Department of Biological and Environmental Science

‘’Sources of birch pollen from April to June 2023 registered at 3 monitoring sites in Sweden. Does a currently used automated forecast model agree with realized pollen concentrations?’’

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Image source: Medical University of Viena, 2018

Abstract

Allergies caused by birch pollen seem to irritate around 22% of the population in Europe and Sweden, making a priority for creating forecasting models of pollen concentrations to assist people preparing for every year's allergy season. Lot of studies have been conducted regarding the allergens of the pollen and how they affect human health , while other studies are focusing on different environmental parameters that could affect the release of the pollen in the atmosphere but also, how these parameters can interact with the pollen concentrations while they are transferring from one area to another. This master thesis aims to be a part of a bigger study regarding the pollen existence in the atmosphere. The study is focusing on the pollen season of 2023 , starting on around 3rd week of April and ending around 2nd of June and concerns the areas of Göteborg, Malmö and Umeå. The choice was made due to their geographical areas since Umeå is in the North , Malmö is in the South and Göteborg is South -central. It is a comparison between the measurements of real concentrations of pollen and the model concentrations of the SILAM program with the aim of detecting differences and trying to explain with the use of statistics why the difference between the concentrations occurs. Due to the fact that a number of meteorological parameters are affecting the pollen concentrations in the atmosphere, relative humidity was chosen to be studied, with the aim of detecting correlations of this parameter with the pollen concentrations. The results concluded to a difference between the model and real pollen concentrations, with the model predicted significantly higher than the real for all the areas, with a moderate to strong correlation between them as well. The correlations between real pollen concentrations and real relative humidity concluded to a very weak and negative relationship, while comparisons between model values as well as ,between real relative humidity values with model pollen concentrations, presented weak but both negative and positive relationships. So the study indicated that most likely the relative humidity was not the cause for the differences between the forecasted and the registered pollen concentrations.

Keywords: *Birch pollen, Betula species, SILAM, relative humidity, allergy, forecasts*

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Chapter 1: Introduction

1.1 Background

Aerobiology studies the transport, behavior and survival of organic particles such as bacteria, fungal spores, pollen grains, and viruses. *(Beggs, et,al, 2017).* Sweden has some of the oldest pollen laboratories (established in 1975) in Europe. The researchers of the Department of Biology and Environmental Science that working at the domain of aerobiology have been focusing on the airborne pollen and the plants that create it, as well as the way that the pollen travels through the air, the duration that it remains on the atmosphere and the distance it can cover. *(University of Gothenburg, 17/04/2024)* Many studies have been made in the fields of ecology, phenology, as well as aerobiology, and medicine regarding pollen and the plants that produce it. This thesis, focuses on birch pollen. Birch trees usually live until 90-100 years and in rare cases up to 150 years. *(Beck et.al,2016).* Species of birch trees such as the silver birch (*Betula pendula*) and the downy birch (*Betula pubescens*) occur in Northern areas. They are in Eurasia present from the mountains of Southern Europe up to the Northern Fennoscandia, and to Siberia in the east. (*Euforgen, 05/03/2024).* They are also found along the eastern coast of Asia and in North America. (*Sofiev,Siljamo et.al, 2013).* Birches are one of the most prevalent species of deciduous trees in Southern Scandinavia. *(Dahl et, al., 1996).* Silver birch trees *(Betula pendula)* can usually be found in well-drained and drier soils, whereas downy birch trees *(B. pubescens)* are usually detected in wetter areas. *(Newham, et.al, 2013).* Birch trees are very common to be found in urban areas. In Scandinavian countries, it has been recorded that in peak days the pollen concentrations can be above 4000 grains/m3 *(Caillaud, et.al, 2014)*; in fact, the record for Göteborg is 13000 grains/m^3. Also, it is recorded that birch trees can produce large amounts of pollen. (*Maya-Manzano et,al. 2021)* It is estimated that one male *Betula pendula* flower can create around 22000 pollen grains, but an inflorescence with 450 flowers is estimated to create about 10 million grains. *(Piotrowska, et.al, 2012).* According to *Jato, et.al, 2006,* the atmospheric pollen season is the time of year when pollen is prevalent in the atmosphere. Pollen discharge in *Betula pendula* lasts on average about 10 days and in *Betula pubescens* about 15 days, but the largest amount of pollen, around 70-80%, is being released within the first week through, this fact depends a lot on the weather (*Piotrowska, et.al, 2012).*

Birch trees are wind-pollinated, which means that they release a large amount of pollen into the atmosphere to ensure that the pollen will be enough to reach and fertilize the female parts of other trees. (*Sofiev,Siljamo et.al, 2013).* Pollen grains are being transferred through the air, and both the vertical and the mechanical turbulence as well as the force of the wind are responsible for how far the pollen will be transferred. Also, pollen grain is removed from the atmosphere by dry and wet deposition. (*Sofiev, et al. 2013)*. The highest concentration of pollen grains in the atmosphere appears when the weather is dry and warm because these weather conditions make the anthers to mature faster.*(Bartková-Ščevková, 2003)* The tree species of the north are used to survive in a four-season cool climate, so an increasingly warmer climate could affect their growth and functions. (*Oksanen, E. ,2021).* During the last decade, a number of studies observed an increase in birch pollen amount which has been connected to climate change. *(Bjerg et al., 2016; Kubik-Komar, et.al, 2021).* But the intensity of pollen season is connected to the production of pollen by flowers which is affected by the previous year's conditions during the period that the blossom buds are being formed, as well as the amount of catkins shedding pollen during that year, so magnitude of flowering varies from year to year. *(Dahl, et.al, 2013).* A rapid change in the climate has been observed in the last years and it is possible that this phenomenon can affect allergies. *(Lake et.al, 2017; Piotrowska, et.al, 2012).* As I mentioned above, plants release their pollen into the air, to reach another plant of the same species and pollinate it. The drawback of this way is that a part of this pollen ends up being inhaled by humans and cause allergic reactions, because birch pollen releases proteins that promotes the production of antibodies in atopic people (*Silva Palacios, et.al, 2000).* In North and Central Europe birch pollen is the main cause of pollen allergy and can cause allergies and allergic asthma *(Biedermann et.al, 2019).* Studies have shown that a number of 35 pollen grains/m^3 in 24 hours, could be uncomfortable for people. *(Šaulienė, et.al, 2006) ;* in Sweden, the threshold for ''moderate amounts'' used in pubic warnings, when symptoms are supposed to be moderate as well, is 10 grains/m^3 . It is estimated that 40% of the population in Europe suffers from pollen allergy *(D'Amato et al., 2007).* In northern and central parts of Europe, 6.4% to at least 22% of the population is sensitized to birch pollen. *(Myszkowska et.al, 2023).* In west Sweden, more than 22% (*Bjerg et al., 2016).* Other studies have also presented similar results.

The symptoms of allergies connected to pollen depend on the concentration of the pollen, which depends on the plant's presence and flowering intensity, as well as on meteorological factors such as temperature, relative humidity, wind speed, etc. *(Bilińska-Prałat. Et al, 2022).* The symptoms that occur in allergies from birch pollen appear suddenly. *(Piotrowska, et.al, 2012).* Pollen is defined as a local-scale pollutant due to its lifetime in the atmosphere, being from a few hours to a couple of days. In some situations, though, the amount of pollen that was released can be so large that it can cause medical impact at larger distances. *(Sofiev, et al. 2006a ; Sofiev, et al. 2013).* It is also possible to understand if the source of the pollen detected in the Hirst-type volumetric spore trap comes from local scale, regional or long-range transport with knowledge of vegetation and land use over a large area, and by tracking the path of the pollen through the air.

1.2 Aim and Research Question

It is important to develop models that can be accurate and predict the concentrations of pollen in an area. Such models can be used in the preparation of pollen warnings to allergic sufferers, which in Swedish pollen laboratories are produced daily during the pollen season. My aim is to use the pollen concentrations from the birch pollen season of 2023, that actually was registered from pollen traps in different monitoring sites in Sweden and compare them to what was forecasted by the SILAM model. Also, I used meteorological data, specifically relative humidity, to understand possible discrepancies between the forecast and realized concentration. With the aim described the following research question is formulated:

- Do the forecasted birch pollen amounts of the SILAM model agree with the realized amounts registered in the Hirst traps during the corresponding time period? If not, could relative humidity be the cause of the discrepancy?

Chapter 2: Methodology

2.1 Data information

2.1.1 Study areas:

Pollen traps areas	*Longitude (decimal degrees)*	*Latitude (decimal degrees)*	*Above the sea level (m)*
Göteborg	12.0518	57.7334	46
Malmö	13.0035	55.5847	13
Umeå	20.3016	63.8166	24

Table 1: Locations of the traps

Göteborg's pollen trap is located at Sahlgrenska University Hosptital-Östra Sjukhuset's central clinic. The vegetation of the area within a radius of 200m from where the trap is been installed is mostly forest and the dominant species are birch, lawns and ornamental shrubs. Göteborg is located in the Southwestern part of Sweden on the west coast. And according to Köppen climate classification has a suboceanic climate. *(climate change knowledge portal, 2024).*

Malmö's pollen trap is placed at MAS University Hospital. Around the trap within a radius of 200 m there is only park vegetation. Malmö is located also in the Southwestern part of Sweden and from the Köppen climate classification has as well a suboceanic climate. *(climate change knowledge portal, 2024).*

Umeå's trap is placed on the roof of University hospital .Within a radius of 200 m there is parkland, a forest with birch, pine and lawns . Umeå is located in the Northeast area of Sweden and the climate classification is subarctic climate. *(climate change knowledge portal, 2024).*

A picture of the Köppen climate classifications of Sweden is provided in *appendix 1*.

2.1.2 Sampling of the real pollen concentrations

The real data regarding the pollen concentrations have been collected/sampled from the study areas with the use of the Hirst-type volumetric spore traps and have been measured in the lab under a microscope. The air is sucked into the trap through an orifice as the pollen grains are collected on a sticky tape placed around a rotation drum. Exposure during 24 hours corresponds to 48 mm of tape (864 mm^2) and 1 m^3 of air corresponds to 60 mm^2. After the pollen collection, the tape is transferred to the lab where it is embedded in glycerol jelly on a glass slide. The scientists identify the pollen by it's characteristics and count all pollen grains on an area that corresponds to exposure for 1 cubic meter of air, divided into 12 transects 4 mm apart. Every 2 mm of tape represents exposure during 1 hour and the transects thus represent bihourly samples. *(The Pollen Laboratory of University of Gothenburg, 2023).*

2.1.3 SILAM

The SILAM (System for Integrated modeLing of Atmospheric composition) program is a modeling tool made by the Finnish Meteorological Institute. The product of the model is a forecast of a global to meso-scale dispersion regarding air quality, atmospheric composition, land-fire smoke, etc and in our case allergenic pollen. The program cooperates with the European Aeroallergen Network (EAN) and the model can create forecasts for Europe for different species such as Alder , Grass, Ragweed, Birch , Olive, and Mugwort, as well as characteristics of the season such as pollen index, allergy risk, heat sum, pollen left in catkins. The created forecasts are given in a form of a map with 10 km spatial resolution and 1 hour time apart produced every hour. The output of the model *(Figure 1)* provides information about the species of interest, the units of the value, the year, the month the day and the time of the specific forecast. The forecast also uses a scale with colors to present the amount of the pollen in the air. *(Finnish Meteorological Institute, SILAM).* The color scale could be used to detect the impact with regard to symptoms, and the coded amounts were categorized from low-to very high *(Table 2 and Figure 2).*

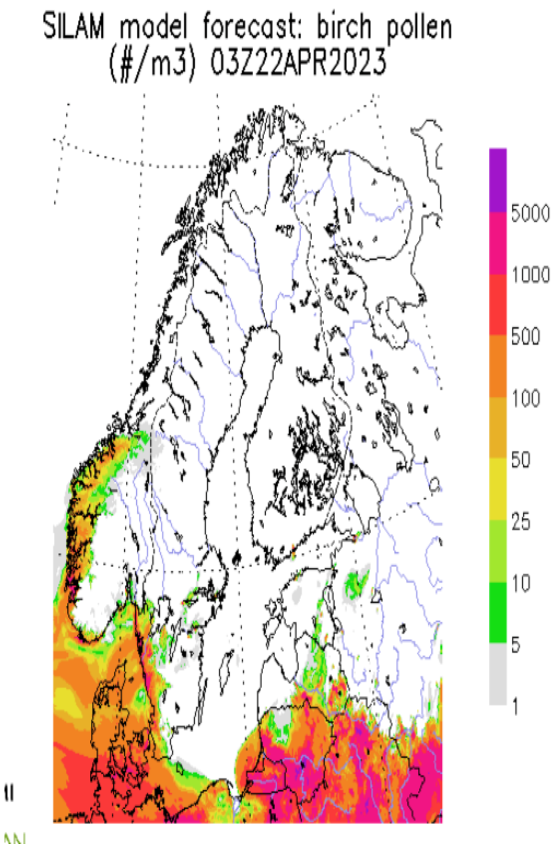


Table 2: Categorization of pollen

Category	*Pollen concentration/ m^3*
Very high	>1000
High	101-1000
Moderate	11-99
Low	0-10

Color	Pollen concentrations/m3	Category
purple	>5001	Very High
pink	1001-5000	
red	501-1000	High
dark orange	101-500	
light orange	51-100	Moderate
yellow	26-50	
light green	11-25	
dark green	6-10	Low
grey	1-5	
white	0	

Figure 1: SILAM forecast of Northern Europe and Scandinavia

Figure 2: Matrix of categorization of pollen with SILAM color scale as well

The forecasted hourly concentrations (pollen grains/m^3) for every day of the pollen season from the SILAM model, as well as the relative humidity modeled data , were provided by the Finnish Meteorological Institute.

2.1.4 SMHI

SMHI is the Swedish Meteorological and Hydrological Institute provides information for climatology, meteorology, hydrology and oceanography. The organization offers a lot of services such as weather forecasts, reports, etc, and in our case historical data. *(SMHI, 2024)*

The historical hourly relative humidity data for the period in interest were downloaded from SMHI's archives, and collected by active stations as close as possible to the pollen's traps locations.(*Table 3).*

Table 3: Locations of SMHI's stations

Station	*Longtitude (decimal degrees)*	*Latitude (decimal degrees)*	*Altitude (above sea level)*	*Mesurment height (above the ground)*
Göteborg A	119.924	577.156	3.038 m	2 m
Malmö A	130.708	555.715	19.757 m	2 m
Umeå Flygplats	202.800	637.931	7.31 m	2m

2.2 Data processing

As was mentioned before the study areas are Göteborg, Malmö and Umeå. The study period of the thesis occurs from approximately 3rd week of April until 2nd week of June year 2023. The real pollen concentrations have been measured bi-hourly corresponding also to the Swedish time zone. The hourly modeled pollen data (SILAM) as well as the hourly relative humidity data both modeled (SILAM) and real (SMHI) correspond to UTC hours. All the hours were converted to equal Sweden's time zone during the Summer period (UTC+ 2 hours) and all the hourly values were converted to bi-hourly (*Table 4).*

Microsoft Excel was used for calculating the differences between the real and model pollen concentrations and creating the plots representing them. I also proceeded in doing the Wilcoxon sum-rank test and Spearman's correlation test as well as Linear Regression graphs in different combinations regarding the parameters *(Table 5)* which provided results for the correlation between them. For performing the statistical tests as well as the Linear Regression graphs I used Python. I chose to handle the data information by working with the study areas separately and studying each month one at a time.

Table 4: Converted time hours

Time period	*Swedish hours*	*UTC hours*
00-02	00+01	22+23 (previous day)
02-04	02+03	00+01
04-06	04+05	02+03
06-08	06+07	04+05
08-10	08+09	06+07
10-12	10+11	08+09
12-14	12+13	10+11
14-16	14+15	12+13
16-18	16+17	14+15
18-20	18+19	16+17
20-22	20+21	18+19
22-24	22+23	20+21

Table 5:Combinations for different tests and graphs

TESTS- GRAPHS	*PARAMETERS*
Wilcoxon sum-rank	Real vs model pollen con
	Real vs model humidity
Spearman's correlation	Real vs model pollen con
	Real vs model humidity
	Real pollen vs real humidity
	Model pollen vs model humidity
	Real humidity vs model pollen
Linear regression	Real pollen vs real humidity
	Model pollen vs model humidity
	Real humidity vs model pollen

2.3 Statistical tests and Graphs

2.3.1 Wilcoxon rank-sum test

The Wilcoxon sum-rank test is designed to work for data, like pollen, that are not normally distributed. The test-statistic is based on setting a null hypothesis (H_0) which means that there is no difference and an alternative hypothesis (H_1) which means that there is a difference. *(Singh, P., & Author, C. 2013).*

The Wilcoxon test compares the p-value with the alpha (0.05) for detecting the level of significance and concludes if to reject or not the null hypothesis. More specifically if the p-value < alpha then it rejects the null hypothesis otherwise it fails to reject the null hypothesis. When the p < 0.05 the result is statistically significant.

We can interpret how strong the evidence is with the following figure *(Singh, P., & Author, C. 2013):*

Values of p	Inference
$p > 0.10$	No evidence against the null hypothesis.
$0.05 < p < 0.10$	Weak evidence against the null hypothesis
$0.01 < p < 0.05$	Moderate evidence against the null hypothesis
$0.05 < p < 0.001$	Good evidence against null hypothesis.
$0.001 < p < 0.01$	Strong evidence against the null hypothesis
$p < 0.001$	Very strong evidence against the null hypothesis

Figure 3: Interpretation of p-value

The Wilcoxon sum-rank test was performed with the use of Python programming language.

2.3.2 Spearman's correlation test

Spearman's correlation test is designed to calculate the ranks of data with non-normal distributions to show the strength of the correlation between two data sets as well as the type of relationship they have. *(Akoglu, H. ,2018).* Rho indicates if the relationship between the compared data is positive (rho>0) or negative (rho<0) monotonic. A positive relationship between two compared data sets indicates that both variables changing in the same direction (both decreasing or increasing), while a negative relationship that they change in different directions (when one increasing the other decreasing). Rho is limited between the numbers -1 and 1 with zero meaning there is no correlation while the closer a value is to 1, the stronger the linear correlation is. *(Akoglu, H. ,2018).* Though, the test cannot work if the values are repeated.

The interpretation of the correlation is generally based on the Cohen's criteria of the effect sizes pointed to small when $0 \leq r \leq 0.29$, medium when $0.30 \leq r \leq 0.49$ and large when $0.50 \leq r \leq 1$ *(cohen,1988).* With those criteria and the limits of the test the analysis could give an even more detailed interpretation of the results.

The Spearman's correlation test was performed with the use of Python programming language, in a similar way as the Wilcoxon test.

2.3.3 Linear Regression Graph

A linear regression model estimates a linear relationship between dependent and independent variables. The slope of the line can indicate the type of relationship (positive/negative), while a slope equal to zero indicates that there is no relationship. This model was chosen for this study to represent the relationship between pollen concentrations and relative humidity values in different combinations of the data. These graphs were also made by the use of Python programing language.

Chapter 3: Results

3.1 Observed results from real data values

In this sector the results will be described separately for every month of all three study areas.

3.1.1 Göteborg

April: The highest pollen concentration (1048 pollen grains/m^3) of the month appeared at 22/04 time 18:00-20:00 , was also the highest concentration of the entire study period for Göteborg. This is characterized as a very high concentration *(Table 2)* . At the same day and time, the measured relative humidity was 27.5 % .

Some more days presented high levels of pollen concentrations (between 101-1000 pollen grains/m^3). Those days are from 22/04-26/04 and 28/04-29/04.

May: The highest pollen concentration measured (246 pollen grains/m^3) appeared at 04/05 time 20:00-22:00, with a relative humidity of 17.5% . This concentration is characterized as ‘’high’’.

There were more days that presented high levels as well, 02/05-05/05, and 08/05-09/05.

June: No high/very high levels of pollen concentration observed for this month. In fact this month was characterized only by low concentrations with the highest of them being 5 pollen grains/m^3 at 01/06 time 18:00-20:00 , with a relative humidity of 28%.

3.1.2 Malmö

April: The highest pollen concentration 248 (pollen grains/m^3) measured at 20/04 time 16:00-18:00 and is characterized as a high level. The relative humidity for the same period was 32%. This concentration was also the highest for this site.

There was also one more day of this month where high levels of pollen appeared, 24/04.

May: No high/very high levels of pollen concentration were observed. The highest count was 46 pollen grains/m^3 which it is categorized as a moderate level and was measured at 02/05 time 04:00-06:00. The relative humidity was 78.5%

June: This month is characterized only by low level concentrations with the highest being 2 pollen grains/m^3 registered four times during the month (01/06 18:00-20:00, 04/06 16:00-18:00, 09/06 12:00-14:00 and 10/06 18:00-20:00). The relative humidity for these days was between 31% to 53.5%

3.1.3 Umeå

April: The month is characterized by low level concentrations. The highest pollen count was 2 pollen grains/m^3 presented at 27/04 time 10:00-16:00 and also at 28/04 time 20:00-22:00. The relative humidity value of these hours was high, between 81% to 91.5%.

May: In this month the highest concentration of this study area was observed. The concentration was 425 pollen grains/m^3 (high level) at 16/05 time 08:00-10:00 with a relative humidity of 61%.

There were also some days during this month when high levels of pollen was registered. Specifically, all the period from 09/05 until 24/05 excluding the days 12/05, 17/05 and 18/05.

June: No high/very high levels of pollen were observed in this month. The highest concentration was 17 pollen grains/m^3 counted at 05/06 time 08:00-10:00, which is considered a moderate category. The relative humidity for this time was 44%.

This information from the real data seems to present an intense period of pollen presence in the atmosphere for Göteborg mostly around the last ten days of April and first ten days of May, for Malmö around the 4th week of April and for Umeå between the second and the 4th week of May for the year 2023.

3.2 Observed results from pollen comparisons.

This section contains tables and plots regarding the observed differences between the real and the model pollen concentrations. I selected only the highest differences of each day due to the amount of the data. Data from all of days where the difference of real and model concentrations were above 1000 pollen grains are provided in the *Appendix 2, 3 and 4*

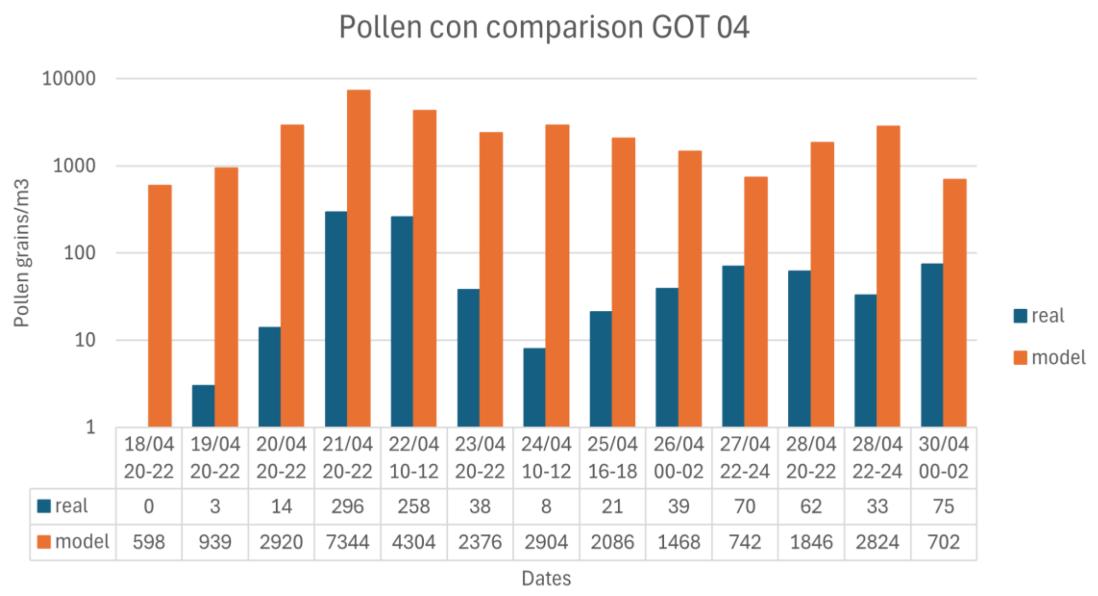
3.2.1 Göteborg

April:

Table 6: Real-model pollen concentration comparisons. Study area: Göteborg, Time period: 18-30 April 2023.

Site	*Period*	*Real pollen (pollen grains/m^3)*	*Model pollen (pollen grains/m^3)*	*difference*
Göteborg	18/04 20-22	0	598	-598
Göteborg	19/04 20-22	3	939	-936
Göteborg	20/04 20-22	14	2920	-2906
Göteborg	21/04 20-22	296	7344	-7048
Göteborg	22/04 10-12	258	4304	-4046
Göteborg	23/04 20-22	38	2376	-2338
Göteborg	24/04 10-12	8	2904	-2896
Göteborg	25/04 16-18	21	2086	-2065

Göteborg	26/04 00-02	39	1468	-1429
Göteborg	27/04 22-24	70	742	-672
Göteborg	28/04 22-24	33	2824	-2791
Göteborg	29/04 00-02	28	2520	-2492
Göteborg	30/04 00-02	75	702	-627



	18/04 20-22	19/04 20-22	20/04 20-22	21/04 20-22	22/04 10-12	23/04 20-22	24/04 10-12	25/04 16-18	26/04 00-02	27/04 22-24	28/04 20-22	28/04 22-24	30/04 00-02
real	0	3	14	296	258	38	8	21	39	70	62	33	75
model	598	939	2920	7344	4304	2376	2904	2086	1468	742	1846	2824	702

Figure 4: The difference between data forecasted by the SILAM model (orange bars) and real data (blue bars). X axis : Days and hours, Y axis: Pollen concentrations in logarithmic scale (base 10). Study area: Göteborg, Time period: 18-30 April 2023. (*) Zero and negative values cannot be plotted correctly.

The values of the real pollen are consistently smaller than the values of the model pollen *(Table 6, Figure 4)*. The differences are large, with 9 out of 13 days being above 1000 pollen grains. The highest difference of 7048 pollen grains apart (real pollen 296 pollen grains/m^3) occurred at 21/04 20:00-22:00.

May:

Table 7: Real-model pollen concentration comparisons. Study area: Göteborg, Time period: 01-31 May 2023.

Site	*period*	*Real pollen (pollen grains/m^3)*	*Model pollen (pollen grains/m^3)*	*difference*
Göteborg	01/05 14-16	12	811	-799
Göteborg	02/05 10-12	78	5264	-5186
Göteborg	03/05 22-24	41	1756	-1715
Göteborg	04/05 22-24	73	1308	-1235
Göteborg	05/05 20-22	28	1132	-1104
Göteborg	06/05 22-24	54	2696	-2642

Göteborg	07/05 22-24	50	2680	-2630
Göteborg	08/05 00-02	61	2456	-2395
Göteborg	09/05 22-24	122	1588	-1466
Göteborg	10/05 00-02	39	1043	-1004
Göteborg	11/05 02-04	34	858	-824
Göteborg	12/05 00-02	21	218	-197
Göteborg	13/05 04-06	11	59	-48
Göteborg	14/05 12-14	27	854	-827
Göteborg	15/05 00-02	4	245	-241
Göteborg	16/05 22-24	3	158	-155
Göteborg	17/05 08-10	10	212	-202
Göteborg	18/05 08-10	2	160	-158
Göteborg	19/05 10-12	4	31	-27
Göteborg	20/05 12-14	0	116	-116
Göteborg	21/05 20-22	6	33	-27
Göteborg	22/05 00-02	1	5	-4
Göteborg	23/05 08-10	0	34	-34
Göteborg	24/05 20-22	0	46	-46
Göteborg	25/05 22-24	0	114	-114
Göteborg	26/05 22-24	0	114	-114
Göteborg	27/05 08-10	0	101	-101
Göteborg	28/05 22-24	0	155	-155
Göteborg	29/05 00-02	0	144	-144
Göteborg	30/05 10-12	1	98	-97
Göteborg	31/05 22-24	2	168	-166

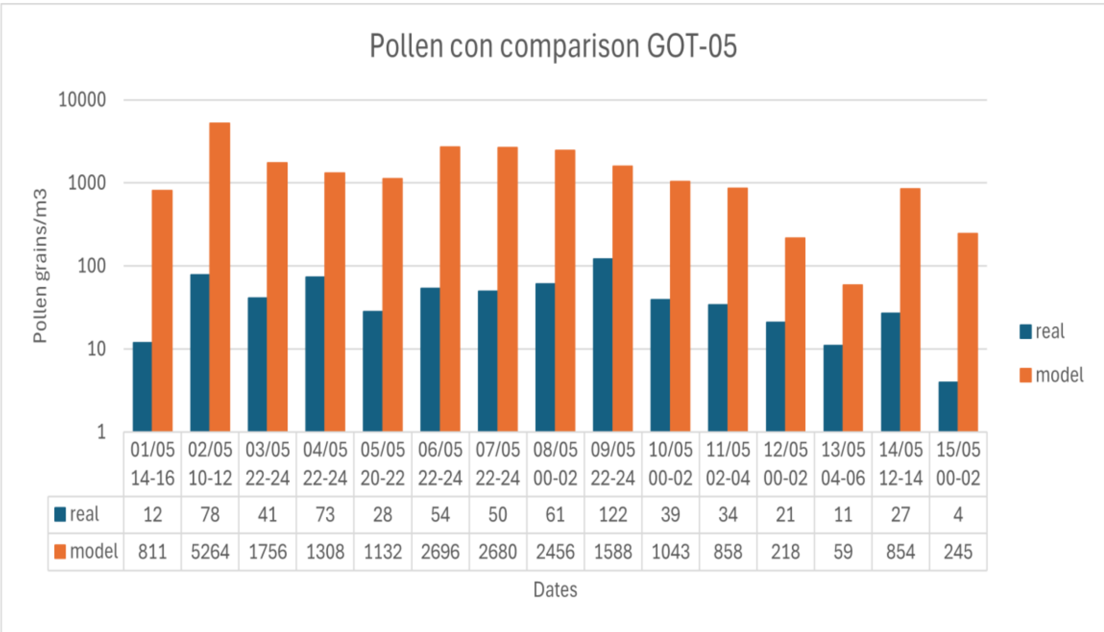


Figure 5: The difference between data forecasted by the SILAM model (orange bars) and real data (blue bars). X axis : Days and hours, Y axis: Pollen concentrations in logarithmic scale (base 10). Study area: Göteborg, Time period: 01-15 May 2023, (*) Zero and negative values cannot be plotted correctly.

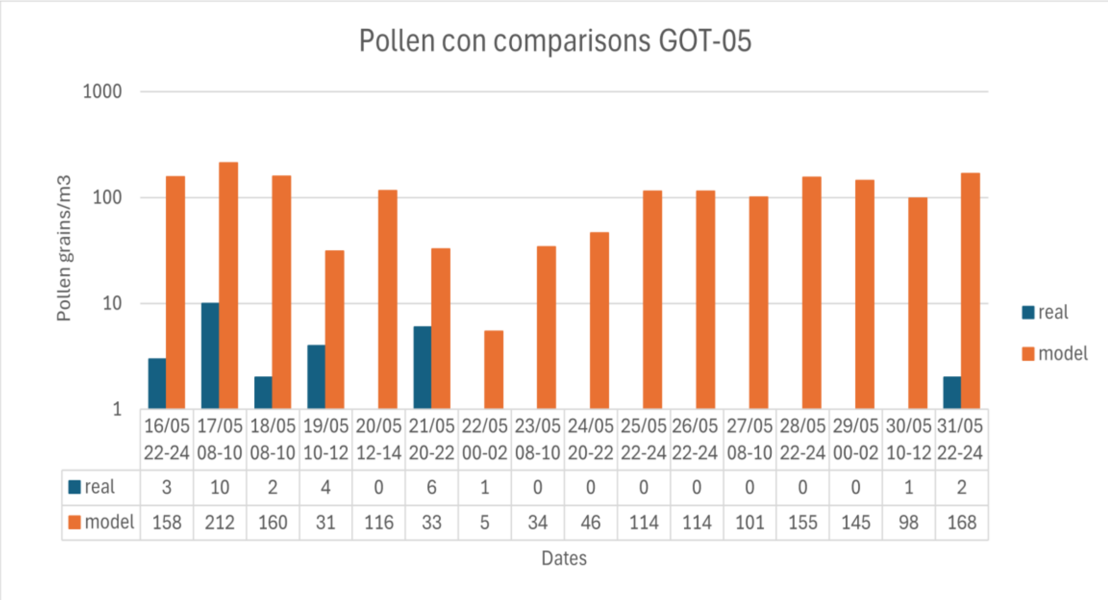


Figure 6: The difference between data forecasted by the SILAM model (orange bars) and real data (blue bars). X axis : Days and hours, Y axis: Pollen concentrations in logarithmic scale (base 10). Study area: Göteborg, Time period: 16/05-31/05 May 2023. (*) Zero and negative values cannot be plotted correctly.

For this month, the modeled pollen concentrations were predicted higher than the real counts *(Table 7, Figures 5 and 6)*. The days that the difference between the compared data was higher than 1000 were 9 days out of 31. The highest difference of 5186 pollen grains was observed at 02/05 time 10:00-12:00 (real pollen 78 pollen grains/m^3).

June:

Table 8: Real-model pollen concentration comparisons. Study area: Göteborg, Time period: 01-10 June 2023.

Site	*period*	*Real pollen (pollen grains/m^3)*	*Model pollen (pollen grains/m^3)*	*difference*
Göteborg	01/06 00-02	1	120	-119
Göteborg	02/06 04-06	1	12	-11
Göteborg	03/06 10-12	0	118	-118
Göteborg	04/06 12-14	2	162	-160
Göteborg	05/06 08-10	2	160	-158
Göteborg	06/06 02-04	0	26	-26
Göteborg	07/06 08-10	0	38	-38
Göteborg	08/06 10-12	2	54	-52
Göteborg	09/06 06-08	0	19	-19
Göteborg	10/06 00-02	0	4	-4

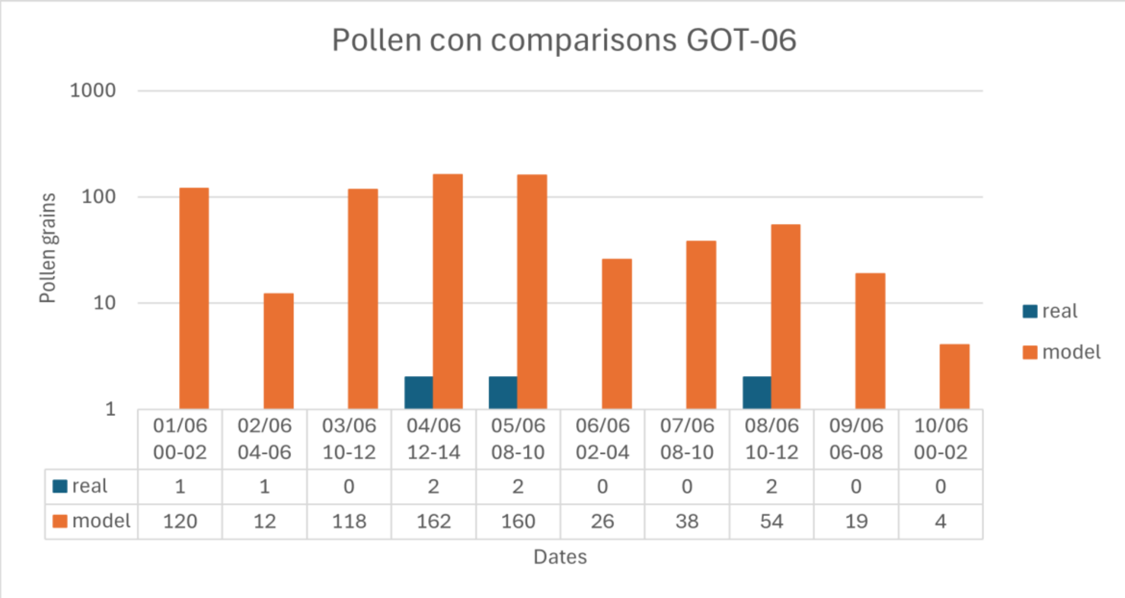


Figure 7: The difference between data forecasted by the SILAM model (orange bars) and real data (blue bars). X axis : Days and hours, Y axis: Pollen concentrations in logarithmic scale (base 10). Study area: Göteborg, Time period:01-10 June 2023. (*) Zero and negative values cannot be plotted correctly.

There are differences between real-model concentrations with the predicted pollen calculated higher than the real *(Table 8, Figure 7)*. For this month, no difference above 1000 was observed. The highest difference of 160 pollen grains/m^3 was at 04/06 time 12:00-14:00 with the real measurement 2 pollen grains/m^3.

The largest differences for Göteborg between the model and real values appeared mostly in April and the first ten days of May.

3.2.2 Malmö

April:

Table 9: Real-model pollen concentration comparisons. Study area: Malmö, Time period: 12-30 April 2023.

Site	*period*	*Real pollen (pollen grains/m^3)*	*Model pollen (pollen grains/m^3)*	*difference*
Malmö	12/04 18-20	0	35	-35
Malmö	13/04 06-08	1	193	-192
Malmö	14/04 06-08	0	193	-193
Malmö	15/04 06-08	0	453	-453
Malmö	16/04 02-04	2	181	-179
Malmö	17/04 20-22	1	333	-332
Malmö	18/04 22-24	1	173	-172
Malmö	19/04 20-22	4	132	-128
Malmö	20/04 20-22	17	281	-264

Malmö	21/04 20-22	10	766	-756
Malmö	22/04 10-12	69	1516	-1447
Malmö	23/04 20-22	4	1452	-1448
Malmö	24/04 20-22	24	1051	-1027
Malmö	25/04 12-14	9	646	-637
Malmö	26/04 02-04	38	215	-177
Malmö	27/04 22-24	10	244	-234
Malmö	28/04 20-22	11	846	-835
Malmö	29/04 00-02	10	622	-612
Malmö	30/04 18-20	13	307	-294

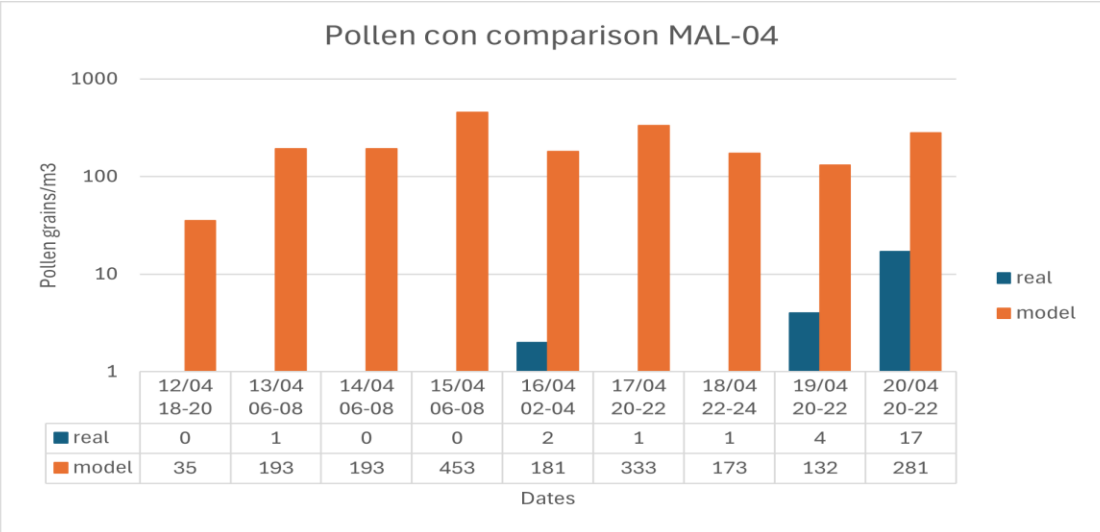


Figure 8: The difference between data forecasted by the SILAM model (orange bars) and real data (blue bars). X axis : Days and hours, Y axis: Pollen concentrations in logarithmic scale (base 10). Study area: Malmö, Time period: 12-20 April 2023. (*) Zero and negative values cannot be plotted correctly.

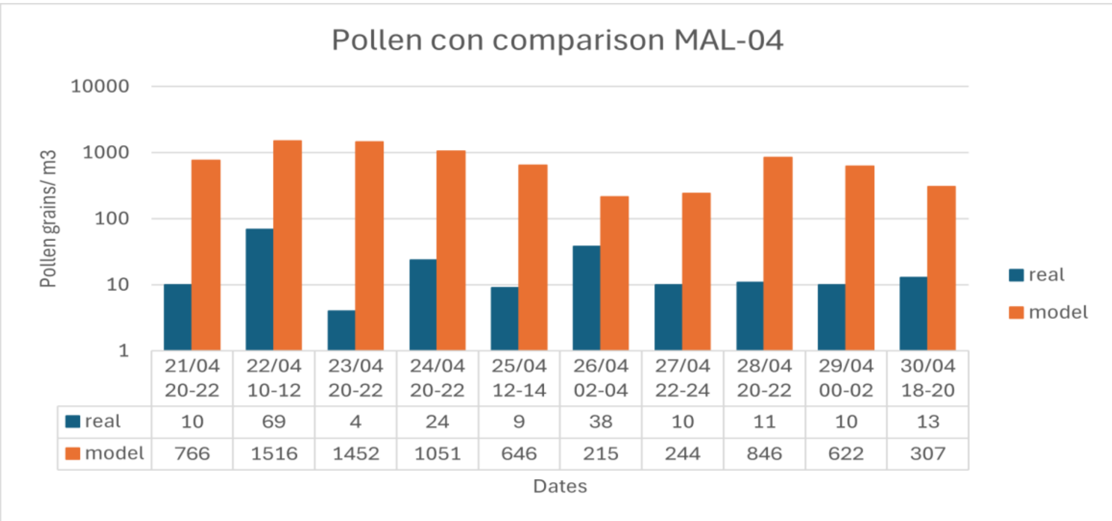


Figure 9: The difference between data forecasted by the SILAM model (orange bars) and real data (blue bars). X axis : Days and hours, Y axis: Pollen concentrations in logarithmic scale (base 10). Study area: Malmö, Time period: 21-30 April 2023. (*) Zero and negative values cannot be plotted correctly.

The model concentrations were higher than the real ones. In 3 days out of 19 the difference between real and model concentrations was above 1000 *(Table 9, Figures 8 and 9)*. The largest difference of 1448 pollen grains/m^3 occurred at 23/04 time 20:00-22:00 with the real pollen concentration being 4 pollen grains/m^3.

May:

Table 10: Real-model pollen concentration comparisons. Study area: Malmö, Time period: 01-30 May 2023.

Site	*period*	*Real pollen (pollen grains/m^3)*	*Model pollen (pollen grains/m^3)*	*difference*
Malmö	01/05 20-22	15	710	-695
Malmö	02/05 22-24	38	317	-279
Malmö	03/05 22-24	14	385	-371
Malmö	04/05 20-22	31	1055	-1024
Malmö	05/05 00-02	1	297	-296
Malmö	06/05 18-20	1	347	-346
Malmö	07/05 20-22	2	738	-736
Malmö	08/05 20-22	5	287	-282
Malmö	09/05 08-10	1	130	-129
Malmö	10/05 20-22	5	120	-115
Malmö	11/05 20-22	3	299	-296
Malmö	12/05 22-24	1	162	-161
Malmö	13/05 22-24	1	427	-426
Malmö	14/05 12-14	3	437	-434
Malmö	15/05 12-14	1	68	-67
Malmö	16/05 22-24	0	38	-38
Malmö	17/05 00-02	1	28	-27
Malmö	18/05 04-06	0	2	-2
Malmö	19/05 08-10	0	12	-12
Malmö	20/05 22-24	0	21	-21
Malmö	21/05 18-20	0	10	-10
Malmö	22/05 22-24	0	49	-49
Malmö	23/05 22-24	0	114	-114
Malmö	24/05 02-04	0	305	-305
Malmö	25/05 12-14	0	69	-69
Malmö	26/05 06-08	0	36	-36
Malmö	27/05 08-10	0	69	-69
Malmö	28/05 18-20	0	1	-1
Malmö	29/05 14-16	0	63	-63
Malmö	30/05 06-08	0	47	-47
Malmö	31/05 20-22	0	20	-20

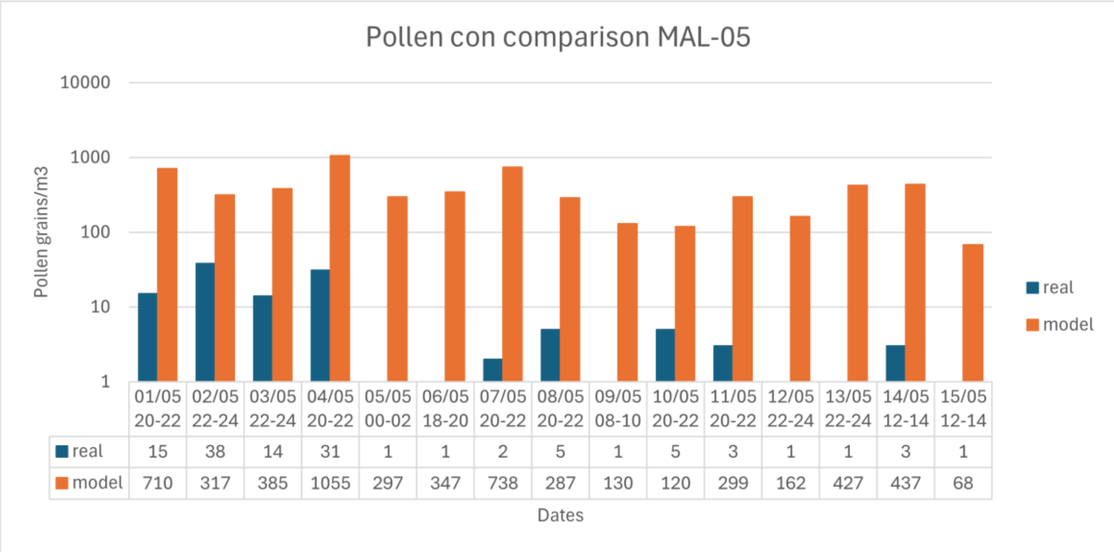


Figure 10: The difference between data forecasted by the SILAM model (orange bars) and real data (blue bars). X axis : Days and hours, Y axis: Pollen concentrations in logarithmic scale (base 10). Study area: Malmö, Time period: 01-15 May 2023. (*) Zero and negative values cannot be plotted correctly.

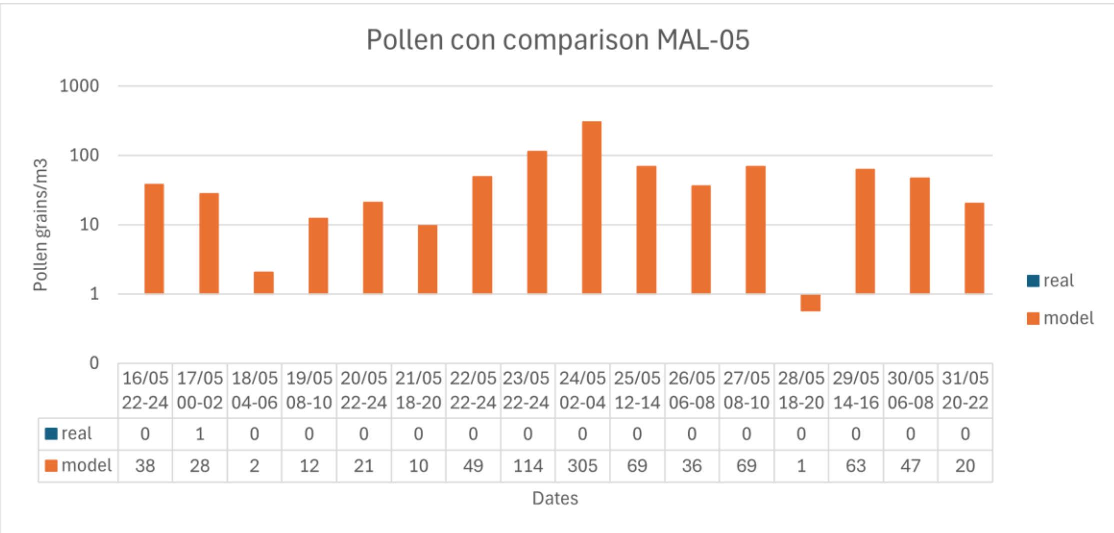


Figure 11: The difference between data forecasted by the SILAM model (orange bars) and real data (blue bars). X axis : Days and hours, Y axis: Pollen concentrations in logarithmic scale (base 10). Study area: Malmö, Time period: 16-31 May 2023. (*) Zero and negative values cannot be plotted correctly.

The real concentrations are non-existing in comparison with the model. The model pollen concentrations were predicted to be higher than the real pollen *(Table 10, Figures 10 and 11)*. Only 1 day out of 31 observed with a difference higher than 1000.

At 04/05 time 20:00-22:00 the difference was 1024 pollen grains with the real concentration measured 31 pollen grains/m^3.

June:

Table 11: Real-model pollen concentration comparisons. Study area: Malmö, Time period: 01-10 June 2023.

Site	*period*	*Real pollen (pollen grains/m^3)*	*Model pollen (pollen grains/m^3)*	*difference*
Malmö	01/06 10-12	0	149	-149
Malmö	02/06 14-16	0	59	-59
Malmö	03/06 14-16	1	54	-53
Malmö	04/06 00-02	0	13	-13
Malmö	05/06 10-12	0	23	-23
Malmö	06/06 12-14	0	9	-9
Malmö	07/06 02-04	0	2	-2
Malmö	08/06 20-22	0	34	-34
Malmö	09/06 00-02	0	33	-33
Malmö	10/06 22-24	0	9	-9

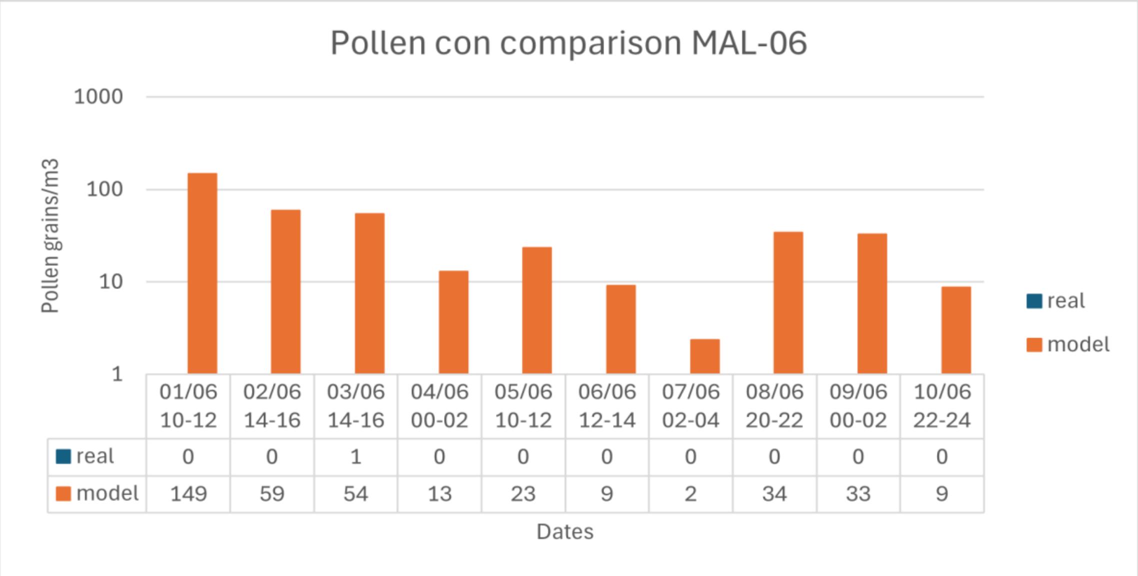


Figure 12: The difference between data forecasted by the SILAM model (orange bars) and real data (blue bars). X axis : Days and hours, Y axis: Pollen concentrations in logarithmic scale (base 10). Study area: Malmö, Time period: 01 - 10 June 2023. (*) Zero and negative values cannot be plotted correctly.

The highest difference between modelled and real data was 149 pollen grains with real count being zero pollen grains/m^3 at 01/06 time 10:00-12:00. *(Table 11, Figure 12).*

The highest differences in the pollen concentrations between real-model values for Malmö, were observed mostly at the end of the fourth and start of the fifth week of April and first week of May.

3.2.3 Umeå

April:

Table 12: Real-model pollen concentration comparisons. Study area: Umeå, Time period: 26-30 April 2023.

Site	*period*	*Real pollen (p. grains/m3)*	*Model pollen (p. grains/m3)*	*difference*
Umeå	26/04 18-20	1	818	-817
Umeå	27/04 00-02	0	186	-186
Umeå	28/04 04-06	0	8	-8
Umeå	29/04 12-14	0	35	-35
Umeå	30/04 18-20	0	59	-59

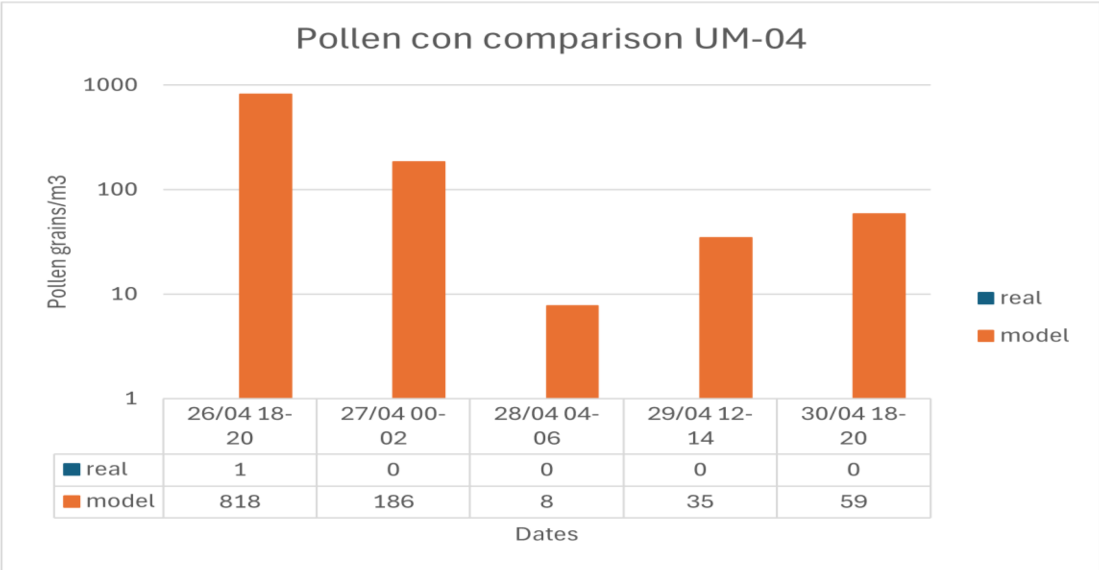


Figure 13: The difference between data forecasted by the SILAM model (orange bars) and real data (blue bars). X axis : Days and hours, Y axis: Pollen concentrations in logarithmic scale (base 10). Study area: Umeå, Time period: 26-30 April 2023. (*) Zero and negative values cannot be plotted correctly.

The real concentrations were smaller in comparison with the model *(Table 12, Figure 13)*. The highest difference of 817 pollen grains between them was at 26/04 time 18:00-20:00 with the real pollen concentration being 1 pollen grain/m^3.

May:

Table 13: Real-model pollen concentration comparisons. Study area: Umeå, Time period: 01-31 May 2023.

Site	*period*	*Real pollen (pollen grains/m³)*	*Model pollen (pollen grains/m³)*	*difference*
Umeå	01/05 18-20	0	11	-11
Umeå	02/05 16-18	0	8	-8
Umeå	03/05 00-02	0	3	-3
Umeå	04/05 08-10	1	0	1
Umeå	05/05 02-04	2	0	2
Umeå	06/05 22-24	2	15	-13
Umeå	07/05 10-12	2	59	-57
Umeå	08/05 02-04	1	6	-5
Umeå	09/05 18-20	8	565	-557
Umeå	10/05 12-14	30	485	-455
Umeå	11/05 16-18	37	726	-689
Umeå	12/05 08-10	8	38	-30
Umeå	13/05 16-18	164	43	121
Umeå	14/05 10-12	374	1027	-653
Umeå	15/05 12-14	131	1111	-980
Umeå	16/05 10-12	274	3586	-3312
Umeå	17/05 18-20	50	666	-616
Umeå	18/05 20-22	48	6704	-6656
Umeå	19/05 08-10	52	4572	-4520
Umeå	20/05 10-12	129	4208	-4079
Umeå	21/05 08-10	121	3224	-3103
Umeå	22/05 18-20	72	5520	-5448
Umeå	23/05 10-12	255	13856	-13601
Umeå	24/05 08-10	348	5936	-5588
Umeå	25/05 06-08	17	4688	-4671
Umeå	26/05 20-22	10	930	-920
Umeå	27/05 22-24	2	654	-652
Umeå	28/05 10-12	1	1468	-1467
Umeå	29/05 00-02	13	251	-238
Umeå	30/05 20-22	2	618	-616
Umeå	31/05 10-12	6	216	-210

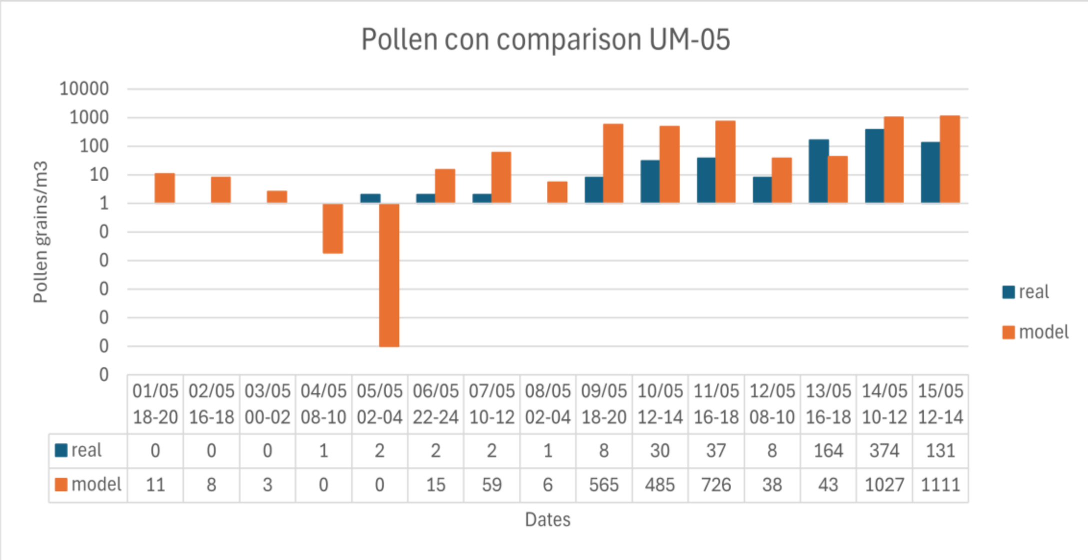


Figure 14: The difference between data forecasted by the SILAM model (orange bars) and real data (blue bars). X axis : Days and hours, Y axis: Pollen concentrations in logarithmic scale (base 10). Study area: Umeå , Time period: 01-15 May 2023. (*) Zero and negative values cannot be plotted correctly.

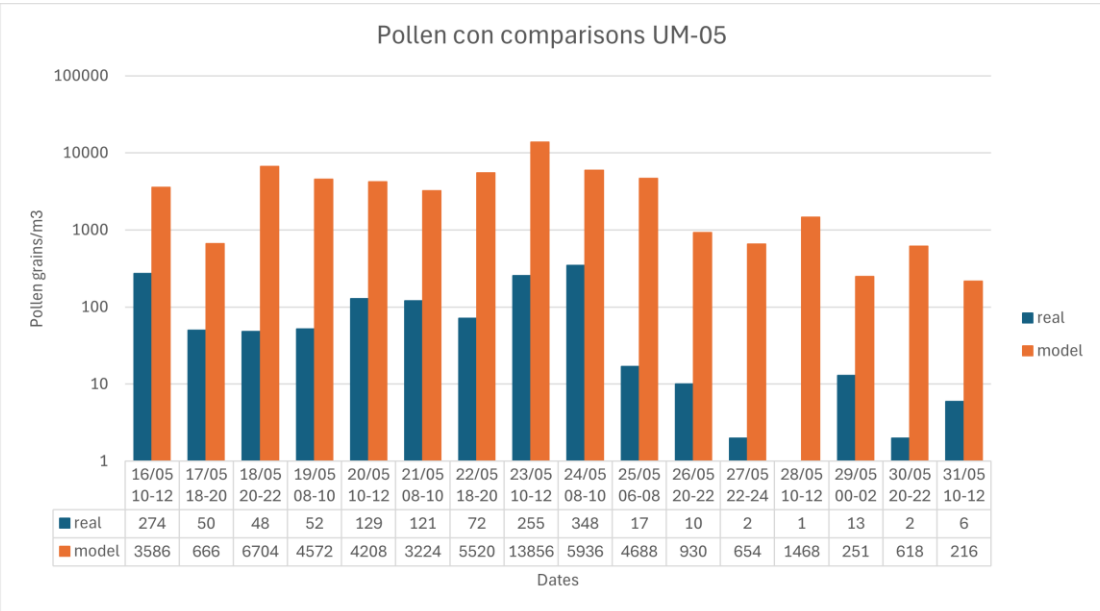


Figure 15: The difference between data forecasted by the SILAM model (orange bars) and real data (blue bars). X axis : Days and hours, Y axis: Pollen concentrations in logarithmic scale (base 10). Study area: Umeå , Time period: 16-31 May 2023. (*) Zero and negative values cannot be plotted correctly.

The real amounts were smaller than the model except the days 04/05 time 08:00-10:00, 05/05 time 02:00-04:00 and 13/05 time 16:00-18:00 when the model predicted lower concentrations than the registered. The highest difference of 13601 pollen grains was observed at 23/05 time 10:00-12:00, with the value of real pollen concentrations being

255 pollen grains/m^3. In 10 out of 31 days there was a difference between the concentrations larger than 1000 pollen grains. (*Table 13, Figures 14 and 15*).

June:

Table 14: Real-model pollen concentration comparisons. Study area: Umeå, Time period: 01-10 June 2023.

Site	*period*	*Real pollen (pollen grains/m^3)*	*Model pollen (pollen grains/m^3)*	*difference*
Umeå	01/06 00-02	1	32	-31
Umeå	02/06 16-18	2	15	-13
Umeå	03/06 18-20	3	127	-124
Umeå	04/06 22-24	2	373	-371
Umeå	05/06 00-02	2	167	-165
Umeå	06/06 22-24	0	85	-85
Umeå	07/06 00-02	1	145	-144
Umeå	08/06 04-06	0	87	-87
Umeå	09/06 08-10	1	37	-36
Umeå	10/06 22-24	2	16	-14

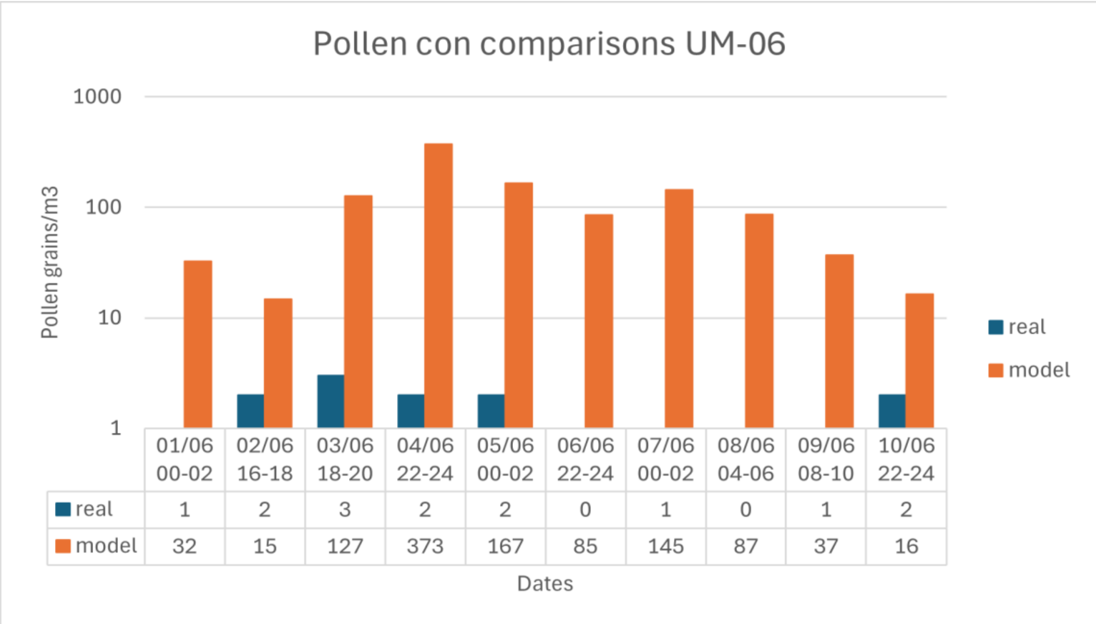


Figure 16: The difference between data forecasted by the SILAM model (orange bars) and real data (blue bars). X axis : Days and hours, Y axis: Pollen concentrations in logarithmic scale (base 10). Study area: Umeå, Time period: 01-10 June 2023. (*) Zero and negative values cannot be plotted correctly.

There is a difference between the real and the model concentrations where the latter are higher than the former. The highest difference of 371 pollen grains was observed 04/06 time 22:00-24:00, when the real data were counted 2 pollen grains/m^3. *(Table 14, Figure 16).*

The highest differences in the pollen concentrations between real-model values for Umeå, were observed mostly at the middle of May during weeks 3 to 5 for the year 2023.

3.3 Results from the Wilcoxon sum rank test

3.3.1 Pollen comparisons (real-model concentrations)

Table 15: Comparisons between the real pollen concentrations and the model pollen concentrations with Wilcoxon sum rank statistical test.

Site	*period*	*Test statistic*	*p-values*
Göteborg	18/04- 30/04	-13.24	5.08e-40
Göteborg	01/05- 31/05	-14.43	3.43e-47
Göteborg	01/06- 10/06	-11.75	6.73e-32
Malmö	12/04- 30/04	-16.20	4.86e-59
Malmö	01/05- 31/05	-18.39	1.69e-75
Malmö	01/06- 10/06	-12.39	2.83e-35
Umeå	26/04- 30/04	-8.80	1.41e-18
Umeå	01/05- 31/05	-11.89	1.28e-32
Umeå	01/06- 10/06	-10.83	2.39e-27

The difference between the compared concentrations for all three study areas for the entire study period are highly significant *(Table 15).* The test indicated that the distribution of the real data tends to be lower than the model data distribution.

3.3.2 Relative humidity comparisons (real-model values)

Table 16: Comparisons between the real and model relative humidity values with Wilcoxon sum rank statistical test.

Site	*period*	*Test statistic*	*p-values*
Göteborg	18/04- 30/04	-3.63	0.0003
Göteborg	01/05- 31/05	-1.89	0.06
Göteborg	01/06- 10/06	0.77	0.44
Malmö	12/04- 30/04	-0.48	0.63
Malmö	01/05- 31/05	1.60	0.11
Malmö	01/06- 10/06	2.24	0.03
Umeå	26/04- 30/04	-3.63	0.0003
Umeå	01/05- 31/05	-4.04	5.41e-05

Umeå	01/06- 10/06	0.97	0.33

The Wilcoxon test presented different results depending on the month and the study area.

In Göteborg the real relative humidity values in April tend to be lower than the model (p= 0.0003) , while for May (p = 0.06) and June (p= 0.44), there was no significance.*(Table 16)*

For Malmö in April (p=0.63) and May (0.11) there was no significant difference between the real and model relative humidity values, but in June (p=0.03) the real values tended to be lower than the model. *(Table 16)*

For Umeå the real values were significantly lower than the model values in April (p= 0.0003) and May (p=5.41e-05), but not in June (p=0.33). *(Table 16)*

3.4 Results from Spearman's correlation test

3.4.1 Pollen correlations (real-model concentrations)

Table 17: Correlations between the real and model pollen concentrations with Spearman's correlation test.

Site	*period*	*Rho correlations*	*p-values*
Göteborg	18/04- 30/04	0.47	4.91e-10
Göteborg	01/05- 31/05	0.69	1.80e-53
Göteborg	01/06- 10/06	-0.02	0.84
Malmö	12/04- 30/04	0.55	2.48e-19
Malmö	01/05- 31/05	0.62	1.61e-41
Malmö	01/06- 10/06	0.14	0.13
Umeå	26/04- 30/04	0.02	0.90
Umeå	01/05- 31/05	0.64	4.48e-45
Umeå	01/06- 10/06	-0.03	0.79

For Göteborg there was a moderate correlation (rho= 0.47, p= 4.91e-10) for April and a strong correlation (rho=0.69, p=1.80e-53) for May between the compared values with a positive monotonic relationship, while for June the correlation was not statistically significant (p=0.84) *(Table 17)*

For Malmö there was a moderate correlation (rho= 0.55, p= 2.48e-19) for April and a strong correlation (rho=0.62, p=1.61e-41) for May between the compared values with a positive monotonic relationship, while for June the correlation was not statistically significant (p=0.13). *(Table 17)*

For Umeå, there was a strong correlation (rho=0.64, p=4.48e-45) for May with a positive monotonic relationship, while for April (p= 0.90) and June (p=0.79) the correlation was not statistically significant. *(Table 17)*

3.4.2 Relative humidity correlations (real- model values)

Table 18: Correlations between the real and model relative humidity values with Spearman's correlation test.

Site	*period*	*Rho correlations*	*p-values*
Göteborg	18/04- 30/04	0.94	1.82e-73
Göteborg	01/05- 31/05	0.89	1.009e-127
Göteborg	01/06- 10/06	0.91	3.91e-48
Malmö	12/04- 30/04	0.91	2.0997e-89
Malmö	01/05- 31/05	0.89	3.46e-126
Malmö	01/06- 10/06	0.92	4.53e-50
Umeå	26/04- 30/04	0.91	1.16e-23
Umeå	01/05- 31/05	0.88	8.18e-121
Umeå	01/06- 10/06	0.81	2.46e-29

The test presented similar results for all study areas the entire period. The relationship between the compared values was positive monotonic and the correlation was very strong (rho > 0.80) and highly significant. *(Table 18)*

3.4.3 Correlations between real pollen concentrations – real relative humidity values

Table 19: Correlations between the real pollen concentrations and the real relative humidity values with Spearman's correlation test.

Site	*period*	*Rho correlations*	*p-values*
Göteborg	18/04- 30/04	-0.06	0.42
Göteborg	01/05- 31/05	-0.51	3.47e-26
Göteborg	01/06- 10/06	-0.17	0.06
Malmö	12/04- 30/04	-0.37	6.61e-09
Malmö	01/05- 31/05	-0.21	4.47e-05
Malmö	01/06- 10/06	-0.19	0.04
Umeå	26/04- 30/04	-0.04	0.77
Umeå	01/05- 31/05	-0.08	0.13
Umeå	01/06- 10/06	-0.33	0.00023

For Göteborg, there was a very weak correlation between real pollen and real relative humidity values (rho= - 0.51, p= 3.47e-26) for May, with a negative monotonic relationship of the compared data, while the correlation was not statistically significant both for April (p=0.42) and June (p=0.06) *(Table 19)*

For Malmö there was a very weak correlation with a negative monotonic relationship for all three months. With rho from -0.19 to -0.37 and low p-values. *(Table 19)*

For Umeå the correlation was not statistically significant both for April (p= 0.77) and May (p=0.13) while it was very weak (rho= - 0.33, p= 0.00023) and negative monotonic for June. *(Table 19)*

3.4.4 Correlations between model pollen concentrations- model relative humidity values

Table 20: Correlations between the model pollen concentrations and model relative humidity values with Spearman's correlation test.

Site	*period*	*Rho correlations*	*p-values*
Göteborg	18/04- 30/04	-0.23	0.004
Göteborg	01/05- 31/05	-0.21	4.06e-05
Göteborg	01/06- 10/06	0.20	0.03
Malmö	12/04- 30/04	-0.24	0.00027
Malmö	01/05- 31/05	-0.11	0.04
Malmö	01/06- 10/06	-0.01	0.95
Umeå	26/04- 30/04	0.38	0.0032
Umeå	01/05- 31/05	-0.11	0.04
Umeå	01/06- 10/06	0.21	0.02

For Göteborg the relationship was negative monotonic and the correlation was very weak for April (rho= -0.23 , p= 0.004) and May (rho= -0.21, p= 4.06e-05), while for June (rho= 0.20, p=0.03) the correlation was very weak but the relationship appeared positive monotonic. *(Table 20)*

For Malmö the relationship was negative monotonic and the correlation was very weak for April (rho= - 0.24 , p=0.00027) and May (rho= -0.11 , p=0.04) while for June the correlation was not statistically significant (p=0.95). *(Table 20)*

For Umeå the relationship was positive monotonic and the correlation was weak for April (rho= 0.38 , p=0.0032) and June (rho=0.21, p=0.02) ,while for May the relationship was negative monotonic and the correlation very weak (rho= -0.11, p=0.04). *(Table 20)*

3.4.5 Correlations between real relative humidity values – model pollen concentrations.

Table 21: Correlations between the model pollen concentrations and real relative humidity values with Spearman's correlation test.

Site	*period*	*Rho correlations*	*p-values*
Göteborg	18/04- 30/04	-0.19	0.02
Göteborg	01/05- 31/05	-0.33	6.73e-11
Göteborg	01/06- 10/06	0.19	0.03
Malmö	12/04- 30/04	-0.21	0.002
Malmö	01/05- 31/05	-0.20	6.95e-05
Malmö	01/06- 10/06	-0.06	0.51
Umeå	26/04- 30/04	0.26	0.05
Umeå	01/05- 31/05	-0.03	0.50
Umeå	01/06- 10/06	0.14	0.13

For Göteborg the relationship was negative monotonic and the correlation was very weak for April (rho= -0.19, p= 0.02) and May (rho= -0.33, p= 6.73e-11), while for June (rho=0.19 , p=0.03) the correlation was very weak but the relationship appeared positive monotonic. *(Table 21)*

For Malmö the relationship was negative monotonic and the correlation was very weak for April (rho= - 0.21 , p=0.002) and May (rho= -0.20 , p=6.95e-05) while for June the correlation was not statistically significant (p=0.51). *(Table 21)*

For Umeå the relationship was positive monotonic and the correlation was weak for April (rho= 0.26 , p=0.05), while for May (p= 0.50) and June (p=0.13) the correlation was not statistically significant. *(Table 21)*

3.5 Results from Linear Regression Models

This sector contains the Linear Regression Models for month April of all study areas, the rest graphs can be found in the *Appendix 5, 6 and 7.*

3.5.1 Real pollen concentrations- real relative humidity values

For Göteborg, there was a negative relationship between the relative humidity and the pollen concentrations for April slope: -2.05 and May slope:- 0.77 . For June, the distribution of the data indicates that the linear regression model is not relevant to describe the relationship between them. *(Figure 17)*

For Malmö there was a negative relationship for April slope: - 0.33 and May slope: - 0.02 . For June, the distribution of the data indicates that the linear regression model is not relevant to describe the relationship between them. *(Figure 17)*

For Umeå there was a negative relationship for May (slope: -0.63) *(Figure 17)* For April and June, the distribution of the data indicates that the linear regression model is not relevant to describe the relationship between them.

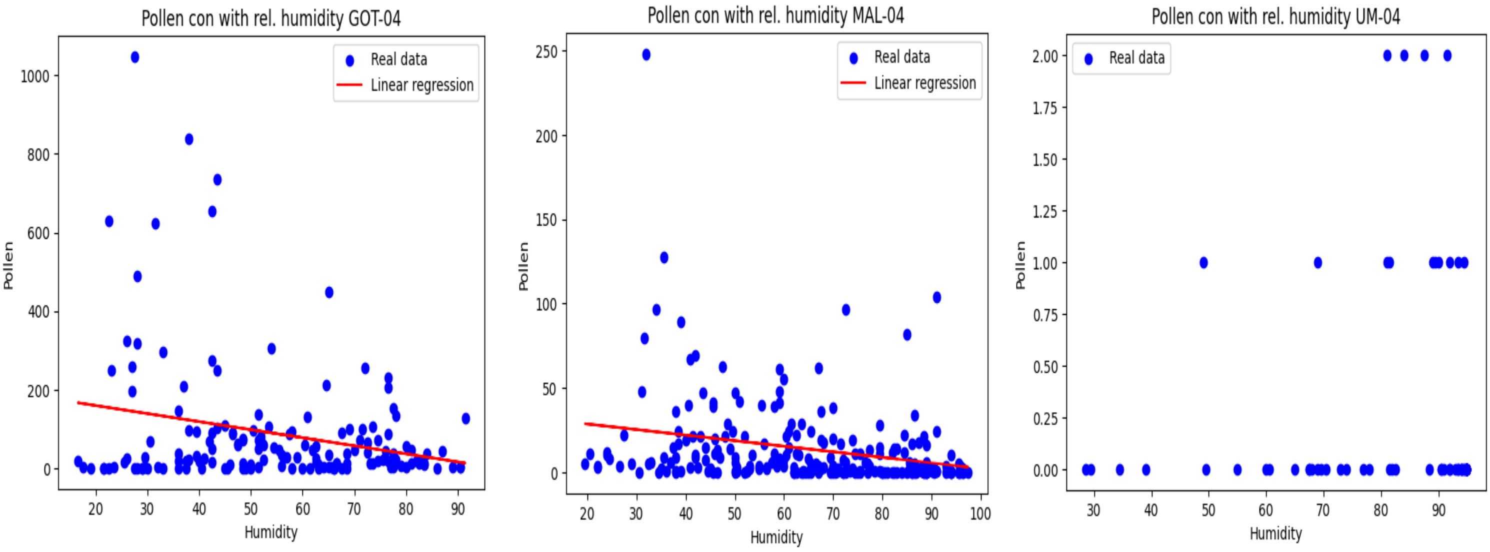


Figure 17: Linear Regression Models of real pollen concentrations (dependent factor) and real relative humidity values (independent factor) . Location: Göteborg(left), Malmö(central), Umeå(right), Period: April 2023.

3.5.2 Model pollen concentrations- model relative humidity values

For Göteborg, there was a negative relationship for both April (slope: -12.87) and May (slope: -5.15) and a positive relationship for June (slope: 0.10) *(Figure 18)*

For Malmö there was a negative relationship for April (slope: -2.27) and May (slope: -0.86) and positive relationship for June (slope: 0.11). *(Figure 18)*

For Umeå, there was a negative relationship for May (slope: -13.63) and a positive relationship for June (slope: 0.47) . For April, the distribution of the data indicates that the linear regression model is not relevant to describe the relationship between them.

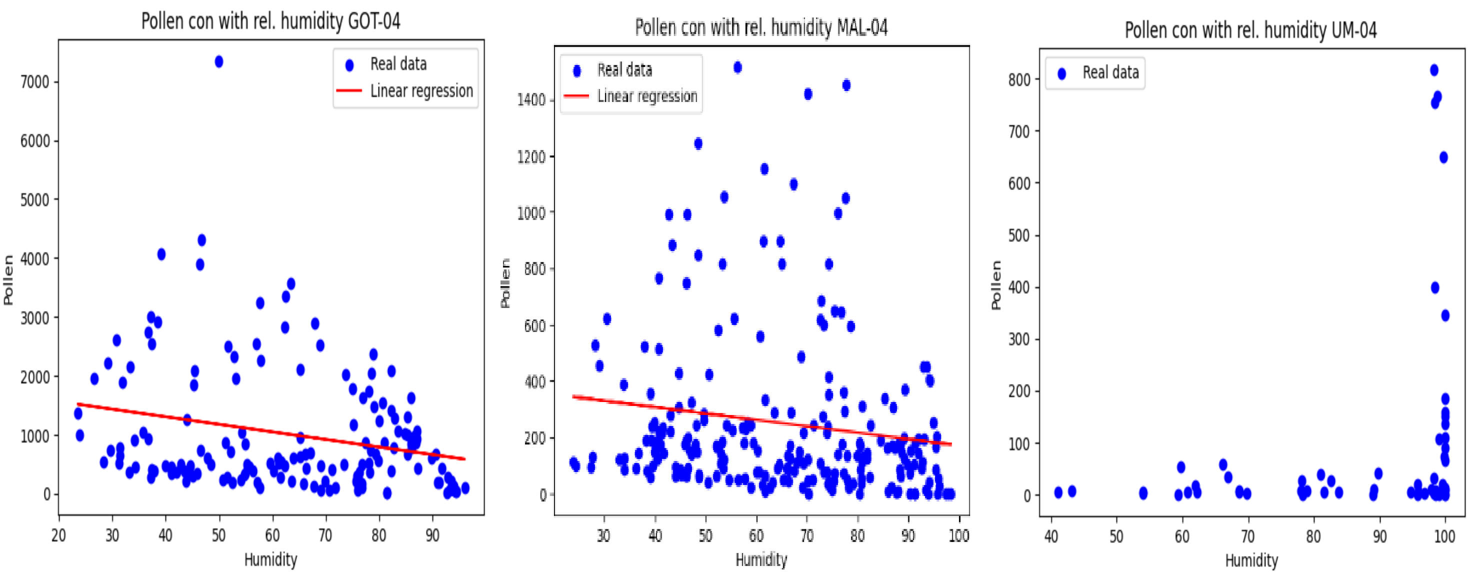


Figure 18: Linear Regression Model of modelled pollen concentrations (dependent factor) and model relative humidity values (independent factor). Location: Göteborg(left), Malmö(central), Umeå(right), Period: April 2023.

3.5.3 Real relative humidity values- model pollen concentrations

For Göteborg there was a negative relationship for both April (slope: -13.97) and May (slope: - 7.20) and a positive relationship for June (slope: 0.23) *(Figure 19)*

For Malmö there was a negative relationship for April (slope: -2.41) and May (slope: -0.83) and a positive relationship for June (slope: 0.03). *(Figure 19)*

For Umeå there was a negative relationship for May (slope: -15.98) and positive relationship both for June (slope: 0.30). For April, the distribution of the data indicates that the linear regression model is not relevant to describe the relationship between them. *(Figure 19)*

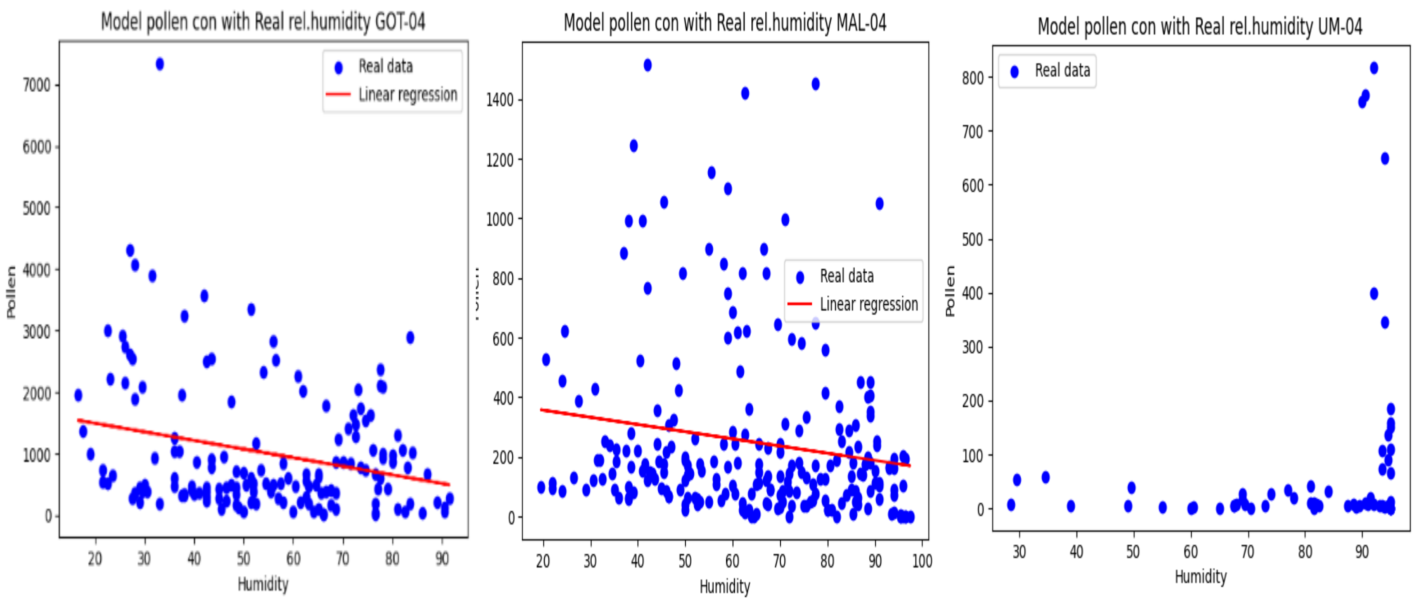


Figure 19: Linear Regression Model of model pollen concentrations (dependent factor) and real relative humidity values (independent factor). Location: Göteborg(left), Malmö(central), Umeå(right), Period: April 2023.

Chapter 4 : Discussion

4.1 Comparisons between real- model pollen concentrations

The model predicted different concentrations than the registered ones for all of three months in the three study areas. More specifically, the model predicted higher concentrations, often excided 1000 pollen grains. Also the results from the Wilcoxon test agreed with my suspicions indicating the significant difference between the compared data concluding that the distribution of the real concentrations tended to be lower than the one of the model. This difference could be due to how the model describes the flowering prosses of birch trees since it does not take into consideration the pollen counts but only the phenological observations. *(Prank, et,al. 2016).* Another factor that could lead to this results could be because the SILAM pollen model depends also on the habitat and the general land use maps, *(Prank, et,al. 2016)* which may not correspond to the reality very precisely. Last but not least, SILAM model is programmed by assuming that every year the same single tree produces the same amount of pollen *(Prank, et,al. 2016)* which can lead to mistaken predictions. Although previous studies in Belgium showed that the SILAM model could predict correctly the pollen levels compared to their observations, this disagrees with the results of this study.*(Verstraeten et.al, 2019)*

For the Spearman's correlation test all three study areas presented a moderate to strong correlation depending on the month except for June which always presented no statistically significant result. A reason that could explain the results of June could be the limited amount of days (10 days) when birch pollen was present; flowering is over in most areas in mid-June. Studies in Belgium showed that there is a correlation between SILAM and observed pollen concentrations up to 50% .*(Verstraeten et.al, 2019).*

4.2 Comparisons between pollen concentrations and relative humidity values

From the Sperman's correlation test the results show a very strong correlation between the real and model values for humidity across months and stations. This means that most likely the SILAM model predictions for humidity are closer to the reality. Both the Spearman's correlation test and the Linear Regression graphs between real relative humidity and real pollen suggest that the only statistically significant correlation is very weak and negative. On the contrary for the model values generally the correlation is weak but could present both negative and positive relationship depending on the area and the month. The results from comparing the real relative humidity values with model pollen presented similar conclusions to the case of model humidity- model pollen. This indicates that the difference of the model representation of pollen compared to observation is likely not caused by relative humidity. Other studies tend to present similar correlations with this study. *Sofiev et al, 2013* in their study, noted that the model for birch pollen emissions takes into consideration the humidity parameter since the humidity suppresses the release of pollen. They also state that in high relative humidity values (>90%) the pollen concentrations are very low, when relative humidity was between 60-90 % the pollen concentrations were intermediate, while in low relative humidity the pollen was high. Other studies also indicate that there is a negative correlation between the pollen concentrations and the relative humidity *(Tseng et.al, 2018)*. While a research study from Poland mention that there is a positive correlation between relative humidity and birch pollen, but also that the pollination is more intense when the relative humidity is low. *(Dabrowska-Zapart et,al, 2022).*

4.3 Limitations

Some possible limitations of this study will be mentioned in this sector. Firstly, the time for conducting the thesis project was limited and wasn't enough for exploring more meteorological parameters. The gathering of the data and the preparation (convert the hours) of data for the observations and creation of graphs have been also very time consuming and lead to some changes from the original plan . Another limitation could be that the birch pollen season in June only lasts the first 10 days . So in June, the results of the tests mostly were non-significant which more likely was caused by the small size of the data . As well, one limitation could be , that the real pollen concentrations were counted bi-hourly so all the data had to be converted in this scale. The results might have been more informative if the data have been treated hourly due to a larger size of data and more precise statistics. Last but not least the study was for 1 year of pollen season (2023) and perhaps the results would have been different if more years have been included. There is a possibility that a pattern of the relationships between the compared data then could have been detected which would provide more knowledge.

Chapter 5 : Conclusion

This study was conducted for the three different areas of Sweden, Göteborg, Malmö and Umeå for a time period started around the middle of April and ended the tenth day of June of the year 2023. The birch pollen has been chosen , due to the fact that birch trees are dominant species in Sweden and a lot of population has been found sensitized in this type of pollen. This study was mainly a comparison between the SILAM pollen model forecasts and the counted pollen collected with the Hirst-type traps, with the aim of detecting differences in the amounts and try to explain a possible cause of these differences by meteorological conditions, in this case, relative humidity.

This study concluded that there was a difference between the compared pollen data with the model concentrations from SILAM being predicted higher than the real counted concentrations for all three areas. The correlations between them varied from moderate to strong with a positive relationship, so the two kinds of data appear to vary in consonance.

Relative humidity was chosen as it is considered an important factor both for the blooming season and while the pollen travels in the atmosphere. This study tested the correlations of real and model pollen concentrations with real and model relative humidity values in different combinations, and the tests presented that most likely, relative humidity was not the cause of the pollen concentration differences. So in the future, it would be important for other factors such as other components of meteorology as well as pollen production and emission, to be tested as well since the SILAM and other forecasting models are very useful tools in the preparation of short-term pollen warnings to sufferers of pollen allergy.

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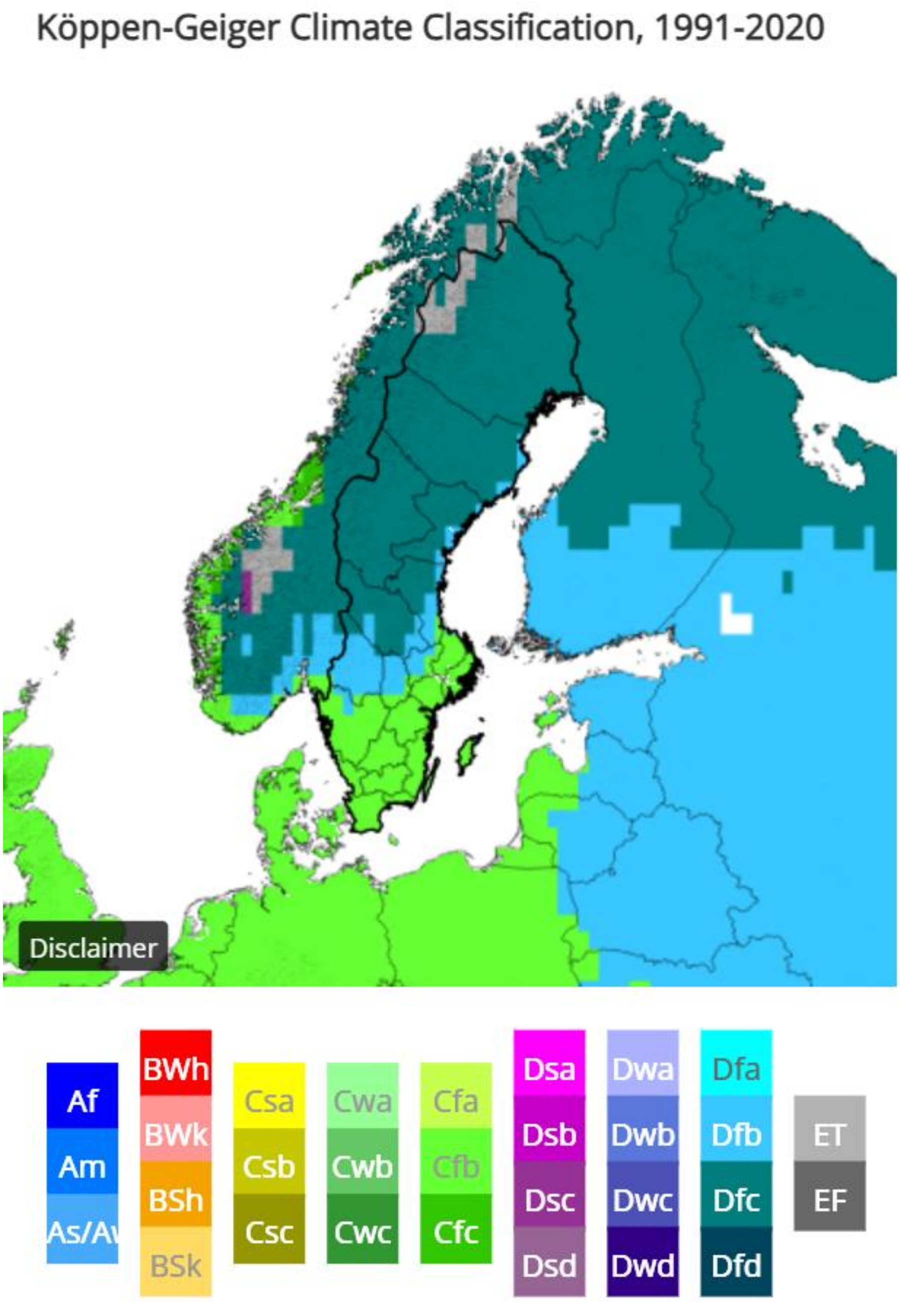
Appendix



Abbreviation	Definition	Abbreviation	Definition	Abbreviation	Definition
Af	Tropical rainforest climate	Cwa	Monsoon-influenced humid tropical climate	Dwa	Monsoon- influenced hot-summer humid continental climate
Am	Tropical monsoon climate	Cwb	Monsoon-influenced temperate oceanic climate/ or	Dwb	Monsoon- influenced warm-summer humid continental climate

			subtropical highland climate		
As/Av	Tropical savanna climate	Cwc	Monsoon-influenced subpolar oceanic climate/or subtropical highland climate	Dwc	Monsoon influenced subarctic climate
BWh	Hot desert climate	Cfa	Humid subtropical climate	Dwd	Monsoon-influenced extremely cold subarctic climate
BWk	Cold desert climate	Cfb	Temperate oceanic climate	Dfa	Hot-summer humid continental climate
BSh	Hot semi-arid climate	Cfc	Subpolar oceanic climate	Dfb	Warm-summer humid continental climate
BSk	Cold semi-arid climate	Dsa	Mediterranean-influenced hot-summer humid continental climate	Dfc	Subarctic climate
Csa	Hot-summer Mediterranean climate	Dsb	Mediterranean-influenced warm-summer humid continental climate	Dfd	Extremely cold subarctic climate
Csb	Warm-summer Mediterranean climate	Dsc	Mediterranean-influenced subarctic climate	ET	Tundra
Csc	Cold-summer Mediterranean climate	Dsd	Mediterranean-influenced extremely cold subarctic climate	EF	Ice cap climate

Appendix 1: Köppen-Geiger Climate Classification of Sweden (CCKP,2024)

Site	*period*	*Real pollen (pollen grains/m^3)*	*Model pollen (pollen grains/m^3)*	*difference*
Göteborg	20/04 16-18	3	1364	-1361
Göteborg	20/04 18-20	19	1950	-1931
Göteborg	20/04 20-22	14	2920	-2906
Göteborg	20/04 22-24	18	1950	-1932
Göteborg	21/04 10-12	28	2078	-2050
Göteborg	21/04 12-14	26	2152	-2126
Göteborg	21/04 14-16	197	2616	-2419
Göteborg	21/04 16-18	324	2744	-2420
Göteborg	21/04 18-20	489	4060	-3571
Göteborg	21/04 20-22	296	7344	-7048
Göteborg	21/04 22-24	69	3564	-3495

Göteborg	22/04 00-02	21	1171	-1150
Göteborg	22/04 06-08	255	1620	-1365
Göteborg	22/04 08-10	138	3352	-3214
Göteborg	22/04 10-12	258	4304	-4046
Göteborg	22/04 12-14	630	3000	-2370
Göteborg	22/04 14-16	248	2222	-1974
Göteborg	22/04 16-18	318	1884	-1566
Göteborg	22/04 18-20	1048	2536	-1488
Göteborg	22/04 20-22	624	3900	-3276
Göteborg	22/04 22-24	840	3240	-2400
Göteborg	23/04 00-02	735	2552	-1817
Göteborg	23/04 02-04	656	2504	-1848
Göteborg	23/04 04-06	306	2328	-2022
Göteborg	23/04 06-08	132	2264	-2132
Göteborg	23/04 16-18	13	1748	-1735
Göteborg	23/04 18-20	12	1780	-1768
Göteborg	23/04 20-22	38	2376	-2338
Göteborg	23/04 22-24	17	1063	-1046
Göteborg	24/04 02-04	45	1292	-1247
Göteborg	24/04 08-10	12	2046	-2034
Göteborg	24/04 10-12	8	2904	-2896
Göteborg	24/04 12-14	152	2110	-1958
Göteborg	24/04 16-18	101	1236	-1135
Göteborg	25/04 14-16	22	1636	-1614
Göteborg	25/04 16-18	21	2086	-2065
Göteborg	25/04 18-20	73	1404	-1331
Göteborg	25/04 20-22	65	1276	-1211
Göteborg	25/04 22-24	18	1548	-1530
Göteborg	26/04 00-02	39	1468	-1429
Göteborg	26/04 02-04	42	1071	-1029
Göteborg	28/04 10-12	18	1035	-1017
Göteborg	28/04 12-14	147	1268	-1121
Göteborg	28/04 20-22	62	1846	-1784
Göteborg	28/04 22-24	33	2824	-2791
Göteborg	29/04 00-02	28	2520	-2492
Göteborg	29/04 02-04	45	2030	-1985
Göteborg	02/05 08-10	6	4524	-4518
Göteborg	02/05 10-12	78	5264	-5186
Göteborg	02/05 12-14	133	2110	-1977
Göteborg	03/05 12-14	104	1220	-1116
Göteborg	03/05 14-16	84	1164	-1080
Göteborg	03/05 20-22	68	1620	-1552
Göteborg	03/05 22-24	41	1756	-1715
Göteborg	04/05 20-22	246	1276	-1030
Göteborg	04/05 22-24	73	1308	-1235
Göteborg	05/05 20-22	28	1132	-1104
Göteborg	05/05 22-24	4	1099	-1095
Göteborg	06/05 16-18	62	1140	-1078
Göteborg	06/05 18-20	69	1516	-1447
Göteborg	06/05 20-22	36	1596	-1560

Göteborg	06/05 22-24	54	2696	-2642
Göteborg	07/05 00-02	28	1292	-1264
Göteborg	07/05 14-16	28	1180	-1152
Göteborg	07/05 20-22	28	1998	-1970
Göteborg	07/05 22-24	50	2680	-2630
Göteborg	08/05 00-02	61	2456	-2395
Göteborg	09/05 00-02	109	1452	-1343
Göteborg	09/05 02-04	46	1244	-1198
Göteborg	09/05 20-22	64	1295	-1231
Göteborg	09/05 22-24	122	1588	-1466
Göteborg	10/05 00-02	39	1043	-1004

Appendix 2: Real-model pollen concentration comparisons, all hours with a difference above 1000 pollen grains. Study area: Göteborg, Time period: 18/04- 10/06 2023.

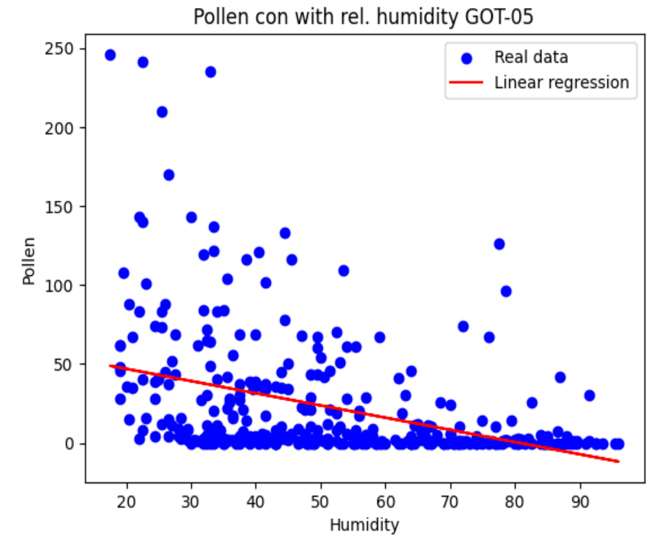
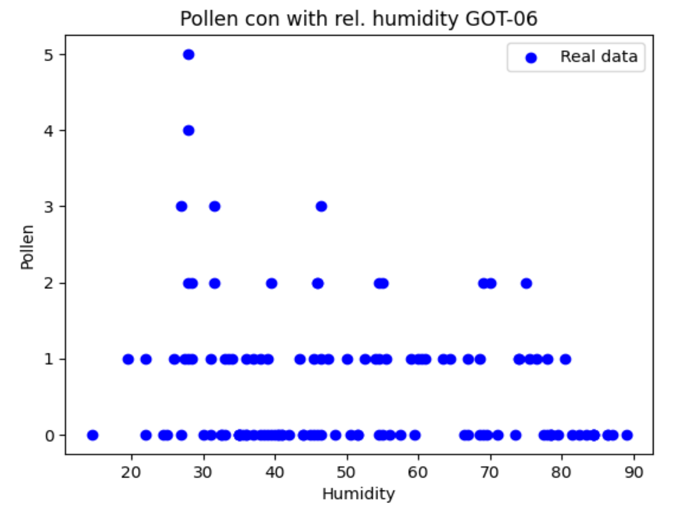
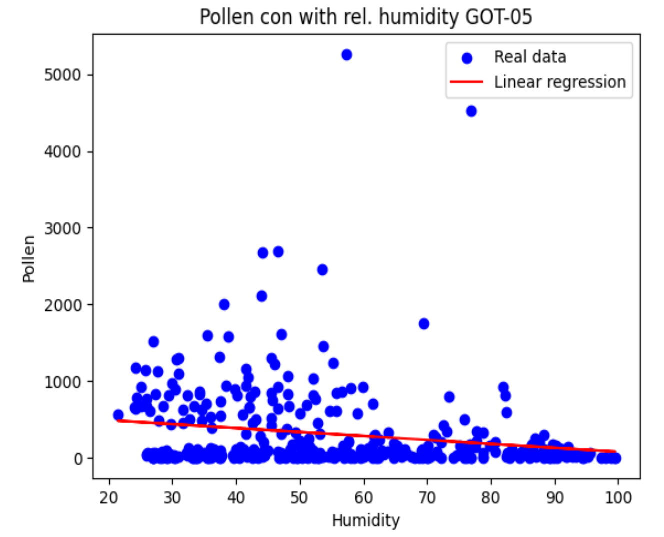
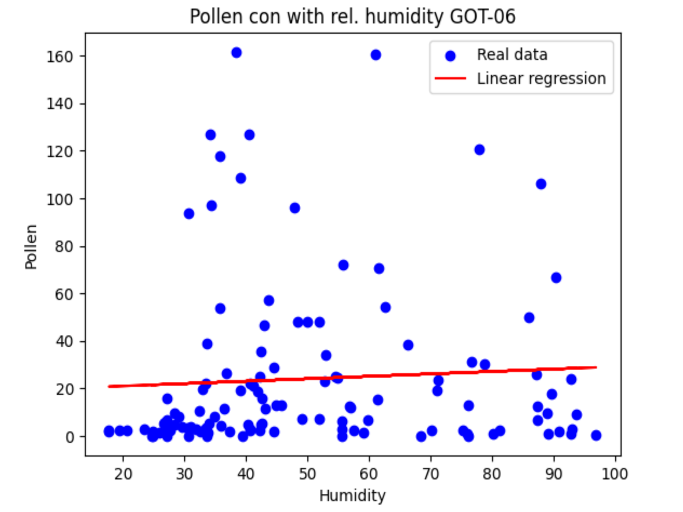
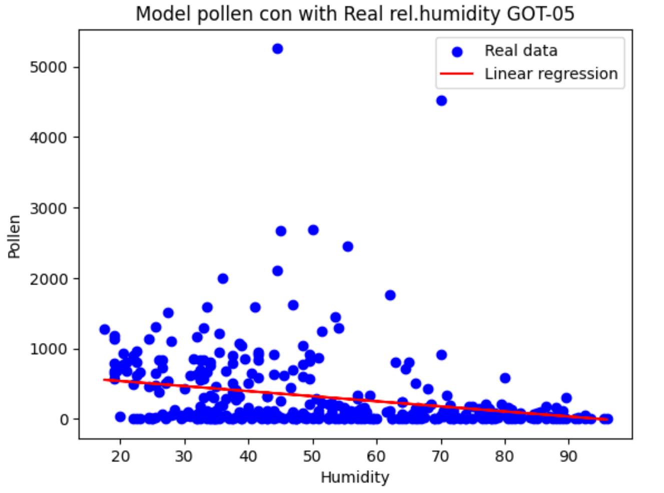
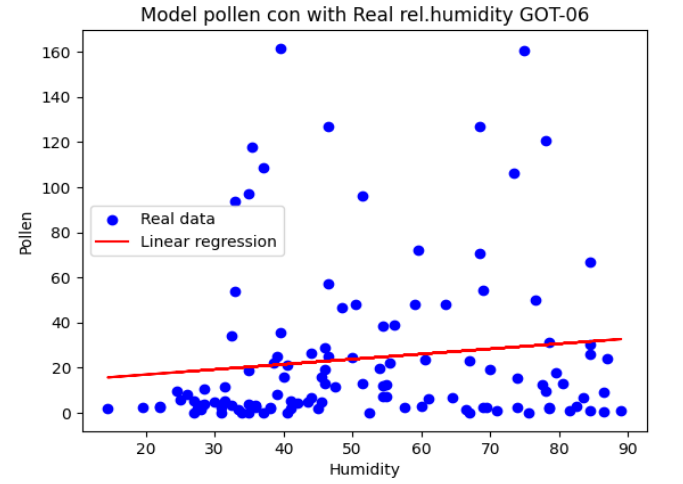
Site	*period*	*Real pollen (pollen grains/m³)*	*Model pollen (pollen grains/m³)*	*difference*
Malmö	22/04 10-12	69	1516	-1447
Malmö	22/04 12-14	89	1244	-1155
Malmö	22/04 20-22	41	1055	-1014
Malmö	22/04 22-24	40	1156	-1116
Malmö	23/04 00-02	41	1100	-1059
Malmö	23/04 18-20	11	1420	-1409
Malmö	23/04 20-22	4	1452	-1448
Malmö	24/04 20-22	24	1051	-1027
Malmö	04/05 20-22	31	1055	-1024

Appendix 3: Real-model pollen concentration comparisons, all hours with a difference above 1000 pollen grains. Study area: Malmö, Time period: 12/04- 10/06 2023.

Site	*period*	*Real pollen (pollen grains/m³)*	*Model pollen (pollen grains/m³)*	*difference*
Umeå	16/05 10-12	274	3586	-3312
Umeå	16/05 12-14	146	2574	-2428
Umeå	16/05 14-16	177	2946	-2769
Umeå	16/05 22-24	2	1548	-1546
Umeå	18/05 06-08	60	1558	-1498
Umeå	18/05 08-10	37	2552	-2515
Umeå	18/05 10-12	37	3720	-3683
Umeå	18/05 12-14	24	1958	-1934
Umeå	18/05 14-16	36	1260	-1224
Umeå	18/05 16-18	64	1484	-1420
Umeå	18/05 18-20	39	3276	-3237
Umeå	18/05 20-22	48	6704	-6656
Umeå	19/05 06-08	2	1103	-1101
Umeå	19/05 08-10	52	4572	-4520

Umeå	19/05 10-12	53	2648	-2595
Umeå	19/05 12-14	42	1980	-1938
Umeå	19/05 14-16	50,	2184	-2134
Umeå	19/05 16-18	122	2312	-2190
Umeå	19/05 18-20	75	2648	-2573
Umeå	19/05 20-22	52	3064	-3012
Umeå	20/05 08-10	70	2454	-2384
Umeå	20/05 10-12	129	4208	-4079
Umeå	20/05 12-14	162	3256	-3094
Umeå	20/05 14-16	85	2984	-2899
Umeå	20/05 16-18	67	3032	-2965
Umeå	20/05 18-20	81	3368	-3287
Umeå	20/05 20-22	36	3240	-3204
Umeå	20/05 22-24	26	1271	-1245
Umeå	21/05 08-10	121	3224	-3103
Umeå	21/05 10-12	115	3144	-3029
Umeå	21/05 12-14	138	2552	-2414
Umeå	21/05 14-16	85	2280	-2195
Umeå	21/05 16-18	49	2184	-2135
Umeå	21/05 18-20	50	2120	-2070
Umeå	21/05 20-22	31	2126	-2095
Umeå	22/05 08-10	93	3240	-3147
Umeå	22/05 10-12	77	3704	-3627
Umeå	22/05 12-14	125	3368	-3243
Umeå	22/05 14-16	81	3448	-3367
Umeå	22/05 16-18	75	4092	-4017
Umeå	22/05 18-20	72	5520	-5448
Umeå	22/05 20-22	44	4812	-4768
Umeå	23/05 02-04	9	1159	-1150
Umeå	23/05 04-06	20	1255	-1235
Umeå	23/05 06-08	36	1283	-1247
Umeå	23/05 08-10	369	9752	-9383
Umeå	23/05 10-12	255	13856	-13601
Umeå	23/05 12-14	240	10528	-10288
Umeå	23/05 14-16	235	8248	-8013
Umeå	23/05 16-18	133	8184	-8051
Umeå	23/05 18-20	132	5840	-5708
Umeå	23/05 20-22	42	3464	-3422
Umeå	23/05 22-24	20	1435	-1415
Umeå	24/05 06-08	17	1886	-1869
Umeå	24/05 08-10	348	5936	-5588
Umeå	24/05 10-12	160	2840	-2680
Umeå	24/05 12-14	86	1564	-1478
Umeå	24/05 14-16	30	1135	-1105
Umeå	25/05 04-06	1	4604	-4603
Umeå	25/05 06-08	17	4688	-4671
Umeå	25/05 08-10	39	2350	-2311
Umeå	25/05 10-12	24	1027	-1003
Umeå	25/05 18-20	19	1332	-1313
Umeå	25/05 20-22	1	1236	-1235
Umeå	25/05 22-24	3	1091	-1088
Umeå	28/05 10-12	1	1468	-1467
Umeå	28/05 12-14	9	1244	-1235

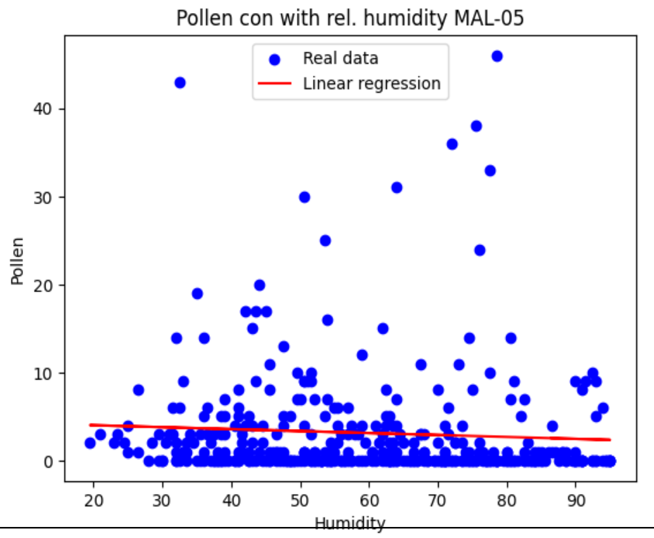
Appendix 4: Real-model pollen concentration comparisons, all hours with a difference above 1000 pollen grains. Study area: Umeå, Time period: 26/04- 10/06 2023.

Real pollen-real relative humidity *Slope May:*-0.77 June: Linear Regression model not relevant		
Model pollen-model relative Humidity *Slope May:*-5.15 *Slope June:* 0.10		
Real relative Humidity-model pollen *Slope may:*-7.20 *Slope June:* 0.23		

Appendix 5: Linear Regression graphs between pollen concentrations and relative humidity values. Location: Göteborg, Period: May and June 2023.

<table>
<tr>
<td>Real pollen-real relative humidity

Slope May:-0.02

June: Linear Regression model not relevant</td>
<td>
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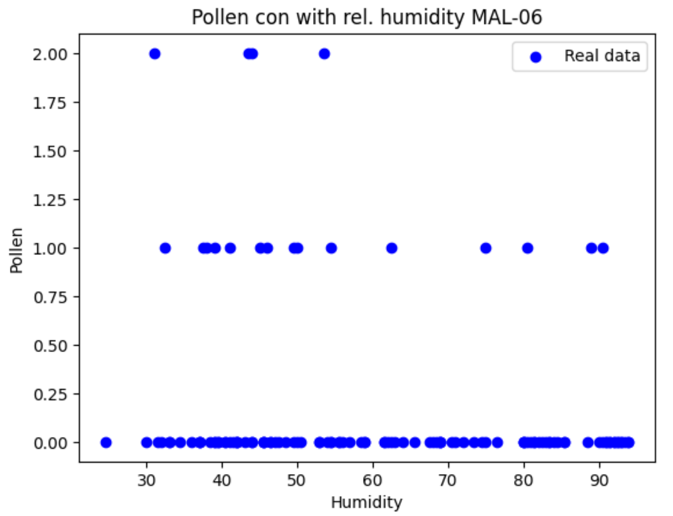
<td>
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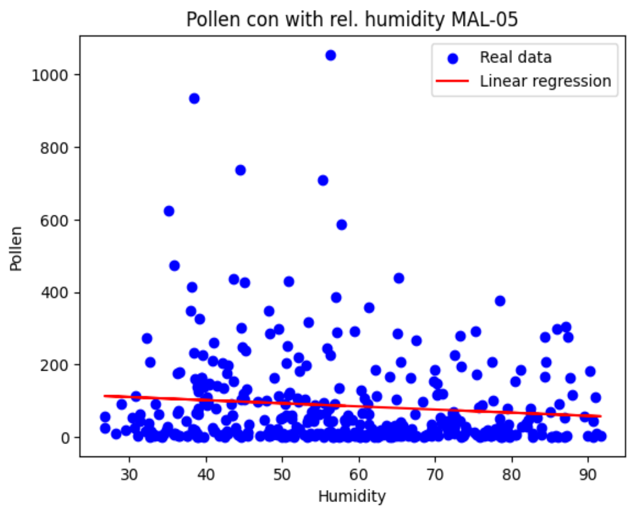
<tr>
<td>Model pollen-model relative Humidity

Slope May: -0.86

Slope June: 0.11</td>
<td>
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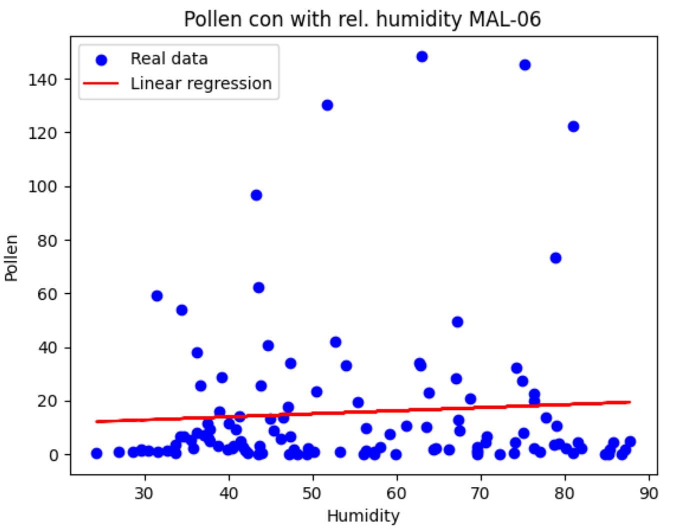
<td>
</td>
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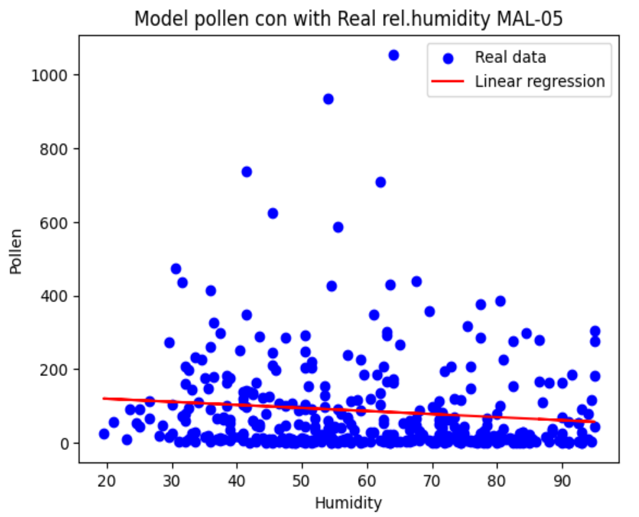
<tr>
<td>Real relative Humidity-model pollen

Slope may: -0.83

Slope June: 0.03</td>
<td>
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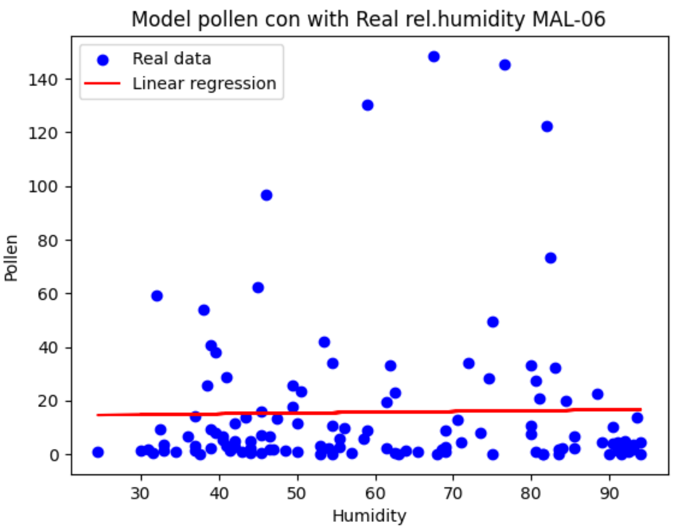
<td>
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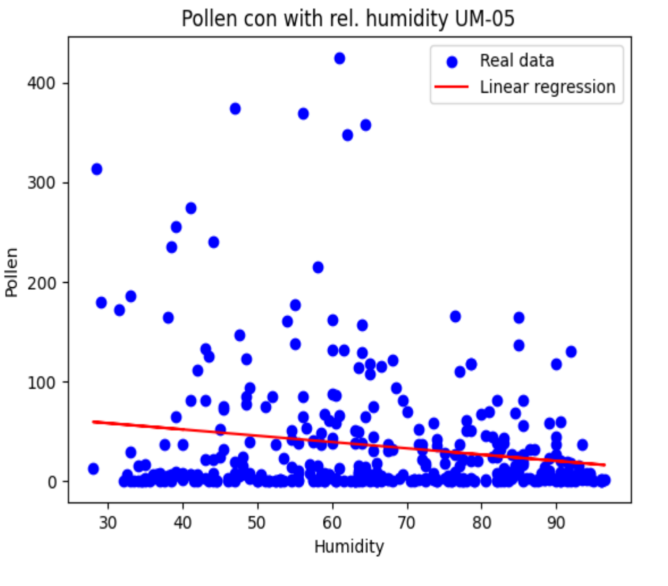
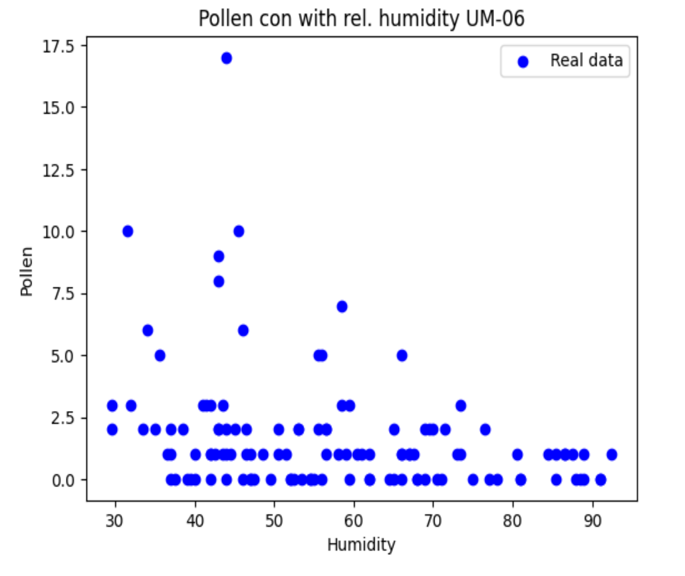
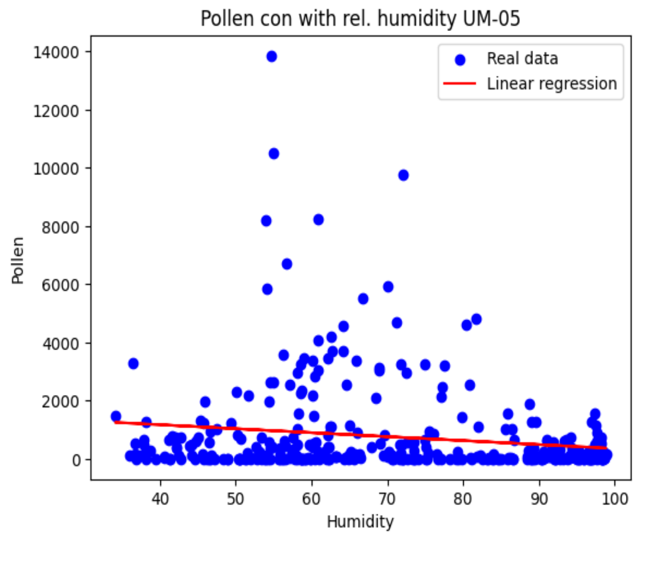
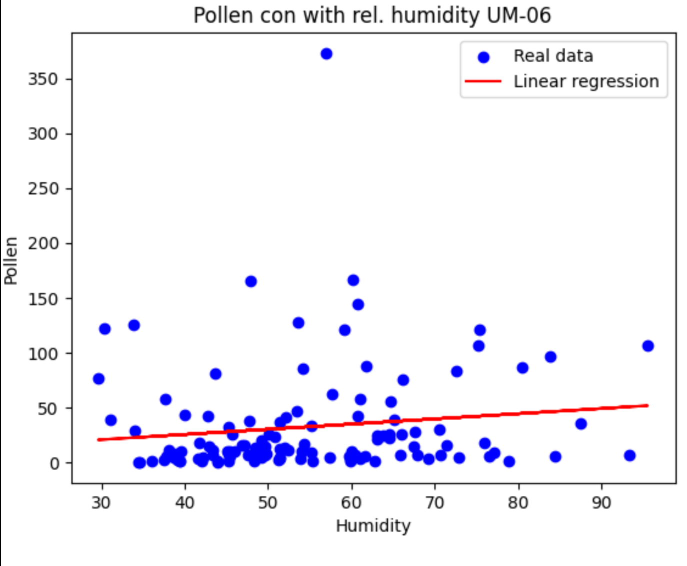
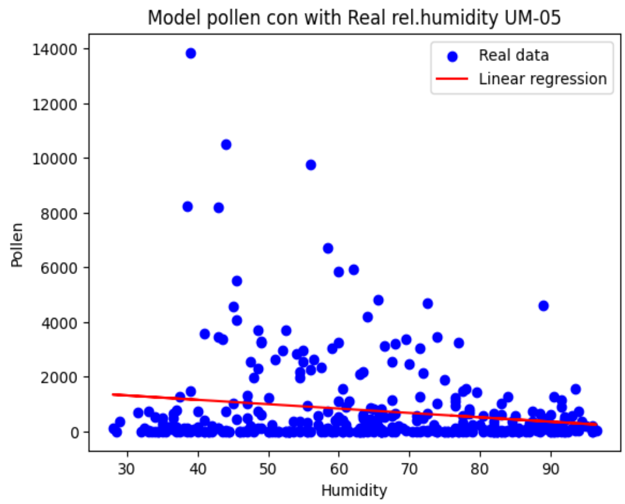
</table>

Appendix 6: Linear Regression graphs between pollen concentrations and relative humidity values. Location: Malmö, Period: May and June 2023.

Real pollen-real relative humidity *Slope May:*-0.63 June: Linear Regression model not relevant		
Model pollen-model relative Humidity *Slope May:* -13.63 *Slope June:* 0.47		

<table>
<tr>
<td>Real relative Humidity-model pollen

Slope may: -15.98

Slope June: 0.30</td>
<td>
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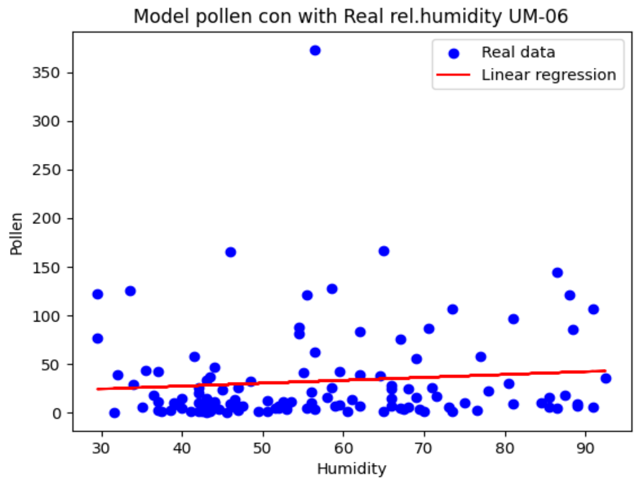
<td>
</td>
</tr>
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Appendix 7: Linear Regression graphs between pollen concentrations and relative humidity values. Location: Umeå, Period: May and June 2023.