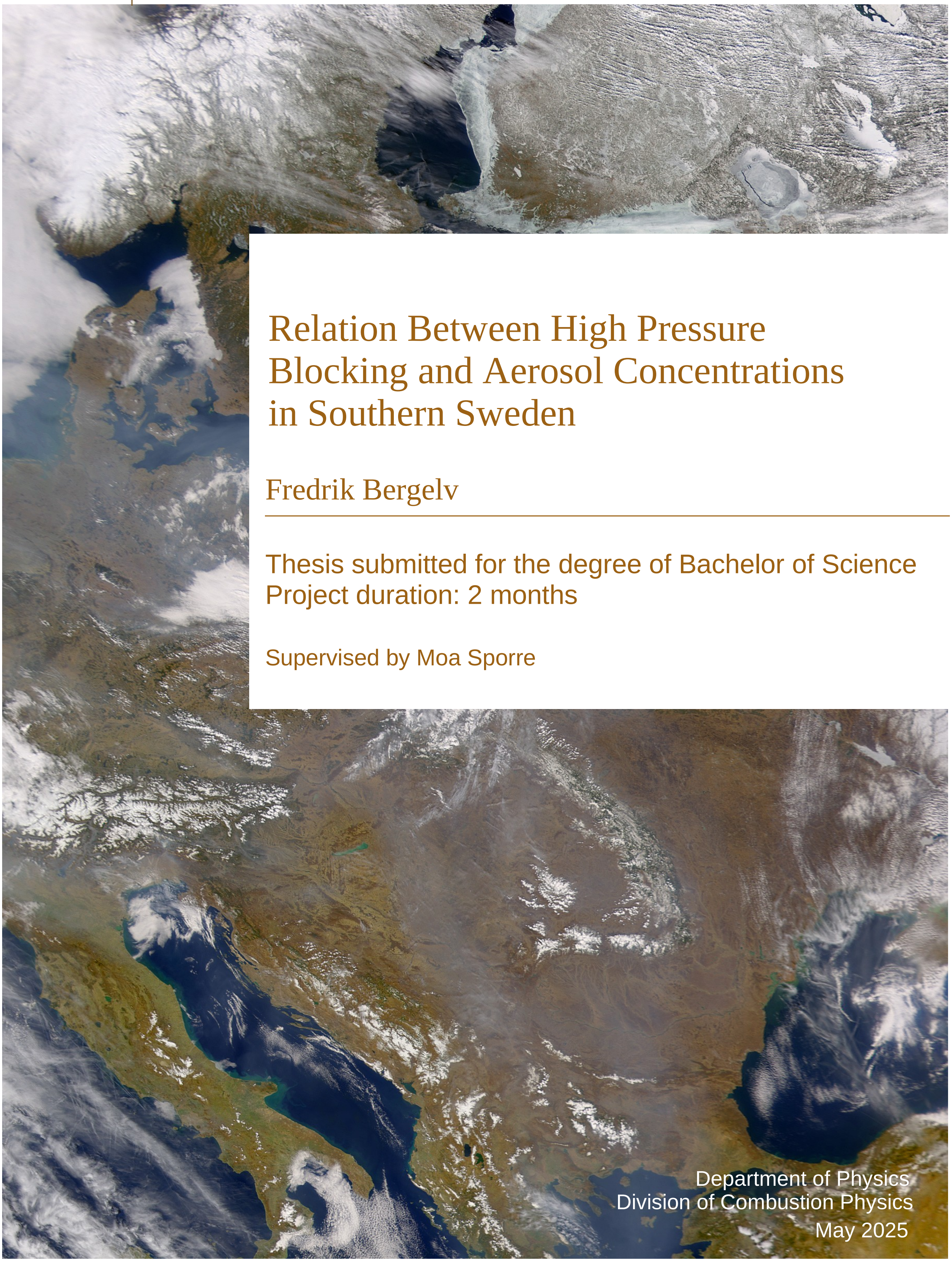
FACULTY
OF SCIENCE



Relation Between High Pressure Blocking and Aerosol Concentrations in Southern Sweden

Fredrik Bergelv

Thesis submitted for the degree of Bachelor of Science
Project duration: 2 months

Supervised by Moa Sporre

Department of Physics
Division of Combustion Physics
May 2025

Acknowledgments

Thank you...

Cover photo taken by SeaWiFS Project, NASA, on March 28 2003 [1].

Abstract

Abstract...

Contents

1 Introduction

It is common knowledge that Earth's increasing temperature has many side effects. One such effect is the increase in frequency of extreme weather phenomena [2]. One such phenomenon, which lacks extensive research, is high-pressure blocking. High-pressure blocking is an anticyclone that covers an area for a prolonged period of time and often blocks other types of weather, hence the name. This results in clearer weather and more extreme temperatures [3]. However, an anticyclone is also associated with lower air movement and wind, causing the air to remain stagnant. This can lead to an accumulation of aerosols such as $PM_{2.5}$ in the region [4].

To investigate the relationship between $PM_{2.5}$ and high-pressure blocking, one must analyze periods of high-pressure blocking and examine the concentration of $PM_{2.5}$ during these periods. The goal of this thesis is to analyze the concentration of $PM_{2.5}$ during periods of high-pressure blocking by examining data from the Swedish Meteorological and Hydrological Institute (SMHI) and $PM_{2.5}$ data from rural (Vavihill, Svalöv Skåne län) and urban (Malmö, Skåne län) areas.

2 Theory

2.1 The physics behind anticyclones

Anticyclones are meteorological high-pressure systems in which air sinks toward the ground, creating high pressure [5]. This occurs due to the convergence of air from all directions, which forces the air to move downward. The descending air undergoes adiabatic compression, resulting in an increase in the energy of air molecules, or, in other words, a higher temperature. This rise in energy inhibits cloud formation, as the air molecules are unable to ascend due to the lack of cooling. The absence of clouds allows solar radiation to significantly impact the temperature during an anticyclone. Consequently, this leads to a large temperature difference between day and night, with summer anticyclones associated with high temperatures and winter anticyclones with low temperatures. Due to the Coriolis effect, anticyclones rotate in a clockwise direction in the Northern Hemisphere.

more on anticyclones

A high-pressure blocking period refers to a prolonged anticyclone characterized by higher surface pressure covering a large area [3]. Since the blocking system extends over a vast region, the pressure gradient remains small due to minimal fluctuations. As a result, winds tend to be calm to gentle breezes. A blocking period is typically defined as lasting between five and ten days, although no single definition exists. While the concept has been recognized in meteorology for over a century, the long-term consequences of blocking events are not yet fully understood. High-pressure blocking periods are more common in the Northern Hemisphere compared to the Southern Hemisphere. Research has indicated that the frequency of blocking periods has increased in recent years [3].

Recurring anticyclones can be classified into Hess and Brezowsky (1977) macrocirculation types, such as the Fennoscandian High (Hfa), the Southeast Anticyclone (Sea), and the Central European High (HM) [6]. These anticyclones are commonly located at specific geographic points. Since anticyclones exhibit winds rotating clockwise around their center, the winds from (Hfa), (Sea), and (HM) tend to blow toward southern Sweden from the south and east. The transport of airborne pollutants, such as ozone, can occur via these winds [7]. Consequently, it can be hypothesized that other airborne aerosols, such as $PM_{2.5}$, should also be transported through these wind patterns.

Moving anticyclones

2.2 The physics behind PM 2.5

$PM_{2.5}$ refers to particulate matter with a diameter of 2.5 µm or less. Although these aerosols can form naturally in the atmosphere, their primary sources include solid fuel combustion for domestic heating, industrial activities, and road transportation [8]. A significant contributor to $PM_{2.5}$ pollution is the bonding of aerosols to ammonia emitted from agricultural activities. The European Union has set an annual mean limit for $PM_{2.5}$ concentrations at 25 $\mu g\,m^{-3}$. This threshold has been exceeded in several countries, including Croatia, Bosnia and Herzegovina, Italy, Poland, North Macedonia, and Türkiye [**?**]. Studies have demonstrated a correlation between elevated $PM_{2.5}$ concentrations and an increased risk of respiratory, cardiovascular, and cerebrovascular diseases, as well as diabetes.

Since $PM_{2.5}$ emissions are particularly high in countries such as Poland, anticyclonic winds from (Hfa), (Sea), and (HM) are expected to increase $PM_{2.5}$ concentrations in southern Sweden [8]. These aerosols would be transported to southern Sweden via southerly to easterly winds during the anticyclone. If this occurs during a high-pressure blocking event, the aerosols may accumulate over the region while continuously being advected by southerly and easterly winds. Studies in China have shown that the dispersion of aerosols during high-pressure blocking is inhibited [4]. Whether the same occurs in southern Sweden is of interest for further study.

2.3 The Mann-Kendall test

3 Method

The relevant data was downloaded from the SMHI's website as CSV files. These files included hourly atmospheric pressure data, hourly rain data, and hourly wind data (speed and direction). Hourly $PM_{2.5}$ data, measured over one-hour intervals, was also downloaded. Since the goal of this project is to analyze $PM_{2.5}$ concentrations in Southern Sweden during high-pressure blocking events, one urban and one rural site were selected. The locations were chosen based on their classification as rural or urban and the length of time the stations had been in operation, where more data was considered better.

The rural measuring station with the most data was Vavihill (Svalöv, Skåne County, Sweden). This station was active from September 28, 1999, to November 15, 2017. However, due to missing data on some days, only 57 % of the period contained non-NaN values. Additionally, between 2017 and 2018, the Vavihill station was relocated to nearby Hallahus, where it operated from May 10, 2018, to December 31, 2022, with 93 % of the period containing non-NaN values. Combining these datasets resulted in a total of 5,371 days of hourly data. For urban locations in Southern Sweden, Malmö had the most data, with measurements recorded from June 3, 1999, to December 31, 2023. Here, 90 % of the recorded values were non-NaN, resulting in 8,074 days of data.

The choice of atmospheric pressure measurement station was Helsingborg, located 25 km from Vavihill and 49 km from Malmö. This location was chosen based on its proximity to both $PM_{2.5}$ measuring stations, the fact that neither Malmö nor Vavihill have pressure measurements from this period, and the fact that the station has been in use from August 2, 1995, to October 10, 2024, with measurements taken every hour without any missing (NaN) values. This station thus covers the entire period of the $PM_{2.5}$ data. It is important to note that the measurements are shown as sea-level pressure.

The relevant rain and wind data were gathered from two different stations. For Vavihill, the station at Hörby, located 35 km away, was used, and for Malmö, a weather station just 6 km away was used. The weather station at Hörby was chosen instead of Helsingborg since neither Vavihill nor Hörby are located along the coast, whereas Helsingborg is. The wind and rain data from Hörby were measured from August 1, 1995, to October 1, 2020, with measurements taken every hour without any missing (NaN) values. It is important to note that the Hörby station was temporarily relocated for a short period in 2021. The rain data from Malmö was measured from November 21, 1995, and the wind data from January 1, 1990, with both measurements ending on December 31, 2020. These stations did not lack any data.

To evaluate when there was a high-pressure blocking event for Vavihill or Malmö, the rain data and atmospheric air pressure were used. For a period to be defined as a high-pressure event, the atmospheric pressure had to be over 1014 hPa, and the rainfall had to be less than $0.5\,\mathrm{mm\,h^{-1}}$. These values were based on the fact that 1014 hPa was the mean atmospheric pressure from Helsingborg, and $0.5\,\mathrm{mm\,h^{-1}}$ was chosen since this is considered light rain. For a high-pressure event to be considered a high-pressure blocking event, the criteria for a high-pressure event had to persist for at least 120 h (5 days). This value was chosen since a 5-day limit is often considered when classifying high-pressure blocking events.

The data was analysed by taking the mean and standard deviation of each hour of the high-pressure blocking event, from hour one, to evaluate the average progression of a blocking over time using the Python packages `NumPy` and `pandas`. Since the blocking events varied in length, the number of data points was also plotted, with the requirement that each hour consist of at least 8 data points. This resulted in a plot of the mean concentration of $PM_{2.5}$ for every hour from the beginning of the blocking period, for both Vavihill and Malmö. All of the $PM_{2.5}$ plots were evaluated together with the mean value when there was no blocking and the EU annual mean limit for $PM_{2.5}$.

Afterwards, the data was sorted in different ways to explore how the $PM_{2.5}$ concentration depended on different parameters. Firstly, the data was sorted into one of four wind categories: North-East (310° to 70°), South-East (70° to 190°), West (190° to 310°), and no specific direction. This was done by categorizing the data if 60 % of the wind directional data fell into one of these categories, with no wind being handled as a NaN value.

Secondly, the data was sorted based on the season of the blocking. This was evaluated by taking the midpoint date of the blocking and categorizing the season by the month it occupied. December, January, and February were considered winter; June, July, and August were considered summer; and spring and autumn were the remaining months. Lastly, the data was categorized based on the strength of the high-pressure blocking, where a weak high-pressure blocking event had a mean atmospheric pressure between 1014 hPa and 1020 hPa, a medium-strength blocking event had a mean atmospheric pressure between 1020 hPa and 1025 hPa, and a strong blocking event had a mean atmospheric pressure over 1025 hPa.

To evaluate if the plots produced significant results, two tests were performed. The first test compared the mean and standard deviation of $PM_{2.5}$ during high-pressure blocking events with the mean and standard deviation during periods without high-pressure blocking. Secondly, the Mann-Kendall test was performed to evaluate whether the $PM_{2.5}$ mean during high-pressure blocking events had actually increased, and if so, by how much. This was done by assessing whether the p-value was below 0.05 and whether τ was above 0.5.

The second task was to evaluate whether high-pressure blocking events had become increasingly more common. This was evaluated in two different ways: by calculating the number of high-pressure blocking events per year, and the number and lengths of high-pressure blocking events per year. The number of days of blocking was also sorted by the season of the blocking to provide more insight into the nature of the high-pressure blocking events. For this evaluation, atmospheric pressure data from Ängelholm was used instead of Helsingborg due to the pressure data from Ängelholm being active from January 5, 1946, to October 1, 2024, meaning it has been in service for 49 years longer than that from Helsingborg. This station is located 44 km from Vavihill and 76 km from Malmö. However, the pressure values differed only by a mean of 0.25 hPa and a standard deviation of 0.20 hPa. The rain data was also expanded by using rain data from Örja since this data was gathered from September 1, 1986, to December 8, 1992. Thus, the rain data was used together with Hörby to categorize high-pressure blocking events over a large period of time. The Örja station was located 14 km from Vavihill and 32 km from Malmö.

3.1 The meteorological measuring devices

The wind data from both Hörby and Helsingborg used the high-performance wind sensor Vaisala WAA15A for the wind speed and Vaisala WAV15A for the wind direction. These instruments were serviced and calibrated every year or every other year, and had been in use since 1995. The WAA15A anemometer measured wind speed with an accuracy of 0.17 $m\,s^{-1}$, and the WAV15A wind vane measured the wind direction with an accuracy better than 3°[9]. The WAA15A anemometer works by a rotating chopper disc that interrupts an infrared beam, resulting in a laser pulse proportional to the wind speed. The WAV15A wind vane uses a counterbalanced vane with an optical disc. When the vane turns, infrared LEDs detect the change in angle with the disc and phototransistors, resulting in a precise measurement of the wind angle. For rain monitoring, the Geonor T200 device had been in use for all stations since 1995. Like the wind monitor, this device had been serviced and calibrated every year or every other year. This device works by measuring precipitation with a vibrating wire sensor that detects weight changes from the water droplets[10]. The device has a measurement accuracy better than 0.1 mm.

The barometer that has been in use for Helsingborg is a Vaisala PTB201A for the entire period, except for the periods from April 15, 2015, to April 17, 2025, and from September 19, 2004, to May 23, 2014, when a Vaisala PTB220 was used instead. Even then, the device has been serviced every year or every other year. The PTB201A digital barometer operates using a silicon capacitive absolute pressure sensor, providing stable and accurate pressure values [11]. The sensor functions by means of a flexed diaphragm inside a capacitor that bends in response to air pressure, causing a change in the capacitor's distance and thus a variation in the current. This device measures pressure in the range of 600 hPa to 1100 hPa, with an accuracy of 0.3 hPa. Errors in the device may arise due to environmental factors, such as exposure to condensing gases. The Vaisala PTB220 digital barometer operates in a similar manner but offers a wider measurement range of 500 hPa to 1100 hPa, with an improved accuracy of 0.15 hPa [12].

How was wind and rain in Malmö measured?

How was pressure in Ängelholm and rain in Örja measured?

what PM2.5 measurement devices was used in Vavihill/ Malmö?

4 Result

4.1 The evolution of PM 2.5 over time

The first part of the goals mentioned above has been achieved using Pandas in Python by extracting periods of high-pressure blocking based on a pressure limit and a rainfall limit. The pressure limit was chosen to be 1015 hPa, meaning that a high-pressure blocking event must maintain at least 1015 hPa throughout the entire period. The rainfall limit was set to 0.5 mm, meaning the period can have a maximum of 0.5 mm rainfall during the entire period. The minimum period length was set to 5 days. The result during the year 2001 can be seen in Figure 1.

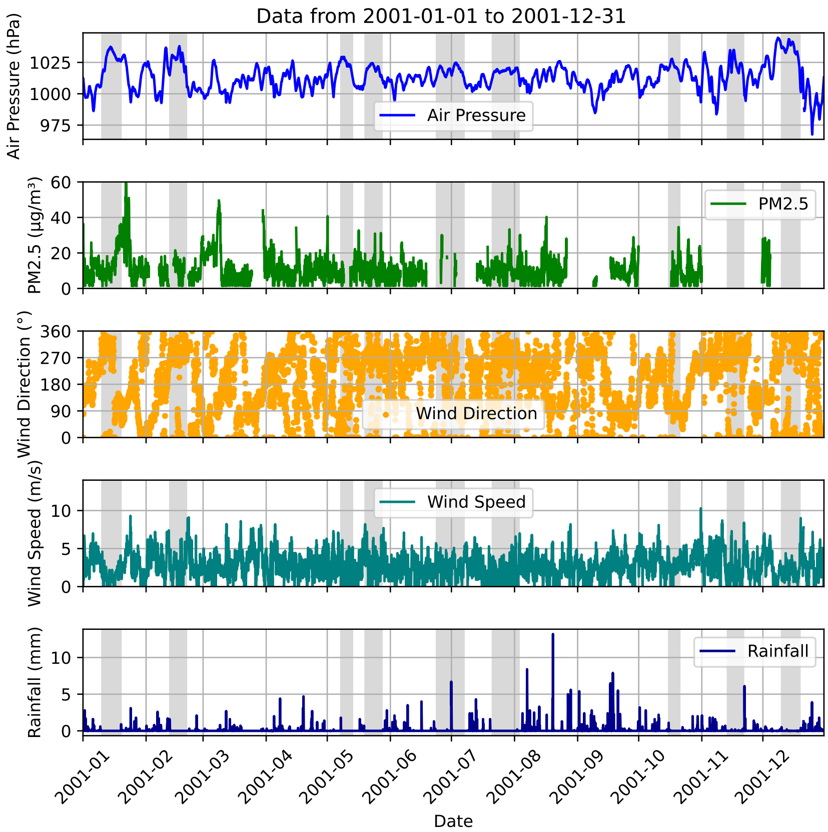
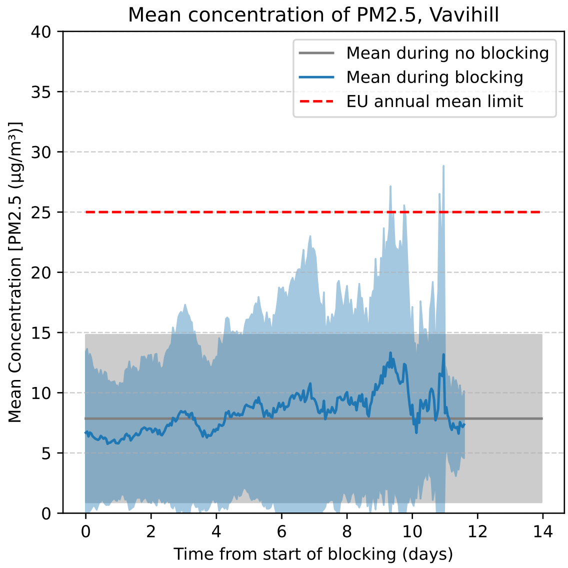
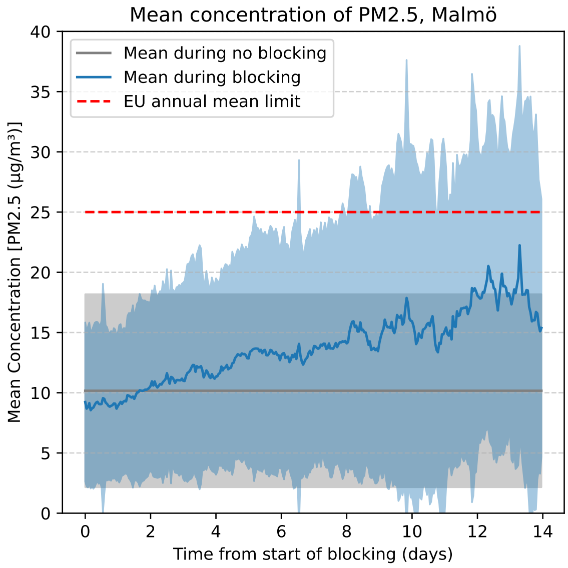


Figure 1: This example plot displays the air pressure, $PM_{2.5}$ concentrations, wind direction, wind speed, temperature and rainfall during the year 2001. The periods which was filtered as periods of high pressure blocking are shown in gray.

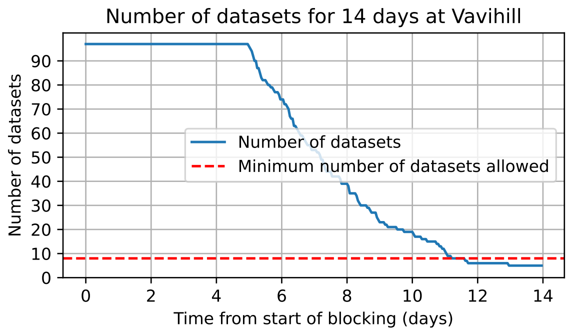
The second task was to evaluate the $PM_{2.5}$ concentrations during periods of high pressure blocking using statistics. This was done by taking the mean of all the different blockings displaying this together with the standard deviation. This can be seen in Figure 2. The data is compared with the overall mean taken from the data. A slight increase in the normal concentrations of $PM_{2.5}$ can be seen in Malmö, while the same is hard to say about Vavihill.



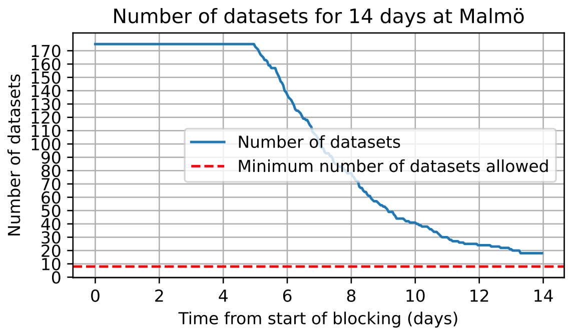
(a) This figure shows the mean $PM_{2.5}$ concentrations over time in Vavihill. The data is analyzed to observe trends and variations in air pollution levels in a rural setting.



(b) This figure shows the mean $PM_{2.5}$ concentrations over time in Malmö. The data is analyzed to observe trends and variations in air pollution levels in an urban environment.



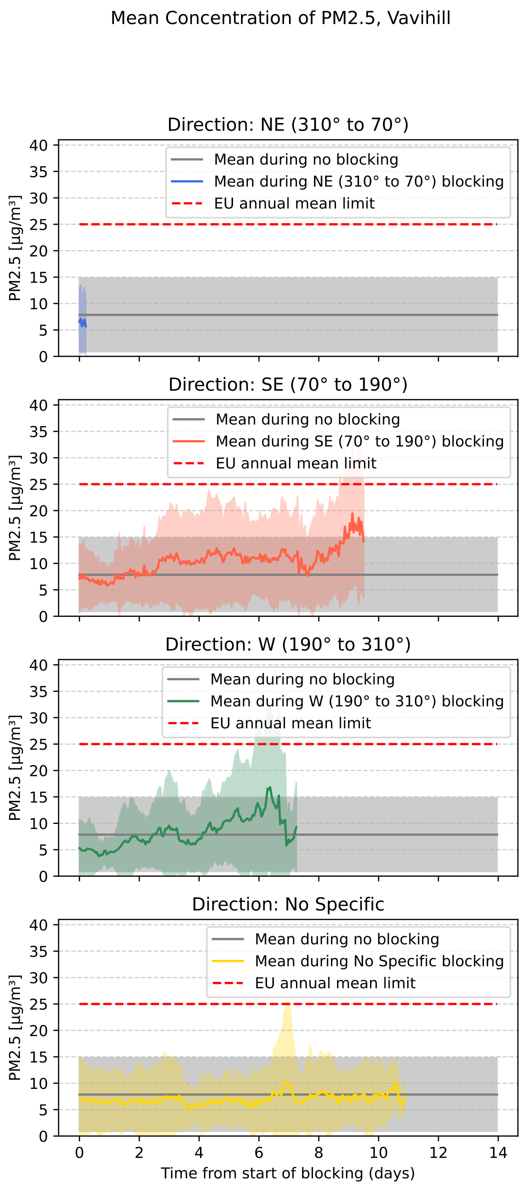
(c) This plot shows the number of datatsets used per day for the calculation above at Vavihill.



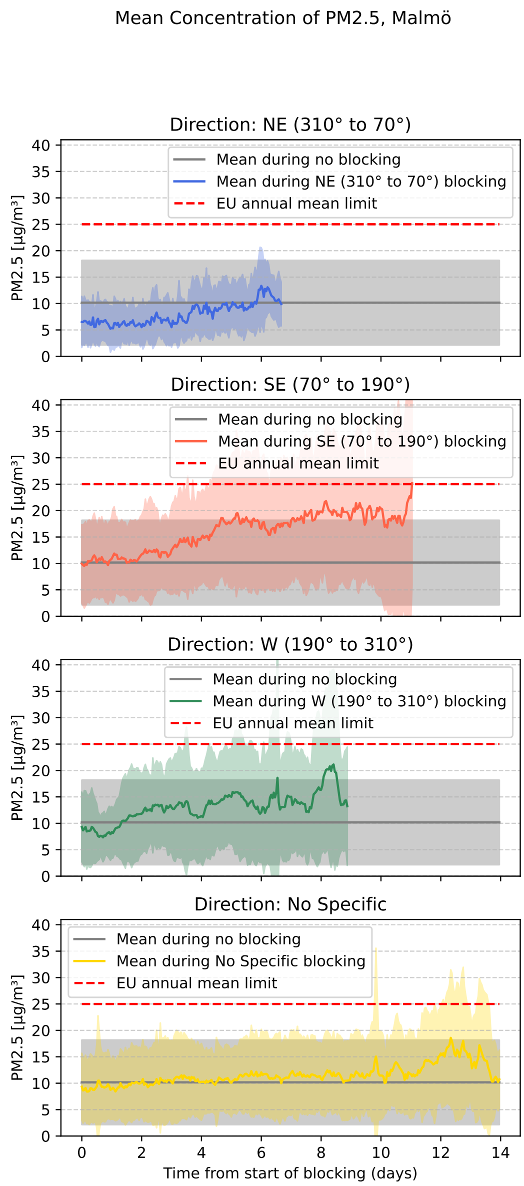
(d) This plot shows the number of datatsets used per day for the calculation above at Malmö.

Figure 2: Comparison of mean $PM_{2.5}$ concentrations in Vavihill and Malmö, highlighting differences between rural and urban air quality.

Figure 3 shows the increase in $PM_{2.5}$ concentrations in vavihill and Malmö for different wind directions. Even though the Concentration increased more in Malmö than in Vavihill, the directional dependence is less prominent.This may suggest that the accumulation of $PM_{2.5}$ in Malmö may be due to the local emissions in Malmö being much greater than those in Vavihill, while the increase of $PM_{2.5}$ in Vavihill may be more to the aerosols being transported to the area via the anticyclonic winds.

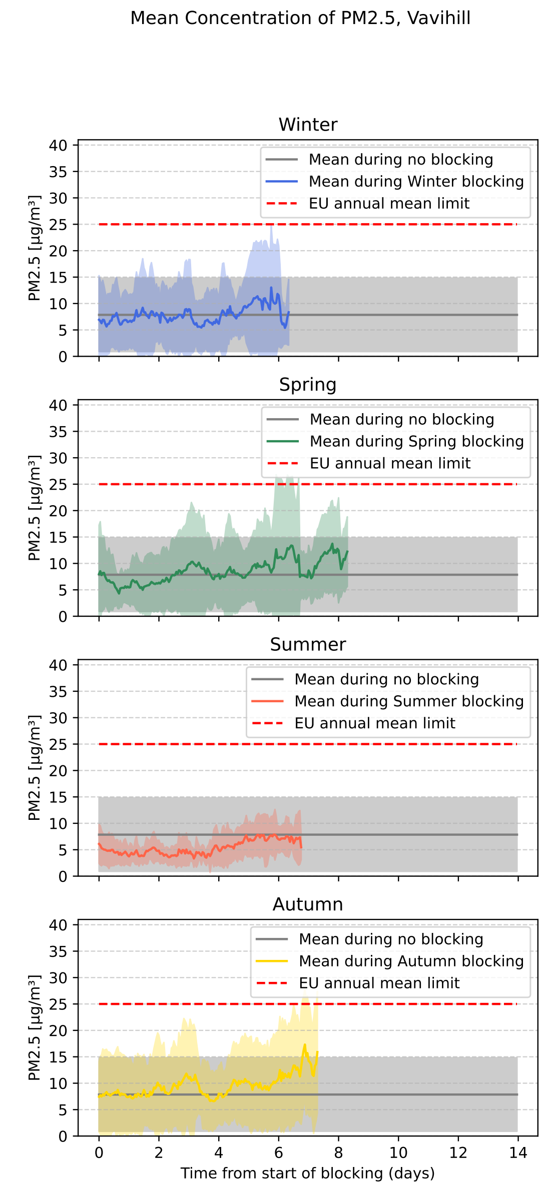


(a) These plots show how $PM_{2.5}$ concentrations change in Vavihill for different wind directions. It is important to note that 4.9% of the winds came from the Northeast (310° to 70°), 27.2% from the Southeast (70° to 190°), 18.5% from the West (190° to 310°) and 49.4% from no specific direction.

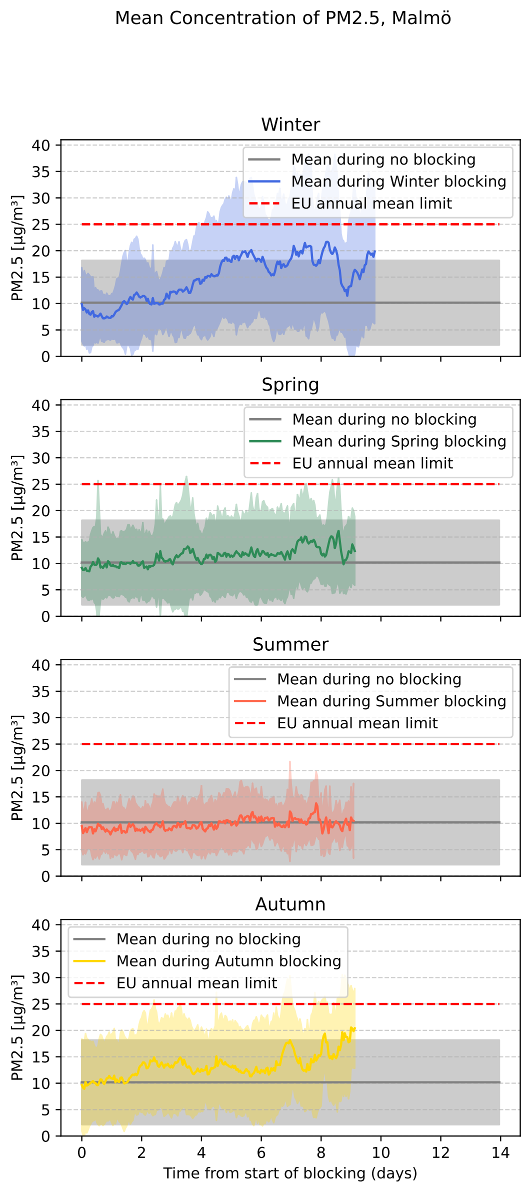


(b) These plots show how $PM_{2.5}$ concentrations change in Malmö for different wind directions. It is important to note that 5.2% of the winds came from the Northeast (310° to 70°), 26.6% from the Southeast (70° to 190°), 22.1% from the West (190° to 310°) and 46.1% from no specific direction.

Figure 3: Comparison of $PM_{2.5}$ concentrations in Vavihill and Malmö for different wind directions. Note that a minimum number of datasets was still put to 8, resulting in some directions having very little data.

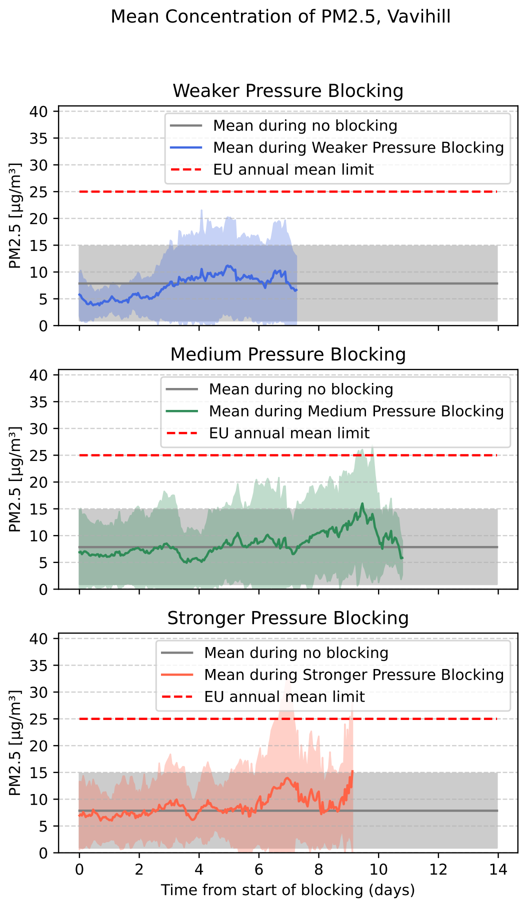


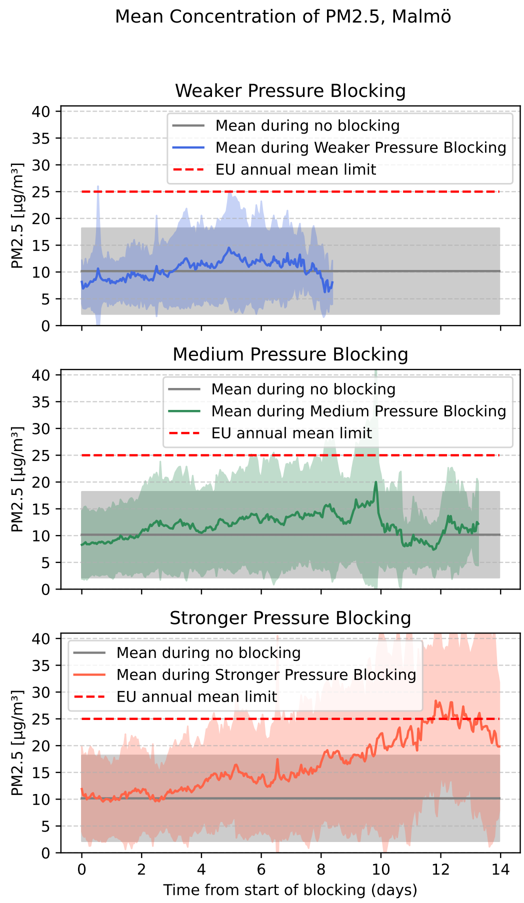
(a) These plots show how $PM_{2.5}$ concentrations change in Vavihill for different seasons. It is important to note that 21.3% of the blockings occured during the winter, 37.7% during the spring, 16.4% during the summer and 24.6% during the autumn.



(b) These plots show how $PM_{2.5}$ concentrations change in Malmö for different seasons. It is important to note that 26.4% of the blockings occurred during the winter, 33.1% during the spring, 18.2% during the summer and 22.3% during the autumn.

Figure 4: Comparison of $PM_{2.5}$ concentrations in Vavihill and Malmö for different seasons. Note that a minimum number of datasets was still put to 8.





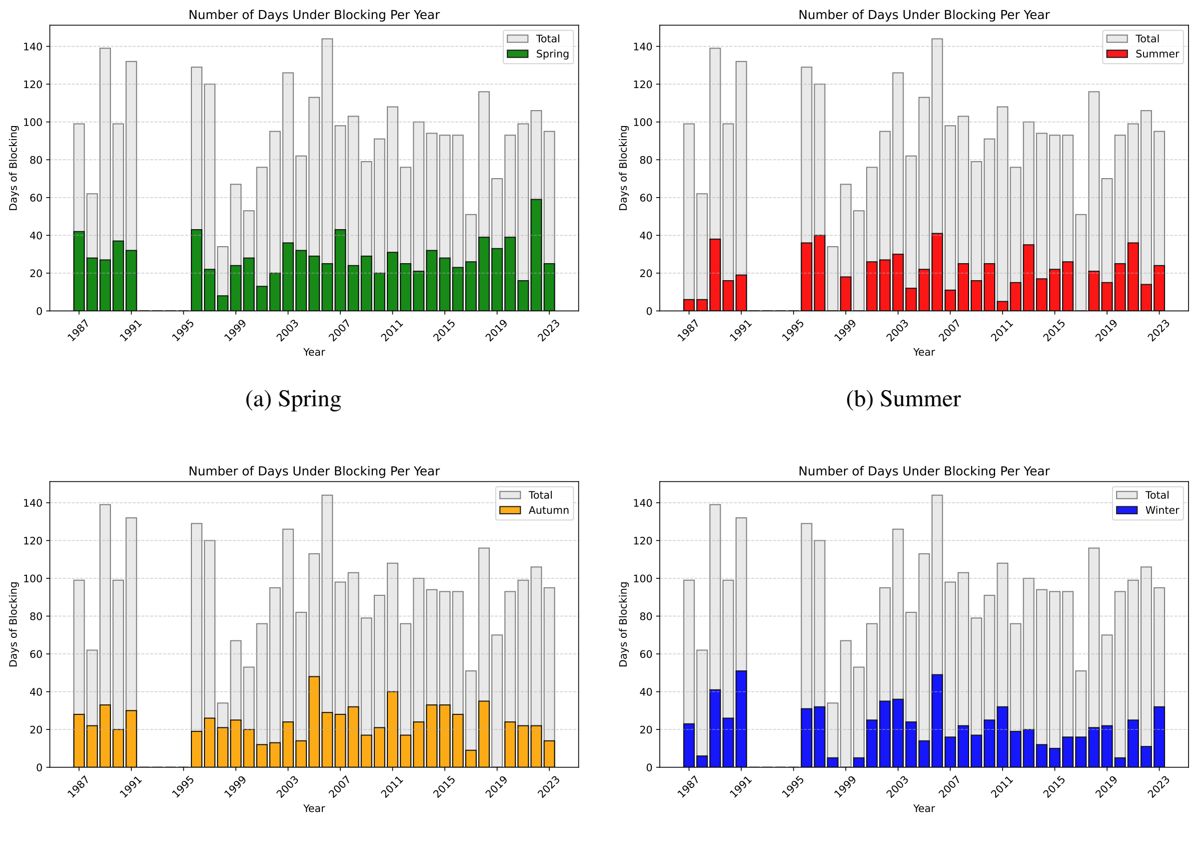
(a) These plots show how $PM_{2.5}$ concentrations change in Vavihill for different seasons. It is important to note that 11.1% of the blockings occurred with a mean pressure below 1020 hPa 46.9% occurred between 1020 and 1025 hPa and 42.0% occurred with a mean pressure over 1025hPa.

(b) These plots show how $PM_{2.5}$ concentrations change in Malmö for different seasons. It is important to note that 10.4% of the blockings occurred with a mean pressure below 1020 hPa 50.0% occurred between 1020 and 1025 hPa and 39.6% occurred with a mean pressure over 1025hPa.

Figure 5: Comparison of $PM_{2.5}$ concentrations in Vavihill and Malmö for different strength of the high pressure blocking. Note that a minimum number of datasets was still put to 8.

4.2 The frequency of high pressure blocking events

The last task was to determine if the number of days under high-pressure blockings has increased, in Figure 6, it can be seen that this is not the case. The seasonal dependency was also accounted for, which can be observed in the plots.



(a) Spring (b) Summer

(c) Autumn (d) Winter

Figure 6: Histograms for different seasons.

One can in Figure 7 see that the number of events with high pressure blocking per year has also not increased.

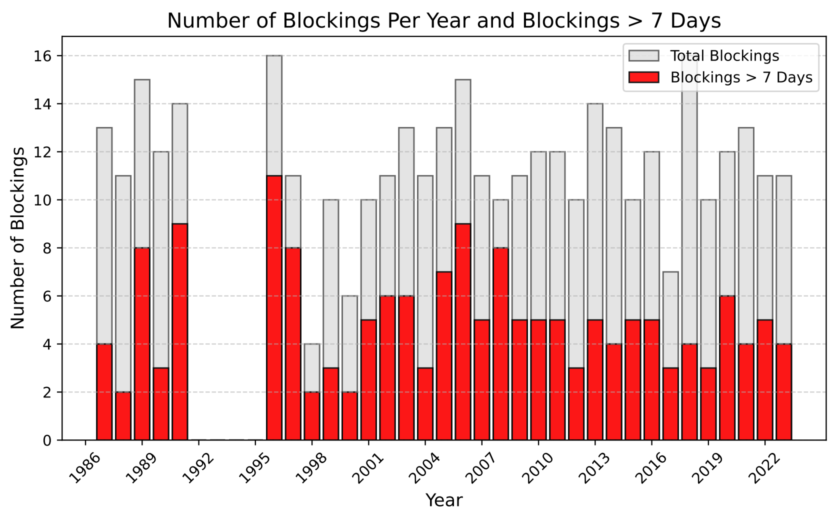


Figure 7: This figure shows the number of high-pressure blockings per year, highlighting any trends or variations over time.

5 Discussion

6 Conclusion

7 Outlook

References

[1] NASA. Haze over Europe. https://earthobservatory.nasa.gov/images/11219/haze-over-europe, March 2003.

[2] John F. B. Mitchell, Jason Lowe, Richard A. Wood, and Michael Vellinga. Extreme events due to human-induced climate change. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 364(1845):2117–2133, 2006.

[3] Anthony R. Lupo. Atmospheric blocking events: A review. https://nyaspubs.onlinelibrary.wiley.com/doi/abs/10.1111/nyas.1455 December 2020.

[4] Wenyue Cai, Xiangde Xu, Xinghong Cheng, Fengying Wei, Xinfa Qiu, and Wenhui Zhu. Impact of "blocking" structure in the troposphere on the wintertime persistent heavy air pollution in northern China. *Science of The Total Environment*, 741:140325, 2020.

[5] Vlado Spiridonov and Ćurić Mladjen. Cyclones and Anticyclones | SpringerLink. https://link.springer.com/chapter/10.1007/978-3-030-52655-9_17, November 2020.

[6] Judit Bartholy, Rita Pongracz, and Margit Pattantyús-Ábrahám. European Cyclone Track Analysis Based on ECMWF ERA-40 Data Sets. *International Journal of Climatology*, 26(11):1517–1527, 2006.

[7] Noelia Otero, Oscar E. Jurado, Tim Butler, and Henning W. Rust. The impact of atmospheric blocking on the compounding effect of ozone pollution and temperature: A copula-based approach. *Atmospheric Chemistry and Physics*, 22(3):1905–1919, 2022.

[8] European Environment Agency. Europe's air quality status 2024. https://www.eea.europa.eu/publications/europes-air-quality-status-2024, 2024.

[9] VAISALA. Wind Set WA15 and WA25. https://www.vaisala.com/en/products/weather-environmental-sensors/wind-set-wa15, January 2021.

[10] GEONOR, Inc. T-200B Series All Weather Gauge. https://www.geonor.com/t-200b-all-weather-precipitation—rain-gauge, 2019.

[11] VAISALA. PTB 200 DIGITAL BAROMETERS USER'S GUIDE, February 1993.

[12] VAISALA. PTB220 Series Digital Barometers USER'S GUIDE, August 2001.