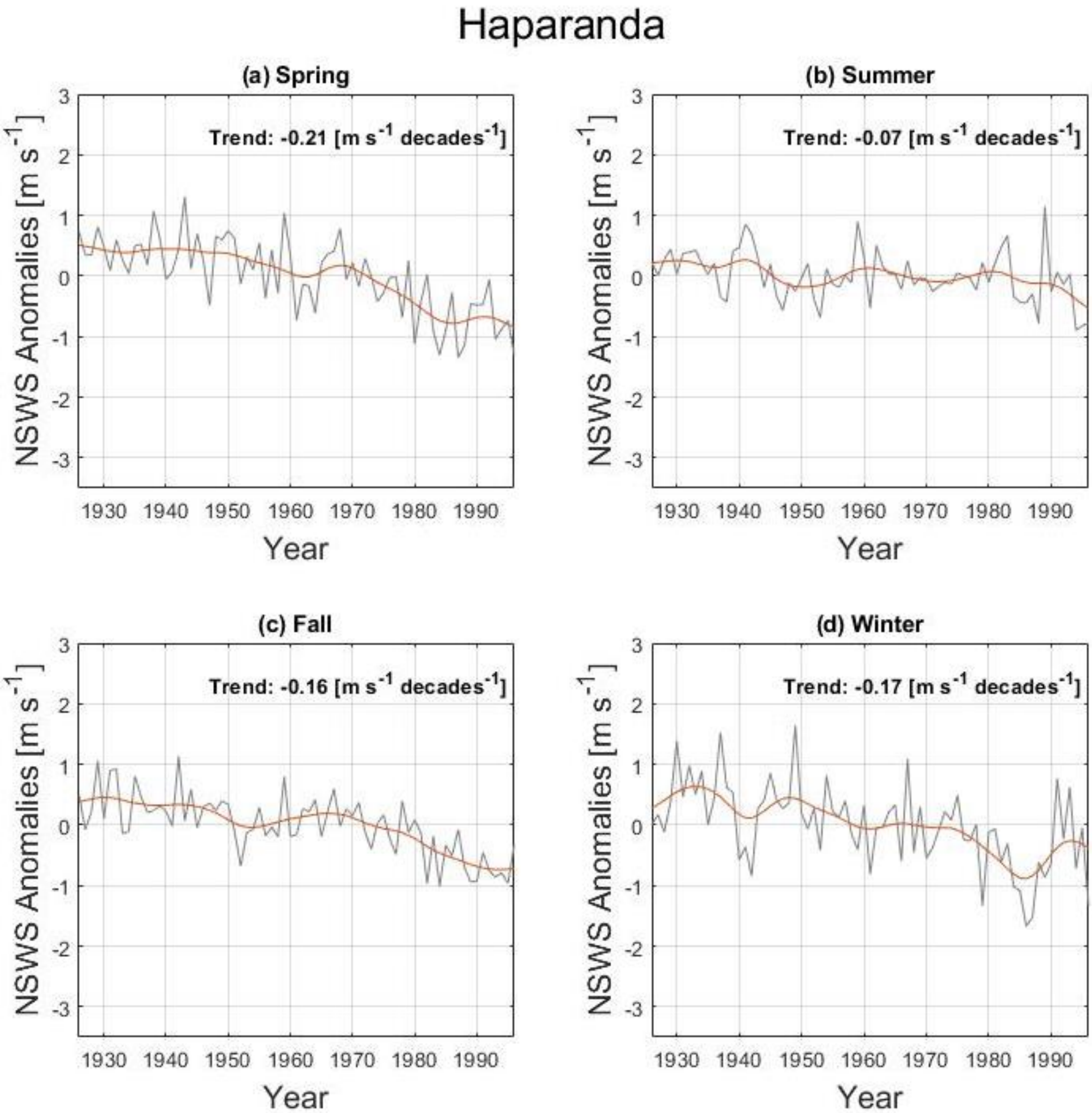

Figure S6. *Series of Haparanda station (black line) during 1926-1996 for the seasons Spring (March, April, May (a)), Summer (June, July, August (b)), Fall (September, October, November(c)) and Winter (December, January, February (d)). The low-frequency variability is with the applied Gaussian-weighted average filter (15-year window; red line). Wind speed anomalies are relative to the station mean for the each season. The 1926-1996 trend is reported in bold black font if statistically significant at $p < 0.05$, normal black font if statistically significant at $p < 0.1$ and normal red font if non-statistical significant at $p > 0.1$.*

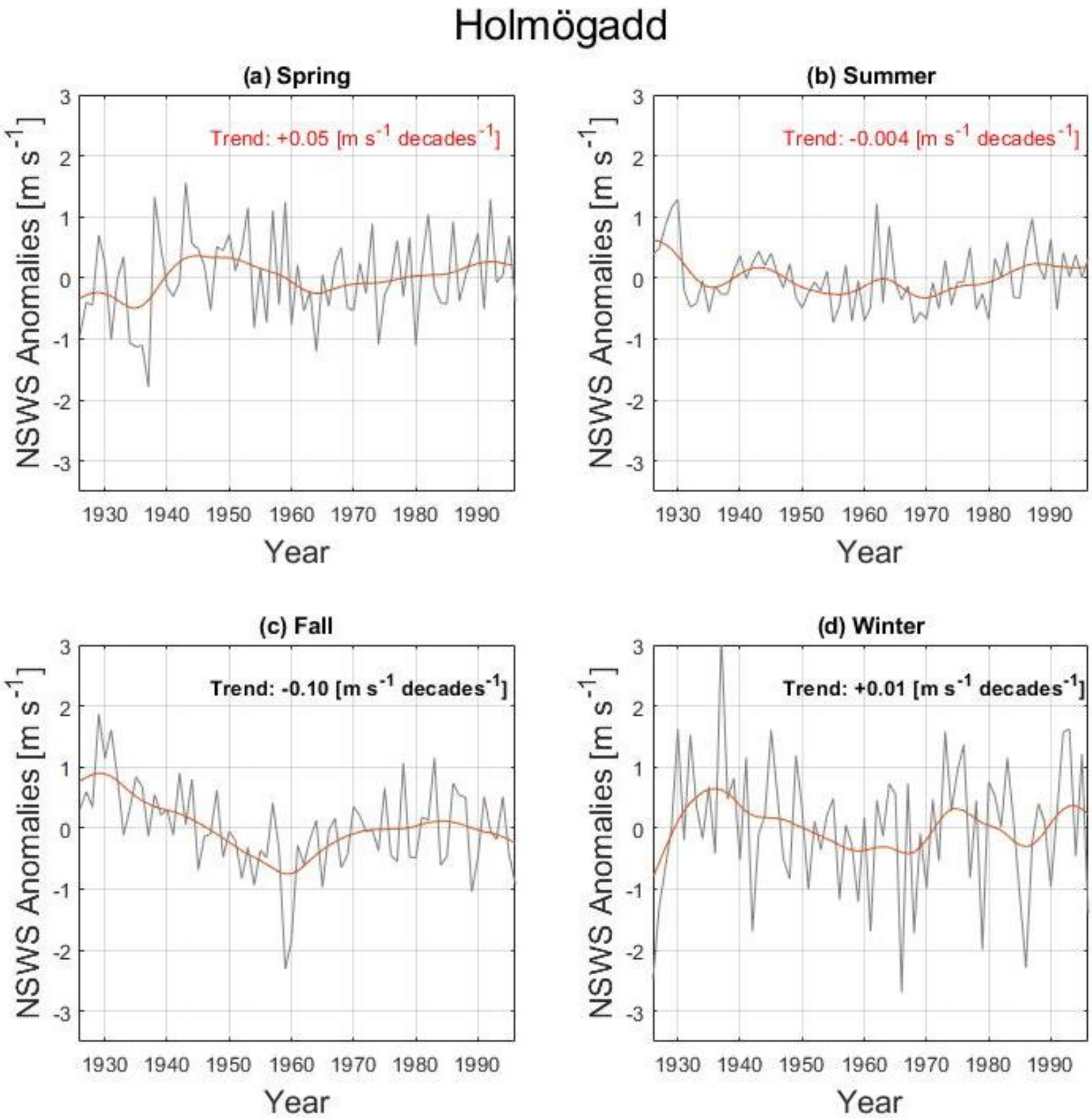

Figure S7. *Series of Holmögadd station (black line) during 1926-1996 for the seasons Spring (March, April, May (a)), Summer (June, July, August (b)), Fall (September, October, November(c)) and Winter (December, January, February (d)). The low-frequency variability is with the applied Gaussian-weighted average filter (15-year window; red line). Wind speed anomalies are relative to the station mean for the each season. The 1926-1996 trend is reported in bold black font if statistically significant at $p < 0.05$, normal black font if statistically significant at $p < 0.1$ and normal red font if non-statistical significant at $p > 0.1$.*

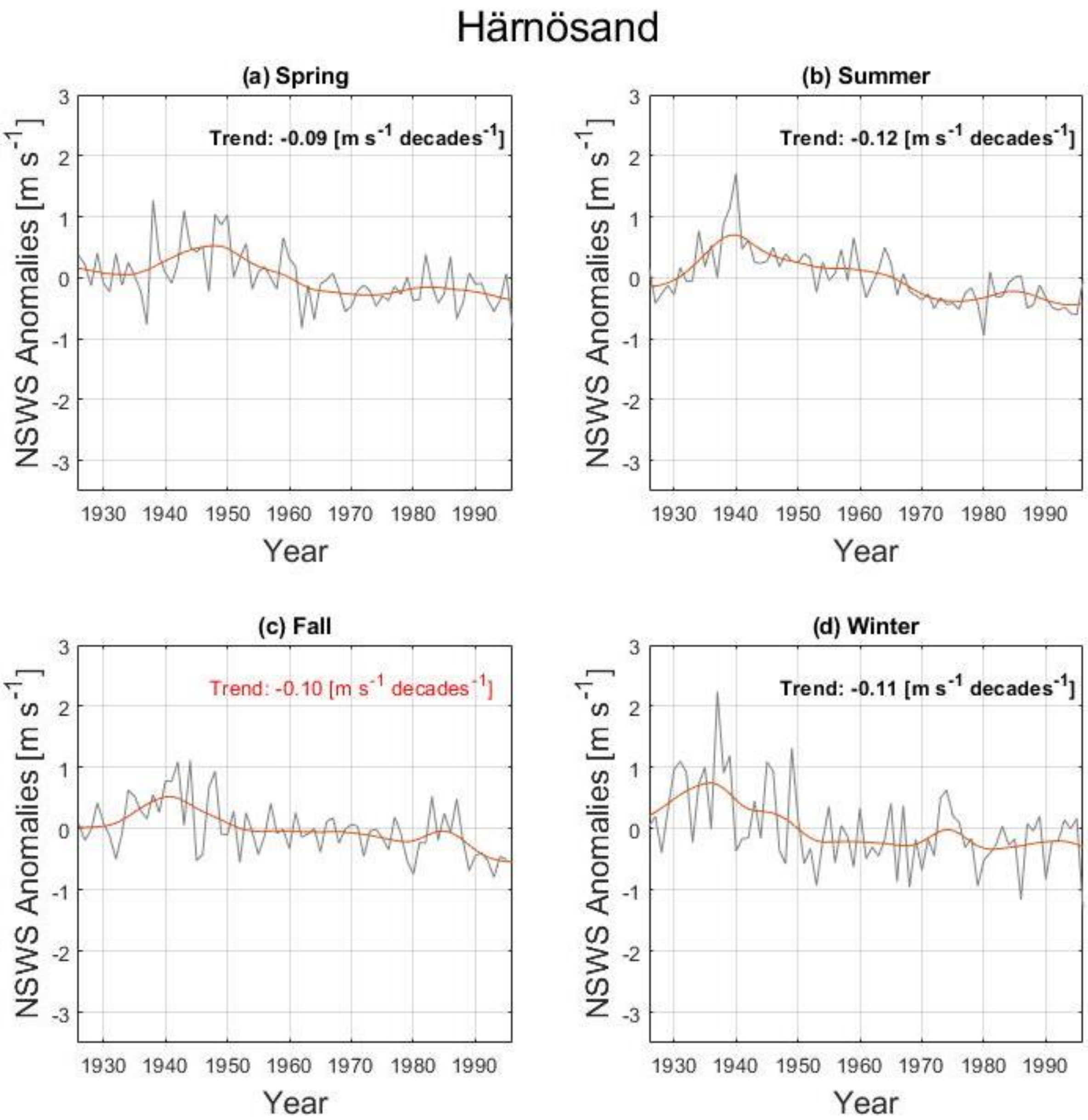

Figure S8. *Series of Härnösand station (black line) during 1926-1996 for the seasons Spring (March, April, May (a)), Summer (June, July, August (b)), Fall (September, October, November(c)) and Winter (December, January, February (d)). The low-frequency variability is with the applied Gaussian-weighted average filter (15-year window; red line). Wind speed anomalies are relative to the station mean for the each season. The 1926-1996 trend is reported in bold black font if statistically significant at $p < 0.05$, normal black font if statistically significant at $p < 0.1$ and normal red font if non-statistical significant at $p > 0.1$.*

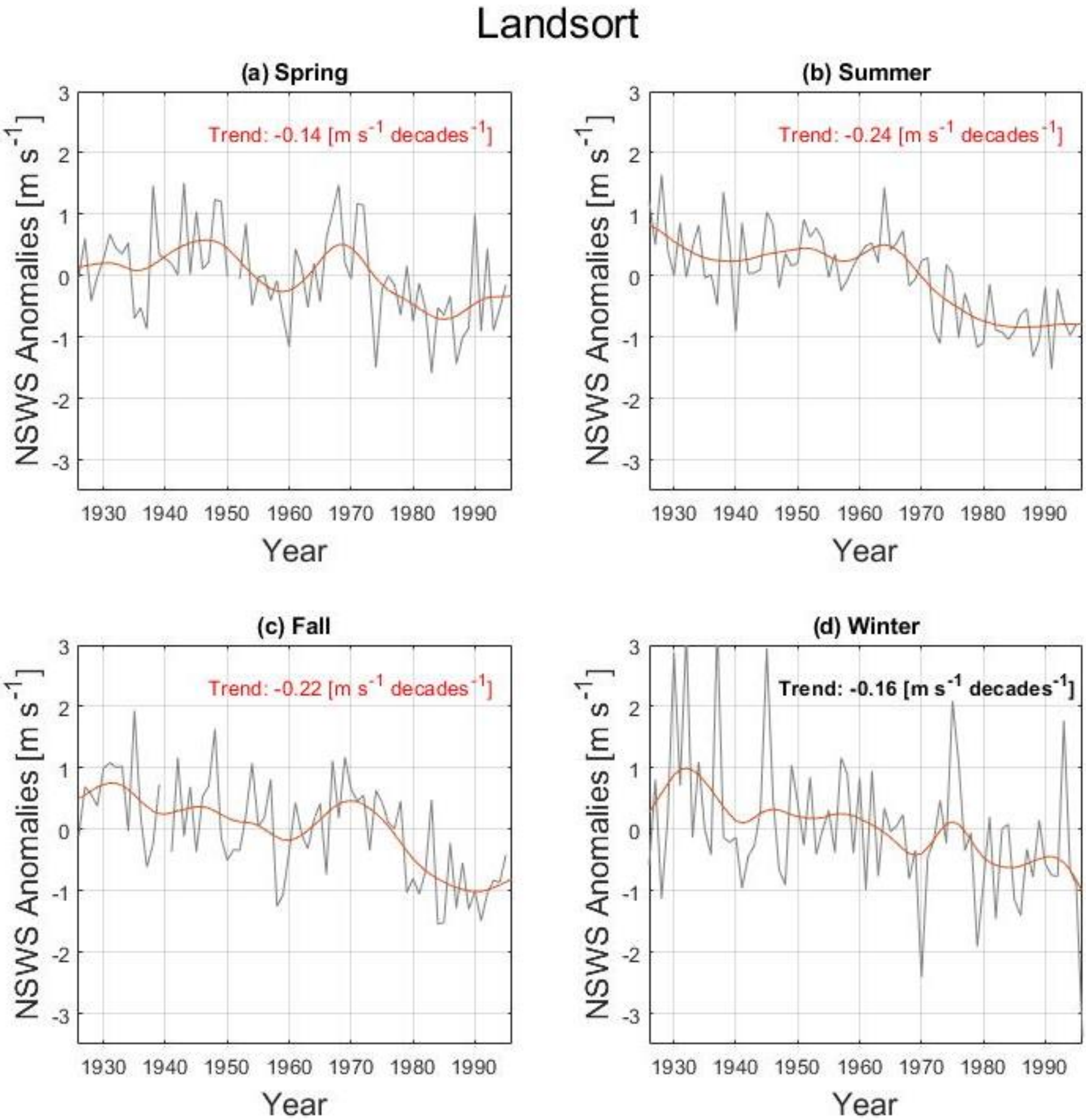

Figure S9. *Series of Landsort station (black line) during 1926-1996 for the seasons Spring (March, April, May (a)), Summer (June, July, August (b)), Fall (September, October, November(c)) and Winter (December, January, February (d)). The low-frequency variability is with the applied Gaussian-weighted average filter (15-year window; red line). Wind speed anomalies are relative to the station mean for the each season. The 1926-1996 trend is reported in bold black font if statistically significant at $p < 0.05$, normal black font if statistically significant at $p < 0.1$ and normal red font if non-statistical significant at $p > 0.1$.*

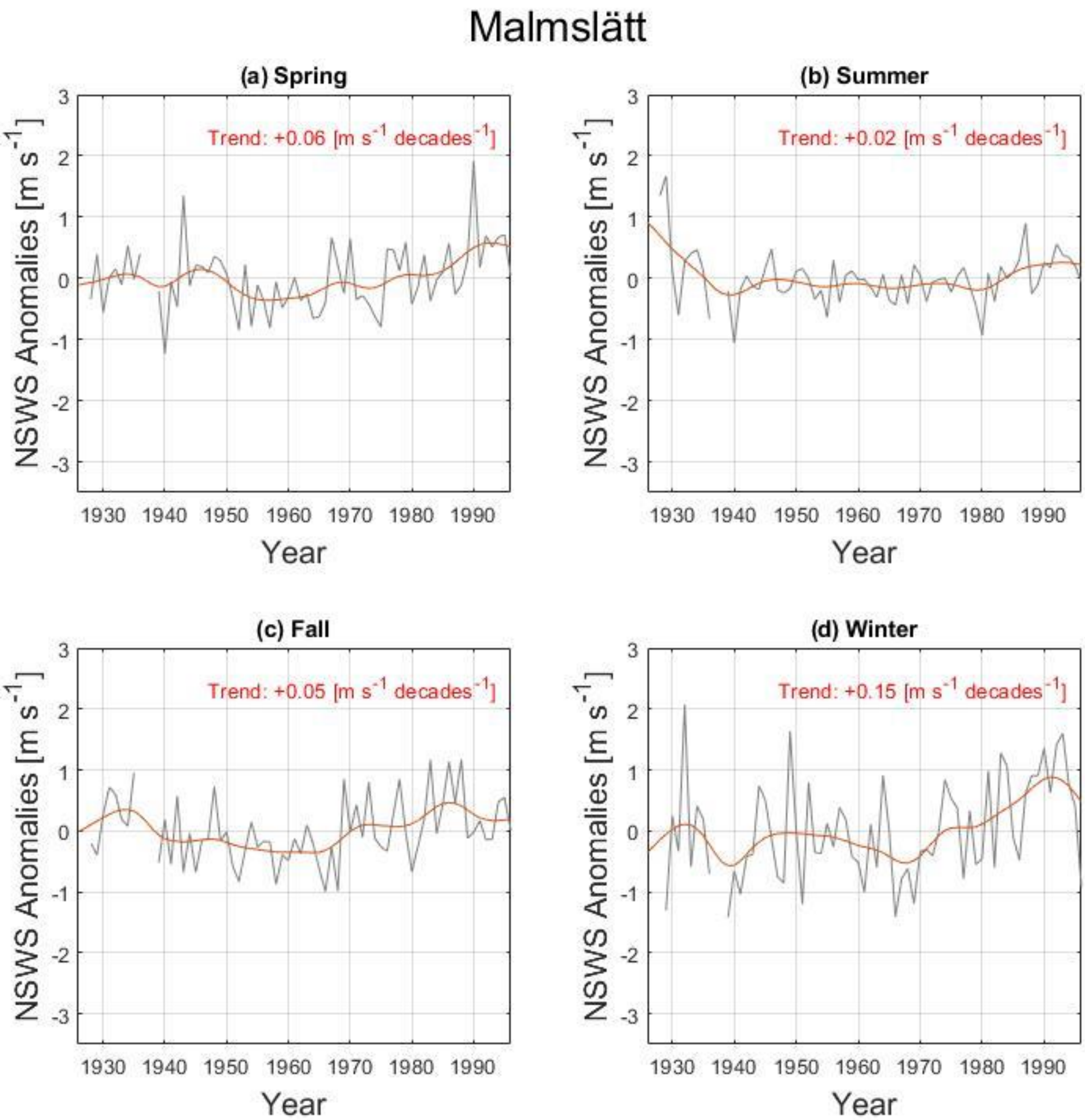

Figure S10. *Series of Malmslätt station (black line) during 1926-1996 for the seasons Spring (March, April, May (a)), Summer (June, July, August (b)), Fall (September, October, November(c)) and Winter (December, January, February (d)). The low-frequency variability is with the applied Gaussian-weighted average filter (15-year window; red line). Wind speed anomalies are relative to the station mean for the each season. The 1926-1996 trend is reported in bold black font if statistically significant at $p < 0.05$, normal black font if statistically significant at $p < 0.1$ and normal red font if non-statistical significant at $p > 0.1$.*

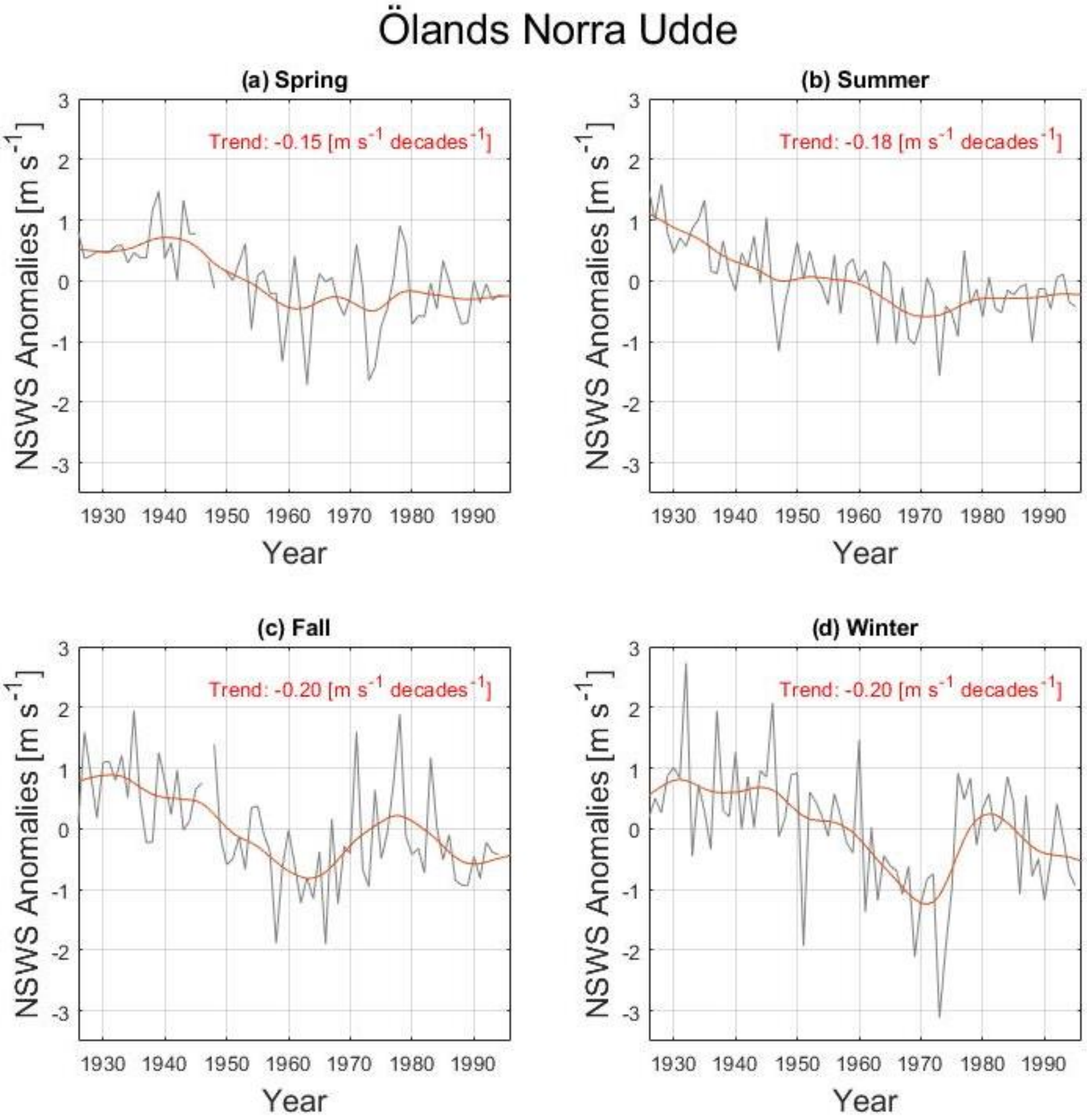

Figure S11. *Series of Ölands station (black line) during 1926-1996 for the seasons Spring (March, April, May (a)), Summer (June, July, August (b)), Fall (September, October, November(c)) and Winter (December, January, February (d)). The low-frequency variability is with the applied Gaussian-weighted average filter (15-year window; red line). Wind speed anomalies are relative to the station mean for the each season. The 1926-1996 trend is reported in bold black font if statistically significant at $p < 0.05$, normal black font if statistically significant at $p < 0.1$ and normal red font if non-statistical significant at $p > 0.1$.*