Bachelor's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Mechanical and Industrial Engineering

Sander Grødal

Long-term meteorological data collection in Prato Piazza

Data analysis of meteorological conditions

Bachelor's thesis in Mechanical Engineering
Supervisor: Chiara Bertolin
Co-supervisor: Stefano Cavazzani
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Contents

List of Figures

List of Tables

Preface

This bachelor thesis is an interdisciplinary study conducting various topics including data analysis, programming, climatology, meteorology and mathematical modelling. The aim of this thesis is to provide a comprehensive understanding of the the impact long-term weather data adheres to the process of determination of weather station components, and to present the various challenges that arise during meterological conditions. The thesis was originally a group project, but due to the workload, it has been split into two separate bachelor theses.

Moreover, I would like to take this opportunity to express my sincere gratitude to my close friend Sander for his invaluable programming assistance, which proved crucial in overcoming many of the technical challenges I encountered during the project. I am also grateful to my bachelor supervisors Chiara Bertolin and Stefano Cavazzani for their guidance throughout the entire process, from the the preliminary phase to the very end. Their expertise and insightful feedback have been invaluable in shaping the direction and scope of this thesis. Finally, I would like to extend my appreciation to Associate Professor Anna Olsen for her helpful input and support throughout the project.

Abstract

This bachelor's thesis is an interdisciplinary study in programming, climatology, meteorology, and mathematical modeling with the aim of utilizing long-term weather data from an area in the Dolomites called Prato Piazza. Furthermore, this includes an investigation of temperature, precipitation patterns, cloud cover, and other relevant weather parameters. To conduct this study, the student will collect and process large amounts of weather data, use the computer tools OriginLab and Python to plot the weather data and be able to look for climate change. By combining knowledge from various fields, the thesis seeks to identify patterns, trends, and relationships in weather data to develop mathematical models and forecasting tools.

Sammendrag

Denne oppgaven tar for seg tverrfaglige teknikker til å belære seg om matematisk modellering, klimatologi og meterologi ved å benytte programmering. Hensikten med oppgaven er å føre værstatistikk av området Prato Piazza fra 1948 til 2023. Meterologiske parametre som nedbør, temperatur, skydekke blir blant annet undersøkt til datainnsamling ved hjelp av OriginLab og Python. Dermed skal det være mulig å forutse værtrender ved å utvikle programmeringslinjer og grafer.

Abbreviations

AOD	Aerosol Optical Depth
CAD	Computer Aided Design
CC	Total cloud cover
CF	Cloud fraction
EOS	Earth Observing System
ESA	European Space Agency
GOES	Geostationary Operational Environmental Satellite
LIDAR	Light Detection and Ranging
MOD	Terra satellite
MODIS	Moderate Resolution Spectroradiometer
MYD	Aqua satellite
NTNU	Norwegian University of Technology and Science
PV	Photovoltaic
RTD	Resistance temperature detector
S	Total sky cover
UN	United Nations
UNIPD	University of Padua
WMO	World Meteorological Organization

Chapter 1

Introduction

1.1 Background

Among the Italian borders of the Alps lies Prato Piazza. A mountain range situated in the Dolomites that is characteristically prominent of its magnificent nature. The mountain range expands through Austria, and is located at an altitude of approximately 2000 m.a.s.l. Not only does the area attract hiking and nature enthusiasts, but it also draws the attention of researchers. Given its height and geographical location, it is therefore of best interest to investigate the diverse meteorological conditions of Prato Piazza for weather research in this thesis. Specifically, the investigation will primarily focus on Prato Piazza defined by the coordinates $E\ 12°06'' - E\ 012°21''$, $N\ 46°30'' - N\ 46°45''$

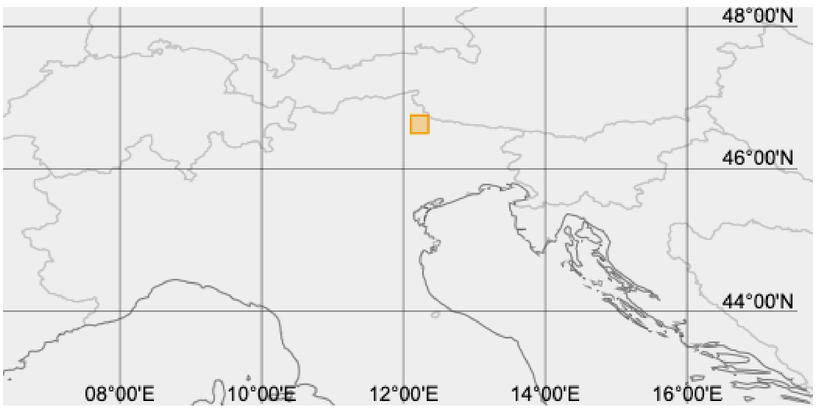


Figure 1.1: Geographical location of Prato Piazza.(giovanni.it).

The project derives from a interdisciplinary collaboration established between the University of Padua (UNIPD) and the Norwegian University of Science and Technology (NTNU). The thesis was proposed by professor Chiara Bertolin at the Department of Industrial and Mechanical Engineering at NTNU. Prato Piazza is an already-existing test site used for The primary objective of the project in Prato Piazza is to execute climatology research from long-term data collection from 1948 to 2014 consisting of the parameters temperature and precipitation. The datasets are collected in a combination of ground-based and satellite-based data. Given the absence of available datasets after 2014, a comparative analysis will also be conducted to examine the current climatic conditions of Prato Piazza, to see any increment of trends and patterns compared to the datasets from 1948-2014. Consequently, the aim of this objective is to see both annual and daily weather trends and patterns in reference to climate change.

Additionally, the second objective of this thesis will be to propose innovative weather station components for the existing weather stations in terms of cost-efficiency, choice of material, and sustainability. By implementing innovative weather station components, one can contribute to improved data acquisition and optimize the operation and maintenance of weather stations. The possibilities of research options of this specific topic.

One of the requirements for writing the bachelor's thesis at the Department of Mechanical and Industrial Engineering was to include sustainability. Therefore, this thesis was inspired by the Sustainable Development Goals, specifically goal 9 and 13.

Figure 1.2: Sustainable Development Goals 9 and 13.

The Sustainable Development Goals are a set of 17 global goals distributed by the United Nations with the aim of obtaining development globally. In other words, these development goals were, in principle, designed to address the greatest challenges affecting the globe. These development goals address various factors such as poverty, inequality, justice, peace, and climate change. Of the 17 global development goals, goal number 9 is particularly relevant for promoting innovative weather station components to improve meteorological data acquisition. Goal 13 is particularly relevant in relation to weather trends and patterns, including temperature and precipitation, and their impact on climate change

1.2 Thesis statement

The objective of the project at the test site of Prato Piazza is to create a comprehensive system to evaluate atmospheric conditions with the help of four weather stations placed around the sampling perimeter. In the thesis description, it is specified that the atmospheric conditions of relevance imply to relative humidity, aerosol optical depth, temperatures, wind intensity and direction, precipitation, cloud cover and sky quality.

These weather stations must follow guidelines provided by The World Meteorological Organization to ensure their reliability as observational stations. Such requirements imply to the design of the weather stations must be integrated with the surrounding environment, including visual impact and colour. The design of the weather stations must meet these requirements while also considering cost efficiency and sustainability factors to ensure that they are economically viable and environmentally friendly.

Additionally, it has been suggested that the weather stations should be equipped with both standard meteorological weather station components, and innovative, existing weather station components to measure the atmospheric conditions. Considering the complexity of the project, it has been decided to primarily focus on measuring atmospheric conditions using weather stations for temperature, precipitation, Aerosol Optical Depth, and cloud coverage. The utilization of drones and laser links, including vertical and horizontal laser links, will be avoided due to their complexity.

Therefore, the thesis statement is to execute data analysis of meteorological weather data in Prato Piazza to conduct feasibility test with respect to the meteorological conditions temperature, precipitation, cloud coverage and Aerosol Optical Depth.

1.3 Scope and limitations

1.3.1 Performance goals and measures

Performance goals refer to goals of the project to achieve within the set time frame. The regarding performance goals were:

- Literature study on previous test sites in terms of various meterological phenomena.
- Perform climatology study of long-term weather data of Prato Piazza by Excel, OriginLab and Python.
- Propose innovative weather station components in regards to the collected weather data

Performance measures are tools to assess if the project were successfully, adhering to the performance goals. The regarding performance measures were:

- **Clarity of thesis statement:** It was expected that the thesis statement should establish the groundwork during the thesis writing, and that it should be comprehensible for all parties involved.
- **Literary quality:** The literary quality of the paper should be characterized by a thorough specification and comprehensive exposition of the topic, providing the reader with a profound understanding from the introduction to the conclusion.
- **Research methodology & data collection:** In order to obtain the necessary information, various research methods were utilized, both qualitative and quantitative. Weather data was primarily utilized as an important source for performing quantitative analyses, in addition to documents and articles used for the qualitative research.
- **Contribution:** The purpose of the thesis is to contribute to the project with expertise in mechanical engineering, as well as to utilize tools, e.g. Excel, Python and

OriginLAB, to assist with research in meteorology. As there was no prior knowledge of the field, it was important to receive guidance and feedback from supervisors

all assessments regarding cost-effectiveness, sustainable choices, and component selection were conducted to ensure that the project was optimally designed and executed. This would contribute to secure that the project was both economically and environmentally sustainable, while also meeting the necessary requirements and goals for evaluating atmospheric conditions.

1.3.2 Limitations

Since the project relies on the location of the test site in Prato Pizza in Italy, conducting the project from Trondheim in Norway would be necessary. To limit practical activities, it was necessary to gather both theoretical information and weather data. Theoretical information were obtained from research articles and websites, while weather data were retrieved from co-supervisor Stefano Cavazzani. Due to the project's complexity and responsibility, it has also been agreed to divide the research into two separate bachelor's theses instead. Therefore, it has also been agreed to extend the submission deadline to the 2nd of June, due to the development of new thesis statements.

The guidance meetings were primarily held in the office with supervisor Chiara Bertolin, while assistance was provided digitally on Zoom by co-supervisor Stefano Cavazzani.

Chapter 2

Theory

This section encompass the studies of climatology, global warming, meterology, and mathematical modelling. Additionally, this section provides the application of meteorological weather stations.

2.1 Literature Review

A comprehensive literature review on site testing based on meteorological parameters such as aerosol optical depth, (AOD) and cloud coverage is pivotal for gaining a more comprehension of established methodologies. Additionally, it is also important to comprehend the impact of these parameters on test sites to determine the most optimal test sites. In introduction, this thesis will firstly rely on research articles of satellite data directed at several test sites.

Satellite-derived parameters for astronomical site testing provides a detailed analysis of the use of satellite-derived parameters for assessing meteorological conditions and cloud coverage at meteorological observatories. The article emphasizes the importance of selecting appropriate test sites for studying atmospheric conditions and cloud coverage in order to improve astronomical observations and instrumentation.

Cavazzani used satellite-derived parameters such as Aerosol Optical Depth (AOD) and cloud coverage to investigate several test sites located in Chile, Spain (Canary Islands), and the USA. The authors found that different sites had varying levels of cloud cover depending on their location and local climate conditions. For example, Paranal Observatory in Chile had the highest percentage of satellite-derived clear nights (88%), while Mauna Kea Observatory in Hawaii had the lowest percentage of clear nights (59 %).

Satellite characterization of four interesting sites for astronomical instrumentation involves obtained data acquisition from the GOES12 satellite of cloud coverage at various test sites. These test sites are located in the Canary Islands, Mexico and Argentina with distinctive topographies as presented in Figure 2.1. Furthermore, Cavazzani classified types of cloud coverage, where the degree of cloud coverage is presented in a range from $0-100$. The higher the percentage of cloud coverage, the more covered nights are depicted.

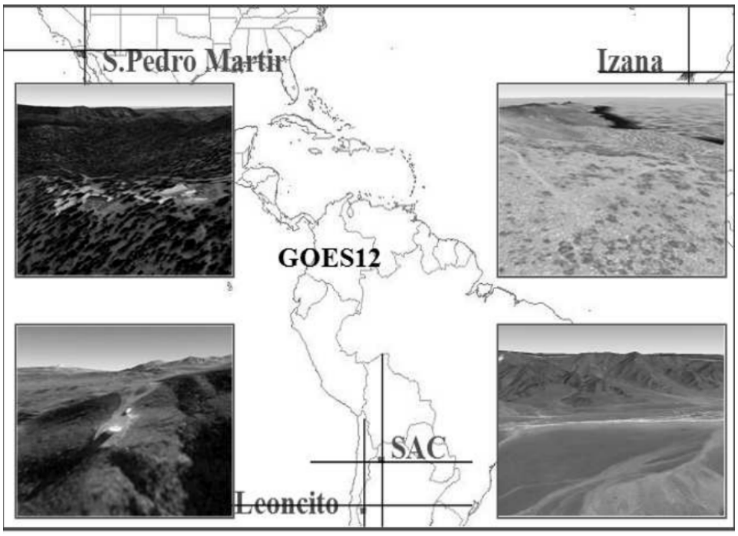


Figure 2.1: Location of the four sites involved in *Satellite characterization of four interesting sites for astronomical instrumentation.*

2.2 Weather Stations

2.2.1 History and Purpose of Weather Stations

Weather stations have played a vital role throughout history in monitoring and recording meteorological data. In the past, weather stations primarily served the purpose of providing weather forecasts and warnings to support agricultural practices and maritime navigation. Earliest recorded weather station in the world were the The Radcliffe Meteorological Station at Oxford University (1760) [34], and it consisted of simple instruments such as a thermometer, a wind vane and certainly an anemometer. Considering that the weather station were founded in the 16th century, most of the related equipments were manually operated. Over time, their significance has expanded to encompass various sectors, including aviation and climate research. Modern weather stations are equipped with advanced instruments and technologies to gather comprehensive data on temperature, humidity, wind speed and direction, precipitation, atmospheric pressure, and more. This data is essential for understanding weather patterns, climate change, and facilitating accurate forecasts and climate projections.

Figure 2.2: Radcliffe Meteorological Station.

2.2.2 Standard weather station instruments

A weather station is a facility equipped with various instruments and sensors to collect meteorological data related to atmospheric conditions, such as temperature, humidity, air pressure, wind speed and direction, precipitation, and solar radiation. In contrast, a meteorological weather station specifically emphasizes the measurement and analysis of atmospheric parameters for meteorological research. By performing this critical function, it substantially contributes to the weather monitoring, climate studies, and environmental analysis.

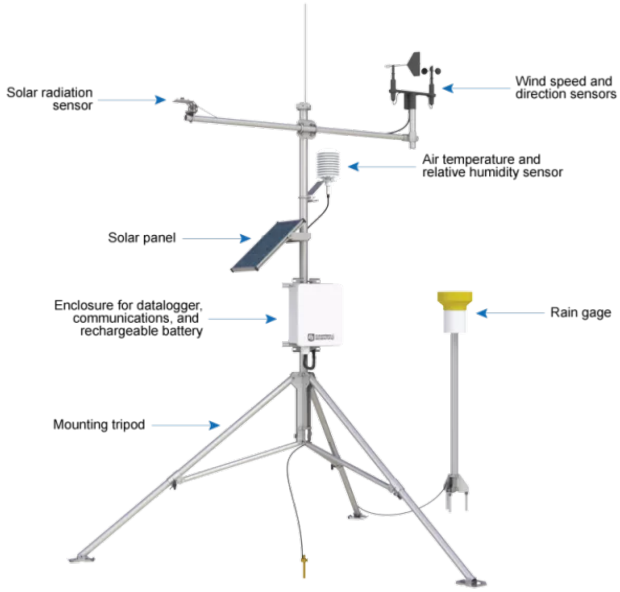


Figure 2.3: Meteorological weather station equipped with essential instruments.

Enumerated below are the fundamental components typically present in a typical meteorological weather station tree:

- Thermometer: Used to measure air temperature. It can be a traditional mercury or alcohol-filled thermometer, or a modern electronic sensor such as a thermistor or resistance temperature detector (RTD). The temperature measurement is typically recorded in Celsius or Fahrenheit.

- Barometer: Used to measure atmospheric pressure, which indicates the weight of the air above the surface. It helps monitor changes in weather patterns. Common types of barometers include mercury barometers, which use the height of a mercury column to measure pressure, and aneroid barometers, which use a flexible metal cell that expands or contracts with changes in pressure.

- Anemometer: Used to measure wind velocity. It provides information about the intensity of air movement. Common types of anemometers include cup anemometers, which have rotating cups that catch the wind, propeller anemometers, which have rotating blades, and sonic anemometers, which use sound waves to measure wind velocity.

- Wind vane: The wind vane, generally known as a weather vane, determines the wind direction. It consists of a pointer that moves with the direction of the wind. Wind vanes often have cardinal directions (north, south, east, west) marked on them to indicate the wind's orientation.

- Rain gauge: The rain gauge collects and measures the amount of precipitation that falls over a specific time period. It helps monitor rainfall patterns and amounts. Rain gauges can be simple cylinders or funnels that collect rainwater and measure it in millimeters or inches.

- Sunshine recorder: The sunshine recorder measures the duration and intensity of sunlight. It typically consists of a glass sphere or cylindrical lens that focuses sunlight onto a photosensitive surface. By tracking the movement of the focused light, the sunshine recorder creates a record of sunshine hours, which is important for understanding solar radiation patterns.

2.2.3 Innovative weather station instruments

This section presents a comprehensive overview of frequently employed instruments in weather stations. In section 3.5, the particular focus is on employment of innovative instruments intended for integration within the weather station framework.

All Sky Camera

The All Sky Camera is a highly advanced instrument used to capture images of the entire sky hemisphere, with the intention of monitoring weather conditions. Such weather conditions could be cloud coverage and precipitation, which are stated in subsection 2.4.4 and subsection 2.4.2. An All Sky Camera provides valuable information on cloud cover, cloud types, and their movement patterns. Equipped with a fish-eye lens, this camera offers an unobstructed view of the sky. The captured images are used for cloud identification, cloud fraction analysis, and the assessment of sky conditions. All Sky Cameras are typically designed to to be weather-resistant and durable. Materials such as aluminum or stainless steel are therefore frequently employed for housing the housing the lenses. (Kilder)

Figure 2.4: TYTEA All Sky Camera.

PV Panel

PV Panels, Photovaltic panels, are instruments aimed to measure solar radiaton. These panels comprise of semiconductor materials, e.g. silicon, where the mode of operation is to convert sunlight into electricity through the photovoltaic effect. In other words, photovoltaic effect is the absorption of light photons and emission of electrons. In addition, PV panels are also composed of a protective layer, usually glass with low iron that prevents mechanical wear from wind and water. This is well suited for PV panels that are installed at high altitudes, as PV panels have optimal inclination at 90 degrees minus the latitude. [30]

Figure 2.5: PV panel aligned with the weather station tree.

2.3 Climate

2.3.1 Introduction to climate studies

Climatology is the scientific study of climate regarding observations of climate patterns, analyzes of historical climate data and identifying aspects that impact climate change. In other words, researchers of climate aim to study long-term weather data in order to see trends and changes in the seasons. To investigate past, present and future climate conditions, climatologists employ statistical methodologies, mathematical models, and data analysis techniques. Another interchangeably terminology opposed to climatology is climate. In contrast to climatology, climate is the long-term weather data that can potentially be observed in a specific region.

2.3.2 Geographical climate zones of Italy

Italy is renowned for its diverse climate due to its geographical location in central Europe and the range of topographic characteristics. Encompassing scorching temperatures in the Mediterranean to reaching snow-covered landscapes in the northernmost of the Alps, Italy exhibits a variety of 4 domain distinct climate zones. Accordingly, the influence from these climate regions showcase a compelling variety of weather patterns and atmospheric conditions across Italy. Climate zones are typically characterized by the Koppen-Geiger climate classification. Koppen-Geiger climate classification utilize colours and shades to decide the climatic zone. These climate regions are as listed below:

- **Mediterranean climate**: Within close proximity to the coastal Mediterranean, one can identify warm summers and mild, wet winters. In regards to the temperatures, the temperature usually surpass $30°C$ during the summer, and occasionally above the freezing point during the winter (Source).

- **Alpine climate**: In the northernmost part of Italy one can locate the Alps, where the climate is predominantly described as extremely cold for the winters, and shorter and cooler summers. In essence, the temperatures are typically below the freezing point, whereas indicated prior the summers are of lesser extent than they are elsewhere in Italy.

- **Peninsular climate**: Peninsular climate represents partly cloudy summers to chilling winters.

- **Po valley climate**: The Po Valley climate, originated from the Po Valley, is heavily characterized by cold winters and warm summers. For clarification, Po Valley climate typically features in the areas of Milano and Alessandria.

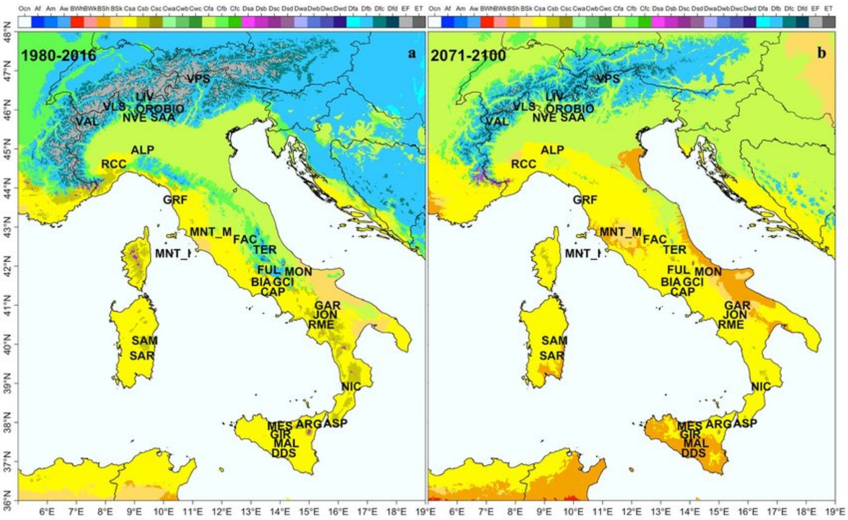


Figure 2.6: Koppen-Geiger map of Italy. [12]

Zone A	tropical or equatorial zone
Zone B	arid or dry zone
Zone C	warm/mild temperate zone
Zone D	continental zone
Zone E	polar zone

Table 2.1: Climate zones after the Koppen-Geiger where the cell colours depict the shade of climate on the map.

2.3.3 Global Warming: Importance and implications

With irregular weather patterns, Italy is significantly impacted by climate change. As a country with a varied topography and extensive coastlines, Italy experience several challenges related to global warming and extreme weather conditions. One of the most notable and recent effects of climate change in Italy is the increase in average temperature. According to IEA, Italy has experienced an average temperature increase around $1°C$

over the past 100 years [11]. As a consequence, the increasing temperature has entailed to changes in both temperature and precipitation patterns.

Global warming has also led to an increased risk of extreme weather conditions in Italy. The country has experienced more frequent and more intense heat waves, especially in the southern and central regions. In addition, increased rainfall has also led to an increased risk of flooding in areas with poor drainage and along rivers. Recently in 2023, the region Emilia Romagna experienced a colossal flooding which lead to 15 kills and thousand homeless [28].

As indicated prior, the average temperature of Italy has increased by $1.0°C$ the past 100 years. Agreements such as Paris Agreement enforce to combat the rise of climate change. The Paris Agreement is a treaty signed by Italy and the rest of the world to reduce the global average temperature, where the long-term aim is to limit the increase in global temperature to below $2°C$ by the end of the century [27]

2.4 Meteorological parameters

Meteorological parameters incorporate important measurements for research purposes and observations in understanding weather conditions and meteorological processes like climate trends. An assortment of such parameters include temperature, precipitation, wind speed & direction, cloud cover and atmospheric pressure.

2.4.1 Temperature

Temperature is by definition the degree of hotness or coldness of an object [29]. More theoretically applied, temperature is a measure of the average kinetic energy of particles in a substance. A few properties of temperature is that the freezing point is at $0°C$, and the boiling point is at $100°C$. Furthermore, the temperature is measured in either Kelvin or Celsius, with Celsius being the preferred unit in meteorological studies. It is of best interest to note that temperature should not be confused with heat. While temperature depicts the intensity of thermal energy, heat rather pertains to the transfer of thermal energy between objects or systems. An excellent example of this is a cup of hot tea. When you touch the cup, you can feel the heat being transferred from the cup to your hand. The thermal energy of the tea water can be measured as temperature.

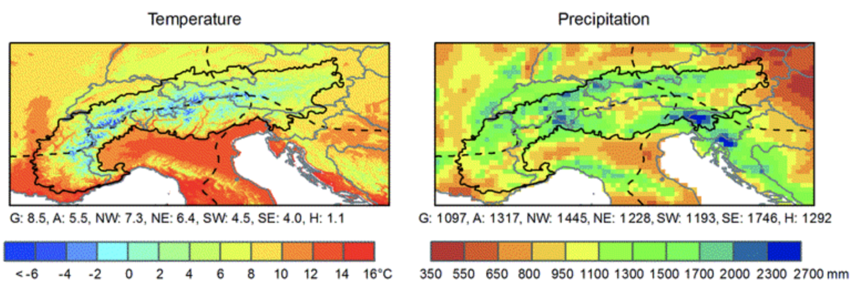


Figure 2.7: Distribution of mean temperature and precipitation in the Italian Alps (1961-1990).

2.4.2 Precipitation

In accordance with National Geographic, precipitation is defined as *any liquid or frozen water that forms in the atmosphere and falls to Earth.* [31] Precipitation encompasses various forms including rainfall, snow, sleet and hail among other things with each of their own methods of measurements. However, rainfall is considered the most common form of precipitation, where it is typically measured in millimeter with the instrument rain gauge. On the other hand, snowfall and hail present challenges in terms of measurement of precipitation. Snow, with its fluctuating density, might make accurate measurement challenging. Additionally, hail poses a measurement challenge as it is a form of precipitation that falls below the freezing point. Therefore, the primary focus of precipitation in this thesis will only contain rainfall.

2.4.3 Aerosol Optical Depth (AOD)

Aerosol Optical Depth (AOD) is a fundamental parameter used to quantify the solar radiation reduction due to aerosol particles present in the atmosphere [32]. It provides crucial information about air quality, visibility, and the direct and indirect effects of aerosols on climate, making it vital for understanding atmospheric composition and its implications for various fields, including meterology and engineering.

AOD is typically measured utilizing sun photometers, which are specialized instruments designed to measure the intensity of solar radiation at different wavelengths. These measurements are essential for deriving AOD values, as different wavelengths offer insights into the size distribution, composition, and scattering properties of aerosol particles.

One widely used sun photometer is the Microtops *II* handheld instrument, which measures the direct solar irradiance at multiple wavelengths. These measurements are collected during cloud-free conditions and calibrated against a reference standard. The retrieved AOD values at specific wavelengths, such as 305 nm, 943 nm, or 1020 nm, are subsequently used for analysis. [33]

Figure 2.8: Microtops *II* sun and ozone photometer.

The prevailing values of wavelengths can further be utilized to determine the Aerosol

Optical Depth. With all the correct values intact, one can determine the Aerosol Optical Depth through the utilization of the simplified Ångström's formula, named after the Swedish physist Johan Ångström:

$$\tau(\lambda) = \tau_0 \left(\frac{\lambda}{\lambda_0} \right)^{-\alpha} \tag{2.1}$$

This formula explicitly describes how Aerosol Optical Depth changes with the wavelength λ as a ratio with λ_0. The parameters τ_0, λ_0 and α denote the reference values for optical depth, wavelength and the Ångström's exponent as a scaling factor.

2.4.4 Cloud fraction and coverage

Cloud coverage and cloud fraction are two essential phrases utilized to describe the measuring of the amount of skies covered by clouds. However, they both both fluctuate from each other as they utilize different measurement methods and units. Firstly, cloud fraction is a ratio of the area covered by clouds to the total area observed, expressed as a decimal or percentage. In contrast, cloud coverage is a measure of the physical extent of clouds in the atmosphere, usually expressed as a percentage of the total sky area covered by clouds. In essence, 0.1 is the typical threshold for Aerosol Optical Depth, as values below the threshold provide less aerosols. For this thesis, the primarily focus will be centered around cloud fraction, as it provides more accurate measurements of cloud cover since this method also includes different altitudes and thickness of the clouds. Mathematically, the formulas of cloud coverage and cloud fraction are expressed as:

$$CF = \frac{C}{S} \tag{2.2}$$

Where CF refers to cloud fraction, C refers to total cloud cover and S refers to the total sky cover.

$$CC = \frac{A_{cloud}}{A_{sky}} \times 100\% \tag{2.3}$$

Where CC refers to cloud fraction, A_{cloud} refers to area of the sky covered by clouds and

A_{sky} refers to total area of the observed skies.

To be able to utilize both mathematical formulas concerning cloud cover, one must also employ various methods applied to measurement methods. The prevailing methods of measuring cloud cover additionally to the formulas are data collection through ground-based observations, satellite imagery and remote sensing methods. Each method has its own advantages and limitations, and one may frequently combine multiple of these methods in aiding the optimal cloud cover measurement. A commonality all three methods share is that they utilize various instruments to execute cloud coverage and cloud fraction measurements.

Ground-based weather instruments such as ceilometers or sky cameras provide real-time data on cloud coverage at specific locations. These instruments offer localized observations, allowing for detailed analysis of cloud patterns and variations. A ceilometer works by emitting a laser or other light source vertically into the atmosphere and measuring the time it takes for the light to reflect back off of particles in the air. This information can then be used to determine cloud height and cloud thickness. A sky camera on the other hand, works primarily by capturing the sky approximately every minute, to monitor cloud cover.

Figure 2.9: LIDAR based celiometer from ESA and OMEA 3x/6x Sky Camera.

Satellite imagery, such as those obtained from MODIS (Moderate Resolution Imaging

Spectroradiometer) or GOES (Geostationary Operational Environmental Satellite), are satellites that provide a broader perspective by capturing cloud patterns over larger areas. These images are valuable for studying cloud systems, identifying cloud types, and monitoring their movement and changes over time. The weather data in the thesis will primarily focus on the satellite imagery obtained from NASA, TERRA (MOD) and AQUA (MYD).

Figure 2.10: TERRA and AQUA satellites.

AQUA and TERRA, as represented in Figure 2.10, are two satellite instruments that are a part of NASA's Earth Observing System (EOS) programme, collecting meteorological data on the Earth. The functioning of these satellites is that the AQUA satellite can collect data on Earth's systems such as atmospheric conditions and climate change, while the TERRA satellite can collect data on the water cycle in reference to temperature and precipitation. Both MODIS satellites aid in understanding climate change and meteorological research through satellite observations from outer space.

Remote sensing is the science of obtaining information about objects or areas from a distance through the help of sensors. As illustrated in Figure 2.11, there are two types of remote sensing. Such sensors can be placed in satellites, in aircrafts and also on the ground. An instance of this is the active remote sensor LIDAR (Light Detection and Ranging), that as indicated prior is utilized for determining the thickness and heigth of clouds from the ground. The technology of LIDAR enables the acquisition of detailed vertical profiles of cloud distribution, and primarily works by emitting laser pulses and measure the time it takes for the light to return after scattering off cloud particles. In general, remote sensing methods apply for gathering information on environmental aspects such as topography, temperature and cloud cover.

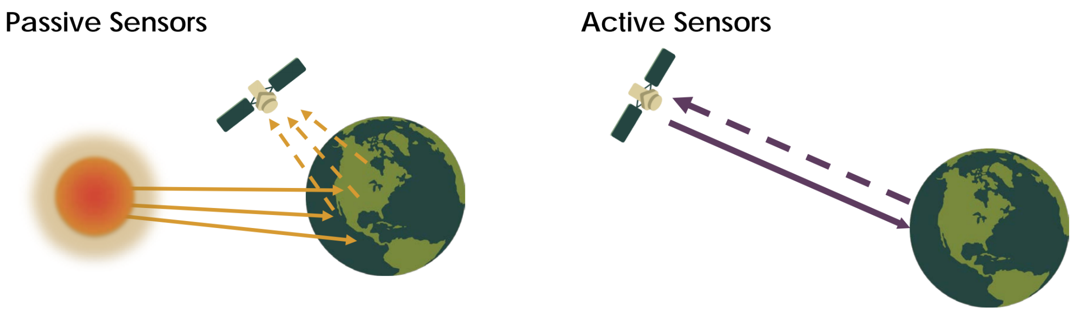


Figure 2.11: Passive sensors measure natural, available energy, while active sensors provide their own eneregy source for illumination. (SkyWatch)

Parameter	**Unit**
Temperature	Celsius (°C)
Cloud fraction	Percantage (%)
Aerosol Optical Depth	Unitless -
Precipitation	Millimeters (mm)
Solar Radiation	Watts per square meter (W/m^2)

Table 2.2: Typical meteorological parameters.

2.5 Mathematical modelling: Precipitation and Temperature

The role of mathematical modelling in interpreting meteorological data acquired from an observational weather station is of great importance. This data can be used to study the climate patterns of an area and to make predictions about future weather conditions. Mathematical modelling aid in analyzing the data, detecting trends and patterns, and making predictions with a certain level of accuracy. The employment of mathematical methods with a statistical approach, including the average, anomalies and time-series analysis is important in the field of meteorology.

Time-series analysis is a specific way of analyzing a sequence of data points collected over an interval of time [22]. This method can aid in detecting trends and patterns in meteorological data. In other words, time-series analysis can be utilized to predict future meteorological data derived from past patterns and trends in regards to average and anomalies. Time-series analysis are usually performed by plotting past patterns and trends in Cartesian graphs with optional meteorological parameter in question as a function of time. Additionally, it is also custom to create linear trend lines to see change by time. For instance, one can create a linear trend line in a graph representing annual average temperature.

In meteorological context, average refers to a statistical calculation of weather data over a specific time period at a specific area. This may include averages of temperatures, rainfall and wind velocity. The process for calculating the average involves summing all values of the relevant variable over a given time period, and subsequently dividing this sum by the total number of measurements taken. One instance of this to calculate the annual average temperature, as presented in Equation 2.5

.

The standard formula for calculating the average degree is given by:

$$\overline{T}_{\text{average}} = \frac{1}{n}\sum_{i=1}^{n} T_i \tag{2.4}$$

where $\bar{T}_{\text{annual}}$ represents the average temperature, n is the number of temperature measurements, and T_i represents each individual temperature measurement.

Normally, there are 365 days of the year, and sometimes there are leap years with one additional day of the year. Therefore will the regular formula Equation 2.9 of annual average temperature be displayed as:

$$\overline{T}_{\text{annual}} = \frac{1}{365} \sum_{i=1}^{365} T_i \tag{2.5}$$

for the years consisting of 365 days, and for the leap years of the annual average year will be:

$$\overline{T}_{\text{annual}} = \frac{1}{366} \sum_{i=1}^{366} T_i \tag{2.6}$$

Additionally, the procedure of calculating the standard average precipitation and annual average precipitation with respect to leap years are given down below:

$$\overline{P}_{\text{average}} = \frac{1}{n} \sum_{i=1}^{n} P_i \tag{2.7}$$

$$\overline{P}_{\text{annual}} = \frac{1}{365} \sum_{i=1}^{n} P_i \tag{2.8}$$

$$\overline{P}_{\text{average}} = \frac{1}{366} \sum_{i=1}^{n} P_i \tag{2.9}$$

As indicated prior, data collection of meteorological data can be used to determine a certain weather pattern. To identify such information, one approach in studying long-term trends and deviations from normal or expected conditions is anomalies. An anomaly in statistical behaviour refers to observations or measurements that significantly deviates from expected or typical patterns within a dataset. One example could be to calculate long-term anomalies of temperature at a certain area to assess errors, outliers or infrequent occurrences. An instance of this is to subtract the average temperature over a specific year or calendar day with the corresponding observed temperature:

$$T_A = T - T_{average} \tag{2.10}$$

Where T_A denotes the temperature anomalies, T denotes the observed temperature at a specific time or location and $T_{average}$ refers to the average temperature.

Another parameter to measure its deviations would be to detect anomalies in precipitation. Instead of subtracting the values from each other, a different approach is to determine the obtained ratio by dividing the observed temperature by the mean temperature for a specific year or calendar day:

$$R_A = \frac{R}{R_{average}} \tag{2.11}$$

Chapter 3

Methodologies

This chapter pertains the various methodologies utilized throughout the thesis, encompassing the application of meteorological data acquisition, Python and OriginLab.

3.1 Selection of methodologies

In determining the most suitable methodologies for this thesis, careful consideration is given to selecting approaches that align with the research objectives. The project involved several steps, including gathering weather data from various sources, , propose innovative weather station components and employing mathematical methods to detect anomalies and plot graphs with Excel, OriginLab and Python. The deliberate adoption and implementation of specific methodologies enable the effective exploration and resolution of research problems, ensuring that the project's requirements are met and objectives are addressed.

The selected methodologies for the thesis are as follows:

- Collect historical weather data on precipitation, temperature, AOD and cloud fraction of Prato Piazza, and organize it to Excel sheets for further analysis.

- Quantitative climate analysis of the collected historical weather data to depict trends or meteorological patterns with graphs in OriginLab and Python.

- Propose innovative weather station components in optimization of existing ones.

3.2 Historical weather data acquisition: Excel

To analyze weather patterns and trends, it is of pivotal importance to contribute to meteorological research. Such acquisition of historical weather data enables prediction of climate change, identification of potential risks, and development of effective strategies to mitigate their impact. In other words, acquiring historical weather data is essential for understanding how climate patterns evolve in a specific area over an extended time, but also in seeing which factors contribute to climate change. This section consist of the methodology of obtaining long-term weather data of Prato Piazza with Excel:

- Initially, a comprehensive research online were conducted to find reliable and accessible weather data of Prato Piazza, Italy. This objective denoted one had to find historical weather data around the mountain range, that were not easily accessible at first glance. Hence, the primarily weather data of Prato Piazza from 1948 until 2014 were retrieved from co-supervisor Stefano Cavazzani. The weather data consisted of satellite data of Aerosol Optical Depth, cloud fraction, precipitation and temperatures

- Furthermore, the obtained weather data were downloaded on the computer, and then 4, separate Excel files were respectively created for input of the raw weather data.

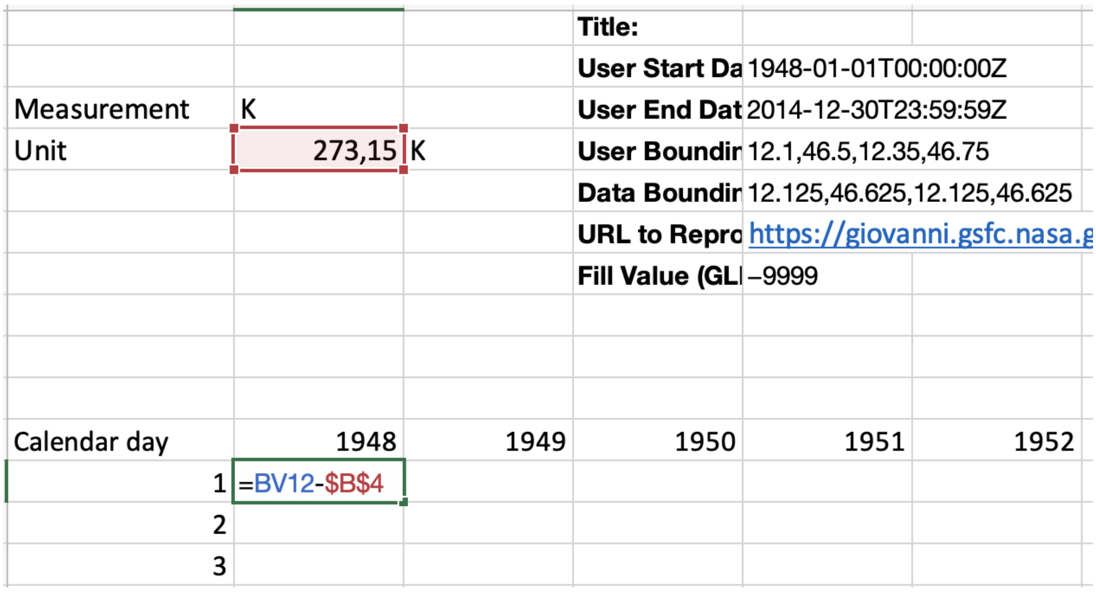
The next following subsections will consist of the adaptation of methodologies utilized in acquisition of the temperature, precipitation, AOD and cloud fraction.

3.2.1 Acquisition of Temperature in Excel

1. Subsequently, a table of the daily raw data temperatures of Prato Piazza were created, and then \$273.15\$ were entered as an additional reference cell.

2. Moreover, changed the missing values referred as -9999 to 0 by marking the entire table, then clicking $Cmd + shift + H$ to replace the -9999 with 0.

3. Converted the raw data temperatures from Kelvin to Celsius by subtracting the reference cell of \$273.15\$ from the cell referring to 1st of January 1948 valued Kelvin, as presented in Figure 3.1.



			Title:		
			User Start Da	1948-01-01T00:00:00Z	
Measurement	K		User End Dat	2014-12-30T23:59:59Z	
Unit	273,15	K	User Boundir	12.1,46.5,12.35,46.75	
			Data Boundir	12.125,46.625,12.125,46.625	
			URL to Repro	https://giovanni.gsfc.nasa.g	
			Fill Value (GLI	-9999	
Calendar day	1948	1949	1950	1951	1952
1	=BV12-B4				
2					
3					

Figure 3.1: Conversion of Kelvin to Celsius.

4. Then double clicked on the cell edge and dragged the cell from cell $B11$ to cell $BP377$ vertically

5. Started to find the daily temperature with the aid of the command 'AVERAGE' including $= AVERAGE(B12 : BP12)$, and then double clicked on the cell edge as indicated in item 4.

6. Performed identical operation for the annual average temperature with the aid of the command 'AVERAGE' too. Included cells $= AVERAGE(B12 : B777)$ in the average command, double clicked and dragged the cells horizontally until cell $BP12$.

7. Calculated daily average temperature from the reference years 1961 until 1990 $= AVERAGE(O12 : AR12)$, double clicked and dragged the cells vertically from $BR12$ to $BR377$

8. Then the annual average temperature for the reference period of 1961-1990 was calculated by averaging the mean temperatures of each year, using the formula $= AVERAGE(O10 : AR10)$ in cell B8. B8 were also made as a reference cell indicating $\$B\$8$.

9. After that, the daily temperature anomalies were calculated by subtracting the daily average in the reference period 1961 to 1990 from the daily average, given the Excel command $= AVERAGE(BQ12 - BR12)$, double click the cell edge and drag the cells vertically from $BS12$ to $BS377$.

10. Additionally, the anomalies for the annual temperature were executed too by substantially subtracting the the annual average temperature of the period 1961-1990 from the annual average temperature like $= AVERAGE(B10 - \$B\$8)$

3.2.2 Acquisition of Precipitation in Excel

1. Made a table of the daily raw data precipitation of Prato Piazza, and added \$86400\$ as an additional reference cell.

2. Moreover, changed the blank cells and missing values, referred as -9999, to 0. This was performed by marking the entire table, then clicking $Cmd+shift+H$ to replace the -9999 with 0.

3. Converted the raw data temperatures from $Kg \cdot m/s^2$ to mm by subtracting the reference cell of \$86400\$ from the cell referring to 1st of January 1948, as presented in Figure 3.2.

4. Then double clicked on the cell edge and dragged the cell from cell $B384$ to cell $B749$ vertically

5. Started to find the daily average precipitation with the aid of the command 'AVERAGE' including $= AVERAGE(B384 : BP384)$, and then double clicked on the cell edge as indicated in item 4.

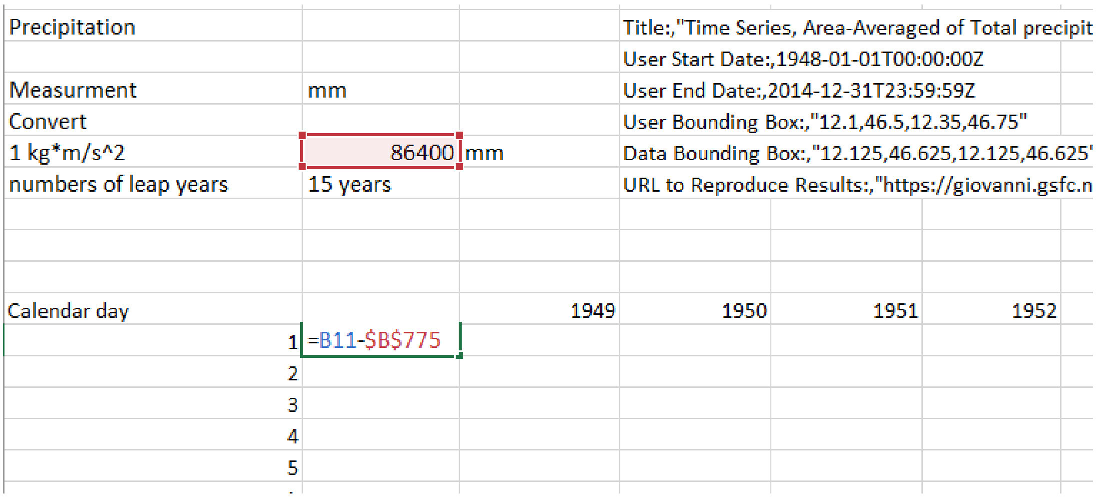


Figure 3.2: Conversion of $Kg \cdot m/s^2$ to mm.

6. Performed identical operation for the annual average precipitation with the aid of the command 'AVERAGE' too. Included cells $= AVERAGE(B384 : B749)$ in the average command, double clicked and dragged the cells horizontally until cell $BP381$.

7. After that, the daily precipitation anomalies were calculated by dividing the daily average precipitation with the daily average in the reference period 1961 to 1990, given the Excel command $= AVERAGE(BQ384/BR384)$, double clicked the cell edge and dragged the cells vertically from $BS12$ to $BS377$.

8. Calculated the annual average of the period 1961-1990 with the annual average precipitation from that period. Given the formula $= AVERAGE(O382 : AR382)$ in cell $B379$

9. Additionally, the anomalies for the annual precipitation were conducted as well by dividing the annual average precipitation with the annual average precipitation of the period 1961-1990. This was executed by $= AVERAGE(B381/\$B\$379)$

10. Calculated the total, annual amount of precipitation individually by utilizing $= SUM(B384 : B749)$ for 1948, and so for the recurrent years.

3.2.3 Acquisition of Aerosol Optical Depth

1. Started to input all satellite data of Aerosol Optical Depth in two separate sheets, signifying satellite data from TERRA and AQUA of Prato Piazza from 2003-2022.

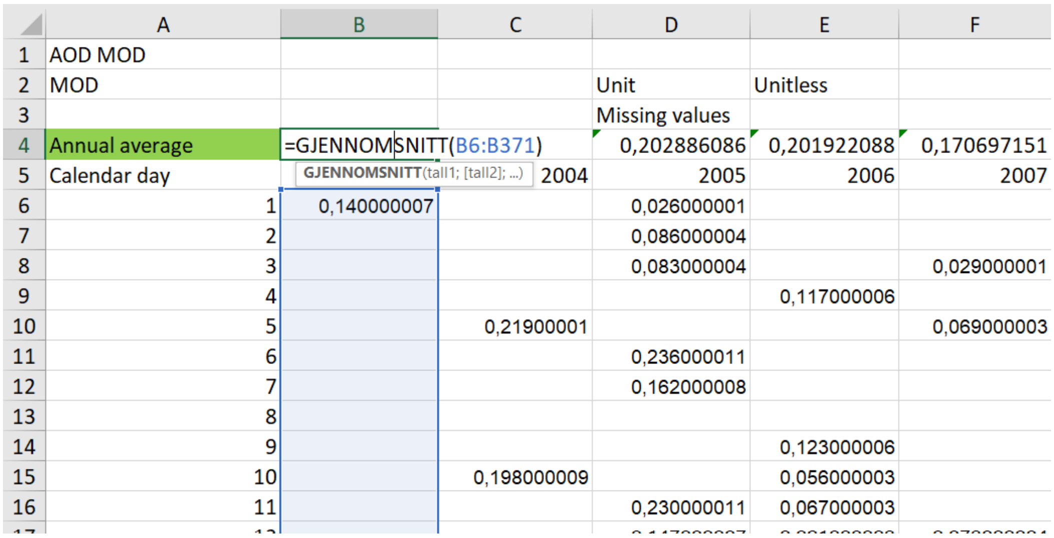
2. Furthermore, created a table for the AOD from TERRA (MOD), and substantially one for AQUA (MYD) with respect to calendar days and years.

3. Changed missing values referred as -9999 to blank cells for both tables. This was performed by marking the entire table, then clicking $Cmd + shift + H$ to replace the -9999 with blank cells.

4. Calculated daily average AOD with the command $= AVERAGE(B6 : U6)$ for TERRA, and $= AVERAGE(B11 : U11)$ for AQUA. To apply the same command to all cells in the AQUA and TERRA columns, both cells were double-clicked and dragged vertically down until the formula reached cell $V376$ for AQUA and $V371$ for TERRA.

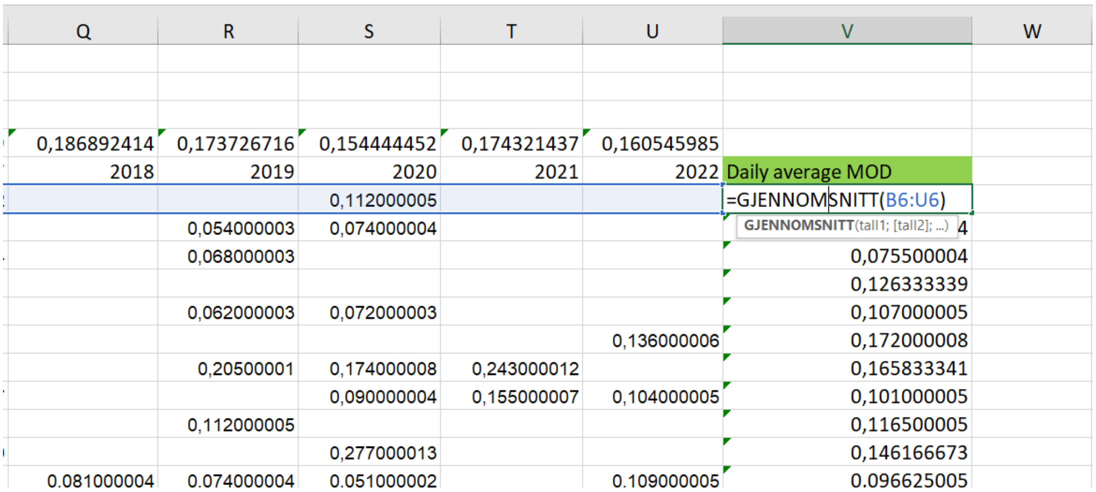
5. Additionally, the annual average AOD was also calculated for TERRA and AQUA through the utilization of $(= AVERAGE(B6 : B371))$ and $(= AVERAGE(B11 : B367))$, where the cell ranges represent the averages of each day combined.

6. Then dragged the calculated average AOD cells horizontally until $U4$ and $U9$.



	A	B	C	D	E	F
1	AOD MOD					
2	MOD			Unit	Unitless	
3				Missing values		
4	Annual average	=GJENNOMSNITT(B6:B371)		0,202886086	0,201922088	0,170697151
5	Calendar day	GJENNOMSNITT(tall1; [tall2]; ...)	2004	2005	2006	2007
6	1	0,140000007		0,026000001		
7	2			0,086000004		
8	3			0,083000004		0,029000001
9	4				0,117000006	
10	5		0,21900001			0,069000003
11	6			0,236000011		
12	7			0,162000008		
13	8					
14	9				0,123000006	
15	10		0,198000009		0,056000003	
16	11			0,230000011	0,067000003	

Figure 3.3: Method of calculating the annual average AOD for TERRA.



Q	R	S	T	U	V	W
0,186892414	0,173726716	0,154444452	0,174321437	0,160545985		
2018	2019	2020	2021	2022	Daily average MOD	
		0,112000005			=GJENNOMSNITT(B6:U6)	
	0,054000003	0,074000004			GJENNOMSNITT(tall1; [tall2]; ...) 4	
	0,068000003				0,075500004	
					0,126333339	
	0,062000003	0,072000003			0,107000005	
				0,136000006	0,172000008	
	0,20500001	0,174000008	0,243000012		0,165833341	
		0,090000004	0,155000007	0,104000005	0,101000005	
	0,112000005				0,116500005	
		0,277000013			0,146166673	
0.081000004	0.074000004	0.051000002		0.109000005	0.096625005	

Figure 3.4: Method of calculating the daily average AOD for TERRA.

3.2.4 Acquisition of Cloud Fraction

1. Cloud fraction data from AQUA and TERRA were plotted in tables separately in Excel sheets. Cloud fraction data from AQUA was plotted alongside AOD AQUA, while cloud fraction data from TERRA was plotted alongside AOD TERRA.

2. Moreover, the cloud fraction where divided into two separate tables consisting of cloud coverage during day for the first table, and cloud coverage during night for the second table. These tables applied to two separate tables for AQUA, and two tables for TERRA.

3. Subsequently, the numerical values in the sheets were converted from exponential format to standard format by right clicking on all selected table cells, and selected Standard in "Format cells".

4. Then the daily average of cloud coverage during day and night for the TERRA satellite were conducted. They were conducted by the Excel command $= AVERAGE(B377 : U377)$ for cloud coverage during the day for TERRA, and $= AVERAGE(B382 : U382)$ during the night for TERRA.

5. After that, both columns consisting of the daily average cloud fraction for calendar day 1 were double-clicked, and dragged vertically down to the cells $V742$ for TERRA and 747 for AQUA.

6. Additionally, the annual cloud coverage during day for TERRA and AQUA were calculated by the utilization of $(= AVERAGE(B377 : B742))$ and $(= AVERAGE(B382 : B747))$.

7. Thereafter, preceding steps item 3, item 4, item 5 and item 6 were repeated for cloud coverage during night for both TERRA and AQUA.

750								
751								
752	0,620927457	0,686348476	0,639311491	0,583856615	0,594671414	0,589710905		
753	2017	2018	2019	2020	2021	2022	Daily average cc night	
754	0,026399999	0,718899982	0,205199995	0,0067	0,984499975	0,132599997	=GJENNOMSNITT(B754:U754)	
755	0,994899975	0,920399977	0,102899997	0,0088	0,723499982	0,78229998	GJENNOMSNITT(tall1; [tall2]; ...)	
756	0,154099996	0,998399975	0,819699979	0,231899994	0,40179999	0,488399988	0,525324987	
757	0,609599985	0,070799998	0,038799999	0,294699993	0,821399979	0,999999975	0,569889986	
758	0,149399996	0,994799975	0,056999999	0,0079	0,963999976	0,987499975	0,580764985	
759	0,032499999	0,80229998	0,188699995	0,056499999	0,915999977	0,224499994	0,540049986	
760	0,185599995	0,999999975	0,759199981	0,0049	0,092999998	0,725399982	0,607184985	
761	0,070599998	0,712099982	0,822099979	0,694499982	0,082899998	0,999999975	0,613910511	
762	0,896699977	0,999999975	0,708799982	0,005	0,77489998	0,999999975	0,638374984	

Figure 3.5: Method of calculating the daily average cloud fraction during night for AQUA.

751	MYD	Cloud coverage	night	mean			
752	Annual average cc night	=GJENNOMSNITT(B754:B1119)		0,648920094	0,635152182	0,602257128	0,663711459
753	Calendar day	GJENNOMSNITT(tall1; [tall2]; ...)	04	2005	2006	2007	2008
754	1	0,480099988	0,994899975	0,990799975	0,999999975	0,845299979	0,048499999
755	2	0,313699992	0,348199991	0,145899996	0,977599975	0,233599994	0,552999986
756	3	0,724099982	0,710099982	0,273499993	0,043599999	0,514599987	0,999199975
757	4	0,929999977	0,044799999	0,034299999	0,982299975	0,145099996	0,77469998
758	5	0,434499989	0,042899999	0,850399979	0,615099984	0,891899977	0,999999975
759	6	0,999999975	0,343699991	0,022199999	0,999399975	0,979599975	0,173499996
760	7	0,986799975	0,184399995	0,102299997	0,993899975	0,936899976	0,235199994
761	8	0,999999975	0,999999975	0,999099975	0,299999992	0,77649998	0,572999986
762	9	0,999099975	0,839499979	0,192799995	0,0088	0,80149998	0,022599999
763	10	0,549099986	0,194599995	0,201899995	0,0068	0,876499978	0,553999986
764	11	0,157299996	0,999999975	0,0202	0,0142	0,566099986	0,829599979
765	12	0,0217	0,145999996	0,297999992	0,035399999	0,042399999	0,999999975

Figure 3.6: Method of calculating the annual average cloud fraction during night for AQUA.

3.3 Data plotting: OriginLab

To create plots for long-term weather data of Prato Piazza, comprising the desired data range (1948-2014), the software application OriginLab were utilized. OriginLab is a powerful data analysis and graphing software widely used in scientific research and data visualization. The choice of software fell on OriginLab because of its popularity among researchers and engineers, as well as due to its visualization capabilities for mathematical modeling, analyses and graph creation.

Figure 3.7: The software application Origin for data analysis.

The following methodology outlines the steps involved in creating plots of the obtained long-term weather data using OriginLab:

- Initally, created more storage capacity on the computer, and then downloaded a trial version of the software Origin.

- Then launched OriginalLab ensuring to have prepared access of the licensed version.

- Imported all weather data on precipitation, temperature, aerosol optical dept and cloud fraction in horizontal cells by transpose. This was executed by selecting desired cells, use the command $Cmd + C$ and right click on a cell in OriginLab and chose Transpose.

- Imported also the recurring weather data from vertical cell in Excel to OriginLab. The method were the same as in Figure 3.3, except that transpose were replaced by the command $Cmd + V$.

3.3.1 Procedure of plotting temperature graphs

1. Started to make subplots for temperature consisting of 4 plots. This was executed by selecting the tool plot, multi-panel and then 4 panel.

2. Added $A(X) = Years$ and $B(Y) =$ Annual average temperature as Layer 1 with lined and scattered plots.

3. Added $E(X) = Years$ and $F(Y) =$ Annual temperature anomalies as Layer 2 with lined and scattered plots.

4. Added $M(X) = Days$ and $N(Y) =$ Daily average temperature as Layer 4 with lined and scattered plots.

5. Added $I(X) = Days$ and $J(Y) =$ Daily anomalies as Layer 3 with lined and scattered plots.

6. Executed the plot by clicking OK.

7. Adjusted the Cartesian x-axes for the upper plots to every 30th year from 1947 to 2015 in "Scale", 30 as selected value for "Increment type", and Years as title.

8. Selected Annual average temperature and Annual temperature anomalies as titles.

9. Same procedure for the lower plots as in item 7, except that years were replaced by a 0-370 days, and increment set as 60.

10. Selected daily anomalies and daily average temperature as titles for the lower plots.

11. Additionally, select show top and right line and ticks

12. Finish the subplot by selecting Analysis, Fitting and Linear Fitting. Inserted also at straight, horizontal line at value 0.

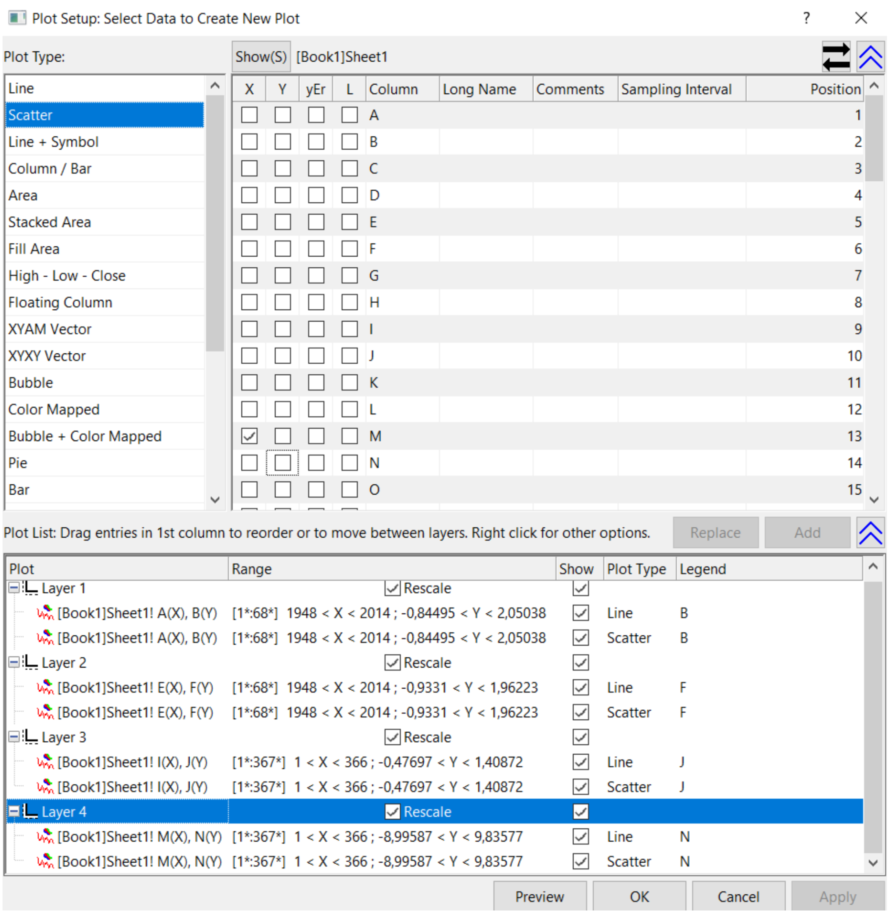


Figure 3.8: Overview of the layers that constitute the temperature subplot in OriginLab.

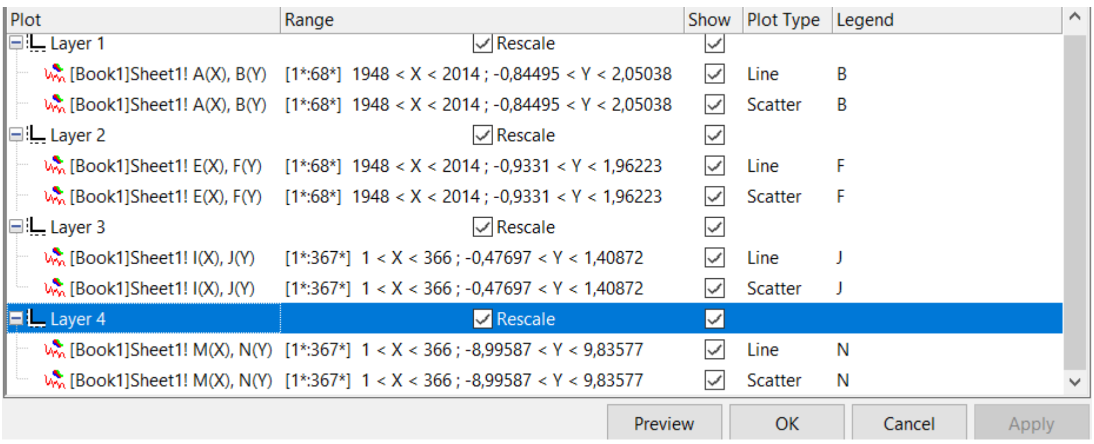


Figure 3.9: Settings of the temperature subplot.

3.3.2 Procedure of plotting precipitation graphs

1. Started to make subplots for precipitation consisting of 4 plots. This was executed by selecting the tool plot, multi-panel and then 4 panel.

2. Added $I(X)$ = Years and $J(Y)$ = Total annual precipitation as Layer 1 with lined and scattered plots.

3. Added $A(X)$ = Years and $B(Y)$ = Annual precipitation anomalies as Layer 2 with lined and scattered plots.

4. Added $M(X)$ = Days and $N(Y)$ = Daily average precipitation as Layer 3 with lined and scattered plots.

5. Added $E(X)$ = Days and $F(Y)$ = Daily precipitation anomalies as Layer 4 with lined and scattered plots.

6. Executed the plot by clicking OK.

7. Adjusted the Cartesian x-axes for the upper plots to every 30th year from 1947 to 2015 in "Scale", 30 as selected value for "Increment type", and Years as title.

8. Selected Total precipitation and Annual precipitation anomalies as titles.

9. Same procedure for the lower plots as in item 7, except that years were replaced by a 0-370 days, and increment set as 60.

10. Selected daily average precipitation and daily precipitation anomalies as titles for the lower plots.

11. Additionally, select show top and right line and ticks

12. Finish the subplot by selecting Analysis, Fitting and Linear Fitting. Inserted also at straight, horizontal line at value 0.

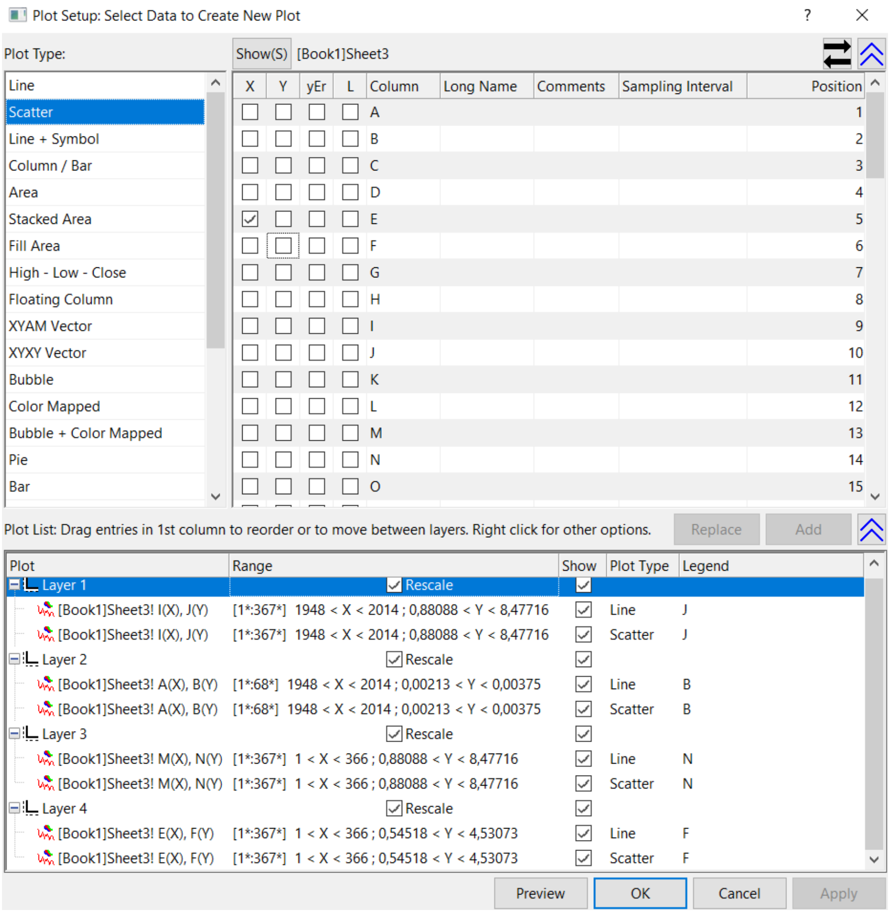


Figure 3.10: Overview of the layers that constitute the precipitation subplot in OriginLab.

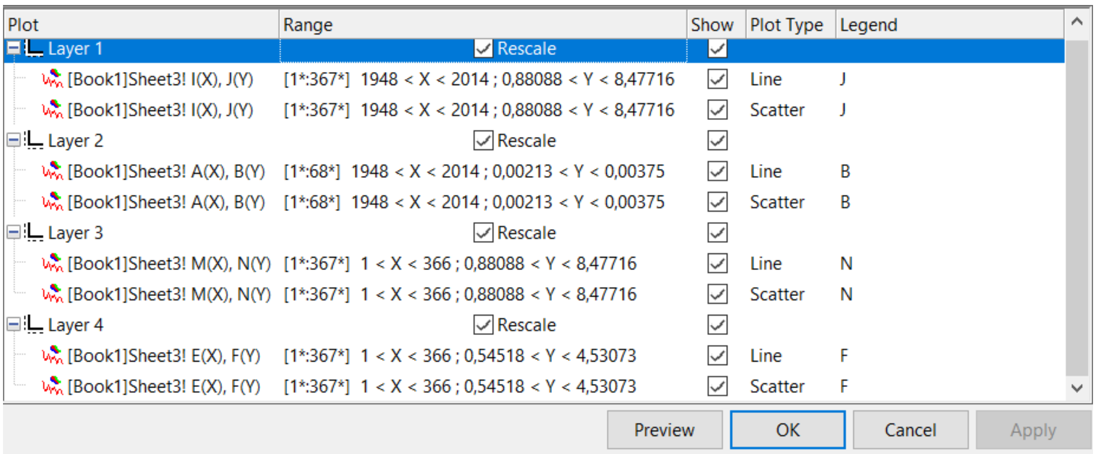


Figure 3.11: Settings of the precipitation subplot.

3.3.3 Procedure of plotting AOD graphs

1. Started to make subplots for AOD consisting of 2 plots. This was executed by selecting the tool plot, multi-panel and then Vertical 2 panel.

2. Added $F(X) =$ Years and $G(Y) =$ MOD as Layer 1 with lined and scattered plots.

3. Added $F(X) =$ Years and $H(Y) =$ MYD as Layer 1 with lined and scattered plots.

4. Added $A(X) =$ Days and $B(Y) =$ MOD as Layer 2 with lined and scattered plots.

5. Added $A(X) =$ Days and $C(Y) =$ MYD as Layer 2 with lined and scattered plots.

6. Executed the plot by clicking OK.

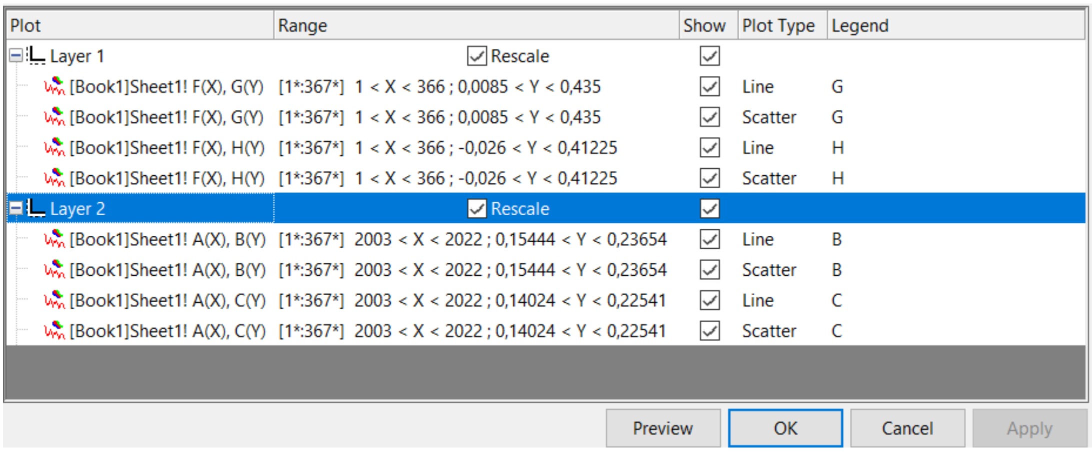
7. Adjusted the Cartesian x-axes for the upper plots to be from 2003 to 2022 in "Scale", 30 as selected value for "Increment type", and Years as title.

8. Selected AOD as title.

9. Same procedure for the lower plots as in item 11, except that years were replaced by a 0-370 days, and increment set as 60.

10. Selected AOD as title for the lower plots as well.

11. Finish the subplot by selecting show top and right line and ticks.



Plot	Range	Show	Plot Type	Legend
Layer 1	Rescale	✓		
[Book1]Sheet1! F(X), G(Y)	[1*:367*] 1 < X < 366 ; 0,0085 < Y < 0,435	✓	Line	G
[Book1]Sheet1! F(X), G(Y)	[1*:367*] 1 < X < 366 ; 0,0085 < Y < 0,435	✓	Scatter	G
[Book1]Sheet1! F(X), H(Y)	[1*:367*] 1 < X < 366 ; -0,026 < Y < 0,41225	✓	Line	H
[Book1]Sheet1! F(X), H(Y)	[1*:367*] 1 < X < 366 ; -0,026 < Y < 0,41225	✓	Scatter	H
Layer 2	Rescale	✓		
[Book1]Sheet1! A(X), B(Y)	[1*:367*] 2003 < X < 2022 ; 0,15444 < Y < 0,23654	✓	Line	B
[Book1]Sheet1! A(X), B(Y)	[1*:367*] 2003 < X < 2022 ; 0,15444 < Y < 0,23654	✓	Scatter	B
[Book1]Sheet1! A(X), C(Y)	[1*:367*] 2003 < X < 2022 ; 0,14024 < Y < 0,22541	✓	Line	C
[Book1]Sheet1! A(X), C(Y)	[1*:367*] 2003 < X < 2022 ; 0,14024 < Y < 0,22541	✓	Scatter	C

Figure 3.12: Settings of the AOD subplot.

3.3.4 Procedure of plotting Cloud Fraction graphs

1. Started to make subplots for AOD consisting of 4 plots. This was executed by selecting the tool plot, multi-panel and then .

2. Added $K(X)$ = Years and $L(Y)$ = CF MOD day as Layer 1 with lined and scattered plots.

3. Added $K(X)$ = Years and $M(Y)$ = CF MOD night as Layer 1 with lined and scattered plots.

4. Added $K(X)$ = Years and $N(Y)$ = CF MYD day as Layer 2 with lined and scattered plots.

5. Added $K(X)$ = Years and $O(Y)$ = CF MYD night as Layer 2 with lined and scattered plots.

6. Added $R(X)$ = Days and $S(Y)$ = CF MYD night as Layer 3 with lined and scattered plots.

7. Added $R(X)$ = Days and $T(Y)$ = CF MYD night as Layer 3 with lined and scattered plots.

8. Added $R(X)$ = Days and $U(Y)$ = CF MYD night as Layer 4 with lined and scattered plots.

9. Added $R(X)$ = Days and $V(Y)$ = CF MYD night as Layer 4 with lined and scattered plots.

10. Executed the plot by clicking OK.

11. Adjusted the Cartesian x-axes for the upper plots to every 30th year from 1947 to 2015 in "Scale", 30 as selected value for "Increment type", and Years as title.

12. Selected CF MOD & MYD as titles.

13. Same procedure for the lower plots as in item 11, except that years were replaced

by a 0-370 days, and increment set as 60.

14. Selected CF MOD & MYD as titles for the lower plots.

15. Scaled the y-axis of Daily average temperature to be from -10 to 10 with an increment of 4, and Daily anomalies between -0.5 and 1.5 with an increment of 0.5.

16. Finish the subplot by selecting show top and right line and ticks.

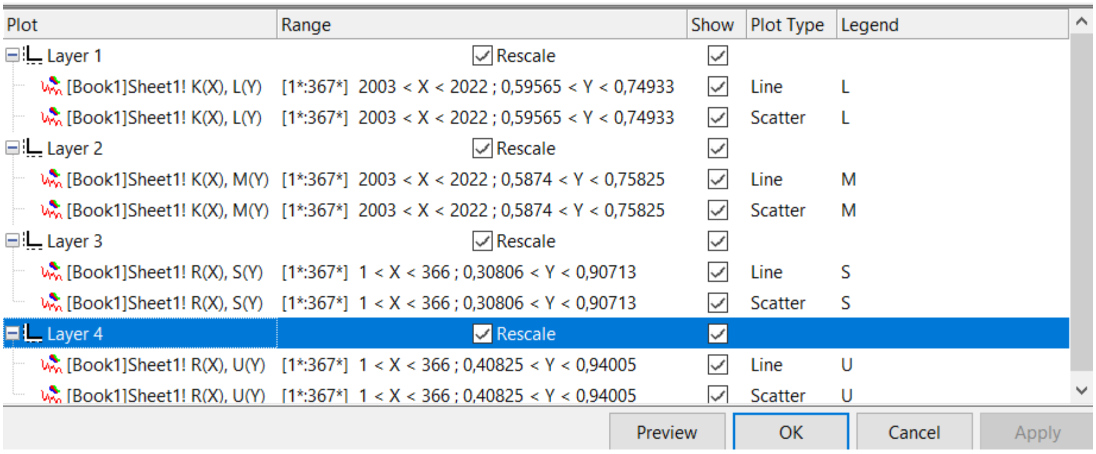


Figure 3.13: Settings of the cloud fraction subplot.

3.4 Data plotting: Python

Furthermore, Python was utilized to perform quantitative weather analyses of the precipitation and temperature of Prato Piazza. Python is an object oriented programming language intended for development of tools and applications [18]. In this section, the evolution of temperature and precipitation were observed by comparing current weather conditions with the collected long-term weather conditions.

The subsequent procedure is the established method of programming in Python:

- Launch Jupyter Notebook and install packages in the terminal, e.g. Numpy, Matplotlib and Datetime.
- Create a new notebook by selecting "New" and "Python 3."
- Write Python code in the cells.
- Execute the Python code by clicking "Run"
- Save and checkpoint the Python code.
- Export the notebook to desired file format, e.g. ipynb or PDF.
- Close the browser window.

Figure 3.14: Python.

3.4.1 Temperture

1. Imported the required libraries `datetime` and `matplot.lib`

2. Defined two lists for dates in `dateformat` and temperatures, containing historical weather data of May 27.

3. Converted the dates to matplotlib date string format utilizing `mdates.date2num(dates)`.

4. Created a linear trend line by utilizing polynomial regression of degree 1 with the `np.polyfit` and `np.polyval` commands.

5. Plotted the graph with the linear trend line utilizing `plt.plot(dates, temperatures, marker='o')` and `plt.plot(dates, trendline, linestyle='- -')`

6. Included `plt.axhline` for a horizontal line at y = 0.

7. Configurated the axes and title by labelling them `plt.xlabel()`, `plt.ylabel()` and `plt.title()`

8. Formatted the x-axis labels to be rotated displayed every 30th value `plt.xticks(rotation=45)` and `plt.gca().xaxis.set_major_locator(mdates.YearLocator(base=30))`.

9. Displayed the graph with `plt.show`

In addition, a python script for temperatures below the freezing point were conducted too. Note that the temperatures from the preceding python script are included:

1. The lists of `date` and `temperature` are defined the same as in the preceding python script.

2. Created a list called `threshold_temperatures` with an `if` signifying temperatures equal or less than $0°C$.

3. Defined `number_days` to count number of days with temperatures equal or less than

$0°C$ with the length `len(threshold_temperatures)`.

4. Printed the results with `("Temperatures less than or equal to 0:")`, `(threshold_temperatures)` and `(f"Number of days with temperature less than or equal to 0:  number_days days")`

3.4.2 Precipitation

Following procedure denotes the Python script in

1. Imported the required libraries numpy, datetime, matplotlib.pyplot and matplotlib.dates.

2. Defined dates for all the 27th of May as datetime, and temperature data for Prato Piazza as lists.

3. Converted the dates to matplotlib date string format utilizing `mdates.date2num(dates_Prato_Piazza)`.

4. Created a linear trend line by utilizing polynomial regression of degree 1 with the `np.polyfit` and `np.polyval` commands.

5. Plotted the graph with the data and the linear trend line with `plt.plot`.

6. Included `plt.axhline` for a horizontal line at y = 0.

7. Configured the axes for name and title with `plt.xlabel, plt.ylabel, plt.title and plt.legend`.

8. Formatted the x-axis labels to be rotated displayed every 30th value `plt.xticks(rotation=45)`, `plt.gca().xaxis.set_major_locator(mdates.YearLocator(base=30))`.

9. Displayed the graph with `plt.show`

Additionally, a python script for precipitation less than 1 mm and number of days with precipitation less than 1 mm were also executed. Note that the dates and temperatures are included from the preceding python script:

1. Imported the required libraries datetime and matplotlib.pyplot
2. Defined dates and temperature as lists like in the preceding ones of item 2
3. Created a list `threshold_precipitation` for precipitation equal or less than 1 mm eliminating the numbers from `precipitation_Prato_Piazza`.
4. Made a variable named `number_days` where the `len()` is utilized to find the length of `threshold_precipitation`
5. Printed `("Precipitation less than or equal to 1 mm:")`, `(threshold_precipitation)` and `(f"Number of days with precipitation less than or equal to 1 mm:number_days days")`

3.5 Innovative weather station components

As the components discussed in subsection 2.2.2 are already in existence, the subsequent focus for this thesis will be towards the innovative components that are being evaluated for potential optimization alongside the existing components. The inclusion of an All-sky camera and PV panel as additional components to weather stations will be represented in the following subsections. Additionally, proposing innovative components come with certain requirements that must be obliged by the WMO.

3.5.1 World Meterological Organization: standards and requirements

WMO (World Meterological Organization) is a specialized organization under the UN whose primary duty is to promote international cooperation in meteorology, climatology and hydrology [16]. Moreover, WMO provides guidelines and standards for installation and operation of weather stations globally. These guidelines ensure certain requirements adhere to selection of reliable weather station sites, instrumentation and and climatic observations. Therefore, guidelines provided from WMO will be derived from the publication *Guidelines on Surface Station Data Quality Control and Quality Assurance for Climate Applications (WMO-No. 1269), as a reference for optimization of weather stations.*

According to section 3.2.1, *Guidelines on Surface Station Data Quality Control and Quality Assurance for Climate Applications (WMO-No. 1269).*, following conditions should be considered when selecting a weather station site:

1. The site should be representative of the meteorological conditions of a larger area.

2. The site should satisfy data users' requirements over as long a period of time as possible.

3. The observation conditions should remain largely unchanged over a long period of time.

4. The site should be free from obstructions that could affect measurements, such as buildings, trees, or other structures.

5. The site should be located away from sources of heat or moisture that could affect measurements, such as paved surfaces or bodies of water.

As for the components and instrumentation in weather stations, the factors covered in Section 4 of the publication are listed down below:

1. The instruments and components should be suitable for the intended purpose and the environmental conditions at the site.

2. The instruments and components should meet the requirements specified in the Guide to Instruments and Methods of Observation (WMO-No. 8).

3. The instruments and components should be calibrated regularly to ensure accurate measurements.

4. Calibration procedures should be documented and followed consistently to ensure that measurements are traceable to international standards.

5. Maintenance procedures should be followed to ensure that instruments and components remain in good working order.

6. Instruments and components should be replaced when they reach the end of their useful life or when they no longer meet performance standards.

3.5.2 Localization of requirements

Besides the requirements and guidelines provided by WMO, there are also several local requirements concerning the test site of Prato Piazza that should be included. The following is the information of the requirements of the test site from the thesis proposal:

- Four weather stations should be designed at the top corners of the site perimeter.
- Each station should be equipped with a drone and vertical and horizontal laser links, in addition to normal meteorological and light pollution sampling instruments.
- The colour and visual impact of the weather stations are important aspects to improve their integration with the surrounding environment.
- The directive of the World Meteorological Organization related to weather stations has to be followed in order to have reliable observational stations that follow minimal requirements.

3.5.3 AllSkyCamera and PV panel

In terms of selecting innovative weather station components, there are a range of factors that emerge. Everything from what kind of weather station components to propose based on meteorological conditions, to cost and to mechanical properties . This section will primarily focus on the AllSkyCamera and PV panel components, specifically their mounting site on the weather station tree

When it came to choosing an All Sky Camera, thorough assessments were made of several factors. These factors included cost, size and the WMO requirements. Finding a camera that was cost-effective and easy to install without being too bulky or heavy was crucial. After careful research and comparisons of different options, the TYTEA All Sky Camera where selected.

Also for PV panels, there were several factors that came into consideration. However, as most PV panels are composed of semiconductor materials and the focus was not solely on energy, the selection of a specific PV panel was less critical. In any case, it was important to have a PV-panel that did not take up much space, regardless of the cost involved.

Chapter 4

Results and discussion

4.1 Climate analysis

After all the weather data were plotted in OriginLab and Python, the only thing that remained was to interpret the results. In this section, the procedure of climate analysis will be conducted to enhance the comprehension of climate change of Prato Piazza. Specifically, elaborate and discuss on the executed plots concerning long-term weather data of the temperature, precipitation, aerosol optical depth and cloud fraction. In order to see climate change. Furthermore, the weather data of precipitation and temperature derives from ground- and satellite-based data of the period 1948 to 2014. The weather data on both aerosol optical depth and cloud fraction derive from the period 2003 to 2022. Additionally, this climate analysis will consist of a quantitative analysis conducting the change of temperature and precipitation from 27th of May 1948 until corresponding day in 2023.

4.1.1 Climate analysis: Temperature

By examining the completed subplots in Figure 4.1, one can see distinctive change of the temperature. The inserted trendlines in the subplots reassure that the incident of temperature change has occured in terms of anomalies and average temperatures.

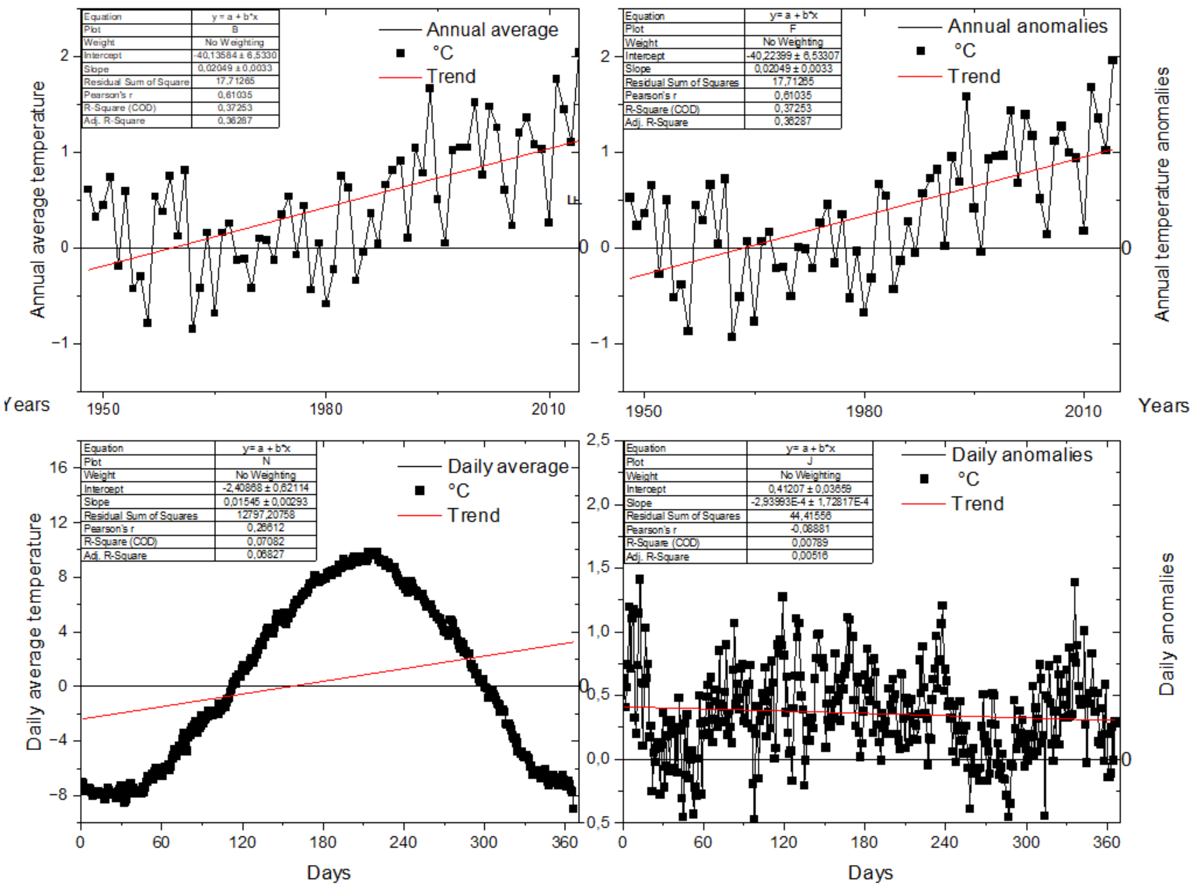


Figure 4.1: Climate analysis of the temperatures.

The first graph in the subplot represent annual average temperatures as a function of years, where the graph somewhat exhibits a linear relationship with the red trendline. In other words, this refers to the scattered points being local maximum and minimum. One specific observation to notice is that the average temperatures solely remain above the freezing point after the 1990s, where the indicated $y = 0$ is situated. This implies that the annual average temperatures of Prato Piazza drastically increase. Given that the annual average temperature of the Alps in general ranges from $-5°C$ to $8°C$, many of the collected temperatures of Prato Piazza remain between $0°C$ and $1°C$. Furthermore, the annual temperature anomalies look identical to the plot of annual average temperature. The reason for this could be that the y-axis were not scaled up enough to differentiate the anomalies apart from the annual average temperatures. A statement that supports this reason are the indicated slopes of the plots located in the tables. The plot of total precipitation signify a slope of 0.00691 ± 0.00688 , while the slope of annual temperature anomalies signify $8.75374E - 4 \pm 2.37658E$. Another instance could be that the annual temperature anomalies could have been computed inaccurately. This is uncertain as the the formula stated in Equation 2.11 was utilized. As a precaution, the wrong numbers might have been plotted.

Furthermore, the daily average temperatures of Prato Piazza are distributed as anticipated. The plot implies that the rise and the fall of temperature can occur seasonally based on the daily average temperatures change polynomially. The maximum point of daily average temperature is situated after 180 days of the year has passed with an approximate temperature of $10°C$, which support the statement of the daily temperature change occurs polynomially. The minimum temperatures are also situated either around the first days of the year, or the last days of the years. Additionally, one can see that the linear trendline support the polynomial growth of the daily average temperature, as the slope of the trendline is estimated at 0.01545 ± 0.00293. Further notice implies that the daily average temperatures also remain above $0°C$ in the period between day 120 to day 300. By examining the plot of daily temperature anomalies, one can verify that the temperatures deviate from each other at some extent. In other words, the daily temperature anomalies indicate that the daily average temperatures deviate significantly. A caused reason could be that the long-term temperature data over a predetermined time reassures the occurrence of climate change. In this case, the daily temperature anomalies range from approximately $-0.5°C$ to $5.0°C$, where most of the anomalies are plotted as clustered points. Particularly, this means that the change of anomalies do not happen instantly, but gradually change during the year. Another points of interest concerning the daily anomalies are the maximum and minimum points. These points denotes that drastic change in daily temperature anomalies may derive from drastic change of weather conditions, in reference to climate change. These daily anomalies deviates negatively as the slope of the plot is estimated at -2.989986 ± 1.7281764.

4.1.2 Climate analysis: Precipitation

Figure 4.2 present a subplot composing of the long-term precipitation data of Prato Piazza from 1948 to 2014. The subplot are primarily composed by the total annual precipitation, annual precipitation anomalies, daily average precipitation and daily precipitation anomalies.

Primary observation depicts that the applied trend line for total annual precipitation and annual precipitation anomalies develop in the opposite direction of each other. While the trend line for total annual precipitation increases, the trend line for annual precipitation anomalies decreases. This might happen since the plots depict 2 incomparable values. Plot of the total precipitation varies differently over the predetermined period, while the annual precipitation anomalies are corresponding to the annual average precipitation instead. This could have been resolved by creating a plot for the annual average precipitation as well to avoid confusion. One commonality the plots for total annual precipitation and annual precipitation anomalies share, regardless of change, is that the values vary slightly. Most of the annual precipitation anomalies are centered in between approximately 0.0020 and 0.0037 millimetres. Such information will then tell that the the annual average precipitation varies slightly, as well as the total annual precipitation.

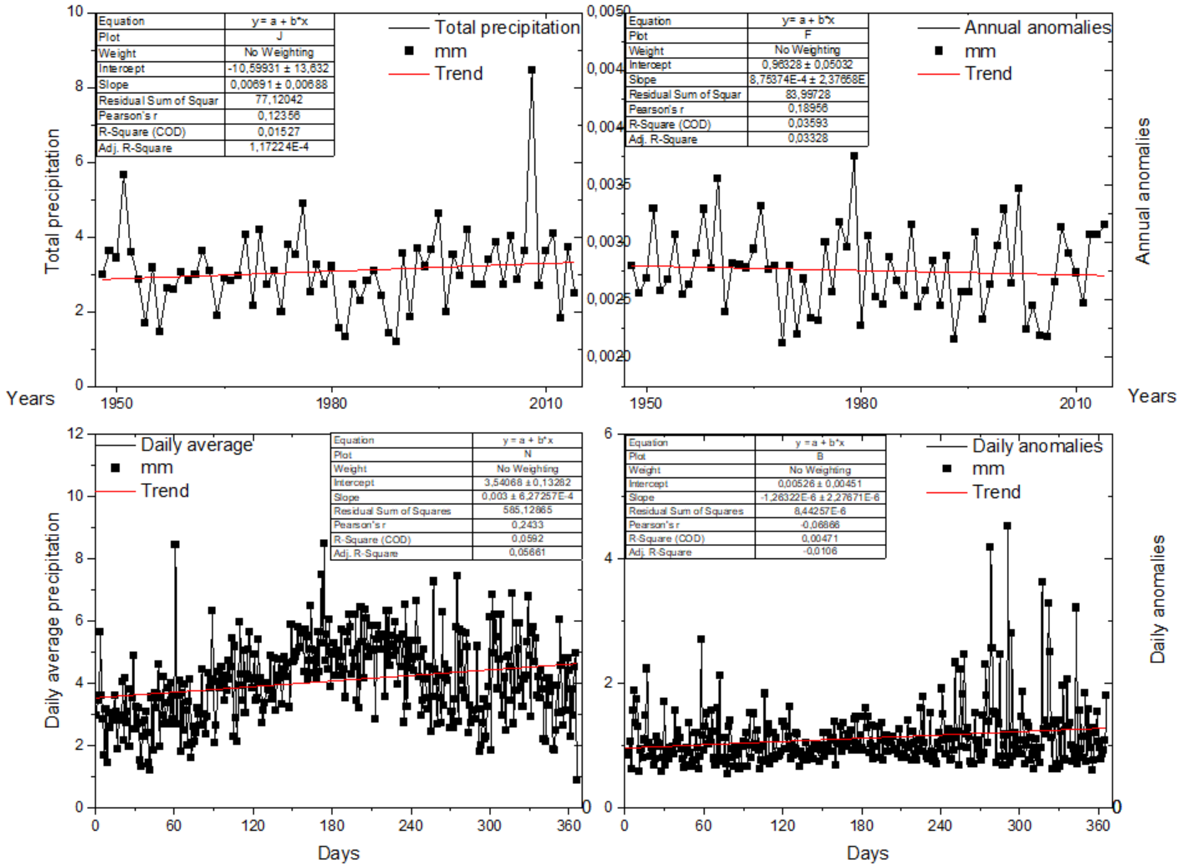


Figure 4.2: Climate analysis of the precipitation

Moreover, the plots for the daily average precipitation and daily precipitation anomalies contain densely clustered points. As for the daily average precipitation plot, one can immediately see the biggest change of precipitation. In other words, this refers to the corresponding plot for daily precipitation anomalies as well. The biggest change of the meteorological parameter occurs statistically later in the year as opposed to the earlier days. An instance of this are the daily precipitation anomalies after the days between day 240 and day 300 also correspond to the dense increase and decrease of the daily average precipitation. Another observation to notify is that the dense daily anomalies in the middle of the year, referring to days around day 180, also lead to clustered days of daily average precipitation of practically no to slight change. It appears that the daily average precipitation are mostly around $4-6mm/day$ in the mountain range with no information about the type of precipitation. Nevertheless, these precipitation measurements pertain to natural climate change as those days are during the summer.

4.1.3 Climate analysis: Python

In this study, Python was utilized to compare today's weather data with long-term weather data. More precisely, recorded weather data for Prato Piazza from May 27th 1948 to 2023. Furthermore, graphs were generated using Python to represent the distribution of temperature and precipitation, and provide an indication of any changes in temperature and precipitation.

Based on the trend line in the graph, the results of the temperature analysis indicated that there has been a general increase in temperature in Prato Piazza from 1948 to 2023. The trend line presents an ascending direction, which displays a positive linear relationship between time and temperature. In other words, plotting the temperatures in Python suggests that the average temperature has increased over time in the area. However, it is crucial to note that the trend line represents an overall trend, and there may be variations and fluctuations in the temperature data from year to year. Certain years may have higher or lower temperatures than expected based on the trend line.

By looking at Figure 4.3 and Figure 4.4, one can see that there are values under the thresholds of $0°C$, and above $5mm$ for the precipitation. Years of a threshold above 5 mm precipitation indicate that the rise of precipitation of Prato Piazza has increased. In terms of the temperature, one can also depict an increase of temperature. A commonality both plots share is that there will be outliers between the years of 2014 and 2023, as there were no weather data from this period for the temperature. Hence the graph are not inaccuretly dispalayed as the previos years until 2014 are not reported.

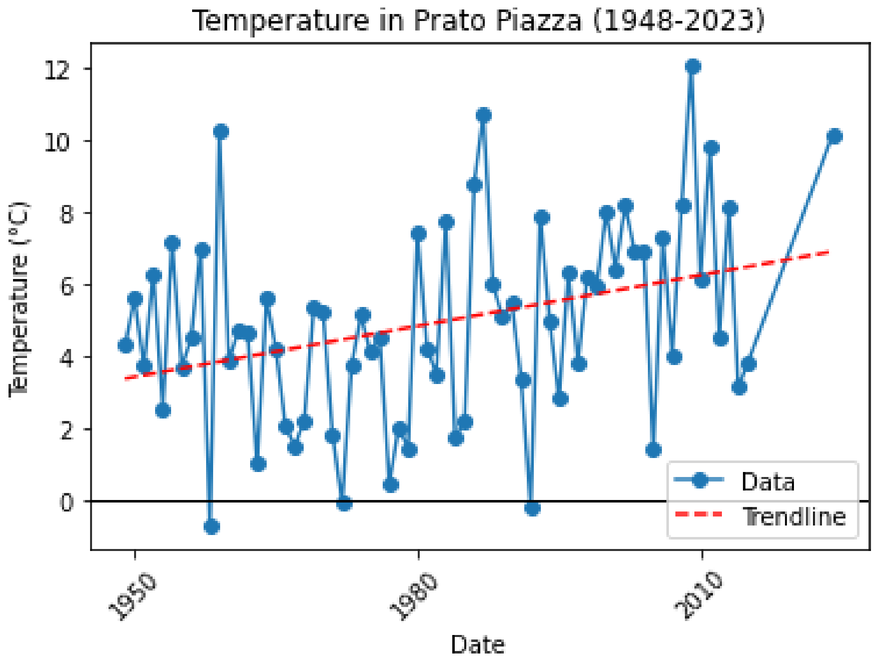


Figure 4.3: Overview of temperature change of Prato Piazza.

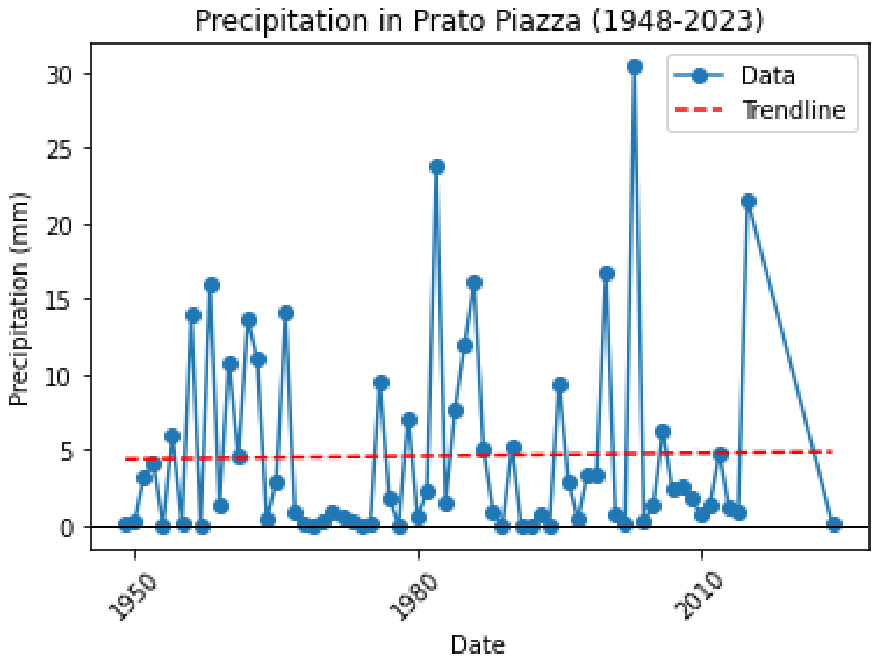


Figure 4.4: Overview of precipitation change of Prato Piazza.

Figure 4.4 denotes a graph representing the precipitation in Prato Piazza from 1948 to 2023. The graph depicts both factual precipitation data and a trend line derived from a linear regression model. Based on the trend line in the graph, one can certainly say there has been a varying trend in the precipitation in Prato Piazza over the time period. The trend line shows the general direction of precipitation changes over time. If the trend line rises, it indicates an increase in rainfall, while if it falls, it indicates a decrease in precipitation. As indicated prior, it is of pivotal importance to note that a trend line only represents an overall trend. Therefore, there can be significant variations in the precipitation data from year to year. Some years may have higher or lower precipitation than expected based on the trend line.

4.1.4 Climate analysis: AOD

With regards to Aerosol Optical Depth, a lot of the range has changed as denoted in Figure 4.5. This section will primarily focus on the collected AOD data of Prato Piazza from the MODIS satellites TERRA (MOD) and AQUA (MYD). More specifically, AOD data of Prato Piazza in the period of 2003 until 2022.

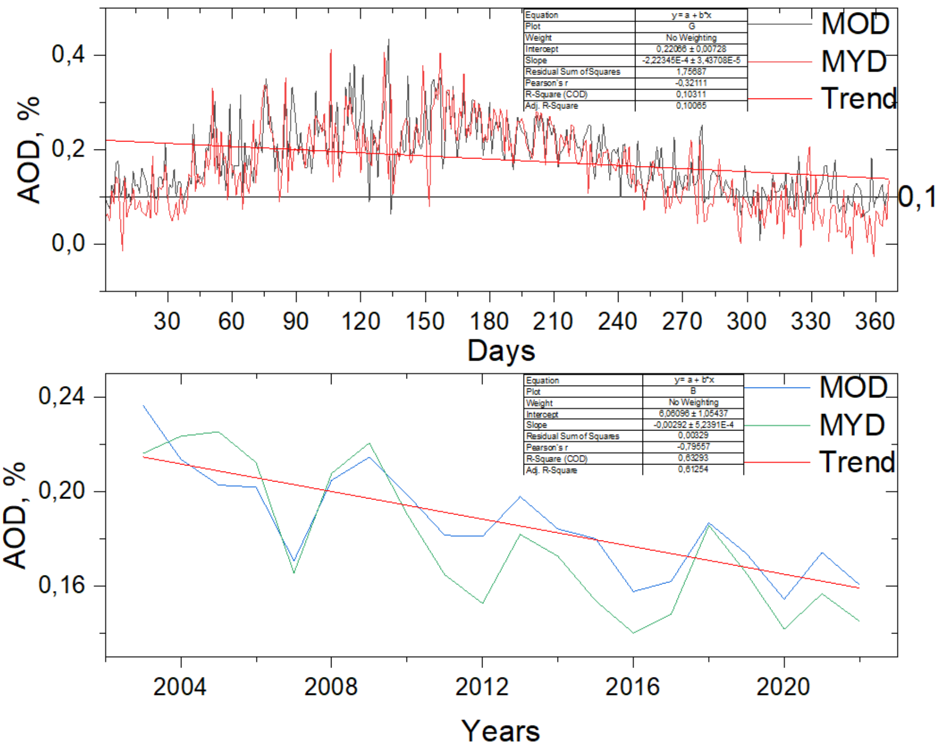


Figure 4.5: Aerosol Optical Depth retrieved through TERRA and AQUA.

Initially, one can observe that the Aerosol Optical Depth levels have decreased over the predetermined time from 2003 to 2022 in Prato Piazza. The linear trendline indicates that the observed AOD levels have decreased for both of the satellites, where the pattern of AOD levels in days correspond to those in years. This is remarkable as the amount of aerosols in the atmosphere decreases. However, there are still no information to be found about the factors of why the AOD levels have decreased in this specific area. The reduction in AOD levels can be attributed to various factors such as geographical location, climate zone, season, or climate change. Regardless of the cause, lower AOD levels can have a positive impact on air quality and help mitigate the effects of global warming. Nevertheless, the pivotal observation of AOD in Figure 4.5 depicts that the reduction of daily AOD levels are also being reduced to less than 0.1. This is a good indicator as AOD values less than 0.1 indicate very clean or pristine atmospheric conditions. Especially in areas with no exposure to pollution. Another important oberservation to notice is that the AOD levels collected from the TERRA satellite (MOD) still carry out most of the representation in AOD levels.

4.1.5 Climate analysis: Cloud Fraction

In addition to climate analysis of AOD, a climate analysis of the cloud fraction was also carried out. The climate analysis of the cloud fraction, as shown in Figure 4.6, represents a subplot concerning cloud fraction of Prato Piazza. These measurements were conducted by acquisition of observational satellite data from TERRA and AQUA.

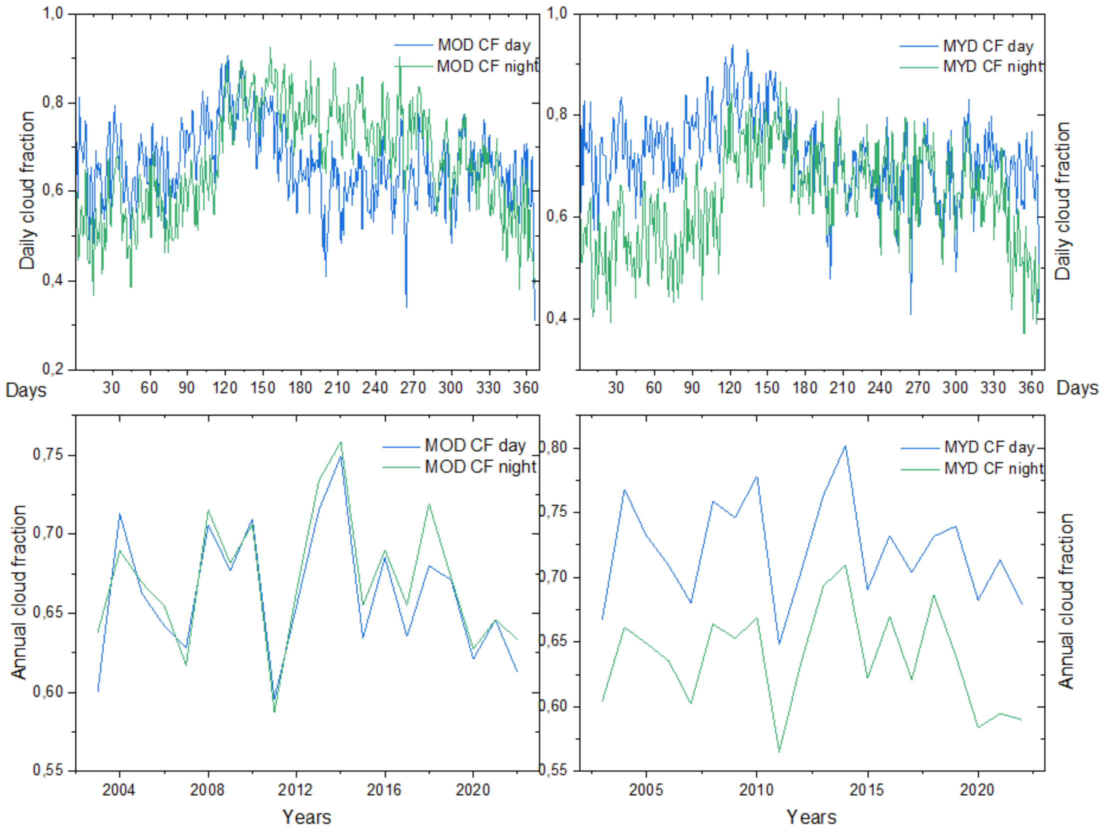


Figure 4.6: Cloud fraction during day and night provided by TERRA and AQUA.

The most prominent observation of the subplot is that the cloud fraction remains less than 1. To clarify, the range of cloud fraction goes from 0 to 1, where the closer to 1, the more cloud coverage are there. This indicates that the acquired cloud fraction data leans more towards mixed and clear nights. In essence, this presents possibilities of additional time to conduct sky observations. A closer look at Figure 4.6 reveals that the plots are similar to each other. The plots of daily cloud fraction during day and night for MOD and MYD show that the collected cloud fractions are mostly similar for daily values, with the exception of the annual cloud fraction during day and night for MYD. This suggests that while the appearance of the daily graphs may be similar, they are not necessarily greatly similar due to differences in their levels of cloud fraction.

4.2 Assessment of innovative components

Based on the climate analysis of Prato Piazza, one can now initiate an assessment of the innovative components. The proposed, additional components were a PV panel and the TYTEA All Sky camera. The primary reason of selecting these components are carried out with the implementation of new components set for observational weather stations in Prato Piazza. Additionally, these components were also selected to check if they are applicable in reference to the requirements proposed by WMO.

After careful consideration, the decision was made to use the TYTEA All Sky Camera for meteorological observations. More specifically, aimed for studying precipitation measurements and cloud cover. However, after further investigation of the sky camera, the intended source of information utilized to select the All Sky Camera only provided specifications. Another source stated that the TYTEA All Sky Camera is discontinued and off the market at the moment. Hence there was no information about the cost of the All Sky Camera, and is there absent in the thesis.

Due to decreasing trends in the cloud fraction, it became desirable to propose a PV panel that could be used for meteorological data acquisition. The primary focus was not on energy production, but only on proposing the PV panel as an innovative component to measure the meteorological parameter it was intended for. Furthermore, another pivotal focus was on the cost of the PV-panel, and to check if it could withstand meteorological parameters in the area. However, this objective could not be acquired within the time frame, and therefore set for future studies of the field.

As there was insufficient information to enable a comparative evaluation of these instruments, it was not possible to utilize the requirements stipulated by the WMO.

Chapter 5

Conclusion

5.1 Conclusion

Based on the meteorological parameters conducted in this bachelor's thesis, it can be inferred that establishing a weather station in Prato Piazza is feasible. Prato Piazza, situated amidst the Italian Alps in the Dolomites, boasts a distinctive geographic location and altitude, rendering it an intriguing region for meteorological research. By examining long-term climate data from 1948 to 2014, particularly temperature and precipitation, it becomes possible to identify annual and daily weather trends and patterns in relation to climate change.

There was a desire to select suitable meteorological components, but there was insufficient information about the selected components. This made it difficult to use WMO's requirements to select the most appropriate components. Due to time constraints, modeling became a low priority, and was therefore excluded.

Consequently, this thesis has established a solid foundation for further investigation and exploration of weather and climate conditions in Prato Piazza. It serves as a valuable resource for advancing scientific knowledge and practical applications in the field of meterology and climate studies.

5.2 Future work

For further work, it is desirable to conduct a more comprehensive climatic analysis and investigate other innovative components that meet the requirements of the World Meteorological Organization (WMO) for weather stations. It is recommended to use CAD, particularly SolidWorks, to realize these innovative weather station components on a small scale. Furthermore, thermal analysis should be performed to assess the heat distribution on various materials used for weather station components. This will ensure that the new components meet the necessary standards for reliable data collection and operation of weather stations. Additionally, cost analyses should be carried out to compare actual costs with each other in order to optimize efficiency while maintaining sustainability. This will contribute to strengthening knowledge about weather and climate in Prato Piazza and optimizing the design of weather stations with regard to efficiency.

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Appendix A

Python code: temperature

Python code: precipitation

Python code: Temperature of Prato Piazza

```
import matplotlib.pyplot as plt
import matplotlib.dates as mdates
import numpy as np
from datetime import datetime

# Define dates and temperature data for May 27th as lists
dates =[
        datetime(1948 ,12, 27), datetime(1949 ,12, 27), datetime(1950
         ↪ ,12, 27), datetime(1951 ,12, 27),
        datetime(1952 ,12, 27), datetime(1953 ,12, 27), datetime(1954
         ↪ ,12, 27), datetime(1955 ,12, 27),
        datetime(1956 ,12, 27), datetime(1957 ,12, 27), datetime(1958
         ↪ ,12, 27), datetime(1959 ,12, 27),
        datetime(1960 ,12, 27), datetime(1961 ,12, 27), datetime(1962
         ↪ ,12, 27), datetime(1963 ,12, 27),
        datetime(1964 ,12, 27), datetime(1965 ,12, 27), datetime(1966
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        datetime(1968 ,12, 27), datetime(1969 ,12, 27), datetime(1970
         ↪ ,12, 27), datetime(1971 ,12, 27),
        datetime(1972 ,12, 27), datetime(1973 ,12, 27), datetime(1974
         ↪ ,12, 27), datetime(1975 ,12, 27),
        datetime(1976 ,12, 27), datetime(1977 ,12, 27), datetime(1978
         ↪ ,12, 27), datetime(1979 ,12, 27),
        datetime(1980 ,12, 27), datetime(1981 ,12, 27), datetime(1982
         ↪ ,12, 27), datetime(1983 ,12, 27),
        datetime(1984 ,12, 27), datetime(1985 ,12, 27), datetime(1986
         ↪ ,12, 27), datetime(1987 ,12, 27),
        datetime(1988 ,12, 27), datetime(1989 ,12, 27), datetime(1990
         ↪ ,12, 27), datetime(1991 ,12, 27),
        datetime(1992 ,12, 27), datetime(1993 ,12, 27), datetime(1994
         ↪ ,12, 27), datetime(1995 ,12, 27),
        datetime(1996 ,12, 27), datetime(1997 ,12, 27), datetime(1998
         ↪ ,12, 27), datetime(1999 ,12, 27),
```

```
        datetime(2000 ,12, 27), datetime(2001 ,12, 27), datetime(2002
         ↪  ,12, 27), datetime(2003 ,12, 27),
        datetime(2004 ,12, 27), datetime(2005 ,12, 27), datetime(2006
         ↪  ,12, 27), datetime(2007 ,12, 27),
        datetime(2008 ,12, 27), datetime(2009 ,12, 27), datetime(2010
         ↪  ,12, 27), datetime(2011 ,12, 27),
        datetime(2012 ,12, 27), datetime(2013 ,12, 27), datetime(2014
         ↪  ,12, 27), datetime(2023 ,12, 27)
]

temperatures = [
                4.282495, 5.600092, 3.705164, 6.268793, 2.534845,
                 ↪  7.136652, 3.666406, 4.479364,
                6.942346, -0.710516, 10.250391, 3.859888, 4.680322,
                 ↪  4.646509, 1.009393, 5.580072,
                4.163019, 2.032495, 1.492639, 2.205774, 5.337244,
                 ↪  5.212213, 1.810449, -0.087378,
                3.717798, 5.118005, 4.116266, 4.499323, 0.44259,
                 ↪  2.015039, 1.429315, 7.430688,
                4.198877, 3.473169, 7.740259, 1.700983, 2.209772,
                 ↪  8.74801, 10.685663, 5.969141,
                5.06524, 5.456567, 3.332239, -0.217078, 7.878717,
                 ↪  4.964807, 2.804651, 6.283807,
                3.796136, 6.20144, 5.928247, 7.987573, 6.401697,
                 ↪  8.168878, 6.897699, 6.916986,
                1.393823, 7.296136, 4.013879, 8.158075, 12.04281,
                 ↪  6.147333, 9.784662, 4.494806,
                8.121271, 3.122522, 3.786707, 10.125
]

# Convert dates to matplotlib date format
matplotlib_dates = mdates.date2num(dates)

# Create a trendline using polynomial regression of degree 1 (linear
 ↪  trendline)
```

```
trendline_coefficients = np.polyfit(matplotlib_dates, temperatures, 1)
trendline = np.polyval(trendline_coefficients, mpl_dates)

# Plot the graph with the trendline
plt.plot(dates, temperatures, marker='o', label='Data')
plt.plot(dates, trendline, linestyle='--', color='r', label='Trendline')

# Add a horizontal line at y = 0
plt.axhline(0, color='k', linestyle='-', linewidth=1)

# Configure the axes
plt.xlabel('Date')
plt.ylabel('Temperature (°C)')
plt.title('Temperature Increase over Time')
plt.legend()

# Format x-axis tick labels
plt.xticks(rotation=45)
plt.gca().xaxis.set_major_locator(mdates.YearLocator(base=30))
plt.gca().xaxis.set_major_formatter(mdates.DateFormatter('%Y'))

# Show the graph
plt.show()
```

```
temperatures = [4.282495, 5.600092, 3.705164, 6.268793, 2.534845,
↪  7.136652, 3.666406, 4.479364,
                6.942346, -0.710516, 10.250391, 3.859888, 4.680322,
                 ↪  4.646509, 1.009393, 5.580072,
                4.163019, 2.032495, 1.492639, 2.205774, 5.337244,
                 ↪  5.212213, 1.810449, -0.087378,
                3.717798, 5.118005, 4.116266, 4.499323, 0.44259,
                 ↪  2.015039, 1.429315, 7.430688,
                4.198877, 3.473169, 7.740259, 1.700983, 2.209772,
                 ↪  8.74801, 10.685663, 5.969141,
                5.06524, 5.456567, 3.332239, -0.217078, 7.878717,
                 ↪  4.964807, 2.804651, 6.283807,
                3.796136, 6.20144, 5.928247, 7.987573, 6.401697,
                 ↪  8.168878, 6.897699, 6.916986,
                1.393823, 7.296136, 4.013879, 8.158075, 12.04281,
                 ↪  6.147333, 9.784662, 4.494806,
                8.121271, 3.122522, 3.786707, 10.125

]

# Find numbers <= 0
threshold_temperatures = [num for num in temperatures if num <= 0]

# Count the number of days with temperatures less than or equal to 0
number_days = len(threshold_temperatures)

# Print the result
print("Temperatures less than or equal to 0:")
print(threshold_temperatures)
print(f"Number of days with temperature less than or equal to 0:
↪  {number_days} days")
```

Python: Precipitation of Prato Piazza

```python
import matplotlib.pyplot as plt
import matplotlib.dates as mdates
import numpy as np
from datetime import datetime

# Define dates and temperature data for May 27th as lists
dates_Prato_Piazza =[
    datetime(1948 ,12, 27), datetime(1949 ,12, 27), datetime(1950 ,12,
    ↪ 27), datetime(1951 ,12, 27),
    datetime(1952 ,12, 27), datetime(1953 ,12, 27), datetime(1954 ,12,
    ↪ 27), datetime(1955 ,12, 27),
    datetime(1956 ,12, 27), datetime(1957 ,12, 27), datetime(1958 ,12,
    ↪ 27), datetime(1959 ,12, 27),
    datetime(1960 ,12, 27), datetime(1961 ,12, 27), datetime(1962 ,12,
    ↪ 27), datetime(1963 ,12, 27),
    datetime(1964 ,12, 27), datetime(1965 ,12, 27), datetime(1966 ,12,
    ↪ 27), datetime(1967 ,12, 27),
    datetime(1968 ,12, 27), datetime(1969 ,12, 27), datetime(1970 ,12,
    ↪ 27), datetime(1971 ,12, 27),
    datetime(1972 ,12, 27), datetime(1973 ,12, 27), datetime(1974 ,12,
    ↪ 27), datetime(1975 ,12, 27),
    datetime(1976 ,12, 27), datetime(1977 ,12, 27), datetime(1978 ,12,
    ↪ 27), datetime(1979 ,12, 27),
    datetime(1980 ,12, 27), datetime(1981 ,12, 27), datetime(1982 ,12,
    ↪ 27), datetime(1983 ,12, 27),
    datetime(1984 ,12, 27), datetime(1985 ,12, 27), datetime(1986 ,12,
    ↪ 27), datetime(1987 ,12, 27),
    datetime(1988 ,12, 27), datetime(1989 ,12, 27), datetime(1990 ,12,
    ↪ 27), datetime(1991 ,12, 27),
    datetime(1992 ,12, 27), datetime(1993 ,12, 27), datetime(1994 ,12,
    ↪ 27), datetime(1995 ,12, 27),
    datetime(1996 ,12, 27), datetime(1997 ,12, 27), datetime(1998 ,12,
    ↪ 27), datetime(1999 ,12, 27),
```

```
    datetime(2000 ,12, 27), datetime(2001 ,12, 27), datetime(2002 ,12,
     ↪  27), datetime(2003 ,12, 27),
    datetime(2004 ,12, 27), datetime(2005 ,12, 27), datetime(2006 ,12,
     ↪  27), datetime(2007 ,12, 27),
    datetime(2008 ,12, 27), datetime(2009 ,12, 27), datetime(2010 ,12,
     ↪  27), datetime(2011 ,12, 27),
    datetime(2012 ,12, 27), datetime(2013 ,12, 27), datetime(2014 ,12,
     ↪  27), datetime(2023 ,12, 27)
]

precipitation_Prato_Piazza = [
    0.094652487, 0.24595875, 3.262259137, 4.104648579, 0, 5.938216505,
     ↪  0.176643247,
    13.90892178, 0, 15.96531401, 1.389986456, 10.80476436, 4.567085718,
     ↪  13.6289406,
    11.00613372, 0.383061487, 2.873791872, 14.08718598, 0.91556746,
     ↪  0.160179829, 0,
    0.345327993,
     ↪  0.893153917,0.642838198,0.304037304,0,0.11402761,9.54932207,
    1.864394842, 0,
     ↪  7.116924159,0.525369191,2.277475203,23.83206745,1.573763092,
    7.731727327, 11.97262417,
     ↪  16.05012287,5.032986996,0.957347139,0,5.24666738,
    0.029599417,
     ↪  0,0.729277518,0,9.388735315,2.88354778,0.421331647,3.315034633,
    3.284148793, 16.7268958,
     ↪  0.768663242,0.060953534,30.38906272,0.330433443,
    1.278496587, 6.28513992, 2.43571841,
     ↪  2.552801702,1.786375719,0.744541199,
    1.294433784,4.810359139, 1.256535271, 0.826016912, 21.56084663, 0.125
]

# Convert dates to matplotlib date format
matplotlib_dates = mdates.date2num(dates_Prato_Piazza)
```

```python
# Create a trendline using polynomial regression of degree 1 (linear
↪   trendline)
trendline_coefficients = np.polyfit(matplotlib_dates,
↪   precipitation_Prato_Piazza, 1)
trendline = np.polyval(trendline_coefficients, matplotlib_dates)

# Plot the graph with the trendline
plt.plot(dates_Prato_Piazza, precipitation_Prato_Piazza, marker='o',
↪   label='Data')
plt.plot(dates_Prato_Piazza, trendline, linestyle='--', color='r',
↪   label='Trendline')

# Add a horizontal line at y = 1
plt.axhline(1, color='k', linestyle='-', linewidth=1)

# Configure the axes
plt.xlabel('Date')
plt.ylabel('Precipitation (mm)')
plt.title('Precipitation Increase over Time')
plt.legend()

# Format x-axis tick labels
plt.xticks(rotation=45)
plt.gca().xaxis.set_major_locator(mdates.YearLocator(base=30))
plt.gca().xaxis.set_major_formatter(mdates.DateFormatter('%Y'))

# Show the graph
plt.show()
```

```python
import matplotlib.pyplot as plt
from datetime import datetime

# Define dates and temperature data for May 27 th as lists
dates_prato_piazza = [
    datetime(1948, 5, 27), datetime(1949, 5, 27), datetime(1950, 5, 27),
     ↪ datetime(1951, 5, 27),
    datetime(1952, 5, 27), datetime(1953, 5, 27), datetime(1954, 5, 27),
     ↪ datetime(1955, 5, 27),
    datetime(1956, 5, 27), datetime(1957, 5, 27), datetime(1958, 5, 27),
     ↪ datetime(1959, 5, 27),
    datetime(1960, 5, 27), datetime(1961, 5, 27), datetime(1962, 5, 27),
     ↪ datetime(1963, 5, 27),
    datetime(1964, 5, 27), datetime(1965, 5, 27), datetime(1966, 5, 27),
     ↪ datetime(1967, 5, 27),
    datetime(1968, 5, 27), datetime(1969, 5, 27), datetime(1970, 5, 27),
     ↪ datetime(1971, 5, 27),
    datetime(1972, 5, 27), datetime(1973, 5, 27), datetime(1974, 5, 27),
     ↪ datetime(1975, 5, 27),
    datetime(1976, 5, 27), datetime(1977, 5, 27), datetime(1978, 5, 27),
     ↪ datetime(1979, 5, 27),
    datetime(1980, 5, 27), datetime(1981, 5, 27), datetime(1982, 5, 27),
     ↪ datetime(1983, 5, 27),
    datetime(1984, 5, 27), datetime(1985, 5, 27), datetime(1986, 5, 27),
     ↪ datetime(1987, 5, 27),
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     ↪ datetime(1991, 5, 27),
    datetime(1992, 5, 27), datetime(1993, 5, 27), datetime(1994, 5, 27),
     ↪ datetime(1995, 5, 27),
    datetime(1996, 5, 27), datetime(1997, 5, 27), datetime(1998, 5, 27),
     ↪ datetime(1999, 5, 27),
    datetime(2000, 5, 27), datetime(2001, 5, 27), datetime(2002, 5, 27),
     ↪ datetime(2003, 5, 27),
```

```
    datetime(2004, 5, 27), datetime(2005, 5, 27), datetime(2006, 5, 27),
     ↪  datetime(2007, 5, 27),
    datetime(2008, 5, 27), datetime(2009, 5, 27), datetime(2010, 5, 27),
     ↪  datetime(2011, 5, 27),
    datetime(2012, 5, 27), datetime(2013, 5, 27), datetime(2014, 5, 27),
     ↪  datetime(2023, 5, 27)
]

precipitation_Prato_Piazza = [

    0.094652487, 0.24595875, 3.262259137, 4.104648579, 0, 5.938216505,
     ↪  0.176643247,
    13.90892178, 0, 15.96531401, 1.389986456, 10.80476436, 4.567085718,
     ↪  13.6289406,
    11.00613372, 0.383061487, 2.873791872, 14.08718598, 0.91556746,
     ↪  0.160179829, 0,
    0.345327993,
     ↪  0.893153917,0.642838198,0.304037304,0,0.11402761,9.54932207,
    1.864394842, 0,
     ↪  7.116924159,0.525369191,2.277475203,23.83206745,1.573763092,
    7.731727327, 11.97262417,
     ↪  16.05012287,5.032986996,0.957347139,0,5.24666738,
    0.029599417,
     ↪  0,0.729277518,0,9.388735315,2.88354778,0.421331647,3.315034633,
    3.284148793, 16.7268958,
     ↪  0.768663242,0.060953534,30.38906272,0.330433443,
    1.278496587, 6.28513992, 2.43571841,
     ↪  2.552801702,1.786375719,0.744541199,
    1.294433784,4.810359139, 1.256535271, 0.826016912, 21.56084663
]
# Find numbers of precipitation <= 1
threshold_precipitation = [num for num in precipitation_Prato_Piazza if
 ↪  num <= 1]

# Count the number of days with temperatures less than or equal to 0
```

```
number_days = len(threshold_precipitation)

# Print the result
print("Precipitation less than or equal to 1 mm: ")
print(threshold_precipitation)
print(f"Number of days with precipitation less than or equal to 1 mm:
↪  {number_days} days")
```

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