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The importance in preserving alpine Azzurro Lake as a natural resource in the context of climate change

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Manster in Landscape Architecture - Land Landscape Heritage

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ABSTRACT

The aim of my dissertation is to analyse the significance of environmental issues, using the disappearance of Lake Azzurro in Motta (borough of Campodolcino) as a starting point.To achieve this, the thesis explores and categorizes the ecosystem services offered by the lake, while also providing an overview of the climate in the Valchiavenna area.

Ecosystem services encompass the benefits provided by ecosystems to humanity, both directly and indirectly. These services take various forms and contribute to human well-being. They can be classified into four categories: provisioning services, regulating services, supporting services, and cultural services. In the region of Lake Azzurro, cultural services are particularly prominent due to the lake's status as a renowned tourist destination for the entire Valchiavenna area. Aside from providing aesthetic and recreational experiences, the lake served as inspiration for the famous Italian poet Giosuè Carducci, who dedicated a poem to it in 1888.To evaluate the ecosystem services provided by the lake, two surveys were conducted. The first survey aimed to collect public opinions on issues related to the disappearance of Lake Azzurro, addressing a broader scope.

The second survey sought to identify and comprehend the cultural ecosystem services associated with the alpine lakes of Valchiavenna.

The distinctive feature of Lake Azzurro lies in the fact that lacks affluents and effluents and inflow depends on precipitation and snowmelt while outflow on evaporation.

Consequently, a climate analysis was conducted to assess the correlation between the reduction in the lake's water level, the rise in temperatures, and the decrease in precipitation. This analysis utilized historical data from ARPA Lombardy and the ERA5-Land reanalysis dataset.

The climate analysis reveals a clear correlation between the lake's disappearance and the temperature increase, a phenomenon particularly pronounced in in the 21st century especially in 2022, which was the hottest year recorded in the past 73 years. It is crucial to emphasize that the disappearance of Lake Azzurro in Motta underscores the urgency of effectively addressing environmental issues. The loss of such an important ecosystem, like the lake, significantly impacts the provision of ecosystem services to the local community and the entire region. Preserving and managing the lake sustainably are essential to ensure environmental balance and enhance the quality of life for present and future generations.

RIASSUNTO

L’obiettivo della mia tesi è analizzare il significato delle questioni ambientali, utilizzando la scomparsa del Lago Azzurro a Motta (frazione di Campodolcino) come punto di partenza. Per raggiungere questo obiettivo, la tesi esplora e categorizza i servizi ecosistemici offerti dal lago, fornendo anche una panoramica sul clima nell’area di Valchiavenna. I servizi ecosistemici comprendono i benefici forniti dagli ecosistemi all’umanità, sia direttamente che indirettamente. Questi servizi assumono varie forme e contribuiscono al benessere umano. Possono essere classificati in quattro categorie: servizi di approvvigionamento, servizi di regolazione, servizi di sostegno e servizi culturali. Nell’ area del Lago Azzurro, i servizi culturali sono particolarmente rilevanti grazie allo status del lago come rinomata meta turistica per l’intera area di Valchiavenna. Oltre a offrire esperienze estetiche e ricreative, il lago ha ispirato il famoso poeta italiano Giosuè Carducci, che gli ha dedicato una poesia nel 1888. Per valutare i servizi ecosistemici forniti dal lago, sono stati condotti due sondaggi. Il primo sondaggio mirava a raccogliere opinioni pubbliche su questioni legate alla scomparsa del Lago Azzurro, affrontando un ambito più ampio. Il secondo sondaggio aveva lo scopo di identificare e comprendere i servizi culturali legati ai laghi alpini di Valchiavenna. La peculiarità del Lago Azzurro risiede nel fatto che non ha affluenti e deflussi, e l’afflusso dipende dalle precipitazioni e dallo scioglimento delle nevi, mentre il deflusso dipende dall’evaporazione. Di conseguenza, è stata condotta un’analisi climatica per valutare la correlazione tra la riduzione del livello d’acqua del lago, l’aumento delle temperature e la diminuzione delle precipitazioni. Questa analisi ha utilizzato dati storici di ARPA Lombardia e dell’insieme di dati di rianalisi ERA5-Land. L’analisi climatica rivela una chiara correlazione tra la scomparsa del lago e l’aumento delle temperature, un fenomeno particolarmente evidente nel XXI secolo, soprattutto nel 2022, che è stato l’anno più caldo registrato negli ultimi 73 anni. È fondamentale sottolineare che la scomparsa del Lago Azzurro a Motta sottolinea l’urgenza di affrontare efficacemente le questioni ambientali. La perdita di un ecosistema così importante, come il lago, influisce significativamente sulla fornitura di servizi ecosistemici alla comunità locale e all’intera regione. Preservare e gestire il lago in modo sostenibile è essenziale per garantire l’equilibrio ambientale e migliorare la qualità della vita delle generazioni presenti e future.

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01

VALCHIAVENNA

Study area

1.1 Territory

Valchiavenna (Fig.1), located in the northwestern part of Valtellina (Fig.2) within the Lombardy region, is a captivating alpine valley. The main town in Valchiavenna, known as Chiavenna, holds historical significance as it rests in the heart of the valley. The valley offers a captivating scenery with its majestic snow-covered peaks, cascading waterfalls, and vibrant green meadows. The harmonious blend of rugged mountains and gentle valleys creates an inspiring landscape. The villages dotted across the area showcase traditional architecture and hold historical importance. The presence of lakes like Lake Mezzola adds a touch of tranquility to this already idyllic setting. Valchiavenna's landscape not only provides visual delight but also symbolizes the profound connection between nature and human civilization. In the northernmost part of this picturesque valley lies Lake Azzurro, surrounded by majestic mountains and lush hills, Lake Azzurro acts as a sanctuary that captivates visitors with its serene beauty. Its glassy surface reflects the nearby landscape, offering a breathtaking view of towering peaks and abundant woods. The lake not only enhances the visual splendor of Valchiavenna but also plays a vital role in supporting the ecosystem by providing a habitat for diverse flora and fauna.

Figure 1.

Novate Mezzola lake at the foot of Valchiavenna, source: www.northlakecomo.net

Figure 2. Valchiavenna localization in the Lombardy region, Provinces and mountain communities

Figure 3. Valchiavenna's borders

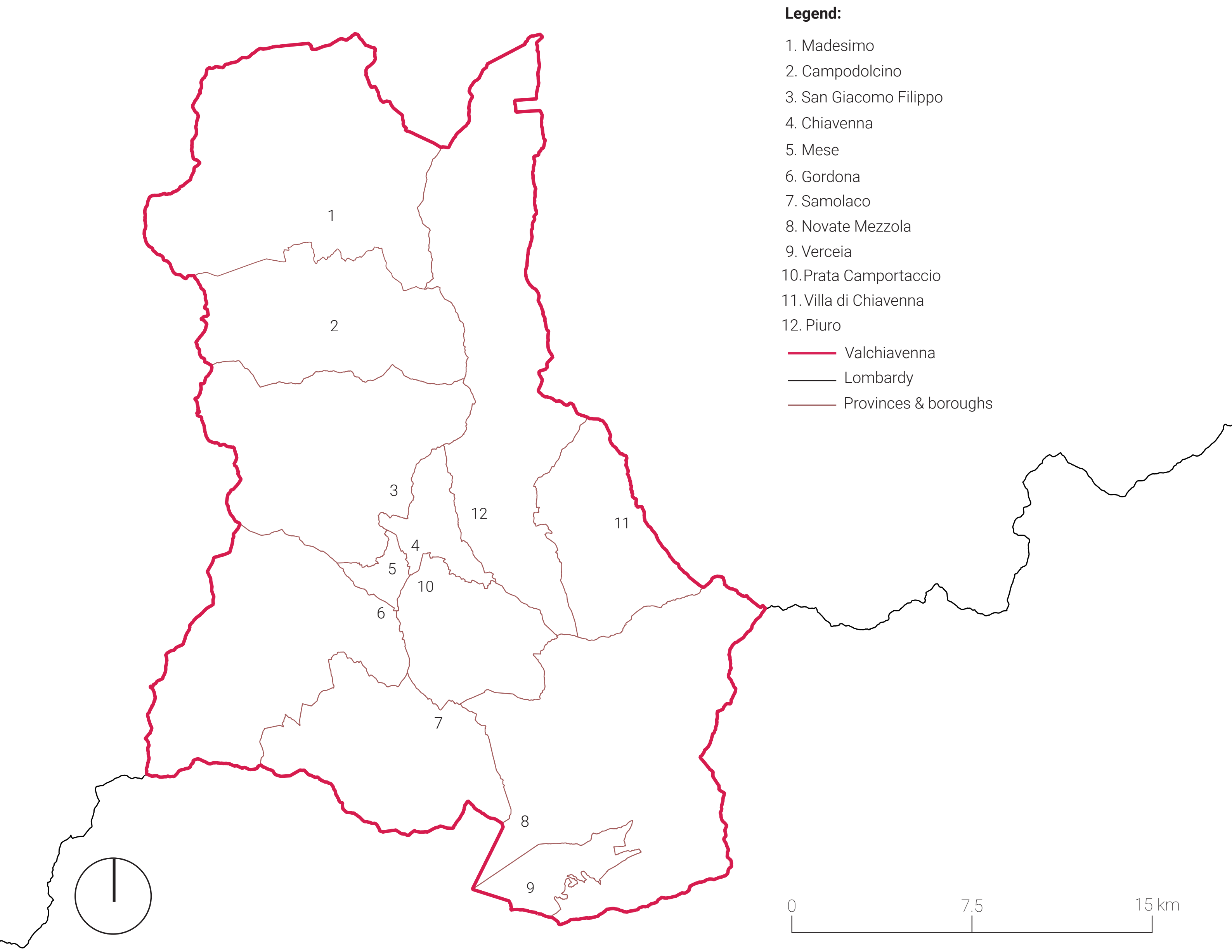


Figure 4.

Samolaco, borough of Chiavenna, source: www.samolacocultura.it

Figure 5.

Campodolcino, source: Alessandro Cabella, 2022

Figure 6.

Andossi, borough of Madesimo, source: www.fraciscio.it

Figure 7.

Alpe Motta, borough of Campodolcino, source: Alessandro Cabella 2023

1.2 Valchiavenna’s infrastructure connections

Valchiavenna boasts well-connected infrastructures that link it to Milan and the Swiss border, offering convenient access to both destinations. The A9 motorway provides a direct route from Milan to the Swiss border, passing through Valchiavenna along the way. This road connection allows for easy travel between the vibrant city of Milan and the picturesque landscapes of Valchiavenna. Additionally, Valchiavenna is connected to Switzerland through the renowned Splügen Pass (Fig. 9, Fig.10). This historic mountain pass offers a scenic and adventurous route that traverses the stunning Alpine landscapes, serving as an important trade route between Switzerland and Italy for centuries. The Splügen Pass not only provides breathtaking views of mountains, valleys, and al-pine meadows but also symbolizes the interconnectedness of Valchiavenna with neighboring re-gions. These infrastructural connections ensure seamless movement and facilitate exploration of the natural beauty and cultural richness that Valchiavenna has to offer. Additionally, the train (Fig. 8) offers an efficient mode of transportation from Milan to Valchiavenna (Fig. 11). The train journey takes around two hours, offering ample time to relax and appreciate the picturesque landscapes.Public transportation not only provides convenience but also aligns with sustainable travel principles

Figure 8.

Chiavenna station, Valchiavenna_ instagram page

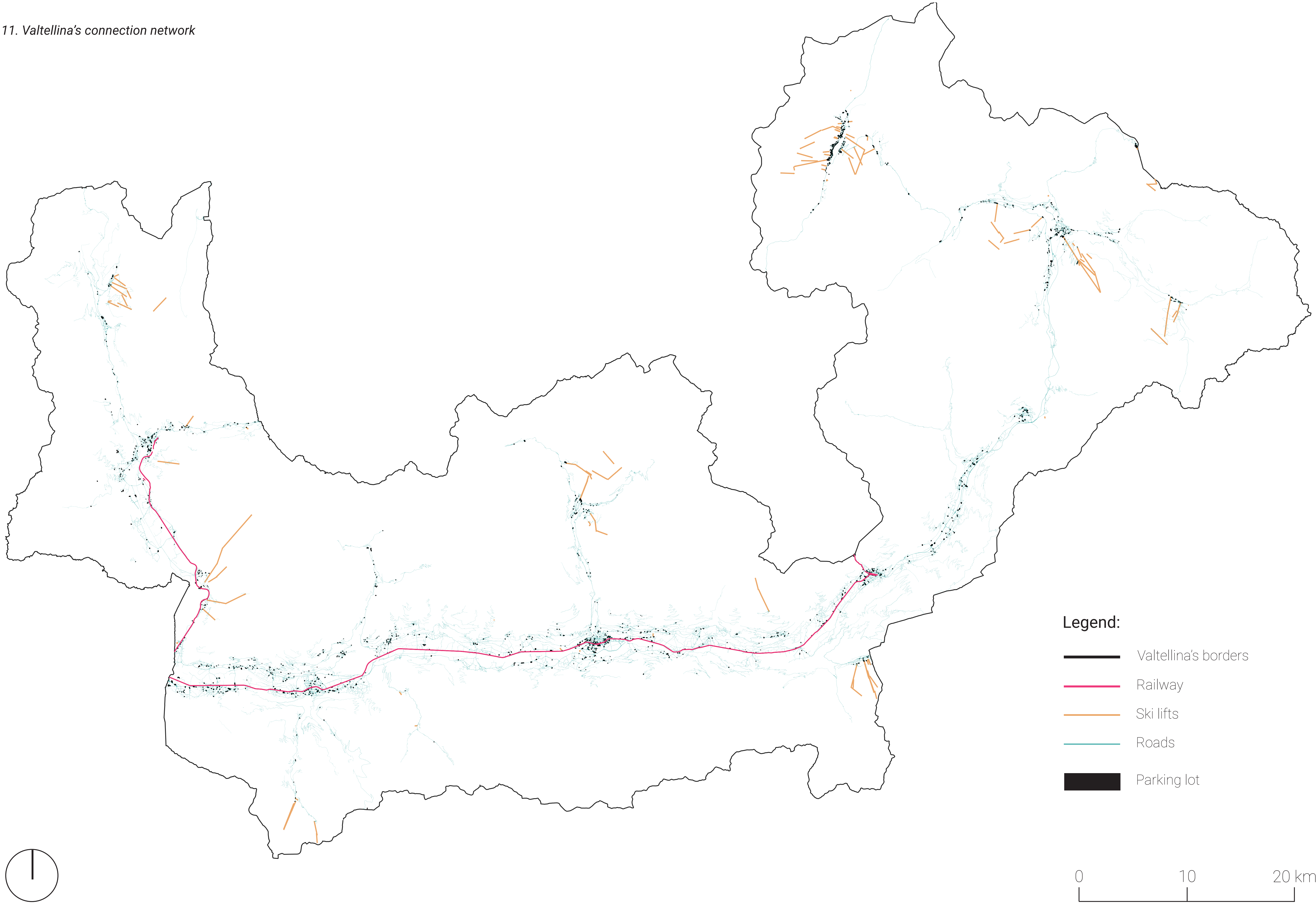
Figure 9.

Splügenpass, source: www.verdidea.com

Figure 10.

Splügenpass, source: Valchiavenna_ instagram page

Figure 11. Valtellina's connection network



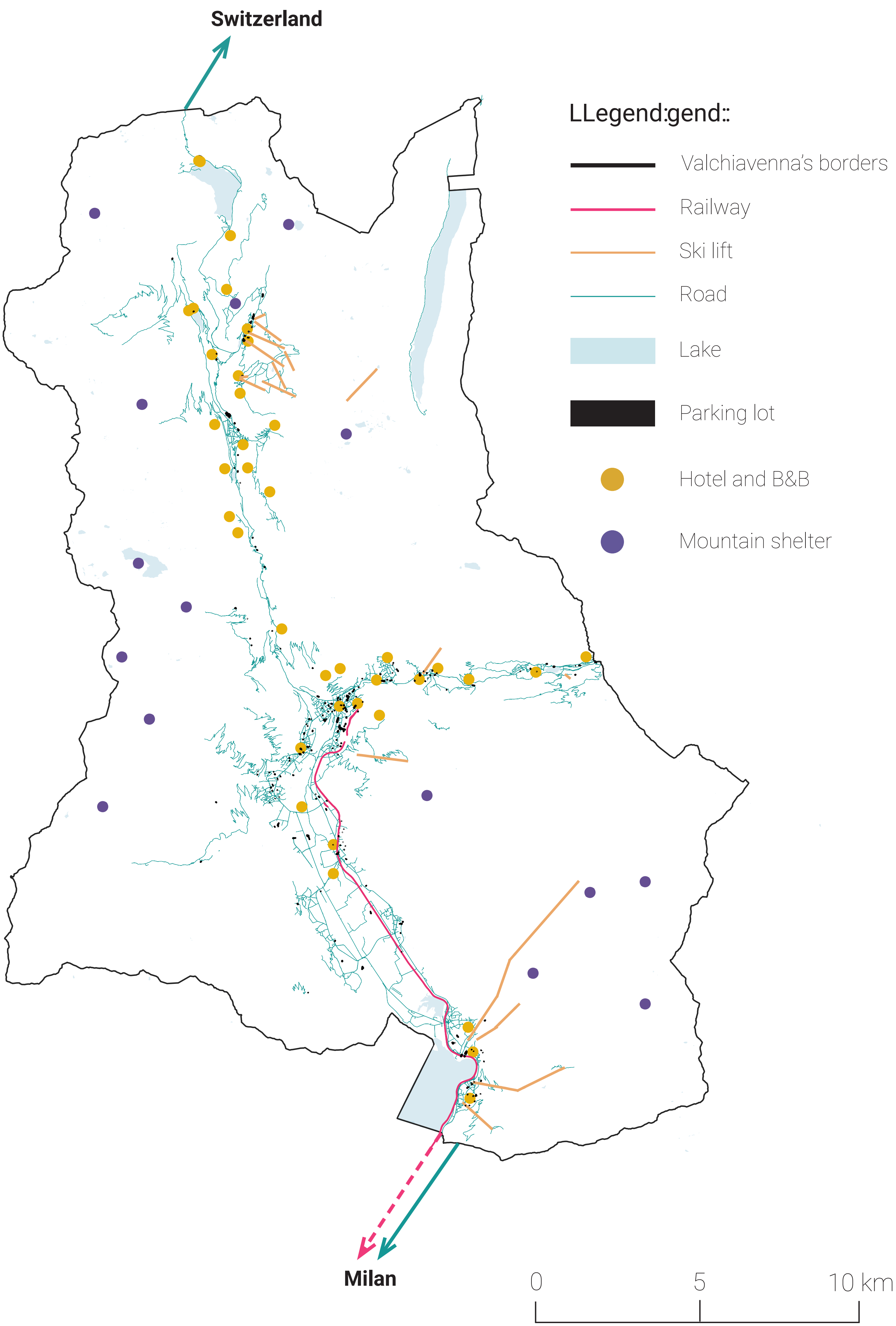
1.3 Valchiavenna's tourism

During the summer months, Valchiavenna is a popular destination for hiking and mountain biking. The valley is home to several well-marked trails that offer stunning views of the surrounding landscape. Valchiavenna is also known for its rich cultural heritage, with several historic towns and villages located throughout the valley. One of the most popular is Chiavenna, a picturesque town located at the con-fluence of two rivers, Mera and Liro. The town is home to several historic buildings and museums, as well as a range of shops and restaurants offering traditional Italian cuisine (www.valchiavenna.com). The most emblematic historic building is "Palazzo Vertemate" (Fig. 12), it was built in the 16th century by the noble family of the Vertemate (a town located North-West from Milan), who were prominent landowners in the region. The building is an excellent example of Renaissance architecture and features a number of de-corative elements that were typical of the period, including intricate frescoes, stucco deco-rations, and ornate wooden ceilings.In addition to the main building, the palace also includes a beautiful garden and a small chapel, both of which are open to visitors. The garden features a variety of plants and flowers, as well as a charming fountain and several outdoor seating areas (Besta,1955). Furthermore, another popular destination in Valchiavenna is the village of Madesimo, a small ski resort town located at the head of the valley. Madesimo offers a range of ski slopes and other winter sports activities, as well as opportunities for hiking and mountain biking du-ring the summer months. The town is also home to several shops and restaurants, as well as a range of accommodation options, including hotels, bed and breakfast and apartments. Valchiavenna is also known for its delicious local cuisine, which features a range of tra-ditional Italian dishes made with locally sourced ingredients.One of the most fa-mous is pizzoccheri della Valchiavenna, other local specialties include brisaola, a type of cured beef, and the delicious local cheeses known as casera and mascarpin. Overall, Valchiavenna is a must visit destination for anyone looking to experience the be-auty and culture of northern Italy. With its stunning natural scenery, rich cultural herita-ge, and range of outdoor activities, it offers something for everyone, whether you're lo-oking to ski, hike, or simply relax and enjoy the local cuisine (www.valchiavenna.com).

Figure 12.

Palazzo Vertemate, Luca Cornago, 2018

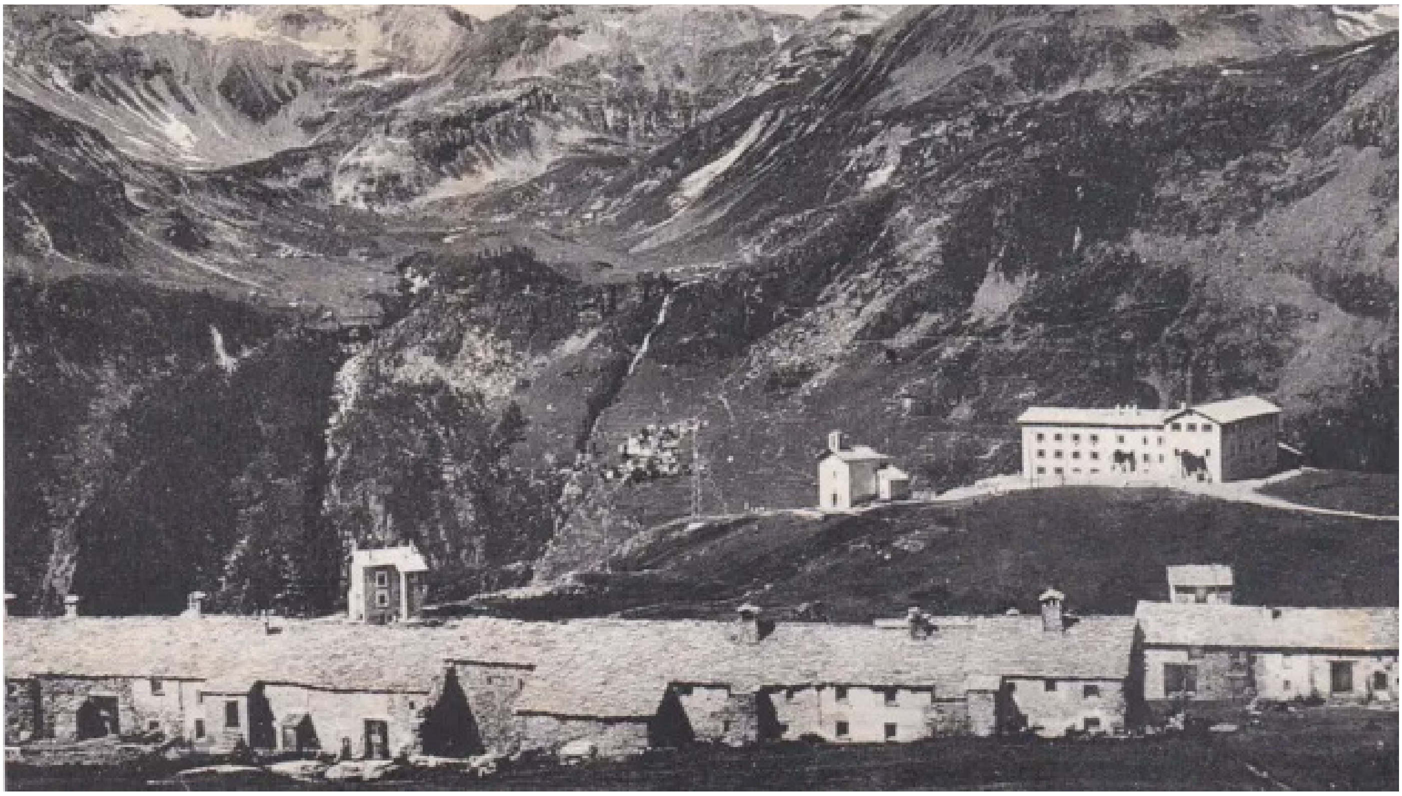
Figure 13. Valchiavenna's connections and touristic facilities



1.4 Madesimo and Alpe Motta's history

Motta is a quaint town situated within the municipality of Campodolcino in Valchiavenna, nestled in the Lombardy region of northern Italy.In the Middle Ages, Motta was a strategic point along the route between Milan and the Splügen Pass, and it played a key role in the battles between the Duchy of Milan and the Swiss Confederation. It has served as an important trade route and transportation corridor for centuries, connecting the Swiss canton of Graubünden with the Italian region of Lombardy. Historically, the Splügen Pass has played a significant role in facilitating trade and cultural exchange between Northern Europe and the Mediterranean region. It has been used since ancient times, but its importance grew during the Roman era when it became part of the Via Spluga. Later, during the 19th and 20th centuries, Motta became known for its agriculture and dairy farming, which remain important economic activities to this day. Motta is also a popular destination for outdoor enthusiasts, with its alpine scenery and numerous hiking trails. Despite its small size, Motta boasts a rich history and a vibrant community that continues to thrive today (Del Giorgio, 2011)

Figure 14.



Alpe Motta in the 60's, source: www.valchiavenna.com

1.4.1 The ascent to Alpe Motta

Since 1662, archival documents reveal that the alpine pasture of Alpe Motta was regulated by an "order". However, this order was later deemed inadequate, and a new one was drafted in 1794 with all the then in force rules. The socio economic situation of the time was characterized by widespread pastoralism until the opening of the Chiavenna-Spluga carriage road and the descent to Splügen in Switzerland in 1821-22, which favored an increase in nomadism between the high Motta) and low valley (Samolaco). The meadows were well-maintained in Motta Bassa Motta Alta (Fig. 17) and Madesimo (Fig. 15), as well as in the small hamlets of Monte, Pianelli, Foppe, and Frasciscio. The hay was stored in the typical "tèc dal fèen," (structure where to store hay, Fig. 16) rustic buildings that date back to the 1600s/1700s, some of which were destroyed by soldiers during political-religious struggles. Today, these buildings are increasingly disappearing due to renovation into homes.
Despite a reduced population, the people of Motta showed remarkable vitality in 1768 when they obtained their own little church dedicated to the saints Ermagora and Vincenzo Ferrari. Following the French Revolution in 1789, the centuries long Grisons domination of Valchiavenna, which had lasted since 1512, was almost put to an end. Difficult years followed until the fall of Napoleon and the subsequent Congress of Vienna in 1815, which marked the beginning of the harsh Austrian domination. The newfound stability brought by the new government immediately led to the start of valuable public works, such as renewing works on the road to Spluga, the first water regulation works, and the first public schools.
New houses were built in Motta Bassa (also called Marcadello), positioned in a row, joined together to facilitate heating during the long and cold winters (Fig. 14). Peat was also used, extracted from the nearby marshy plain and properly dried during the summer. The local economy, included seasonal emigration to Switzerland for adults, such as mowers and domestics. Most of the high alpine pastures in Valle Spluga are owned by people from Samolaco. Until just over a hundred years ago, the population of Samolaco lived almost exclusively on pastoralism, forestry, and agriculture limited to minor cereals. Pastoralism forced almost perpetual nomadism. However, after 1880, the work of embanking the river Mera began, lasting for about 10 years, and transformed approximately 15,000 hectares of previously unproductive land into good arable land.

Figure 15.

Women making hay, Madesimo in 1950, www.valchiavenna.com

Figure 16.

Tèc dal fèen, Del Giorgio, 2011

Figure 17.

The first settlements in Motta Alta, source: Del Giorgio, 2011

After 1860, a strong emigration to America began and lasted for over fifty years, and most of the emigrants returned after 10/12 years and bought large plots of land from the Municipality in the now-reclaimed "Piano" area, transforming them into wheat and corn fields. The Samolaco people, who had been shepherds and loggers, became farmers and large breeders of cows and horses, and moved further down, building new barns, new houses, and thus new towns. With many cows and horses in the barns, the local mountain pastures soon appeared inadequate and insufficient, and the search for new and larger grazing land began. For the original Samolaco people from the upper valley, the task was quite easy since they already owned good portions of the pastures; for the others, who were the majority, it was a matter of making large and not easy purchases. Starting from the last decades of the 1800s, every beginning of summer, long caravans of wagons, livestock, and shepherds slowly ascended towards the Motta Alp. In September, they descended back down. Samolaco people in need of space for their sometimes numerous livestock made many purchases of mountain huts, meadows, and "vaccate,"(grazing rights on the Motta Alp) (Del Giorgio, 2011).

1.4.2 The development of Motta's alpine tourism

The first event after the migration of the Samolachians, which broke the bucolic peace of Motta, was the arrival in the mid 1920s of Don Luigi Re, a brave Milanese priest, in search of a beautiful and unspoiled natural spot for his young explorers. At first, they pitched tents and then built the Motta Alpine House. At the very beggining, the guests were only children, then came the parents and families of the young explorers themselves- The expansions of the Alpine House followed almost annually, so that after the war there were already hundreds of beds and the expansion continued for another twenty years. Meanwhile, the local residents of Motta Bassa, eight or nine families in all, also appeared on the scene. Livestock farming, some logging, and winter work in the city by adults had allowed a pretty meager standard of living until then. The Alpine House was the gateway to the world of tourism. Some became waiters or ski lift operators, and then entrepre-neurs. Already in the mid-thirties, the first skiliftrun began to operate in Motta, and soon after came the longest skilift that went from 1550m a.s.l in Madesimo to 2150m a.s.l in the upper part of the muntain.So towards the end of the 1950s, just before the skiing boom, the Casa Alpina, the local residents of Motta Bassa (Fig. 18), and the samolachesi of Motta Alta (Fig. 17), as three compo-nents, were potential protagonists of the great transformation that had now begun. In 1952, the Casa Alpina built a cable car that took about 15 passengers from Campodolcino to Motta Bassa in six minutes meanwhile, the road from Madesimo was improved. In 1958, Don Re had cleared the first road from Motta Bassa to Motta Alta with a shovel, in order to bring the huge copper statue of the "Madonna", later called the "Madonna of Europe", to the top of "Pian Piccolo" in Motta Alta. After 1960, the transformation became increasingly accelerated, the "Baita del Sole", in a charming position just north of the Lago Azzurro, between Motta Alta and Groppera, became more and more popular with summer tourists and in winter as a refreshment point for skiers. By the end of the 1970s, the issue of the road from Motta Bassa to Motta Alta remained, because the one "cleared" in '58 with the shovel for the transport of the statue of the Madonna was no lon-ger acceptable. In the following years, an unpaved road was built that also allowed cars to reach Motta Alta (Del Giorgio, 2011).

1.4.3 Life in Motta in the 50's

In the second half of the last century, life in the alpine pasture of Motta was very different from the old pastures of Samolaco. Long caravans of wagons, livestock, and shepherds would slowly ascend towards the Motta Alp every beginning of summer and descend in September. Many Samolaco people in need of space for their livestock would purchase mountain huts, meadows, and grazing rights on the Motta Alp. The presence of the Casa Alpina provided highly stimulating civil models in the spiritual cultural and socio economic fields. Many priests were also present to provide religious assistance with catechists, and health assistance was available. The huts were heated and food was cooked using wood from the abundant forest, with provisions from forest rangers being respected. Milk processing was important, with families joining together to share individual milk productions and obtain butter, cheese, and ricotta through the "casèda" (traditional building where they used to store food). The diet was simple, consisting of polenta made of cornmeal, milk, cheese, soup, and rice cooked together with dried chestnuts. Fruits were scarce, with only blue-berries and raspberries available, along with well-cooked mushrooms after Ferragosto. After the second hay cutting down in the village of S. Anna, men rested a little in the alp before cutting hay, letting it dry, and putting it in the barns. Short trips were taken to Motta Bassa, Madesimo, and the Baita del Sole for rest. Fragrant *Achillea moschata* was collected until Ferragosto for liquor ma-nufacturers. Young men would also pick *Leontopodium alpinum* from the dangerous cliffs around Angeloga, bloom them in water in the "casello," and sell them in bunches to tourists. Finally, a small source of income was the sale of eggs from chickens brought up from the village and laid abundantly in the alpine environment

Figure 18.

Alpe Motta Ski area in the 70's, source: Del Giorgio, 2011

1.4.4 The “caselli” of Alpe Motta

Valchiavenna’s caselli are a unique feature of the valley located in the province of Sondrio, Lombardy, Italy (Fig. 19+Fig. 20). They are ancient stone structures used for cheese, milk and hay storage, typical of the traditional architecture of the Alpine region. Each family had one, they are characterized by a rectangular or square plan, with stone walls a roof made of piöde (stone tiles)covered with grassy rind.They usually have small openings used for ventilation and to let the sunlight in. These structu-res are built without the use of cement or mortar, using only the traditional technique of dry-stone masonry, which consists of interlocking stones without any bonding material.Today, many of the caselli have been abandoned or repurposed, but some have been preserved and restored to their original function. They have become a symbol of the rural culture and history of Valchiavenna, and a popular tourist attraction in the area.Valchiavenna’s caselli are considered part of the cultural heritage of the region.
The caselli are a testament to the way of life of the past, and they represent an important aspect of the cultural and historical heritage of Valchiavenna.

Figure 19.

The “caselli” in Motta alta, source: Paolo Del Giorgio, 2023

Figure 20.

The “caselli” in Motta alta, souce: Alessandro Cabella, 2022

Fig 21.

Motta alta, source: Paolo Del Giorgio, 2023

1.4.5 Lake Azzurro as a poetic inspiration

Lake Azzurro (Fig 22,Fig 23.,Fig 25., Fig 26.), situated at an elevation of 1850m above sea level, is the defining feature of Motta Alta in the Alpe Motta region. The lake derives its name from the historical usage of the local dialect in Motta, where people referred to it as "Lecc de sór," pronounced as "lac de sor," meaning "the upper lake." Interestingly, this name bears a striking resemblance to "Lecc azur," although in the dialect of Valchiavenna, the word for "azure" is pronounced as "turchin." As a result, the Italian name "Lago Azzurro" was coined, drawing inspiration from these linguistic connections. Moreover, this glacial body of water possesses a remarkable quality that distinguishes it from others the ability to perfectly mirror the breathtaking natural landscape that envelops its surroundings. The majestic black and white peaks of Suretta, Tambò, and Ferrè, the vibrant green pastures adorning the slopes of Mater and Groppera, and the elegant rows of larch (Fig 24.) and pine trees that grace its shores, all find their reflection in the pristine and translucent waters of Lake Azzurro. In the spring, the lake's crystal clear waters sometimes take on a reddish hue as the rhododendrons bloom, adding another captivating element to its charm. It is worth noting that until the 1970s, the local women of Motta Alta utilized this enchanting lake as a shared communal washing place, further emphasizing its integral role within the community (Fig 26.). Moreover the lake was used as a source of poetic inspiration from Giosuè Carducci. Carducci was a poet and writer who is considered to be one of the most important literary figures in Italian literature.Giosuè Carducci, had a deep connection with Alpe Motta, he visited the area frequently during his travels, and the breath taking beauty of the landscape inspired some of his most famous works. Carducci was particularly fond of the lake at Alpe Motta, which he described as a "blue mirror" reflecting the surrounding mountains and forests. In his poetry, Carducci often wrote about the natural world, and his love for the Alps and the rugged beauty of the landscape is evident in many of his works. To Madesimo and the valley, Carducci dedicated "To a bottle of Valtellina from 1884" (in "Barbarian Odes"), "Elegy of Montespluga" and "Saint Abbondio" (in "Rhymes and Rhythms").Carducci was also a frequent guest at the Casa Alpina, where he spent time with other intellectuals and writers.

In 1888 Carducci wrote a poem dedicated to Motta lake.

"Né con un raggio di sole, né timida un'anima d'aura rincrespa il velo puro de l'acque. S'odea quando a quando lento tinnire il campan de le vacche sparse nel pascol raro fra larici, alto. Quando divenni io qui? Sospese già l'ora il suo passo? O io già vissi, spirito errante, qui?"

Moreover in 1948 an anonymous poet which once worked as a shepherd in Motta Alta, also dedicated a poem to the lake, remembering its astonishing beauty.

"Quanto caro mi sei, ceruleo lago, felice specchio di bellezze austere
Quando, desiose di mirar l'imago lor bella, a te si mostran come a schiere
Larici verdi, chiari massi e il vago rossor dei rododendri, le severe vette nevose e il terso ciel, mi appago allor, ma pur se minacciose e nere
Nubi conturbann l'orizzonte intere.
O dolce amico, di amoroso incanto
Muto, ti ammiro e a te, solo, sincero,
l'animo mio si svela: oh quanto, oh quanto desiderio di amore ho in cuor, ma fiero quant'è il lottar con la coscienza, intanto!"

(Del Giorgio, 2011).

Figure 22.

Lake Azzurro, source: Alessandro Cabella, 2020

Figure 23.

Lake Azzurro, source: Paolo Del Giorgio, 2021

Figure 24.

Larix wood around Lake Azzurro, source: Alessandro Cabella, 2020

Figure 25.

Lake Azzurro, source: Paolo Del Giorgio, 2020

Figure 26.

Lake Azzurro, source: Amleto Del Giorgio, 70's

Figure 27.

Lake Azzurro, source: Enrico Caprio, 2020

02

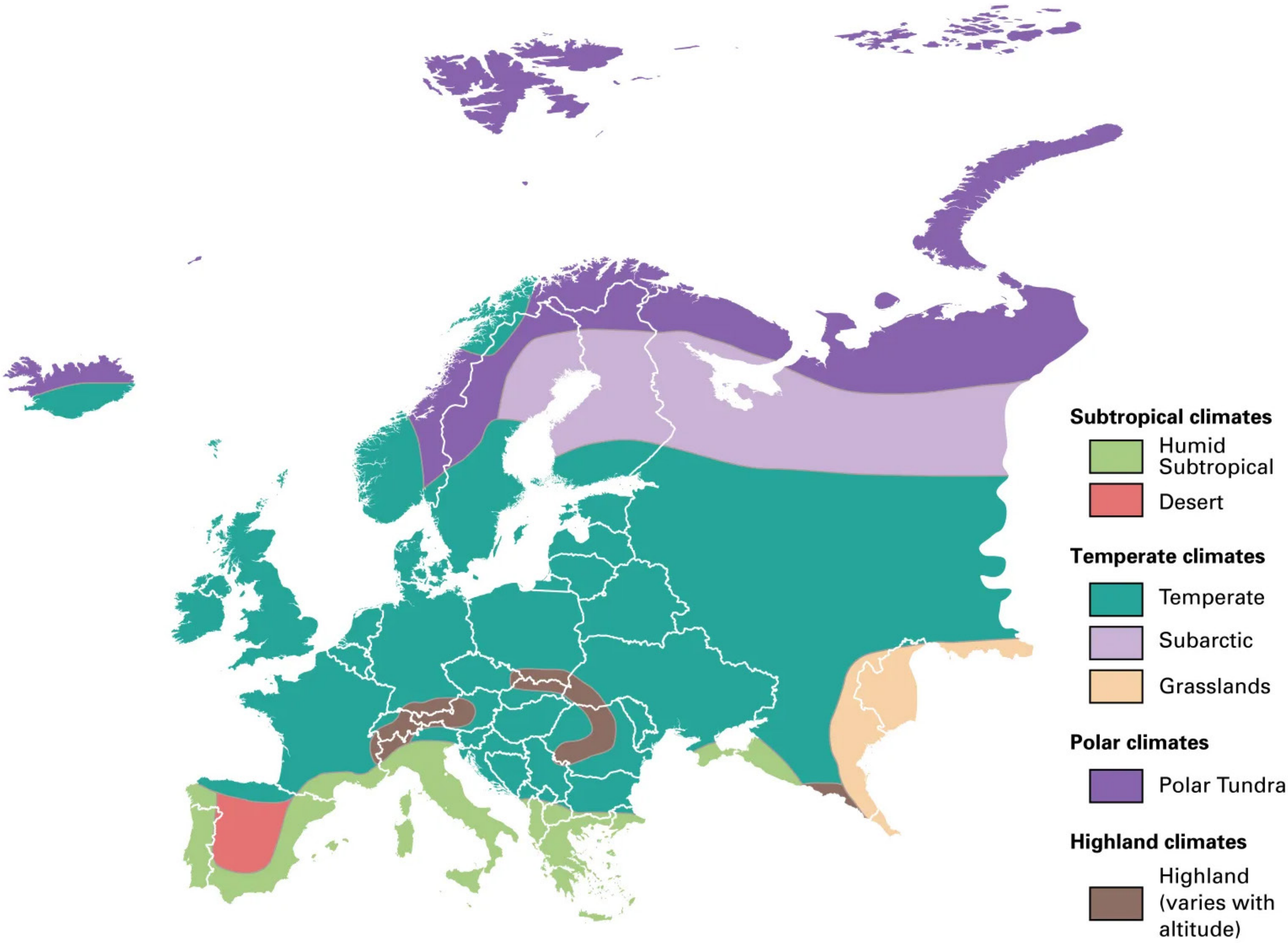
CLIMATE AND ECOSYSTEM

Lake Azzurro case study

2.1 European alpine climate

The European Alpine climate is characterized by its cool temperatures, variable precipitation regime, and distinctive mountain landscapes. The climate is heavily influenced by the region's high altitude and proximity to the Mediterranean Sea, resulting in unique weather patterns and microclimates throughout the mountain range. At higher elevations, the climate is characterized by very cold temperatures and frequent snowfall in winter, with snow cover lasting for much of the year. In the summer months, temperatures may rise, but the cool mountain air and frequent rain showers help to maintain a pleasant climate for visitors (Gobiet et al, 2022).The European Alpine climate is also characterized by a high degree of variability, both within and between seasons. Weather patterns can change rapidly, with sunny skies giving way to sudden storms and vice versa. This variability can make it challenging for visitors to plan outdoor activities, but it also adds to the region's unique character and allure (Gaudard et al, 2013). Despite its many challenges, the European Alpine climate is home to a range of unique plant and animal species that have adapted to the region's harsh conditions. These include alpine flowers, such as edelweiss and gentian, as well as a variety of animals, including chamois, ibex, and marmots. Overall, the European Alpine climate is a unique and challenging environment that has shaped the region's culture and identity for centuries. Whether you're visiting for skiing, hiking, or simply to take in the stunning natural beauty, the European Alps offer a climate and landscape that is unlike any other in the world (Theurillant and Guisan, 2000).

Figure 28. Major climat regions of Europe



source: www.britannica.com

2.2 Italian alpine ecosystem and biodiversity

The Italian Alps ecosystem is a complex and fascinating environment, characterized by a unique set of habitats and species. The region comprises a diverse range of mountain forests, alpine meadows, and glacial lakes, which are home to a variety of plant and animal life. The rocky terrain and high altitude of the Italian Alps create a range of microclimates, leading to an array of ecosystems within the region. The alpine zone hosts over 10000 alpine species, which make up about 4% of all flowering plant species worldwide. Plant species distribution over the altitudinal gradient in alpine regions, creates a mosaic of ecosystems (Viterbi, et al 2013).The flora of the Italian Alps is characterized by a variety of different plant communities, including meadows, grasslands, and forests. Some of the most notable species found in the region include the Edelweiss, a small white flower that is a symbol of the Alps, and the Alpine gentian, a vibrant blue flower found at high altitudes. The forests of the region are dominated by conifers, including the Swiss Pine and the European Larch, which are important for both their ecological and economic value.

A frequent misconception is that the alpine life zone is inhospitable to both plants and animals, and that the low temperatures limit various aspects of life, including productivity. This generalization is incorrect for two reasons: 1) temperatures are highly seasonable with liveable temperatures much of the year , and 2) .Temperatures experienced by species suited to alpine settings are not experienced by them as “cold” when judging temperatures as hostile to life we are judging from a human perspective. Many Alpine organisms would suffer or even perish at temperatures a human would be quite comfortable in (Körner, 2013).

Mountains provide steep environmental gradients for life providing changes over 400 metres in altitude that would only be observed over 4000 kilometres of latitude. Such density of geological diversity creates opportunity for further biological diversification, resulting in unrivalled biodiversity. Mountains are important for conservation in a changing world because they cover such a wide range of environmental conditions and serve as refuges for a variety of organisms.

Agro silvo pastoralism, seasonal transhumance, and other land use management enhance the abundance of small-scale ecosystems with a highly diverse and regionally adapted flora and fauna (Viterbi et al. 2013).

The Italian Alps ecosystem remains a vital resource for the people of the region. The alpine landscape provides a range of goods and services, including water resources, timber, and tourism opportunities. Additionally, traditional agricultural practices such as transhumance, the seasonal movement of livestock between mountain pastures, have played a significant role in shaping the landscape of the Alps and maintaining cultural traditions. Overall, the Italian Alps ecosystem represents a delicate balance between natural resources, human activity, and the need for conservation and preservation (Körner, 2013).

2.2.1 Alpine lakes ecosystem & biodiversity

The ecosystem of alpine lakes is a unique and fragile environment that is home to a wide variety of flora and fauna. These lakes are usually formed by melting glaciers or snow, and they are often located at high altitudes, making them sensitive to changes in temperature and climate. The crystal clear waters of alpine lakes are one of their most distinguishing features, and they are often surrounded by stunning mountain landscapes that attract visitors from all over the world. Alpine lake ecosystems are fascinating and unique habitats nestled amidst majestic mountain ranges. These pristine bodies of water, formed through glacial activity or tectonic processes, possess a delicate balance of ecological factors that sustain a rich biodiversity. The cold and clear waters of alpine lakes provide a haven for a diverse array of species, both aquatic and terrestrial, adapted to survive in the harsh alpine environment.

These lakes often serve as refuges for rare and endemic species that have evolved specific adaptations to thrive in the extreme conditions found at high altitudes.

Biodiversity in alpine lake ecosystems is a testament to nature's resilience and adaptability. The aquatic life in these lakes showcases remarkable adaptations, with species evolving specialized physiological and behavioral traits to cope with the cold temperatures and low oxygen levels. From tiny invertebrates to iconic fish species like trout, alpine lakes harbor a variety of organisms that have found their ecological niche in this unique habitat. Surrounding the lakes, alpine meadows and woods are home to a rich assemblage of flora and fauna, including alpine flowers, small mammals, birds, and elusive predators. The interconnectedness of these ecosystems is crucial for maintaining the delicate balance of biodiversity and preserving the ecological integrity of alpine lake habitats (Camarero, et al. 2009).

2.3 Lake Azzurro case study

2.3.1 Localization

The analysis will concentrate on lake Azzurro, a picturesque alpine lake located in Mot-ta Alta. As mentioned in Chapter 1, Lake Azzurro is situated at an altitude of 1852 meters above sea level and is surrounded by the beautiful peaks of the Italian Alps. It has a subelliptical shape with a major axis N-S of about 200 m and a minor axis of about 90 m, situated in a suggestive dip surrounded by larch trees. The lake lacks any emissaries and estuaries that could maintain a constant hydrological balance of the lake's system (Mariani, et al. 2011). The following images (Fig. 29-Fig. 32) show the framing of the Alpe Motta area, starting from a broader scale, depicting the road connections and tourist infrastructure, and gra-dually zooming in to a smaller scale that reveals the vegetation surrounding Lake Azzurro. This territorial framing work has helped to gain a better understan-ding of the land-scape context around the lake and to have a clearer vision of the lake's structure.

Figure 29.Campodolcino and Madesimo's connection network and touristic facilities

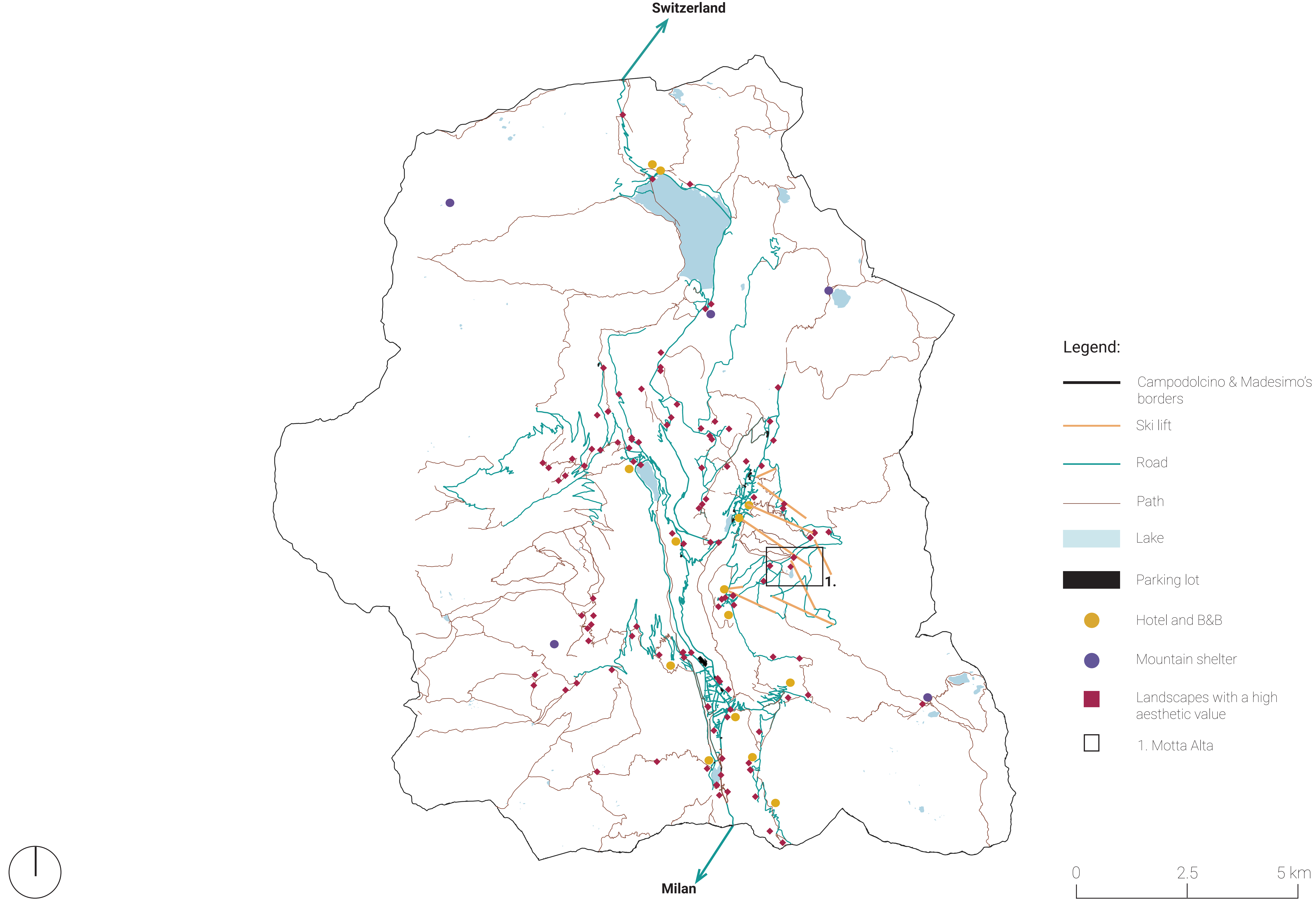


Figure 30.Motta Alta connection network and touristic facilities

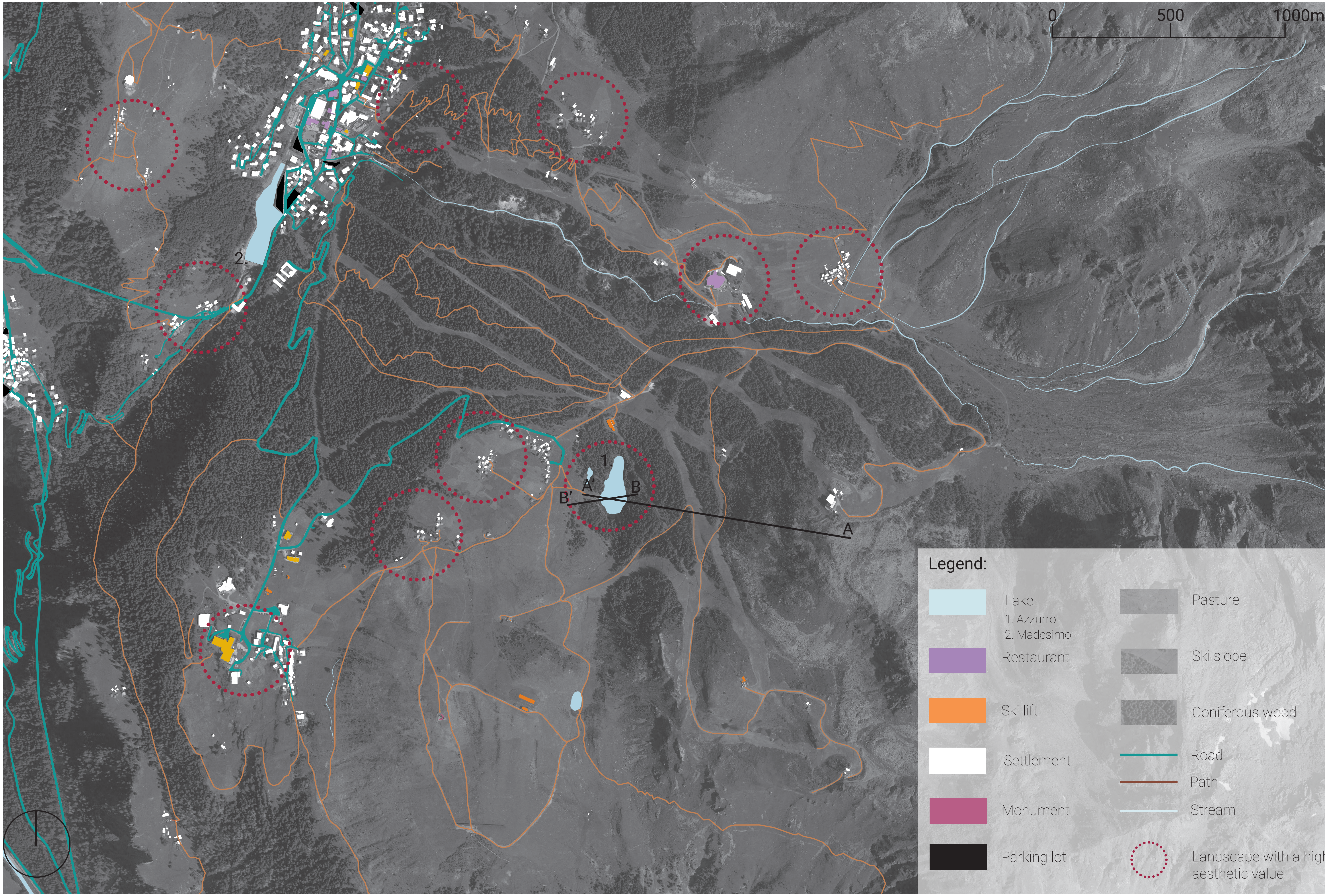


Figure 31. Section AA' 1:3000

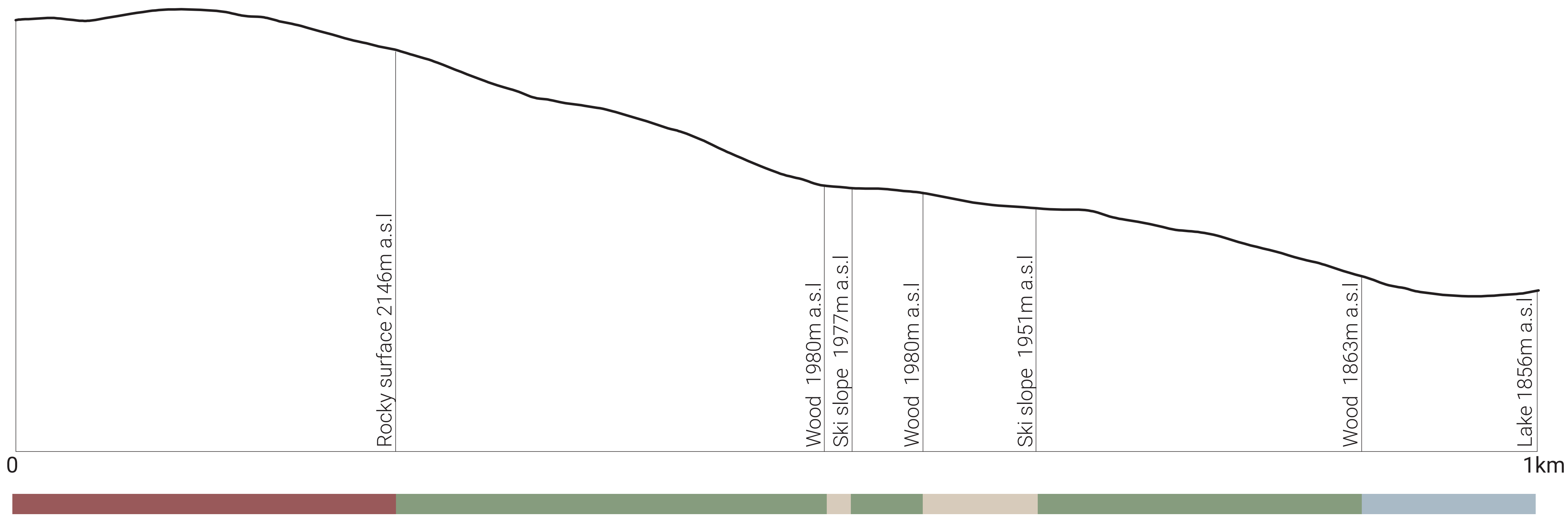
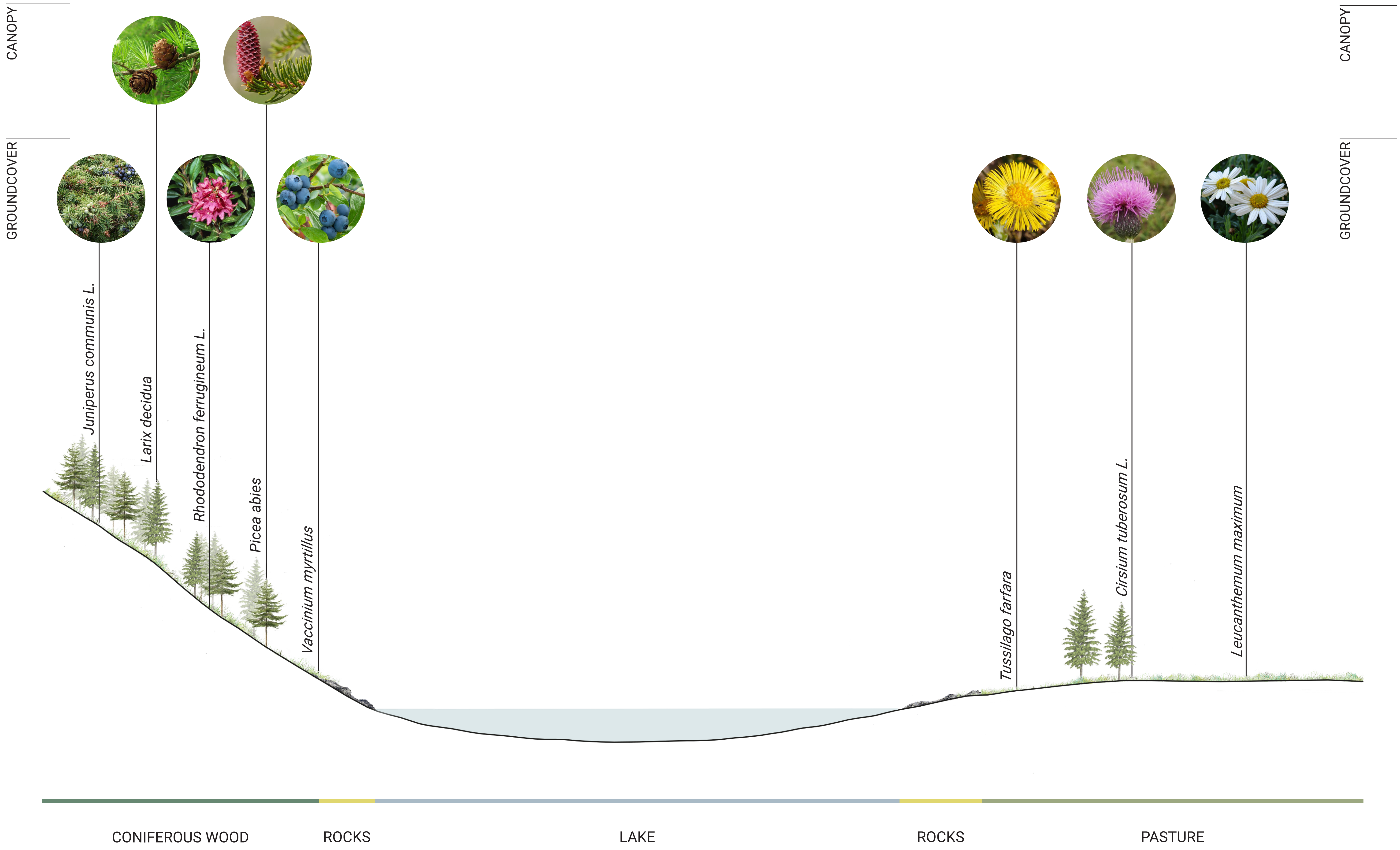


Figure 32. Section AA' 1:3000



2.3.2 Lake Ecosystem & Biodiversity

The plant life around alpine lakes are adapted to survive in harsh conditions, including extreme cold and low levels of nutrients. Mosses, lichens, and alpine meadows are common in these areas, and many of them have developed specialized adaptations to survive in these conditions. The arboreal vegetation surrounding Lake Azzurro exhibits a limited diversity primarily due to the dominant presence of *Larix* trees in the surrounding woodland. However, beneath the canopy, one can discover a variety of species, including *Rhododendron ferrugineum (Fig 33.), Juniperus communis L., and Vaccinium myrtillus*. During the spring season, it is likely to encounter Crocus vernus and Tussilago farfara in the meadows adjoining the woodland. Moreover, during summer, there is an increased abundance of perennial wildflowers, such as *Lupinus polyphyllus, Epilobium angustifolium, Trifolium badium, Crocus (Fig 34.),Campanula cochlearifolia, Gentiana verna, Tanacetum alpinum, Rhododendron ferrugineum, Medicago falcata,* and *Trifolium repens.*These plants possess the ability to attract a diverse range of pollinators, thereby significantly impacting the local biodiversity. Additionally, the presence of water is another crucial factor that profoundly influences the local biodiversity. Water serves as a fundamental resource for alpine animals for various reasons. Firstly, it is essential for their survival and physiological functions. All animals, as living organisms, require water to maintain hydration, regulate body temperature, and support vital metabolic processes.The availability of water in the lake ecosystem attracts animals such as roe deer, ibexes, and foxes. Moreover, water plays a vital role in the ecological interactions of alpine animals, including reproduction, feeding, and habitat maintenance. Many species, especially amphibians, depend on water bodies for breeding and egg-laying. It is to underline the fact that Lake Azzurro provides an ideal environment for the reproduction of *Ichthyosaura alpestris*, commonly known as the alpine newt. Adult alpine newts are small amphibians, typically measuring around 8 to 12 centimeters in length. They possess a slender body with a tail, short limbs, and smooth skin. Males and females exhibit distinct differences in appearance, with males developing a bright orange or red colour on their undersides during the breeding season, while females display a more subdued coloration. The alpine newt undergoes a complex life cycle that involves both aquatic and terrestrial stages. Breeding takes place in the water, usually during spring. Males employ elaborate courtship behaviours to attract females. After mating, females lay individual eggs, which are either wrapped in leaves or attached to submerged vegetation. The hatched larvae spend several months in the water, undergoing metamorphosis into terrestrial juveniles (www.agraria.org). During the site visit on May 17 2023, amphibian eggs were discovered on the completely dry lake bed. These eggs are believed to be from the alpine newt species. Subsequently, the eggs were examined at the laboratories of the National Research Council (CNR), where it was confirmed that they belonged to an amphibian. Unfortunately, it was not possible to confirm whether they specifically belonged to the alpine newt. Nonetheless, this finding reinforces the notion that the lake serves as a habitat for indigenous animal species in the area. The lake serves as a vital water source, sustaining the hydration and survival of numerous organisms.

Figure 33..

Pastures around Lake Azzurro, source: Alessandro Cabella, 2020

Figure 34.

Pastures around Lake Azzurro, source: Alessandro Cabella, 2020

2.3.3 Herbaceous,shrubs and groundcover species in close proximity to the lake

Figure 35.

Tussilago farfara

Cirsium tuberosum

Trollius europaeus

Leucanthemum maximum

Achillea millefolium

Achillea moscata

Vaccinium myrtillus

Rhododendron ferrugineum

Juniperus communis L.

Borago officinalis

Peucedanum ostruthium

Taraxacum officinale

Veratrum album

Calcatreppola ametistina

Cirisium heterophyllum

Silene vulgaris (Moech) Gracke

Rumex acetosa

Gentiana lutea L.

Polytrichum strictum

Polytrichum strictum

Anemone nemorosa

Crocus

Carlina acaulis

Epilobium

Figure 36.

Pasture near Lake Azzurro, source: Alessandro Cabello, 2022

2.3.4 Land use has undergone changes over time

Over the past 80 years, the land usage around Lago Azzurro has undergone significant changes. Initially, the area surrounding the lake was characterized by a more traditional and agricultural landscape, with small-scale farming and pastoral activities. However, with the growing popularity of the lake as a tourist destination, there has been a shift towards the development of tourism related infrastructure and services. This has led to the construction of hotels, holiday homes, restaurants, and recreational facilities in Alpe Motta. Additionally, the expansion of transportation networks has improved accessibility to the area, further promoting tourism and resulting in increased urbanization and commercialization of the surrounding land. As a result, the once predominantly rural and agricultural land has transformed into a more tourism oriented environment, reflecting the changing needs and demands of visitors to Lake Azzurro. The photo below (Fig. 37) dates back to the 1940s (most likely depicting the lake in the year 1944 as it was a particularly dry year) and highlights the significant contrast between land use in the past and present day. In the past, the wood was sparse as it was used for timber production, while now the lake is surrounded by a dense larch wood (Fig. 38).

Figure 37.

Postcard of Madesimo fom the 40's

Figure 38.

Lake Azzurro, Alessandro Cabello, 2020

2.3.5 The lake’s history

Lake Azzurro heavily relies on precipitation and snow melting as its primary water sources. Its natural life cycle involves drying up towards the end of summer and mid-autumn and reappearing by the end of Spring. However, starting in the early 2000s, the lake experienced a concerning phenomenon of remaining dry for consecutive years, specifically between 2004 and 2006. This troubling trend prompted the Università Statale di Milano and FAI (Fondo Ambiente Italiano) to conduct a comprehensive research study on Lake Azzurro, resulting in the publication of their findings in 2008 and 2011.The research conducted by Università Statale di Milano and FAI aimed to analyse the lake’s behaviour and understand the reasons behind its drying patterns. Their study utilized a model that considered data from 1950 to 2008, making a prediction for the last two years. Through their analysis, it was simulated that Lake Azzurro had probably experienced periods of drought in various years, including 1973, 1974, 1984, 1994, 1999, 2004, 2005, and 2006. These findings shed light on the historical occurrences of the lake’s drying cycles, providing valuable insights into its long-term dynamics. Furthermore, the current study on the drying trend of Lake Azzurro primarily relied on historical pictures due to the lack of appropriate materials and data to develop another model. By examining a timeline spanning from 1956 to 2022, a thorough investigation was conducted to verify the accuracy of the research findings and gain a deeper understanding of the lake’s behaviour over an extended period. The collection of historic pictures offered a glimpse into the past conditions of Lake Azzurro, providing visual evidence that supported the research’s predictions. These pictures showcased instances where the lake had indeed dried up during specific years, reinforcing the reliability of the research study and highlighting the significance of the lake’s drying patterns throughout history. The visual documentation revealed the transformative nature of Lake Azzurro, demonstrating its susceptibility to fluctuations in water levels over time. Such visual representations were instrumental in capturing the essence of the lake’s dynamics and further supplementing the findings obtained through the analysis of historical data. Moreover, the successful endeavour of searching for historical pictures of the lake was made possible mainly thanks to Amleto del Giorgio, a former teacher in Samolaco, renowned for his insatiable curiosity about the natural world. Driven by his passion for exploration and meticulous documentation, del Giorgio dedicated himself to accumulating knowledge about Valchiavenna. His invaluable efforts in gathering materials, particularly those related to Alpe Motta, played a significant role in this analysis. Delving into his reports on Alpe Motta, a remarkable discovery emerged: the lake had experienced complete drying only once before 2000, specifically in 1976. This finding contradicts the model developed by the Università Statale and the FAI analysis, emphasizing the essentiality of considering multiple sources of information and embracing diverse perspectives when studying the intricate behavior of natural phenomena.By integrating the insights derived from both the historical pictures and Amleto del Giorgio’s reports, a more comprehensive understanding of the Lake Azzurro’s fluctuations in water levels and drying patterns emerges. The combination of visual evidence and firsthand accounts contributes to a richer narrative surrounding the lake’s ecological dynamics. These findings not only challenge previous assumptions but also underscore the necessity of a multidisciplinary approach in comprehending the complexities of the lake’s behaviour within the context of a changing climate.

Figure 39. Lake depth

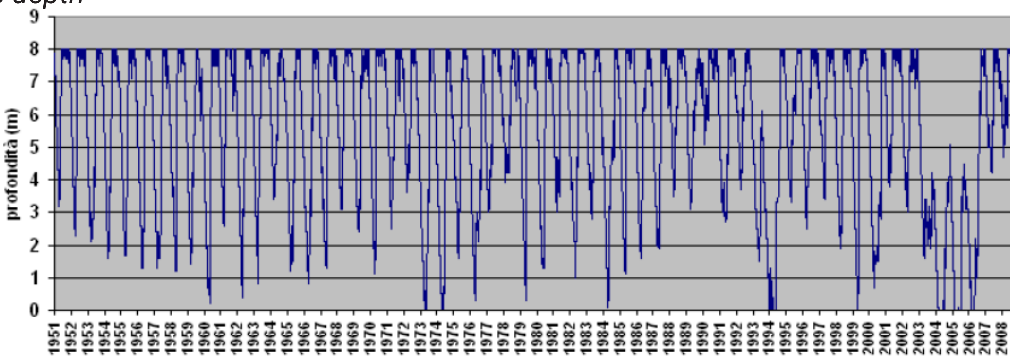
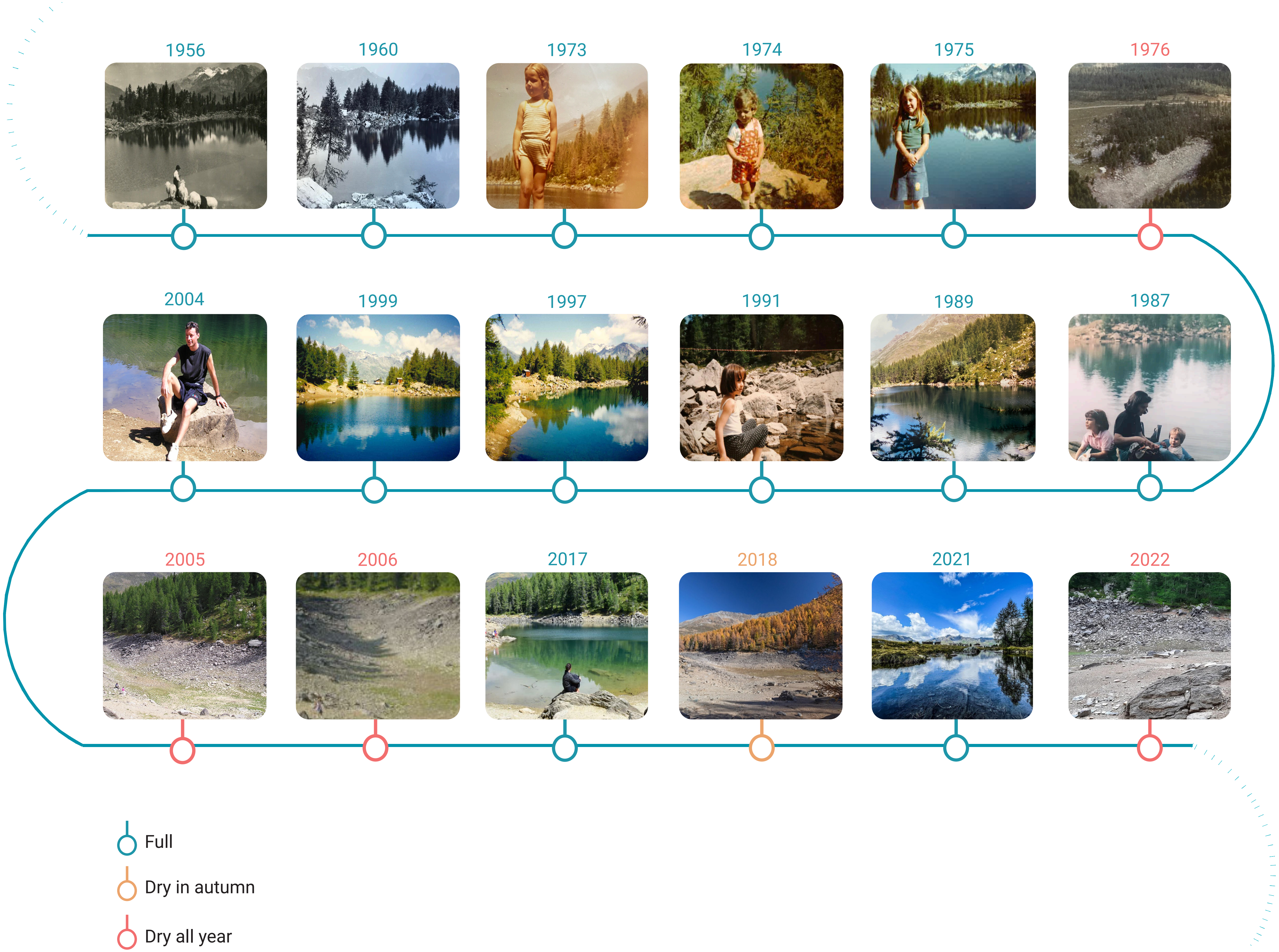


Figure 40.The lake history from the 50's till nowadays



2.3.6 Geology

Lake Azzurro's Geology is very complex (Fig. 41), despite it's size. The lake is the largest and northernmost of a system of small hydrological bodies located at the base of the western shoulder of Pizzo Groppera.The water body is situated in the upper region of Val San Giacomo, in a short and straight groove that runs transversely to the main geological features which define the Alpine chain. The furrow was formed along a string of cracks, due to still-active tectonic activity.

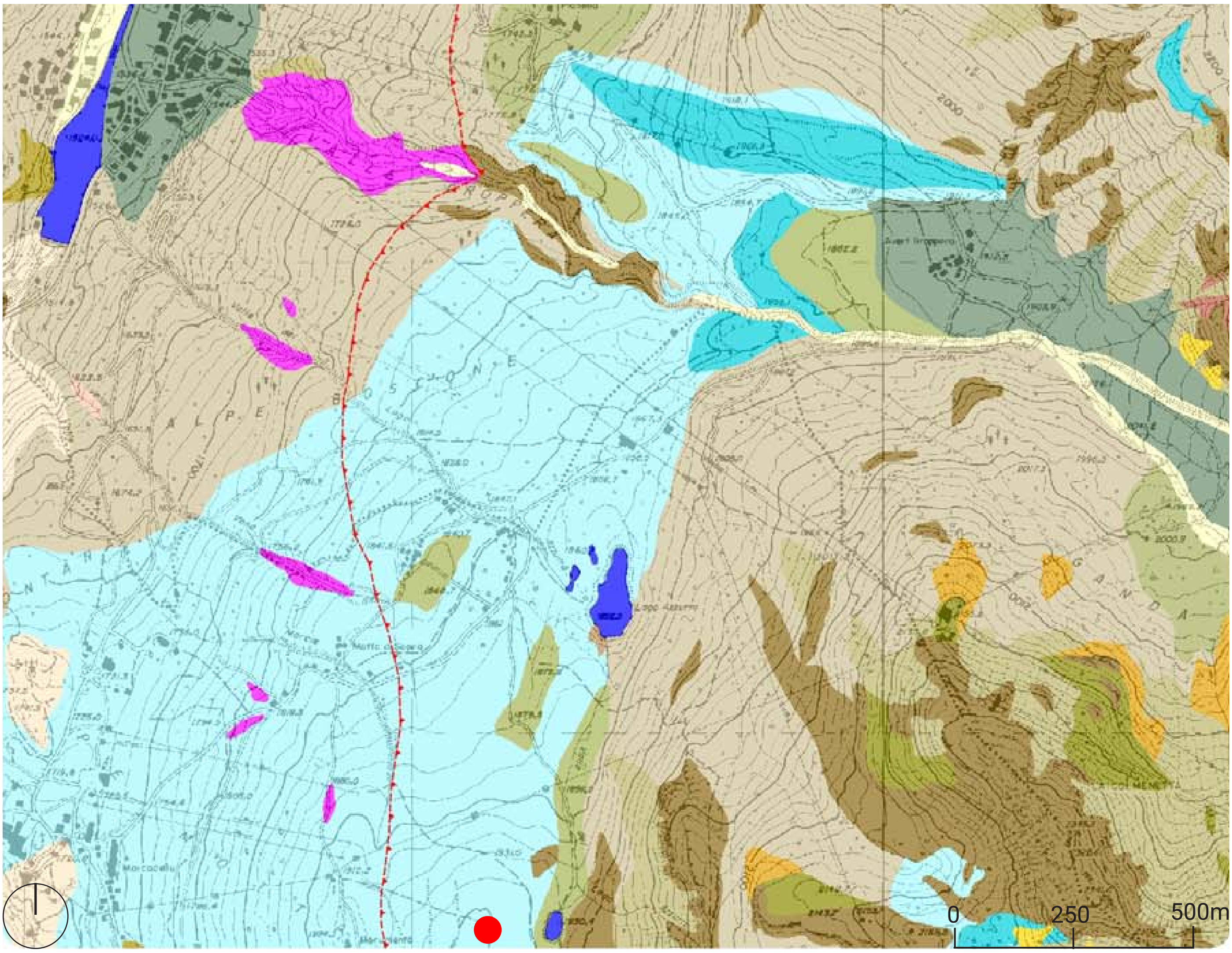
Upper San Giacomo valley's physical landscape reveals a number of morphological features that are fragilely modelled and about N 10° W oriented. At a lower angle, in relation to the fracture system, there is a second network oriented about N 10-15° E and is named Val Niemet system.

This system is more visible near to Switzerland boarders, but is also well developed on the reliefs between Madesimo and Campodolcino.Both sub-meridian trending complexes are cut by further fracture systems oscillating around the E-W direction.Schistous rocks, which are of deep crustal origin, are found in the upper San Giacomo Valley, and are impermeable due to their silicate composition.At lower altitudes and beyond the ridge of the western relief that enclose the lake,

there are marble stones outcropping from the mountain wall.Both silicates and carbonates rocks have undergone the same geodynamic evolution, which was influenced by the action of gravity.

As a result of such evolution an underground system of cracks was created, which enabled a series of subsurface streams.The system of underground streams,is one of the main characteristics of Valchiavenna's geology (Mariani, et al. 2006)

Figure 41. Lithological map of the western slope of Pizzo Groppera



Legend:

Quaternary deposits:
- Quaternary deposits
- Uncolonized debris cone
- Groundwater debris colonized by vegetation
- Groundwater debris colonized by vegetation
- Mixed slope deposits produced by the interaction of several processes and not mapped separately
- Eluvial-colluvial beds
- Partially remodeled undifferentiated glacial deposits
- Undifferentiated glacial deposits, bodies in morphological
- Bog deposits
- Floods and deposits
- Alluvial fan

Bedrock:
- Paragneiss with regularly developed schistosity

Metasedimentary cover of the Tambò stratum:
- Carbonate metasediments
- Metavolcanites and metaconglomerates
- Metapelites and intensely laminated mylonitic horizons
- Intensely laminated metapelites and mylonitic horizons, on outcroppings
- Hydrological bodies
- Contact between Suretta and Tambò stratum

Extract from Mariani. et la publication, 2004

2.4 Valchiavenna's climatic framework

Valchiavenna, situated at an elevation of approximately 1000 meters above sea level, benefits from the surrounding towering mountains, which provide a shield against strong north winds and extreme cold temperatures. Throughout the summer months, the valley enjoys warm and sunny weather. However, winters in Valchiavenna are characterized by cold temperatures and abundant snowfall, often plummeting below freezing. Given its geographical location, the valley is prone to sudden weather fluctuations, including rain and thunderstorms during the summer season. The impact of climate change is becoming increasingly evident in Valchiavenna, with rising temperatures and altered precipitation patterns influencing the region's ecosystem (it.climate-data.org).
In this dissertation, one of the primary objectives is to explore the correlation between the climate crisis and the observed phenomenon of Lake Azzurro no longer filling up as it did in the past. To achieve this, reference is made to a 2006 research study conducted by FAI and Università Statale di Milano. The study sought to comprehensively examine the geology and geomorphology of Lake Azzurro, with a specific focus on understanding the mechanisms behind its water level fluctuations, including both filling and drying processes. The study initially concentrated on the simulated time frame from 1950 to 2008. However, considering the recent occurrence of the lake drying up in 2022, the analysis has been extended to encompass a broader time frame spanning from 1950 to 2022.
To ensure the utmost precision in the study, multiple meteorological stations managed by the ARPA Lombardy region, as well as one meteorological station from A2A, are considered. The meteorological stations included in this analysis are Alpe Motta, Chiavenna, Gordona, Madesimo Spluga, Prata Camportaccio, Samolaco, San Giacomo Filippo, Villa di Chiavenna, and Madesimo. The ARPA Lombardy is the official institution responsible for safeguarding the environment and public health in the Lombardy region of Italy, providing historical data dating back to the 1950s. Additionally, A2A contributes to the research with a relevant source of observed data from 1964 to 2022 near the Madesimo dam, situated at an altitude of 1531m above sea level.
The invaluable contribution of A2A has played a pivotal role in enhancing the analysis phase, as it provided us with an extensive dataset of historical instrumental data encompassing precipitation and temperatures spanning from 1965 to 2022.

This rich and comprehensive dataset has proven to be of immense value, filling the gaps that previously existed in our understanding of the climate dynamics in Madesimo. Prior to receiving this data, our reliance on all the the station, presented certain limitations due to multiple data gaps, rendering it less reliable for our research purposes. The provision of reliable and continuous data by A2A has not only fortified the accuracy and reliability of our analysis but has also significantly expanded our insights into the climate patterns and trends in Madesimo. The collaboration with A2A has been instrumental in facilitating a more robust and comprehensive assessment of the climatic conditions in the region, enabling us to draw more accurate conclusions and make informed decisions based on a solid foundation of reliable data.
To further enhance the analysis, the ERA5-Land dataset, developed by the European Centre for Medium-Range Weather Forecasts (ECMWF), has been utilized. This dataset offers extensive and high-quality data on various land surface parameters, with a spatial resolution of 9 km. ERA5-Land has proven to be particularly valuable in refining and adjusting the data obtained from the ARPA Lombardy stations, which unfortunately contained significant data gaps. By incorporating the ERA5-Land dataset, we have been able to augment the reliability and completeness of our analysis, ensuring a more comprehensive understanding of the climate dynamics in Valchiavenna.
The initial step undertaken in the climate assessment analysis involved the identification of temperature and precipitation changes spanning from 1950 to 2022, utilizing the comprehensive ERA5-Land dataset. This dataset served as a valuable resource in examining the long-term climatic trends and variations. To visualize the observed changes, two maps were meticulously crafted, representing the spatial distribution of these climate parameters over the designated period. The creation of these maps drew inspiration and insights from the esteemed article titled "1961-1990 high-resolution monthly precipitation climatologies for Italy," which provided a robust foundation for understanding precipitation patterns. These maps, prominently depicted as Fig. 42 and Fig. 43, provide a visual representation of the temporal and spatial changes in temperature and precipitation across the studied region.
Additionally, it is worth noting that specific graphs pertinent to the Alpe Motta and Madesimo stations are thoughtfully included below (Fig. 46-Fig. 53), enabling a more focused examination of the climatic trends in these particular locations. The information presented in these graphs contributes to a comprehensive understanding of the localized climate dynamics and further complements the broader analysis. Furthermore, to provide a comprehensive reference for interested readers, a collection of additional graphs, Fig. 1 to Fig. 13, has been thoughtfully appended to the thesis, offering supplementary insights into the observed climatic changes and their implications. These supplementary graphs are located at the end of the thesis, ensuring their accessibility and facilitating further exploration of the comprehensive climate assessment.

This rich and comprehensive dataset has proven to be of immense value, filling the gaps that previously existed in our understanding of the climate dynamics in Madesimo. Prior to receiving this data, our reliance on the Madesimo Spluga station, situated at an elevation of 1915m, presented certain limitations due to multiple data gaps, rendering it less reliable for our research purposes. The provision of reliable and continuous data by A2A has not only fortified the accuracy and reliability of our analysis but has also significantly expanded our insights into the climate patterns and trends in Madesimo. The collaboration with A2A has been instrumental in facilitating a more robust and comprehensive assessment of the climatic conditions in the region, enabling us to draw more accurate conclusions and make informed decisions based on a solid foundation of reliable data.
To further enhance the analysis, the ERA5-Land dataset, developed by the European Centre for Medium-Range Weather Forecasts (ECMWF), has been utilized. This dataset offers extensive and high-quality data on various land surface parameters, with a spatial resolution of 9 km. ERA5-Land has proven to be particularly valuable in refining and adjusting the data obtained from the ARPA Lombardy stations, which unfortunately contained significant data gaps. By incorporating the ERA5-Land dataset, we have been able to augment the reliability and completeness of our analysis, ensuring a more comprehensive understanding of the climate dynamics in Valchiavenna.
In the subsequent pages, various graphs supporting the analysis are depicted. Additionally, it is worth noting that the graphs for the Alpe Motta and Madesimo stations are presented below (Fig.44-Fig.45), while the remaining graphs can be found in the appendix at the end of the thesis (Fig.1-Fig.13).

Figure 42. Yearly mean precipitation (1950-2022), ERA5-Land dataset

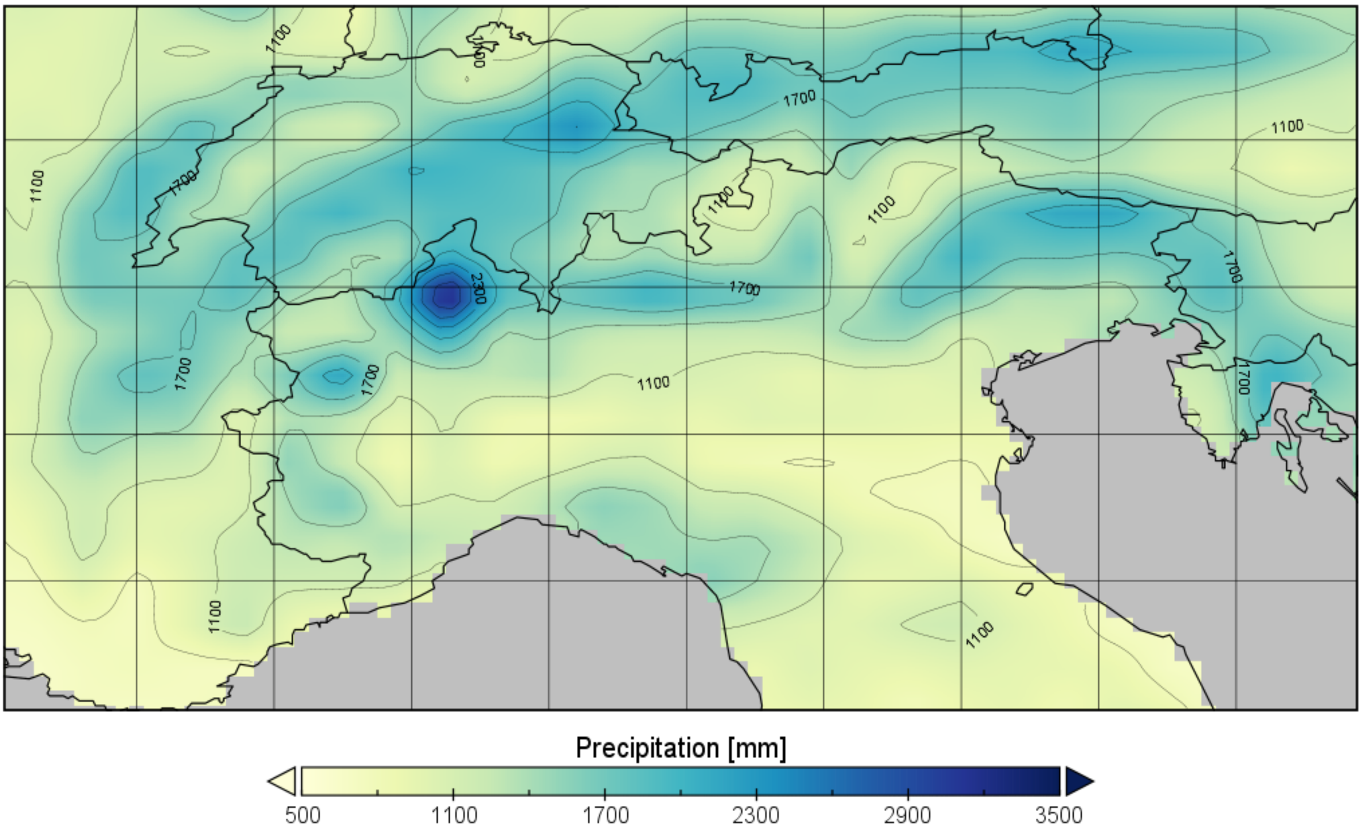


Figure 43. Yearly mean temperature (1950-2022), ERA5-Land dataset

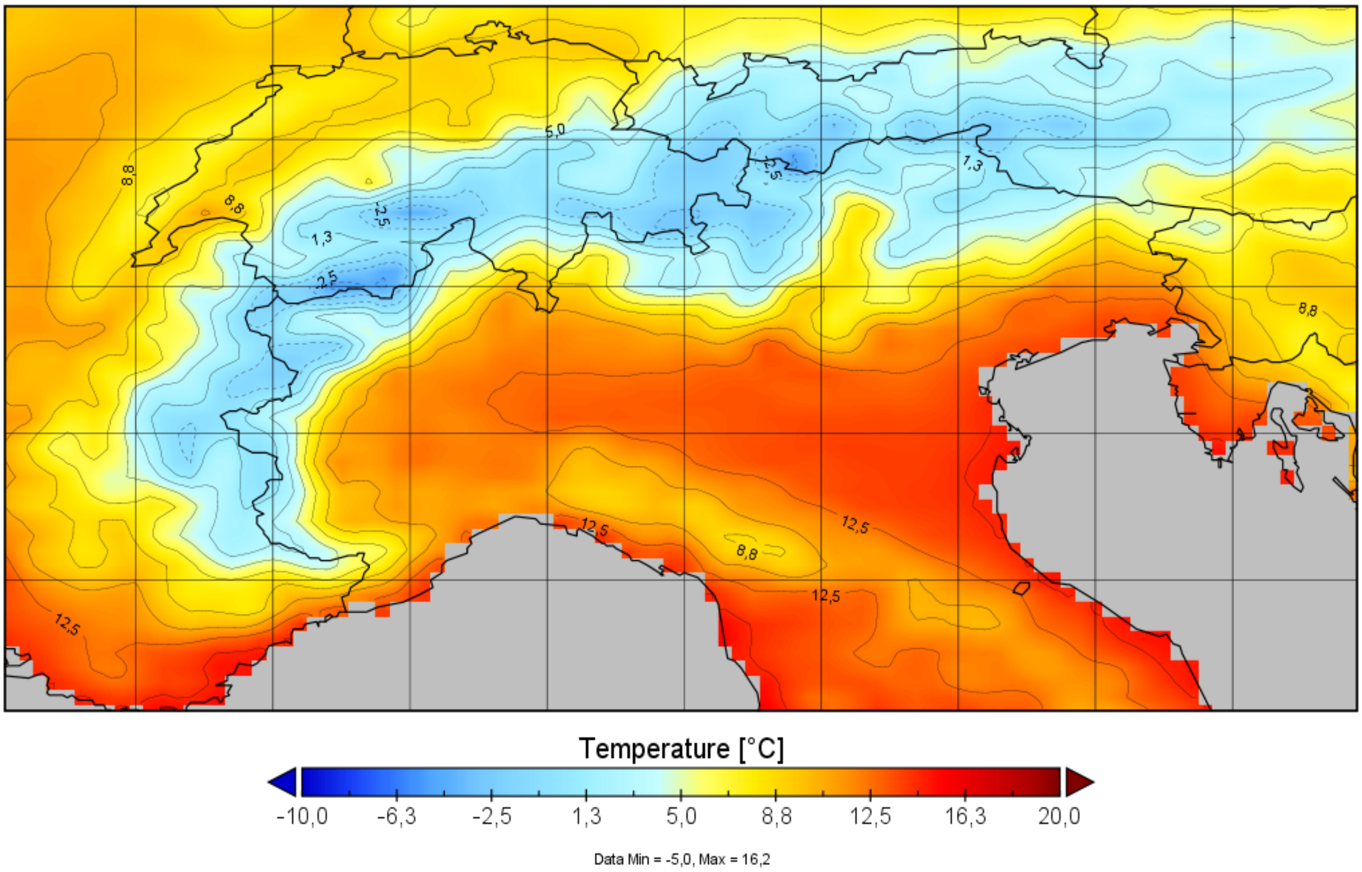
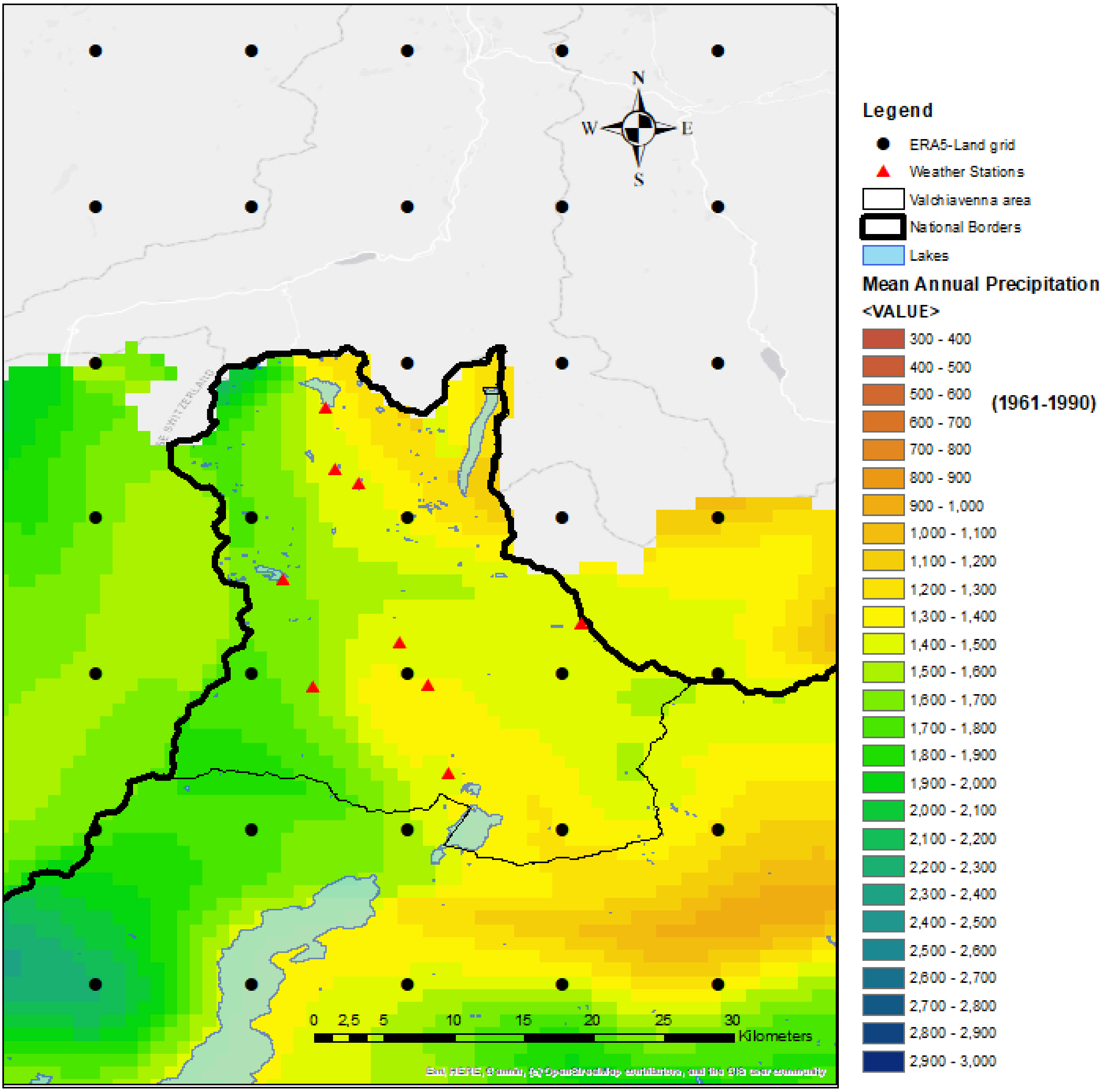


Figure 44.Yearly mean Precipitation in Valchiavenna (1961-1990), Crespi et al



2.4.1 Summary tables

Table 1.

Station	Altitude a.s.l	Weather station historical data series	Weather station average	ERA5-Land [1950-2022] average T adjusted	T Trend ERA5-Land [1950-2022]	R^2(ERA5-Land vs Weather station)
	[m]		[°C]	[°C]	[°C]	[-]
Alpe Motta	1880	2013-2022	+ 4,4	+ 3,1	+ 2,3	0,90
Madesimo Spluga	1915	1987-2018	+ 3,3	+ 2,5	+ 2,1	0,71
Madesimo	1531	1967-2022	+ 5,1	+ 4,9	+ 2,2	0,73
Chiavenna	333	2005-2022	+13,2	+13,6	+ 2,4	0,76
Gordona	1362	2015-2022	+ 8,4	+ 8,4	+ 2,5	0,83
Prata Camportaccio	1035	2017-2022	+ 9,8	+ 8,2	+ 2,4	0,79
Samolaco	206	1996-2022	+21,1	+11,9	+ 2,6	0,63
San Giacomo Filippo Lago Truzzo	2064	1951-2018	+ 4,4	+ 4,5	+ 2,3	0,88
Villa di Chiavenna	665	2006-2022	+10,5	+10.3	+ 2,4	0,37

Table 2.

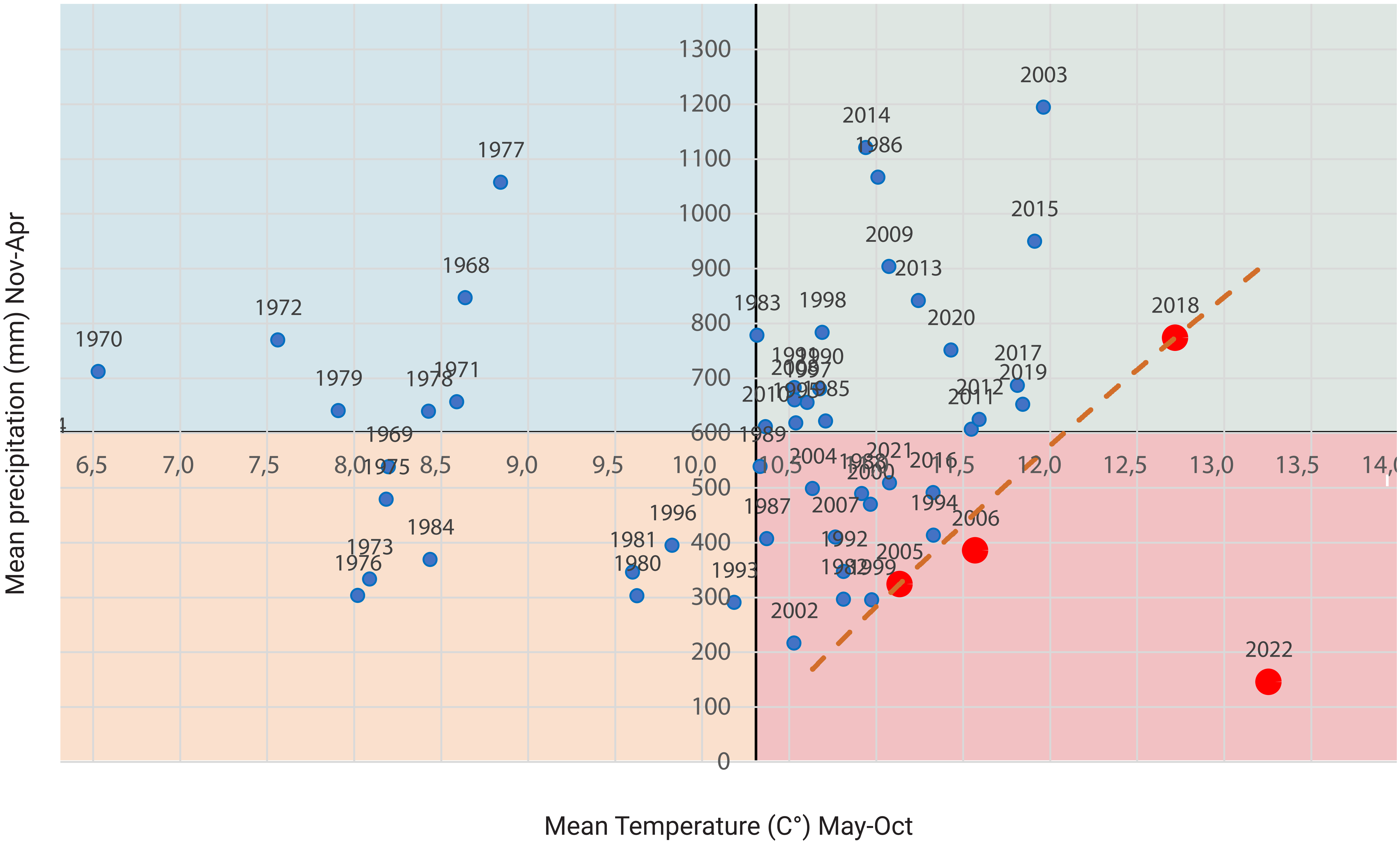
Station	Altitude a.s.l	Weather station historical data series	Weather station average	ERA5-Land [1950-2022] average P adjusted	P Trend ERA5-Land [1950-2022]	R^2 (ERA5-Land vs Weather station)
	[m]		[mm]	[mm]	[mm]	[-]
Alpe Motta	1880	2013-2022	1481,0	1465,9	24,3	0,73
Madesimo Spluga	1915	2011-2022	1170,5	1201,7	65,9	0,13
Madesimo	1531	1967-2022	1653,4	1644,3	24,3	0,70
Chiavenna	333	1989-2005	1406,8	1423,1	12,2	0,76
Gordona	1362	2015-2022	1559,7	1544,8	25,5	0,77
Prata Camportaccio	1035	2017-2022	1347,9	1218,9	12,2	0,75
Samolaco	206	1996-2022	1112,8	1114	-42,7	0,65
San Giacomo Filippo Lago Truzzo	2064	2008-2022	1728	1734,5	18,01	0,63
Villa di Chiavenna	665	2013-2022	1198,9	1241	12	0,13

2.4.2 Examining Climatic Data in Relation to the Periods of Lake Drying and Lake Fullness

Figures 44 and 45 serve the purpose of establishing a clear threshold that distinguishes between periods when Lake Azzurro is dry and when it is not. To aid in interpretation, the graphs are divided into four distinct quadrants, each represented by a unique colour: blue, red, green, and orange. The blue quadrant corresponds to years when the lake consistently maintains its full capacity, indicating moderate to high levels of precipitation during the winter season and relatively non-hot summers. In contrast, the red quadrant represents years when the lake experiences drying, indicating either low winter precipitation and hot summers, or significant winter precipitation but limited rainfall during spring and summer. The remaining two quadrants capture years that present uncertainties, making it challenging to determine whether the lake completely dried or refilled. It is important to acknowledge that this approach may have certain limitations in terms of its accuracy. However, when comparing the data with historical photographs, a compelling correlation emerges, reinforcing the validity of the analysis. Additionally, it is important to mention that for temperature analysis, the graph considers data from the first of May until the 31st of October, while for precipitation, it takes into consideration the period from the 1st of November to the 30th of April. This approach allows for a comprehensive examination of the temperature and precipitation patterns during the relevant seasons, providing a more accurate representation of the climatic conditions influencing Lake Azzurro. Furthermore, it is noteworthy that the graph specifically related to Madesimo was constructed using the historical dataset provided by the A2A company. Conversely, the prediction for Alpe Motta is based solely on data derived from ARPA data set readjusted using ERA5-Land. Intriguingly, both graphs exhibit a similar trend, indicating a consistent pattern and reinforcing the notion that the analysis has been effective.

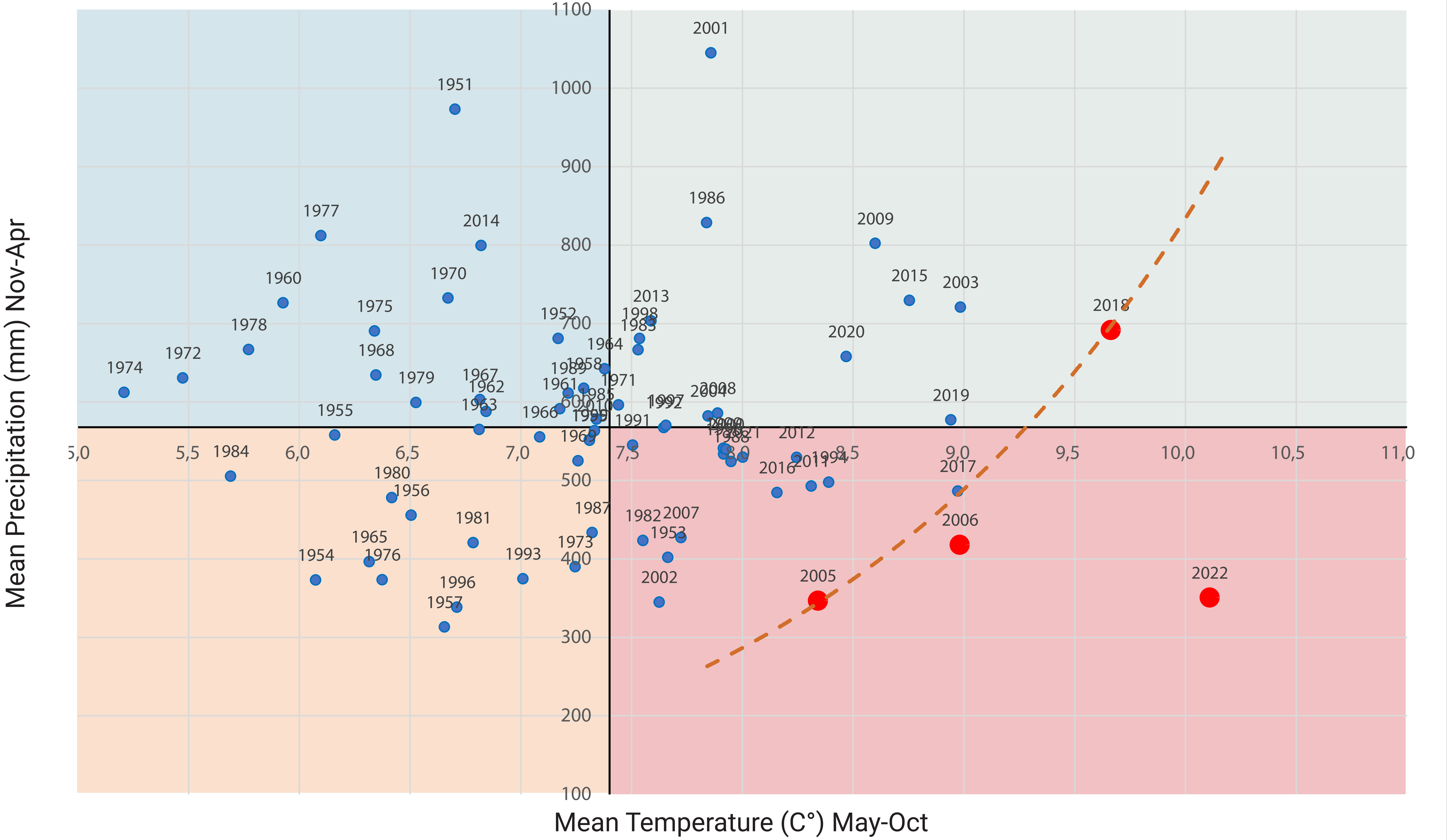
Observed data (1968-2022) Madesimo

Figure 45.



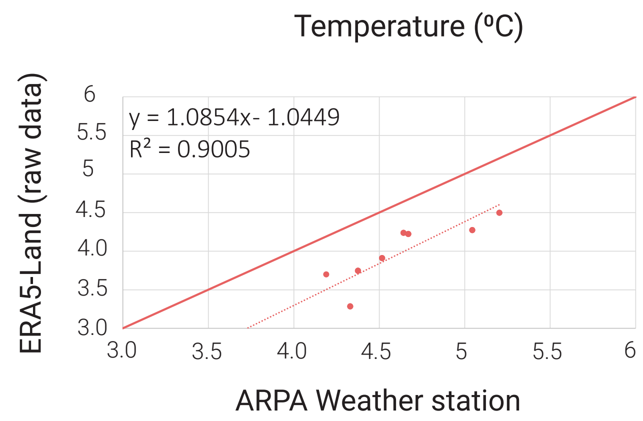
ERA5-Land (1950-2022) Alpe Motta

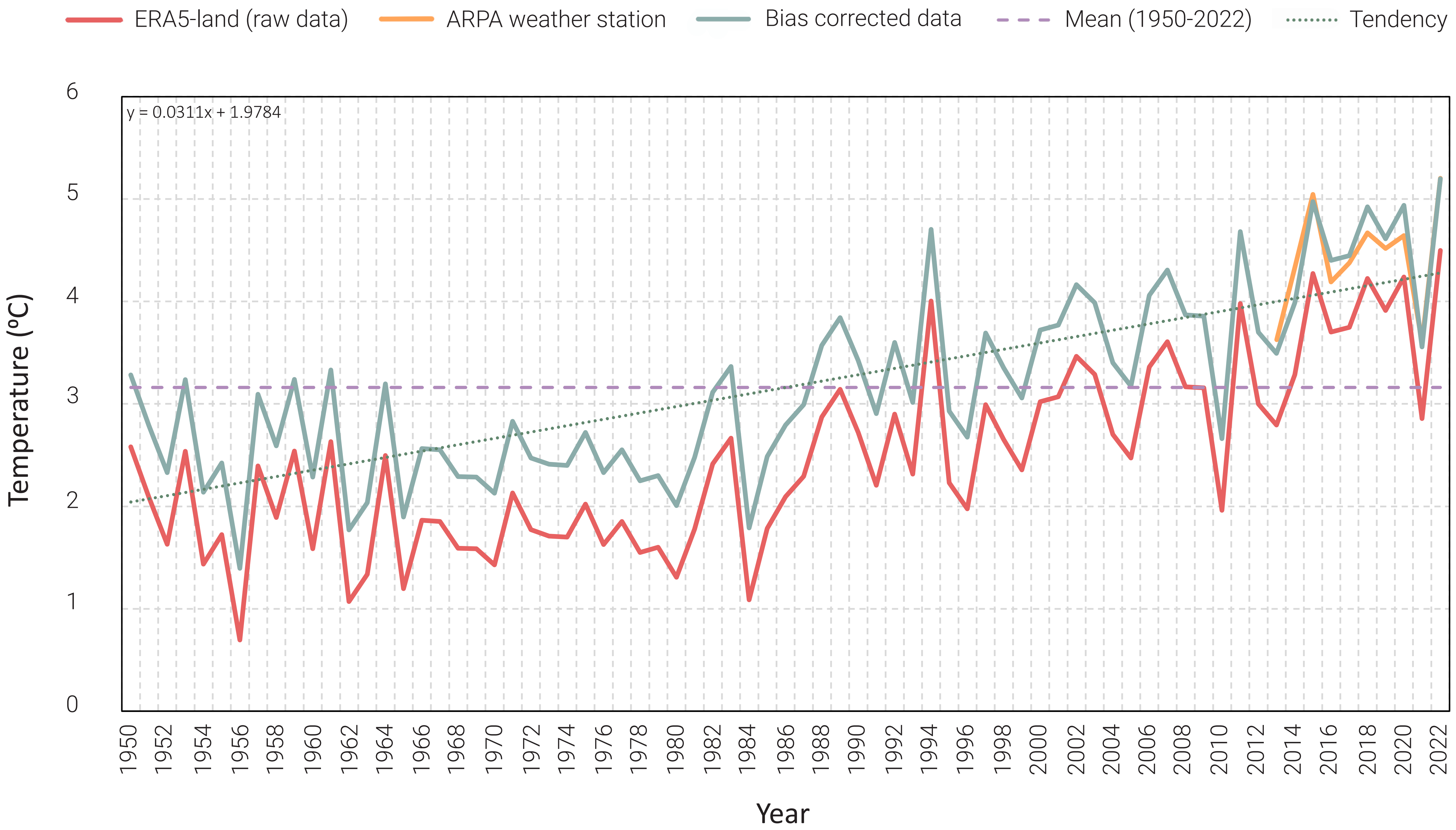
Figure 46.



2.4.3 Yearly mean temperature at Alpe Motta (1880m a.s.l)

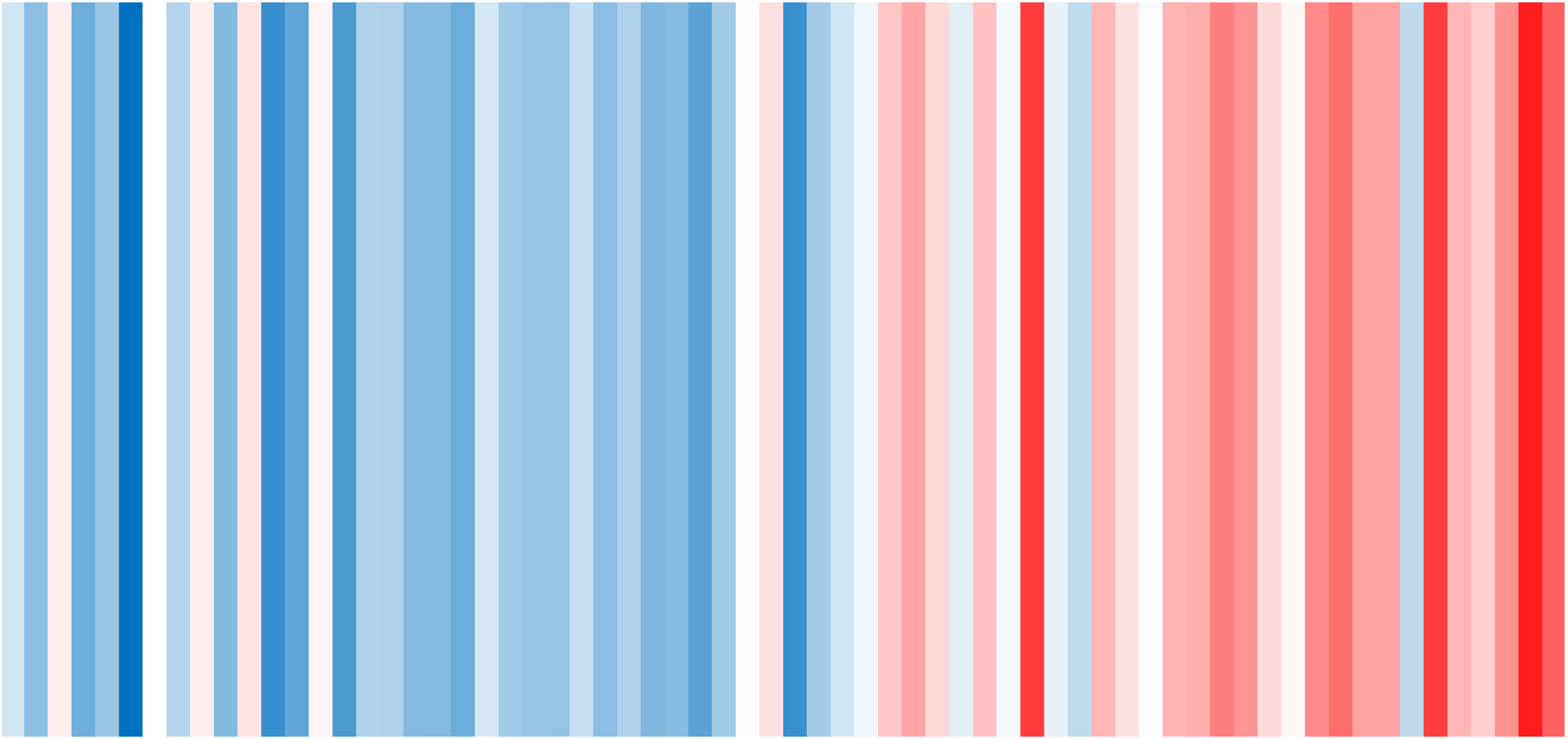
Figure 47.





2.4.4 Warming stripes from 1967 to 2022 in Alpe Motta (1880m a.s.l)

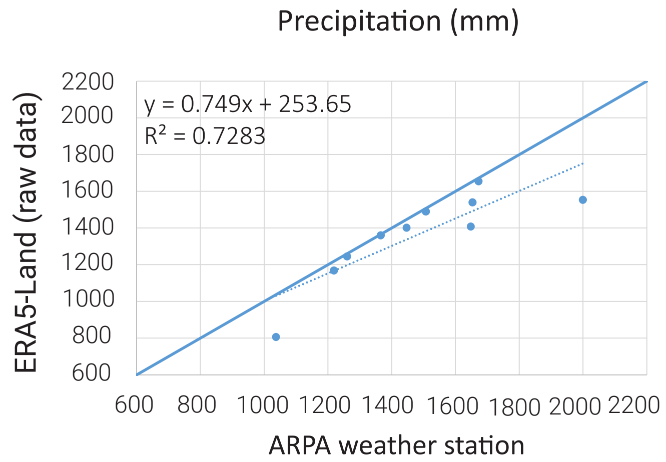
Figure 48.

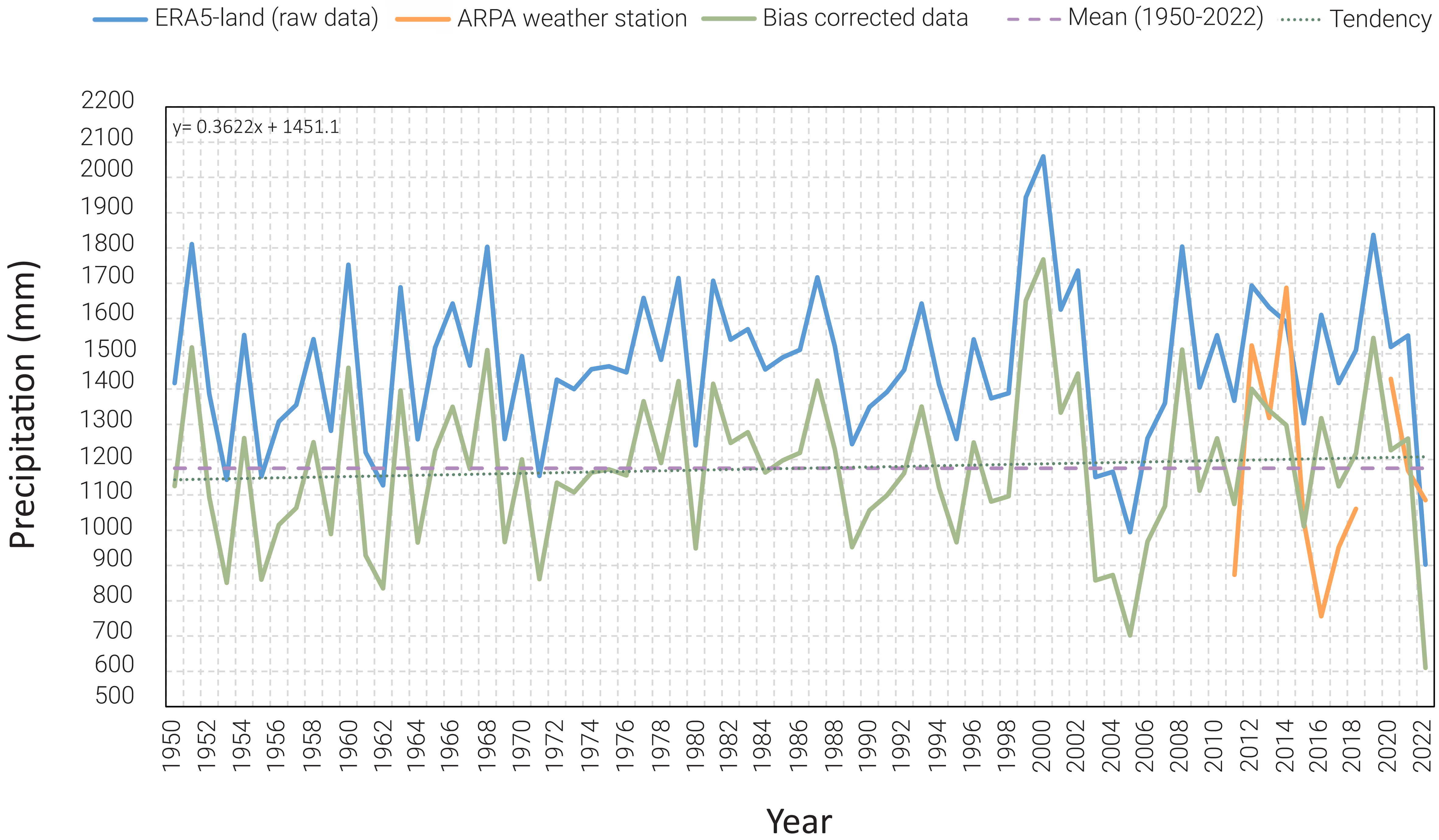


2.4.5 Yearly mean precipitation at Alpe Motta (1880m a.s.l)

Figure 49.

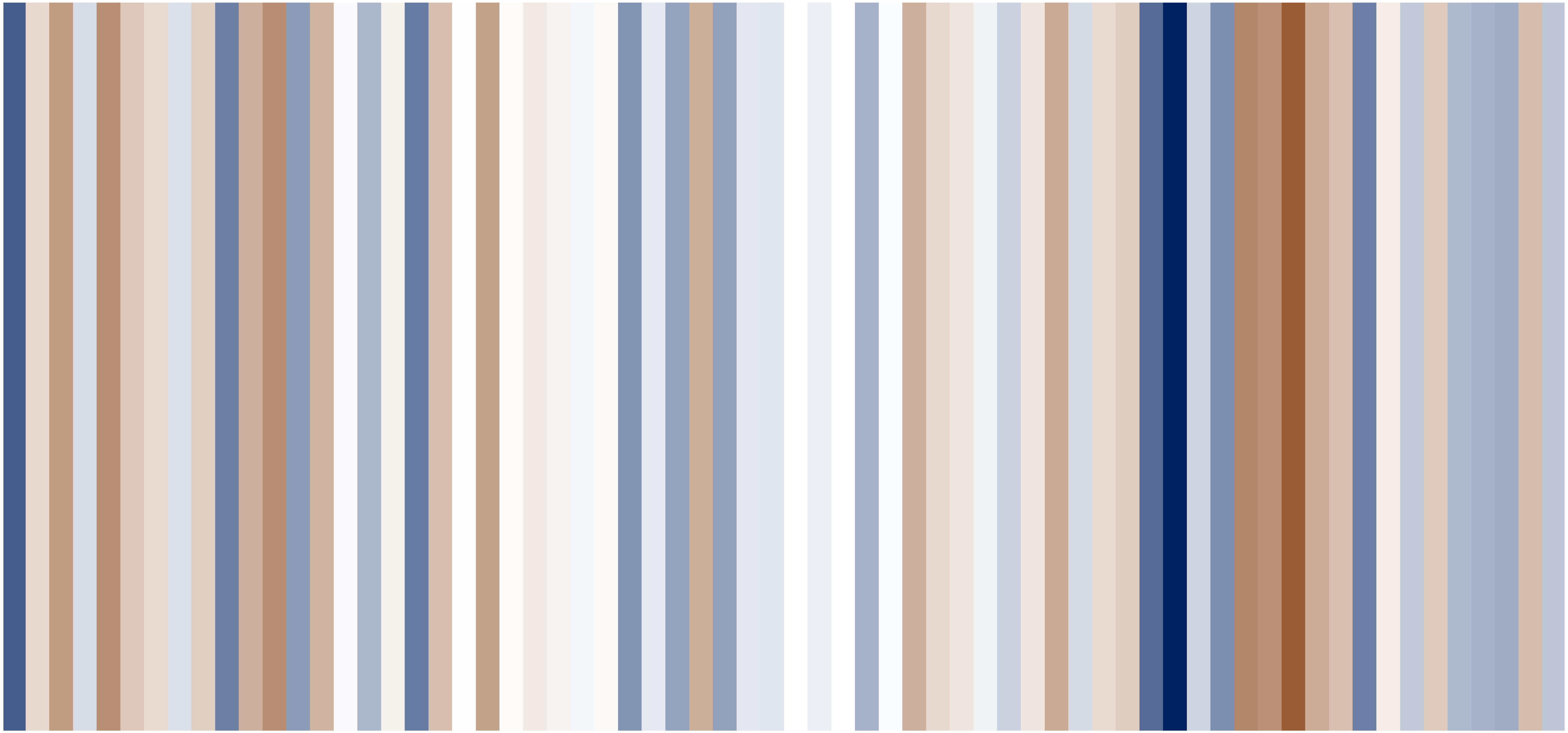
Unheated rain gauge





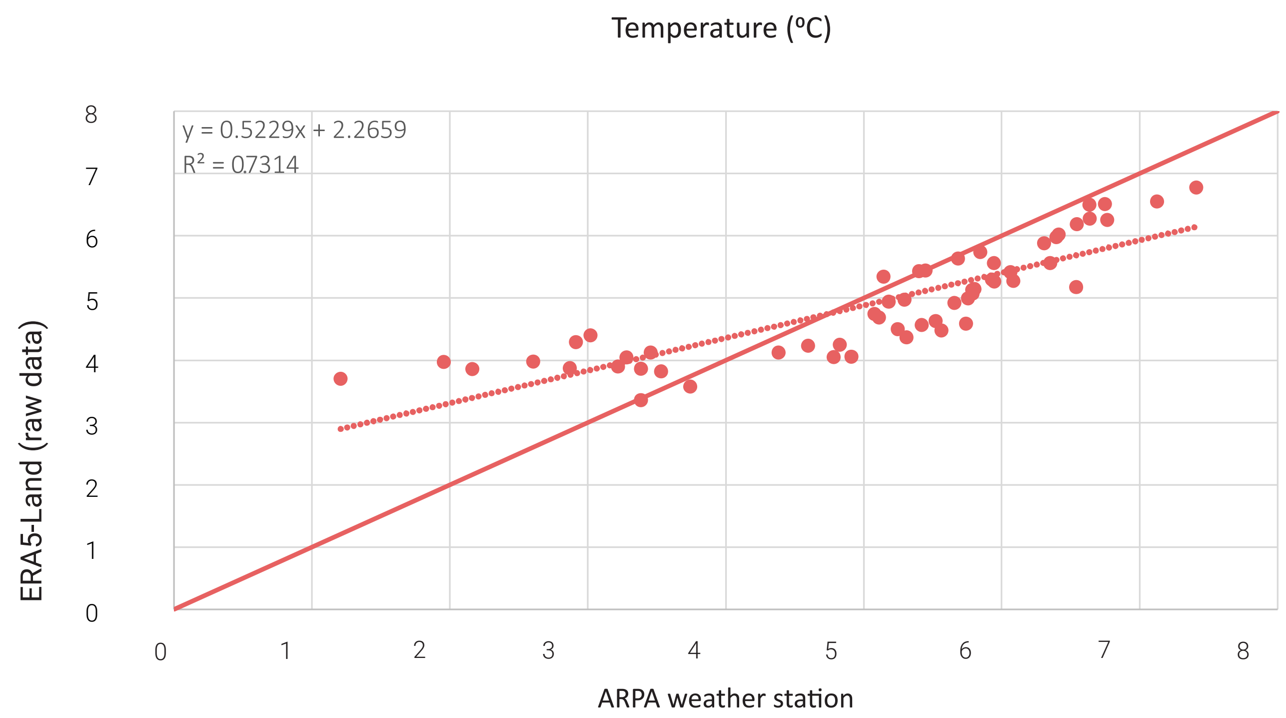
2.4.6 Precipitation stripes from 1950 to 2022 in Alpe Motta

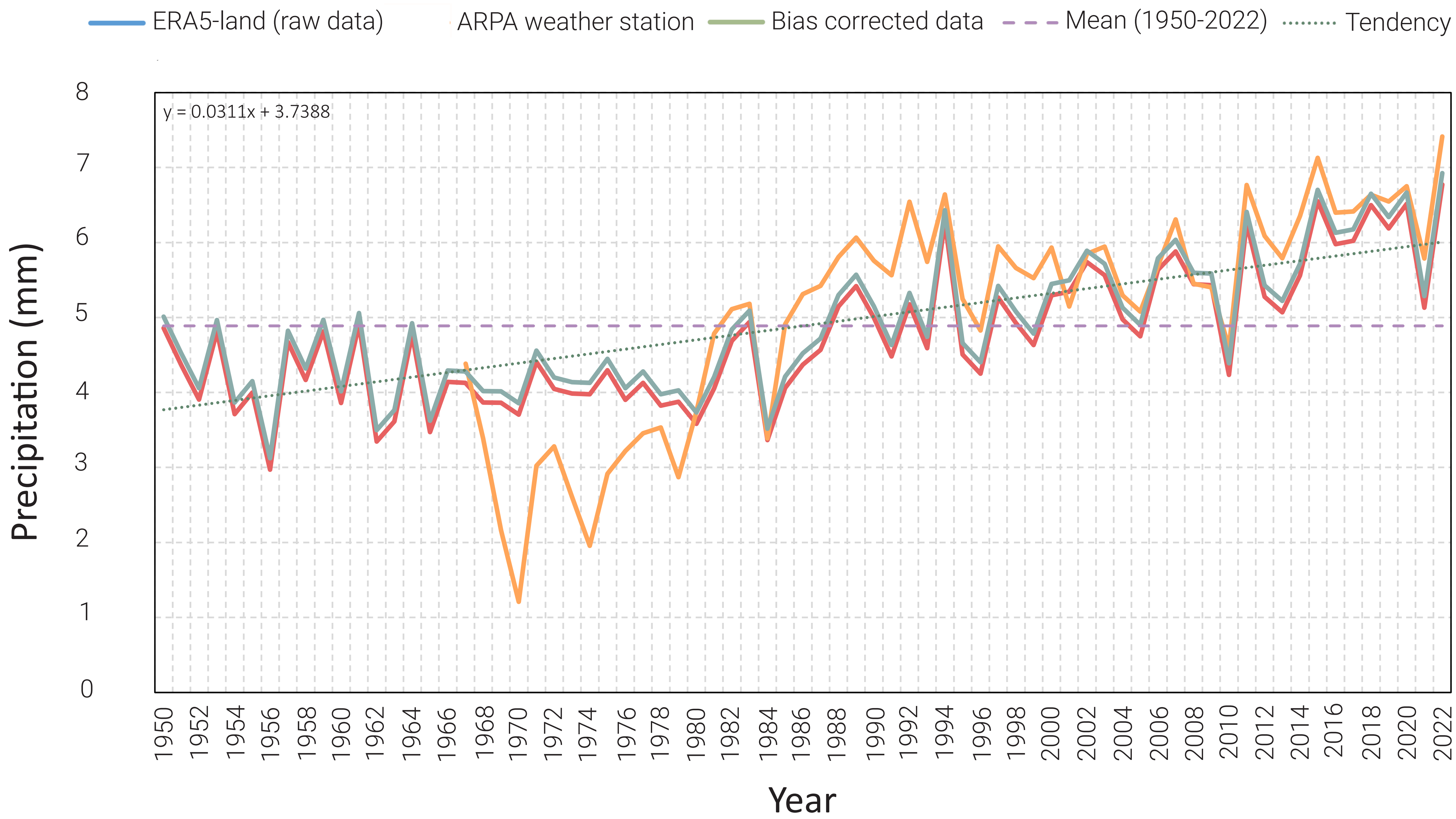
Figure 50.



2.4.7 Yearly mean temperature at Madesimo (1531 m a.s.l)

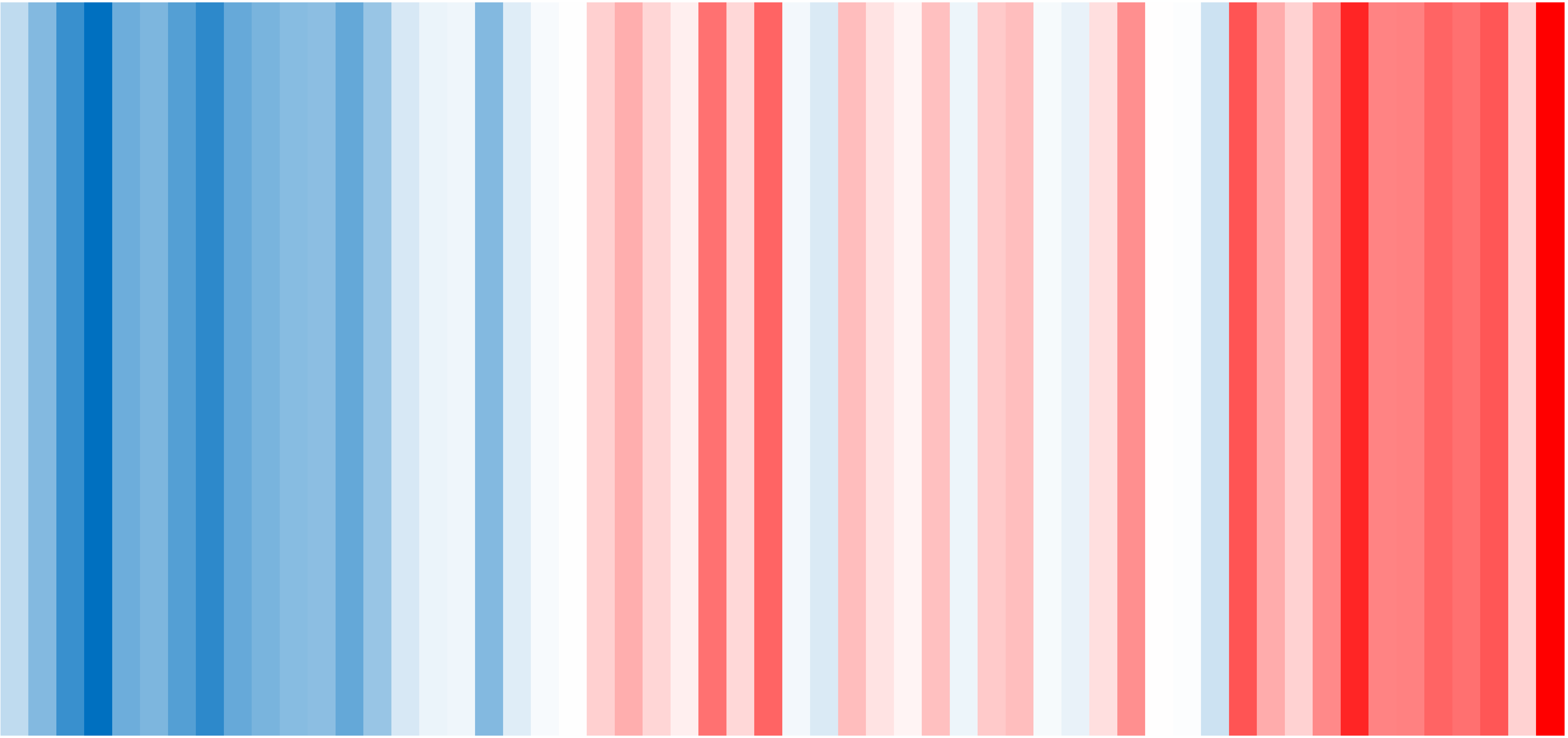
Figure 51.





2.4.8 Warming stripes from 1967 to 2022 in Madesimo (1531 m a.s.l)

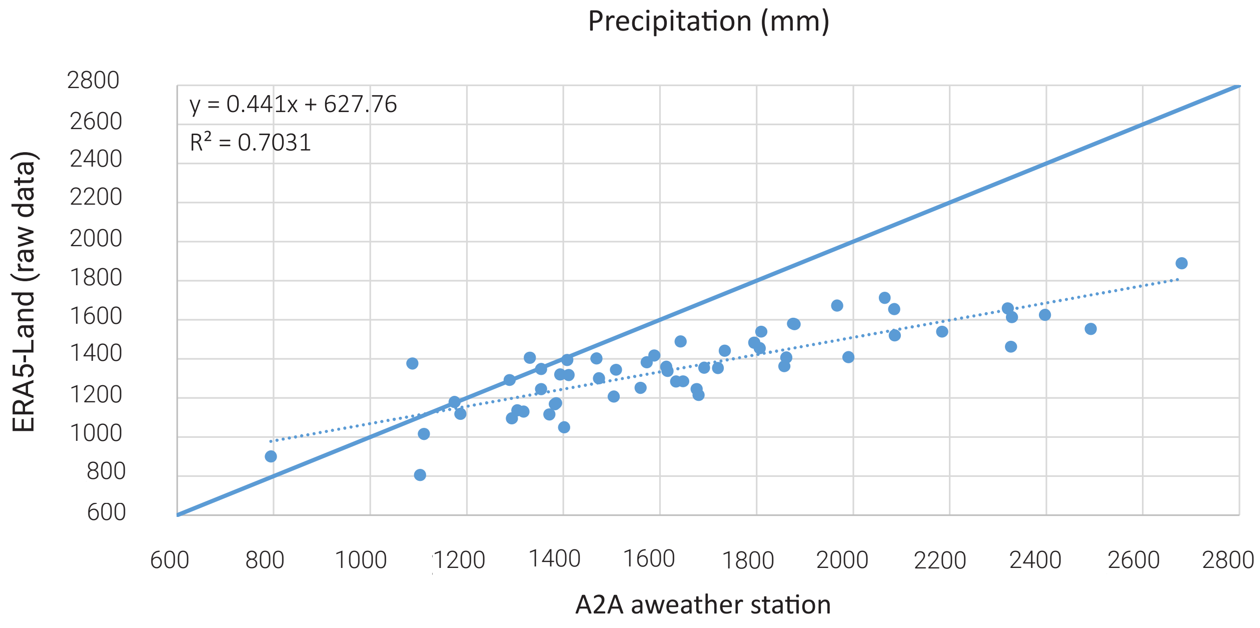
Figure 52.

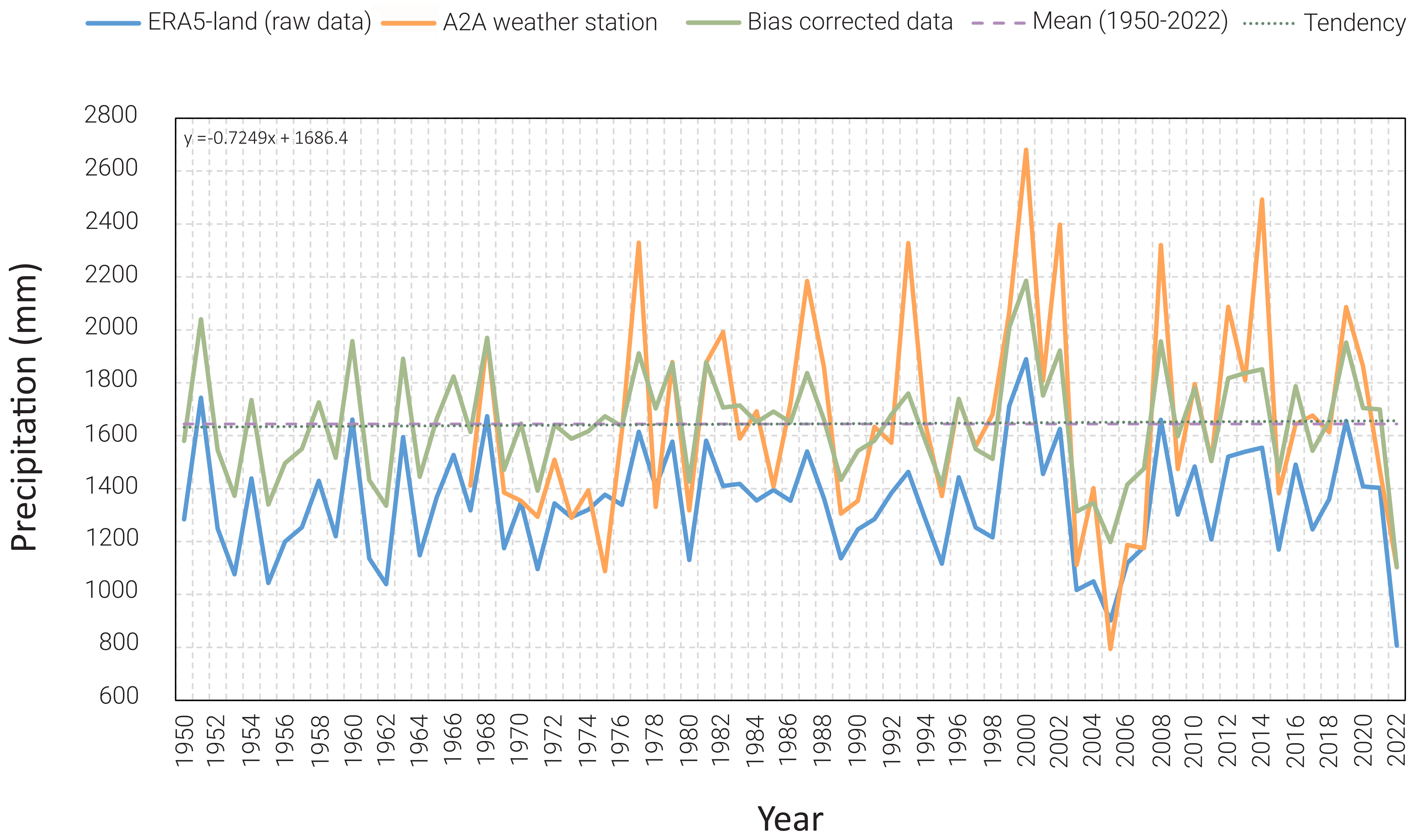


2.4.9 Yearly mean precipitation at Madesimo (1531 m a.s.l)

Figure 53.

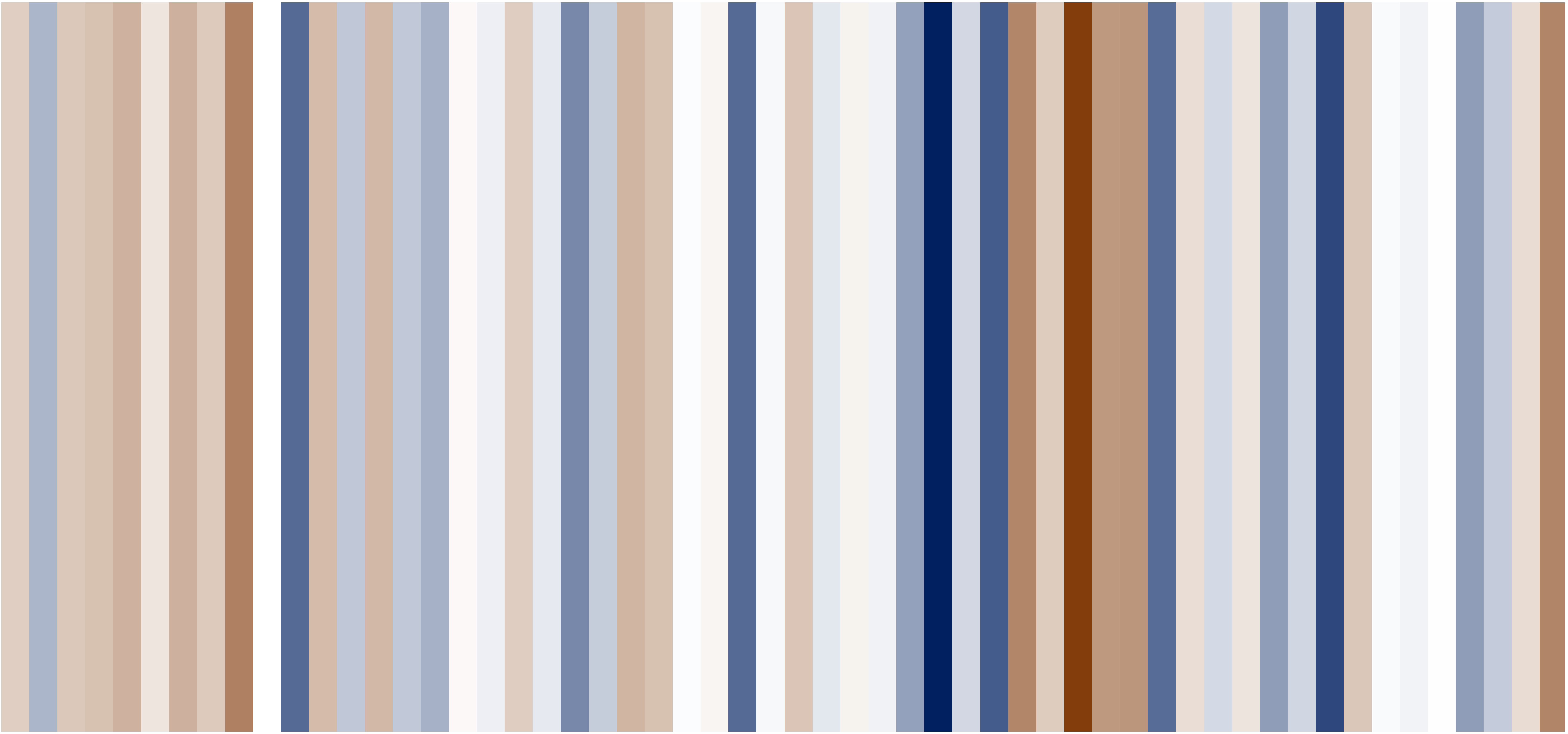
Heated rain gauge





2.4.10 Precipitation stripes from 1967 to 2022 in Madesimo (1531 m a.s.l)

Figure 54.



2.4.11 Climatic framework conclusion

The climate analysis conducted in the Valchiavenna area has provided compelling evidence of a significant increase in temperatures over the past 73 years, while precipitation has remained relatively stable. Specifically, temperatures in Alpe Motta have risen by approximately 2.27 °C, while precipitation has shown little change, hovering around 1470mm with a slight increase of about 24mm over the same period.

While this may provide some reassurance regarding consistent rainfall, it is important to interpret this finding with caution. The absence of noticeable shifts in precipitation should not overshadow the need to address the rising temperatures. Both factors are intricately linked, and understanding their interplay is crucial for developing adaptive measures to protect the region from potential ecological and socio-economic challenges. However, it is essential to acknowledge that the climate analysis results are influenced by data limitations. Some weather stations in the area had missing information, introducing a level of uncertainty into the findings. To mitigate this issue, the analysis focused only on the years with 95% data availability, ensuring a more robust and reliable assessment. This approach resulted in a dataset comprising a total of 347 available annual records, enhancing the credibility of the analysis, and enabling more accurate conclusions to be drawn.

To gain a better understanding of future drought scenarios, the paper titled "Future Droughts in Northern Italy: High-Resolution Projections Using EURO-CORDEX and MED-CORDEX Ensembles" played a significant role. This paper provided valuable insights into high-resolution projections for droughts in the region, utilizing the EURO-CORDEX and MED-CORDEX ensembles. The findings from this study complemented the climate analysis conducted in Valchiavenna and contributed to a more comprehensive assessment of the potential challenges that the region may face. By integrating the insights from this paper, a more robust understanding of the future climate conditions and their implications for Lake Azzurro and the surrounding areas can be gained.

03

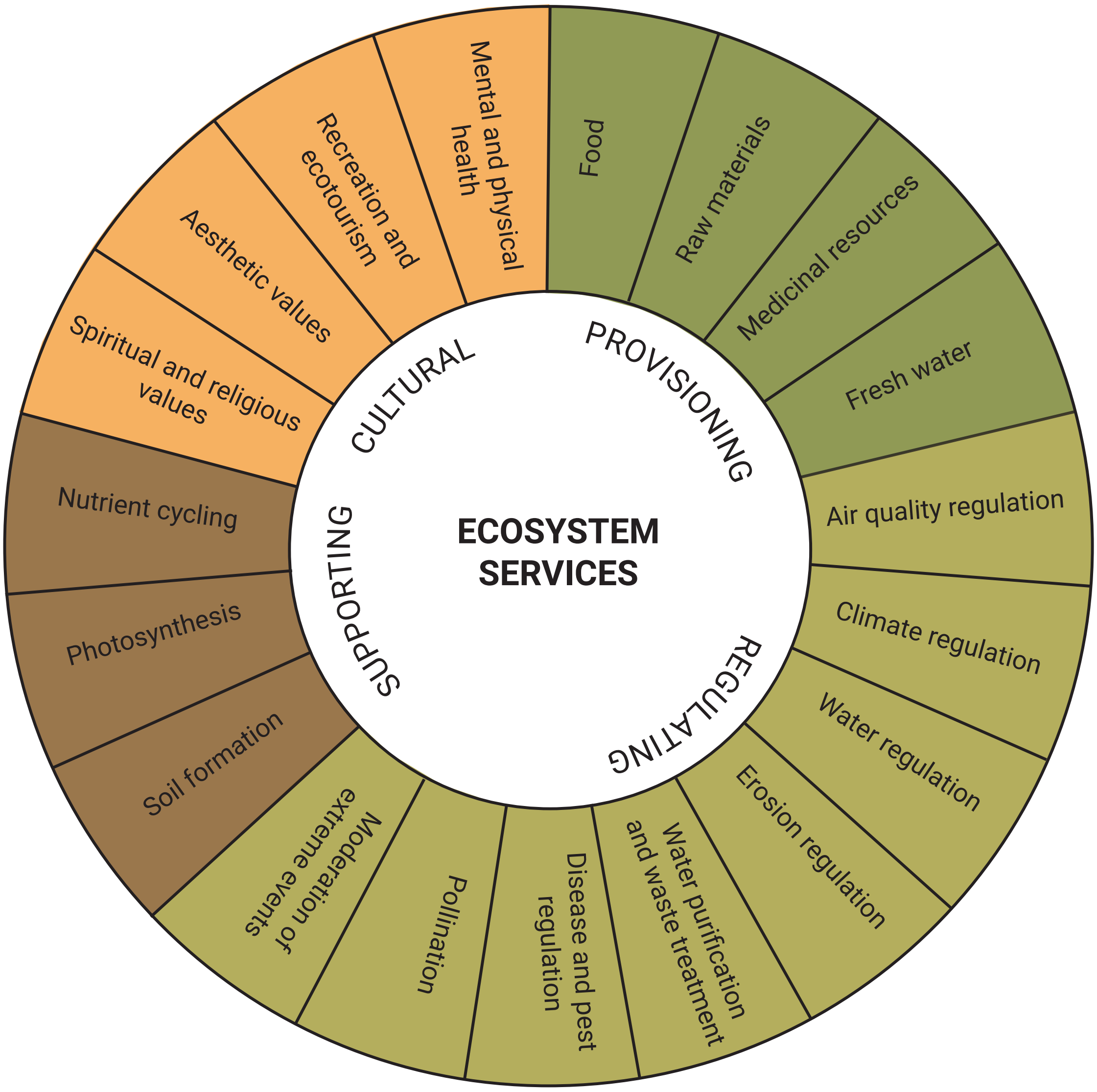
ECOSYSTEM SERVICES

Lake Azzurro ecological benefits

3.1 Meaning & origins

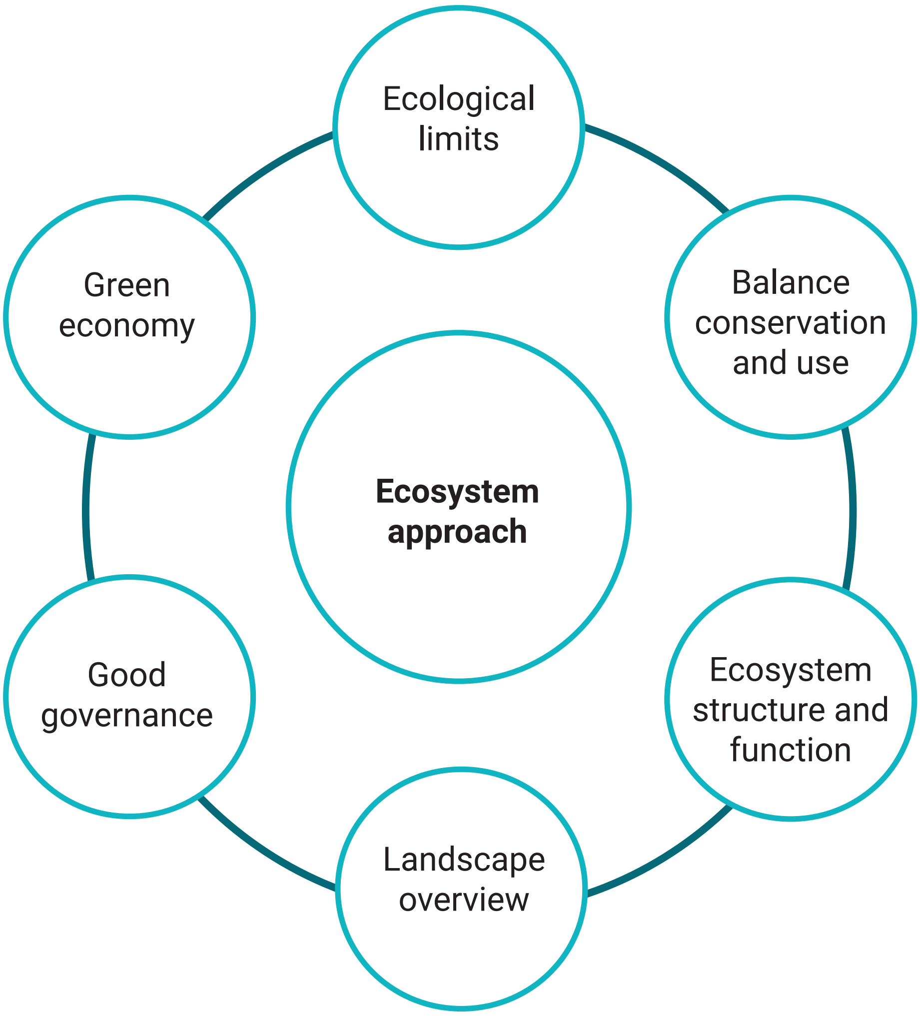
The interactions between the physical and biological elements that comprise the planet's ecosystems are essential for life on the planet, including humans. Thousands of years have passed since these interactions occurred. According to the Millennium Ecosystem Assessment (MEA, 2005), ecosystems are "a dynamic complex of plant, animal, and microorganism communities, as well as the non-living environment". Despite the fact that humans rely on global ecosystems to survive and thrive, anthropogenic activities have degraded many of these ecosystems, resulting in consequences regarding what we derive from them. For millennia human communities have recognized that nature provide benefits, both directly and indirectly.These benefits are so called ecosystem services and it is just in the 1970s that this concept, initially called "environmental services" was established and started evolving. Later, Westman (1977) talked about the importance of what he called "nature's services," or the advantages that ecosystems bring to human society. He went on to say that it might be possible to quantify how human development and physical change affect ecosystems in order to inform society and, in turn, influence policy and management choices that would lessen ecological degradation. In the early to mid 1980s, as concepts and understanding developed, this idea became known as "ecosystem services"; in the mid to late 1990s, it gradually emerged as a viable framework for assessing and safeguarding ecosystems and their biodiversity. This has led to the fusion of the traditionally disparate fields of ecology and economics and permits research into the connections between economies and natural environments (Feeley et al. 2020).

Figure 55.



Since then, researchers have made an effort to try and come to a conceptual understanding between the fields of economy and ecology to define the fundamental nature of human uses of natural resources, but different meanings have evolved for terms that are used frequently. In this regard, various study fields have concentrated heavily on various methods of ES valuation: Ecological valuation measures ES losses and/or gains by measuring ecosystem or biophysical parameters; socio-cultural and economic valuation values ES based on the characteristics of various social and cultural groups observed from a cultural and social conservation perspective and ethical valuation values ES based on the attributes of different social and cultural groups observed under a cultural-social conservation perspective (Hackback et al. 2017).When the United Nations released its Millennium Ecosystem Assessment in 2005, the idea of ecosystem services received more widespread attention (MEA). The MEA was a 1300 scientist research for policymakers that lasted four years. The study emphasized that due to the enormous growth in human populations and rising per capita consumption, the past 50 years had seen the fastest loss and deterioration of the Earth's natural resources and ecosystem services. Over 40 ES have been described, and they fall into four categories: support, supply, regulation, and culture, according to the MEA 2005 (Fig 55.). The importance of the ES connected to water (ESw) is among the highest for human health (Costanza et al. 2014). The "ecosystem approach (Fig.56)," which is defined as "a strategy f or t he integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way," was adopted and endorsed by the Convention on Biological Diversity (CBD, 2000) during this time as a method of intervening to manage ecosystems based on a systemic and participatory approach. Later, the CBD emphasized the advantages of promoting the ecosystem approach by utilizing the ecosystem services concept.

Figure 56.



To promote the ecosystem approach and integrate ecological thinking into policy and practice, the idea of ecosystem services was added to the 12 principles of the ecosystem approach (CBD, 2004).Moreover in 2009 The Common International Classification of Ecosystem Cervices (CICES) was proposed as a new way to classify ecosystem services. It was the result of a gathering held by the European Environment Agency as part of its efforts to create accounts for land and ecosystems (Young-Roy et al. 2011).

More recently, the 2011 CBD Aichi Biodiversity Targets, Strategic Goal D and especially, Target 14 [https://www.cbd.int], urged the preservation of crucial ecosystem services, thar are important for maintaining human health, livelihoods, and well being. As a result, initiatives like Mapping and Assessment of Ecosystems and their Services (MAES) and international and national biodiversity policies now include ecosystem services. The "ecological services framework," was created in response to the 2005 MEA report and the establishment of the CBD (Convention on Biological Diversity), while some authors, prefer the term "ecosystem services framework," as it is less comparable to the "ecosystem approach" and hence less likely to generate misunderstanding. The ecosystem services framework is thought to be an efficient way to communicate with all stakeholders the importance of safeguarding ecosystems in order to keep the flow of advantages (eg. good and services) that they offer to people and their well-being. With the design and implementation of incentives and policies that are appropriate to the contribution of the services offered by an ecosystem, theoretical estimates of this value can be used to justify the extension of conservation efforts with reference to land management (Feeley et al. 2020).

3.1.1 The ecosystem approach and ecosystem services framework

Both the "ecosystem approach" and the "ecosystem services framework" (Tab. 3) attempt to highlight the "ecosystem" as the basis for conservation, decision-making, and policymaking. The ecosystem approach focuses on natural processes and systems and, accordingly, is the basis for modern nature's conservation in many regions of the world. The ecosystem services framework, on the other hand focuses on comprehending how natural systems and the connections between ecosystem structures, processes, and functions result in valued benefits for human welfare, either directly or indirectly.The ecosystem services framework, in its most basic form, offers a mechanism to comprehend how nature provides benefits and services for human well-being (Waylen et al., 2014). It also enables comparison of resources that were previously incomparable and the evaluation of changes in specific ecosystem service flows (Toman, 1998; Salles, 2011); this makes it potentially particularly effective as a tool to assist environmental concerns (Costanza et al., 1997). Although understanding a system in terms of flows of services can support holistic and equitable management, describing them in terms of ecosystem services is not the basis of the ecosystem approach (Fish, 2011). The ecosystem approach has influenced the ecosystem services framework, but ultimately the two approaches are different in their outlook and goals (Feeley et al. 2020).

Table 1. displays a comparison of the two strategies or frameworks.

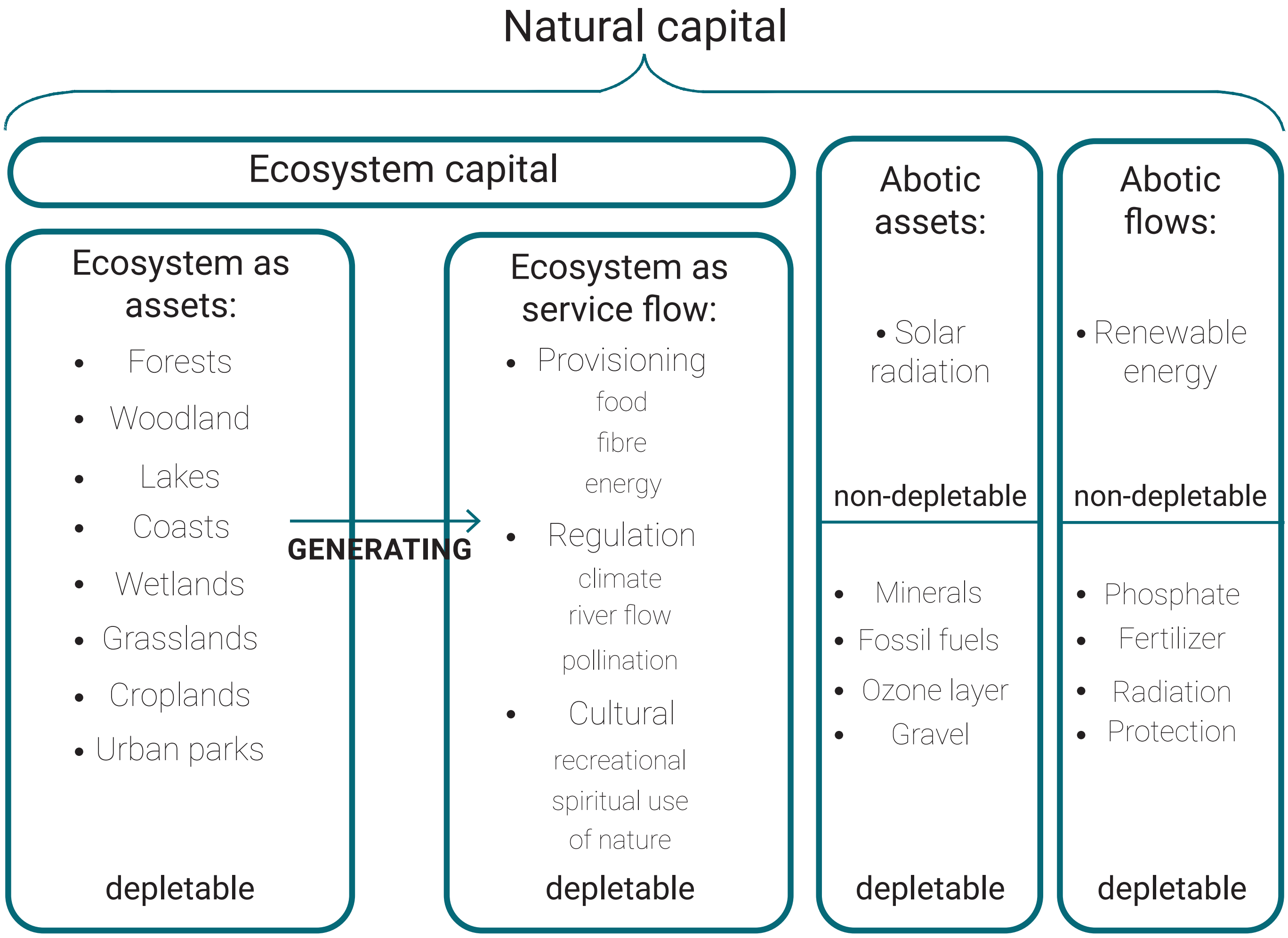
Table 3- adapted from Waylen et al.2014

Ecosystem services framework	Ecosystem approach
A framework for understanding how the biological components of an ecosystem (i.e. nature) deliver benefits and services for human well-being	A way of intervening to manage ecosystems using a systemic and participatory approach
Stakeholders are users or beneficiaries of ecosystem services. They provide knowledge and indicate interests that lead to ecosystem management and planning	Stakeholders provide knowledge and indicate interests that lead to decentralisation of ecosystem management and planning
Part of the process involves identifying which ecosystem services can be provided, how they can be provided and where they can be provided, with the goal of maintaining and improving human well-being	The process involves understanding the complex relationships that comprise socio-ecological systems, including the relationships between people and nature
Ecological functions and processes are included in supporting processes (also called supporting services)	Ecological processes and limits should be appreciated by all who contribute to decision making
The scale of influence is not explicit, ranging from local to global	The scale of influence is not pre-set but decentralisation of management and planning is recommended

3.2 Definition of ecosystem services and their benefits

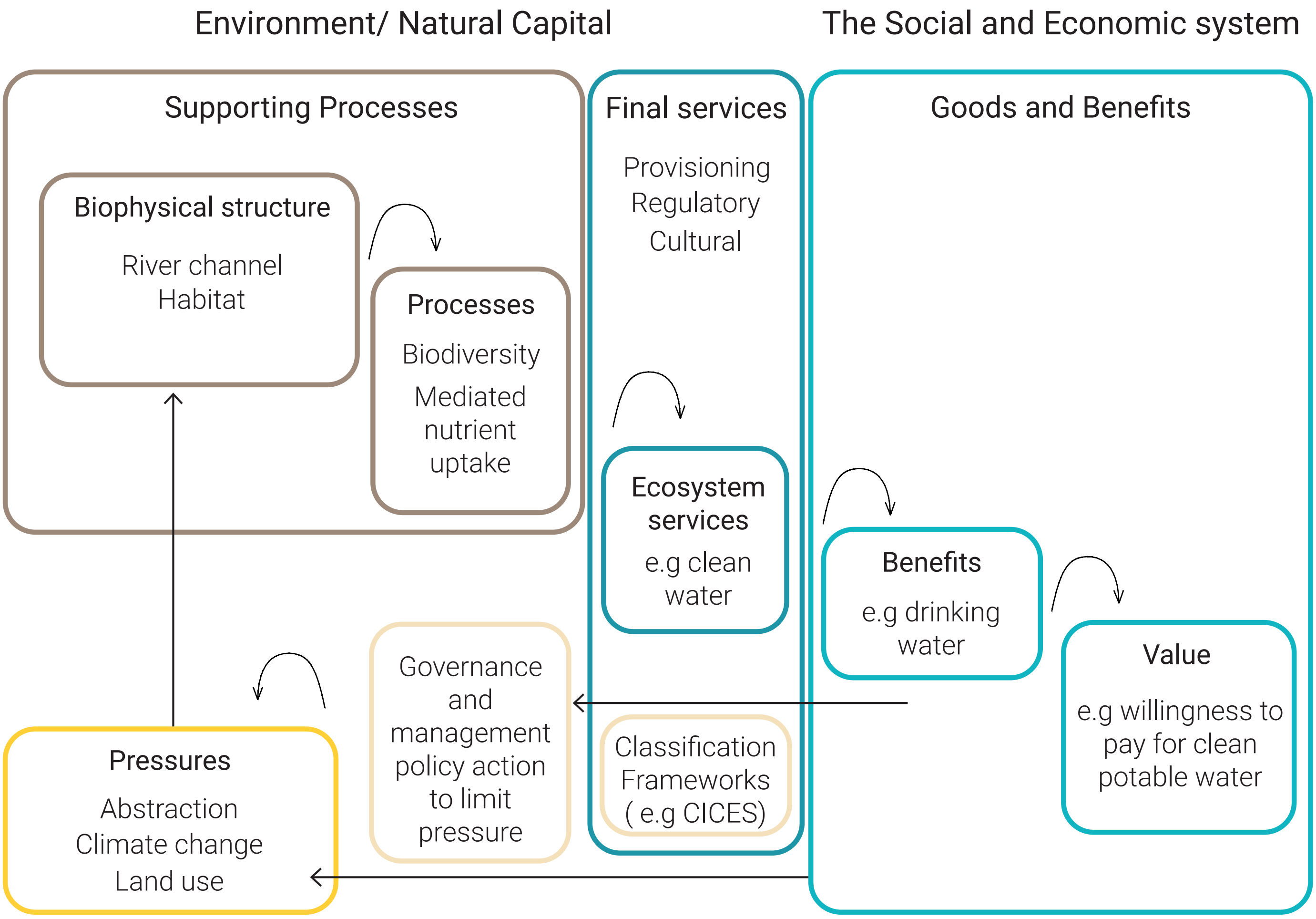
The idea of ES in modern times has several different roots and strands. There has been considerable convergence, but there are also significant differences. One version, created by biologists, initially concentrated on “life-support services,” or those aspects of the biotic environment that are thought to be crucial for human survival on Earth, the organisms one might bring on a spacecraft to establish life-support systems on a lifeless planet. This strategy was broadened to include all indirect advantages that people derive from ecosystem function, such as soil conservation, water purification, waste assimilation, pollination, hydrological regulation, and so forth (also known as “nature’s services”). The concern that “resource depletion, pollution, and extinction” caused by human actions could have serious negative effects on human well-being led to the development of a more comprehensive version, which was created contemporaneously. A group of ecologists like Robert Costanza and Rudolf de Groot and environmental economists like David Pearce and Ed Barbier, starting from analysing this appro-ach, created the concept of “natural capital” (NC, Fig.57). In this interpretation, NC is the stock that produces various benefit flows, including direct benefits or services, indirect benefits or go-ods, and pure conservation (existence or aesthetic) values. This method is what we refer now as “environmental economics.” Environmental services can be used as an alternative to ES even if its usage is confusing, it is used sometimes as a synonym for ES, occasionally to emphasize the human role in ES (Pesche et al. 2012), but it is most frequently used to emphasize the abio-tic components of nature. For instance, rainfall is now referred to as an environmental service while having previously been categorized as an ES. Geosystem services and geodiversity, terms used to describe the advantages of geological deposits, are extreme examples (Lelea et al. 2013). Recent years have seen a proliferation of terminology related to the ecosystem ser-vices concept, which has, to some extent, hindered efforts to express the con-cept and its advantages to numerous parties. Although the language of each de-scription varies slightly, they all emphasize the conception’s anthropocentric focus.

Figure 57. Natural capitaltural capital



Ecosystem services have been more frequently defined as "the benefits people obtain from ecosystems" or "the contributions that ecosystems make to human well-being" in the definitions that are most frequently used, based on the MEA (2005) report or the Common International Classification of Ecosystem Services (CICES) report, respectively (Haines-Young and Potschin, 2013). The term "final" ecosystem services is used by CICES (Haines-Young and Potschin, 2013) to distinguish them from "intermediate" services in order to prevent double counting in evaluation processes. Services are referred to as "final" if they are the byproducts of ecosystems (whether natural, semi-natural, or highly modified) that have the greatest direct impact on human welfare . One important quality of these services,the so called "intermediate services",is that they maintain a relationship to the underlying ecosystem activities, processes, and structures that provide them. Boyd and Banzhaf (2007) further suggested that ecosystem services which they referred to as "intermediate products" cannot encompass the ecosystem processes and activities that carry out the service's delivery. Consequently, there is widespread agreement that there should be a separation between supporting or "intermediate" ecosystem services and "final" ecosystem services. This divergence is clearly displayed in the Potschin and Haines-Young (2011) ecosystem service cascade framework (Fig.58), which emphasizes the placement of the CICES categorization and the "production barrier" between social and economic systems and the environment. Moreover, Fisher and Turner (2008) emphasized that the consumer is able to determines whether there is a strict separation between intermediate services and final services. It's also crucial to understand that a single ecosystem service, such as clean water, can result from two or more ecosystem functions, whereas a single ecological function can influence the production of two or more ecosystem services (Feeleyet al. 2020).

Figure 58. Ecosystem service cascade framework



Classification frameworks are necessary to enable the identification, quantification, and evaluation of specific commodities and services. Several attempts have been made to categorize and classify ecosystem services, but due to the variety and complexity of ecosystem processes and the characteristics of ecosystem services, a number of different classification schemes have been proposed (Costanza, 2008).The MEA (see MEA, 2005), The Economics of Ecosystems and Biodiversity (TEEB, 2010a), and CICES (Haines-Young and Potschin, 2013) are the three main classification schemes. The MEA's (2005) classification system has been widely used. The MEA specifies the following four major categories of ecosystem services: providing, regulating, cultural, or so-called final ecosystem services, and supporting or intermediate services. Although this was mostly semantics, the idea of supporting services for a new category called "habitat services".The CICES classification includes three of these services (provisioning, regulating, and cultural) (Haines-Young and Potschin, 2013).Although the distinction between functions, services, and benefits is crucial, particularly for economic evaluations, it is frequently impossible to create a classification that is totally consistent, especially for the regulation of services (TEEB, 2010a). However, a hierarchical structure has been used in the CICES categorization to ensure that the categories at each level are distinct from one another and are not redundant.CICES developed its typology of ecosystem services on the basis of many of the major concerns raised in the literature (Haines-Young and Potschin, 2013).

The MEA (2005) proposed it as a starting point. Three of the service types employed in the MEA are at the highest level: supplying, regulating and maintaining, and cultural. The user is able to take into account the features of the ecosystem service in question and, in turn, the natural capital, processes, and activities that produce them thanks to the definitions of ecosystem services in CICES. In the end, by defining the fundamental traits, it enables improved management, upkeep, restoration, and general assessment of ecosystem services (Young-Roy et al. 2011). Table 3. depicts the planned organizational structure for CICES, which includes 53 "service kinds" and 23 "service groups" while Table 4. and Table 5. describe in a more detailed way the three distincted categories. The formal definitions of the service themes and classes are provided in Box. 1, along with the justification for each.

Table 3. CICES Basic Structure and Relationship of Classes to TEEB Classification, Young-Roy et al. 2011

CICES Theme	CICES Class	TEEB Categories			
Provisioning	**Nutrition**	Food	Water		
	Materials	Raw Materials	Genetic resources	Medicinal resources	Ornamental resources
	Energy				
Regulating and Maintenance	**Regulation of wastes**	Air purification	Waste treatment (esp. water purification)		
	Flow regulation	Disturbance prevention or moderation	Regulation of water flows	Erosion prevention	
	Regulation of physical environment	Climate regulation (incl. C-sequestration)	Maintaining soil fertility		
	Regulation of biotic environment	Gene pool protection	Lifecycle maintenance	Pollination	Biological control
Cultural	**Symbolic**	Information for cognitive development			
	Intellectual and Experiential	Aesthetic information	Inspiration for culture, art and design	Spiritual experience	Recreation & tourism

Table 4.The CICES Classification (2011), Young-Roy et al. 2011

Theme	Service Class	Service Group	Service Type	Sub-types	Examples and indicative benefits
Provisioning	**Nutrition**	**Terrestrial plant and animal**	Commercial cropping	eg. by crops	Cereals, vegetables, vines etc.
			Subsistence cropping	eg. by crops	Cereals, vegetables, vines etc.
			Commercial animal production	eg. by animal	Sheep, cattle for meat and dairy products
			Subsistence animal production	eg. by animal	Sheep, cattle for meat and dairy products
			Harvesting wild plants and animals for food	eg. by resource	Berries, fungi etc
		Freshwater plant and animal	Commercial fishing (wild populations)	eg. by fishery	By species
			Subsistence fishing	eg. by fishery	By species
			Aquaculture	eg. by fishery	By species
			Harvesting fresh water plants for food	eg. by resource	Water cress
		Marine plant and animal	Commercial fishing (wild populations)	eg. by fishery	Includes crustaceans
			Subsistence fishing	eg. by fishery	Includes crustaceans
			Aquaculture	eg. by fishery	Includes crustaceans
			Harvesting marine plants for food	eg. by resource	Seaweed
		Potable water	Water storage	eg. by feature	Spring, well water, river, reservoir, lake
			Water purification	eg. by habitat	Wetlands
	Materials	**Biotic materials**	Non-food plant fibres	eg. by resource	Timber, straw, flax
			Non-food animal fibres	eg. by resource	Skin, bone etc., guano
			Ornamental resources	eg. by resource	Bulbs, cut flowers, shells, bones and feathers etc. (Stones? Gems?)
			Genetic resources	eg. by resource	Wild species used in breeding programmes
			Medicinal resources	eg. by resource	Bio prospecting activities
		Abiotic materials	Mineral resources		Salt, aggregates, etc. (EXCLUDE subsurface assets)
	Energy	**Renewable biofuels**	Plant based resources	eg. by resource	Wood fuel, energy crops etc.
			Animal based resources	eg. by resource	Dung, fat, oils
		Renewable abiotic energy	Wind	eg. by resource	
			Hydro	eg. by resource	
			Solar	eg. by resource	
			Tidal	eg. by resource	
			Thermal	eg. by resource	

Table 5. The CICES Classification (2011), Young-Roy et al. 2011

Theme	Service Class	Service Group	Service Type	Sub-types	Examples and indicative benefits
Regulation and Maintenance	**Regulation of wastes**	**Bioremediation**	Remediation using plants	eg. by method	Phytoaccumulation, phytodegredation, phytostabilisation, rhizodegradation,
			Remediation using micro-organisms	eg. by method	In situ (Bioremediation), ex situ (composting), bioreactors
		Dilution and sequestration	Dilution	eg. by method	Wastewater treatment
			Filtration	eg. by method	Filtration of particulates and aerosols
			Sequestration and absorption	eg. by method	Sequestration of nutrients in organic sediments, removal of odours
	Flow regulation	**Air flow regulation**	Windbreaks, shelter belts	eg. by process	
			Ventilation	eg. by process	
		Water flow regulation	Attenuation of runoff and discharge rates	eg. by process	Woodlands, wetlands and their impact on discharge rates
			Water storage	eg. by process	Irrigation water
			Sedimentation	eg. by process	Navigation
			Attenuation of wave energy	eg. by process	Mangroves
		Mass flow regulation	Erosion protection	eg. by process	Wetlands reducing discharge peak
			Avalanche protection	eg. by process	Stabilisation of mudflows, erosion protection [reduction]
	Regulation of physical environment	**Atmospheric regulation**	Global climate regulation (incl. C-sequestration)	eg. by process	Atmospheric composition, hydrological cycle
			Local & Regional climate regulation	eg. by process	Modifying temperature, humidity etc.; maintenance of regional precipitation
		Water quality regulation	Water purification and oxygenation	eg. by process	Nutrient retention in buffer strips etc. and translocation of nutrients
			Cooling water	eg. by process	For power production
		Pedogenesis and soil quality regulation	Maintenance of soil fertility	eg. by process	Green mulches; n-fixing plants
			Maintenance of soil structure	eg. by process	Soil organism activity
	Regulation of biotic environment	**Lifecycle maintenance & habitat protection**	Pollination	eg. by process	By plants and animals
			Seed dispersal	eg. by process	By plants and animals
		Pest and disease control	Biological control mechanisms	eg. by process	By plants and animals, control of pathogens
		Gene pool protection	Maintaining nursery populations	eg. by process	Habitat refuges
Cultural	**Symbolic**	**Aesthetic, Heritage**	Landscape character	eg. by resource	Areas of outstanding natural beauty
			Cultural landscapes	eg. by resource	Sense of place
		Spiritual	Wilderness, naturalness	eg. by resource	Tranquillity, isolation
			Sacred places or species	eg. by resource	Woodland cemeteries, sky burials
	Intellectual and Experiential	**Recreation and community activities**	Charismatic or iconic wildlife or habitats	eg. by resource	Bird or whale watching, conservation activities, volunteering
			Prey for hunting or collecting	eg. by resource	Angling, shooting, membership of environmental groups and organisations
		Information & knowledge	Scientific	eg. by resource	Pollen record, tree ring record, genetic patterns
			Educational	eg. by resource	Subject matter for wildlife programmes and books etc.

3.3 Ecosystem services valuation

The maintenance of human existence on earth clearly depends on ecosystem services (ES) and natural capital (NC) (Millennium Ecosystem Assessment, 2005). The main questions are: How significant are ES? What time and space scales are involved? What are the boundaries of humanity's capacity to replace them? How much stress does it take for them to switch to a different (less desired) state? Understanding and modeling the interrelated, changing system of humans and the rest of nature are prerequisites for answering all of these issues (Costanza et al.,2014). Ecosystem services present options and trade-offs for us as humans, and this implies and necessitates "value", since any decision between conflicting alternatives suggests that the one made was "regarded" more highly. (Costanza, 2020).

Several units can be used to describe how much an ecosystem contributes in relation to other factors. Since one of the required contributors to the economy is built capital, expressed in monetary units, and that most people can understand values expressed in monetary units, this is frequently a convenient denominator for expressing the relative contributions of the other forms of capital, including natural capital(Costanza et al. 2014).

The terms "value system," "value," and "valuation" have a wide range of applications and interpretations as well as a long history across numerous fields (c.f. Costanza, 2004; Mazzucato, 2018). Value systems are intrapsychic constellations of rules and principles that direct human decision-making and behavior. They relate to the moral and normative frameworks that people employ to prioritize and justify their beliefs and conduct. Value systems are therefore internal to individuals, yet they are the product of intricate acculturation patterns and can be influenced from the outside, for example, through advertising. There are two common but distinct meanings of "value:" I value biodiversity, but I may also value freedom, fairness, sustainability, money, and many other things. I also value biodiversity, but I value it more than it costs to protect it, which is a relative value that takes into account trade-offs. In its basic definition, value relates to goals or objectives. Value in the second definition refers to an object's or action's contribution to the fulfilment of particular circumstances, aims, or goals. So, a product or activity might help someone achieve their goals without that person completely (or even just faintly) realizing it. This may be crucial for supporting, regulating, and cultural ecosystem services, as these services' relationship to people's wellbeing may not be fully understood at all (Costanza, 2020).

Whether or not a certain thing or action is fully appreciated by people, valuation is the process of determining its contribution to achieving a specific goal. Individual well-being is not the main objective, as was previously mentioned. In a larger sense, sustainable wellbeing encompasses both societal well-being and the health of the natural ecosystems that sustain all life. Consequently, in order to achieve the ultimate aim of ensuring the sustainability of human well-being and that of the rest of nature, i.e. the entire earth system, our goals for valuing must combine individual, societal, and ecosystem goals. Based on the three sub-goals for the sustained health of people and the rest of nature first stated by Daly (1992), Costanza and Folke (1997) and Costanza (2000) described three categories of value for ES and NC are as follows:

1) Sustainable scale: determining and ensuring that human activity levels within the biosphere are ecologically sustainable
2) Fair distribution: distributing assets and property rights fairly among the current and following generations of humans as well as between humans and other species
3) Efficient allocation: efficiently allocating resources, including both marketed and unmarketed resources, as limited and specified by 1 and 2 above.

It is to underline that It's erroneous to believe that valuing ecosystem services in monetary terms equates to their privatization or commodification. (Costanza, 2006; Costanza et al.,2012; McCauley, 2006; Monbiot, 2012). The majority of ecosystem services are either common pool resources (rival but non-excludable) or public goods (non-rival and non-excludable), which makes privatization and traditional markets ineffective, assuming they do function at all (Costanza et al. 2014).

3.4 Ecosystem services monetization

Ecosystem services monetization refers to the process of assigning a monetary value to the various benefits that ecosystems provide to society. This includes things like clean air and water, climate regulation, and biodiversity, which are all critical for human well-being and economic development. There are several reasons why monetizing ecosystem services is important. First, it helps to raise awareness about the value of natural resources and the need for their conservation. By putting a price tag on ecosystem services, it becomes easier for policymakers and the public to understand the true costs and benefits of environmental protection and management. Monetizing ecosystem services can also provide a powerful tool for decision-making, as it allows policymakers and businesses to compare the costs and benefits of different actions and policies. For example, a company may be considering whether to build a new factory near a wetland. By valuing the ecosystem services provided by the wetland, such as water filtration and carbon sequestration, the company can weigh the economic benefits of the factory against the environmental costs of its impact on the wetland. In addition to providing decision-making tools, monetizing ecosystem services can also help to generate new sources of income and investment in natural resource management. For example, payments for ecosystem services programs have been developed in many countries, where landowners are paid for the environmental services their land provides, such as carbon sequestration or watershed protection. However, there are also several challenges associated with monetizing ecosystem services. One of the biggest challenges is determining the appropriate valuation method for different ecosystem services. While some services, such as water filtration or crop pollination, can be valued using standard economic models, other services, such as cultural or spiritual values, may be more difficult to quantify. Another challenge is ensuring that the benefits of ecosystem services are distributed equitably. In some cases, the benefits of ecosystem services may be concentrated in a particular region or community, while the costs of their depletion may be felt elsewhere. Monetizing ecosystem services can help to address this by providing a mechanism for compensating those who contribute to their protection (Cordier M. et al. 2014). Moreover, the use of market-based mechanisms for ecosystem services monetization has been criticized by some environmentalists, who argue that it reduces nature to a mere commodity and allows for the continued exploitation of natural resources. This is because it is feared that the focus on financial returns may overlook broader social and ecological benefits, and also increase the vulnerability of the poor. Despite these challenges, ecosystem services monetization has gained widespread recognition as a tool for sustainable development and environmental management. Many international organizations, including the United Nations, have developed frameworks and guidelines for valuing ecosystem services and promoting their conservation and sustainable use.

Furthermore, it is important to recognize that the monetization of ecosystem services is just one component of a broader strategy for environmental protection and sustainable development. To be effective, it must be accompanied by efforts to reduce environmental degradation and promote more sustainable forms of economic development, such as renewable energy and sustainable agriculture (Termelet et al. 2018).

Overall, ecosystem services monetization is a powerful tool for promoting the conservation and sustainable use of natural resources. While it has its challenges, it also offers opportunities for generating new sources of income, promoting equitable distribution of environmental benefits, and informing decision-making for sustainable development.

3.4.1 Sustainable well-being, ecosystem services and natural capital

When considering the general concept of capital as a stock that generates a flow of services through time, the ecosystems that provide the services are frequently referred to as "natural capital" (NC), Natural capital refers to the stock of renewable and non-renewable resources that provide ecosystem services(Costanza and Daly, 1992).Some forms of capital that do require human agency to create and maintain must interact with natural capital, which neither requires nor benefits from human activity. They consist of: (1) physical or financial capital; (2) labor; and (3) social or cultural capital. The economy is rooted in built and human capital, which is rooted in society, which is rooted in the rest of nature. For any human gain, these four basic types of capital must be used in intricate combinations. In order to gain support for innovative methods to E-valuation, ecosystem services refer to the proportional contribution of natural capital to production. Natural capital is essential for sustainable development as it provides the foundation for ecosystem services that support human well-being. However, natural capital is under increasing pressure due to overexploitation, pollution, and climate change. To ensure sustainable well-being, it is crucial to manage natural capital in a way that balances economic development and environmental protection, ensuring the long-term provision of ecosystem services (Costanza et al. 2014). Sustainable well-being, ecosystem services, and natural capital are interconnected concepts that play a critical role in ensuring a sustainable future for our planet. Sustainable well-being refers to the ability of current and future generations to meet their basic needs while maintaining the planet's ecological health and integrity. It is a holistic approach that considers both human well-being and the environment's health. Sustainable well-being is achieved through sustainable development, which balances economic growth, social progress, and environmental protection. Natural capital refers to the stock of renewable and non-renewable resources that provide ecosystem services. It includes natural resources such as forests, freshwater, and minerals, as well as ecosystems such as wetlands, coral reefs, and grasslands. Natural capital is essential for sustainable development as it provides the foundation for ecosystem services that support human well-being. However, natural capital is under increasing pressure due to overexploitation, pollution, and climate change. To ensure sustainable well-being, it is crucial to manage natural capital in a way that balances economic development and environmental protection, ensuring the long-term provision of ecosystem services (Guerry et al. 2015).

3.4.2 Ecosystem services privatization

A payment for ecosystem services (PES) program is a mechanism that entails offering payments to individuals or entities in exchange for managing land in a manner that preserves or improves the health of the ecosystem. This results in benefits for the public or particular beneficiaries, such as carbon sequestration or the management of water resources. To ensure maximum efficiency, these payments may take the form of either flat-rate subsidies or customized contracts that are negotiated individually. This approach has been implemented in numerous regions worldwide with differing degrees of success and is now being considered more frequently in the United Kingdom as a means of protecting biodiversity (W. Nsoh and C. Reid, 2013).

The privatization of ecosystem services has become a topic of debate in recent years, as some argue that it could lead to more efficient management and conservation of natural resources. However, there are concerns that the privatization of ecosystem services could lead to the exploitation of natural resources for profit, ultimately harming the environment and the well-being of people who depend on these services.

Ecosystem services are the benefits that people derive from nature, including clean water, clean air, fertile soil, and biodiversity. These services are essential for human well-being, but are often undervalued or taken for granted. In recent years, there has been growing interest in the privatization of ecosystem services as a way to create economic incentives for the conservation and management of natural resources.

Proponents of the privatization of ecosystem services argue that it can create more efficient management of natural resources by giving individuals and businesses financial incentives to conserve and manage ecosystems. This can lead to better conservation practices, improved ecosystem health, and more sustainable use of natural resources. Privatization can also provide new sources of income for local communities and landowners, which can help reduce poverty and promote economic development.

However, there are concerns that the privatization of ecosystem services could lead to the exploitation of natural resources for profit, ultimately harming the environment and the well-being of people who depend on these services. There are also concerns that the privatization of ecosystem services could lead to unequal access to these services, as those who can afford to pay for them would have greater access than those who cannot.

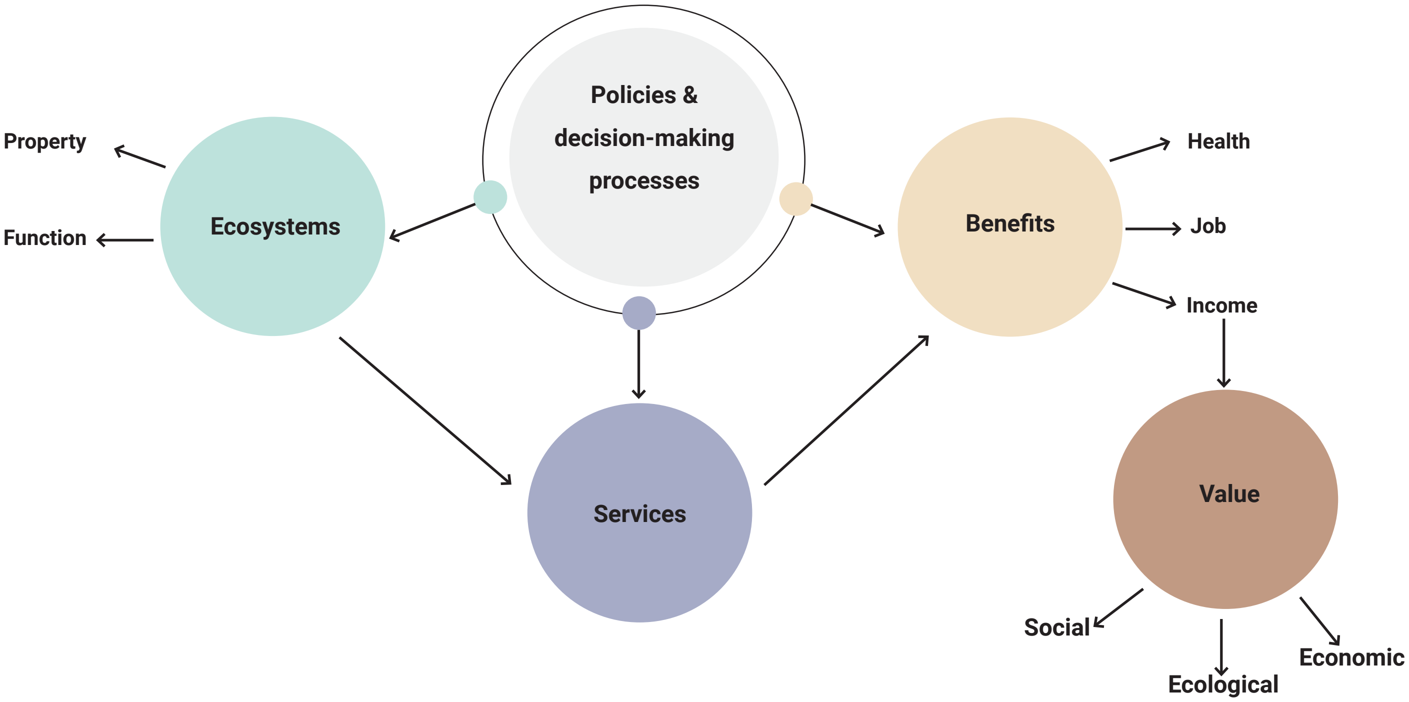
Furthermore, ecosystem services are not commodities that can be bought and sold like other goods and services. They are complex and dynamic systems that provide a wide range of benefits, and it is difficult to quantify and monetize their value. Privatization can also lead to a focus on short-term profits, rather than the long-term sustainability of ecosystems and the services they provide.

Privatization also assumes that the private sector will be better equipped to manage and conserve ecosystems than the public sector. However, the private sector may not have the same incentives to protect and conserve ecosystems as the public sector, which has a responsibility to protect the common good. Additionally, privatization may lead to the fragmentation of ecosystems, as private landowners may prioritize their own interests over the larger ecosystem.

Another concern with the privatization of ecosystem services is that it could lead to a lack of accountability and transparency. Private companies may not be required to report on their management practices, making it difficult for the public to hold them accountable for any negative impacts on the environment.

In conclusion, the privatization of ecosystem services is a complex issue that requires careful consideration. While it may provide economic incentives for the conservation and management of natural resources, it also raises concerns about the exploitation of natural resources for profit, unequal access to ecosystem services, and the focus on short-term profits rather than long-term sustainability. Ultimately, ecosystem services cannot be fully privatized, as they are complex and dynamic systems that provide essential benefits for human well-being and the environment as a whole. It is important to find a balance between economic incentives and the protection of the common good, to ensure the sustainable use and conservation of natural resources for future generations (J. Kaiser et al. 2023).

Figure 59. Evaluation of ecosystem services



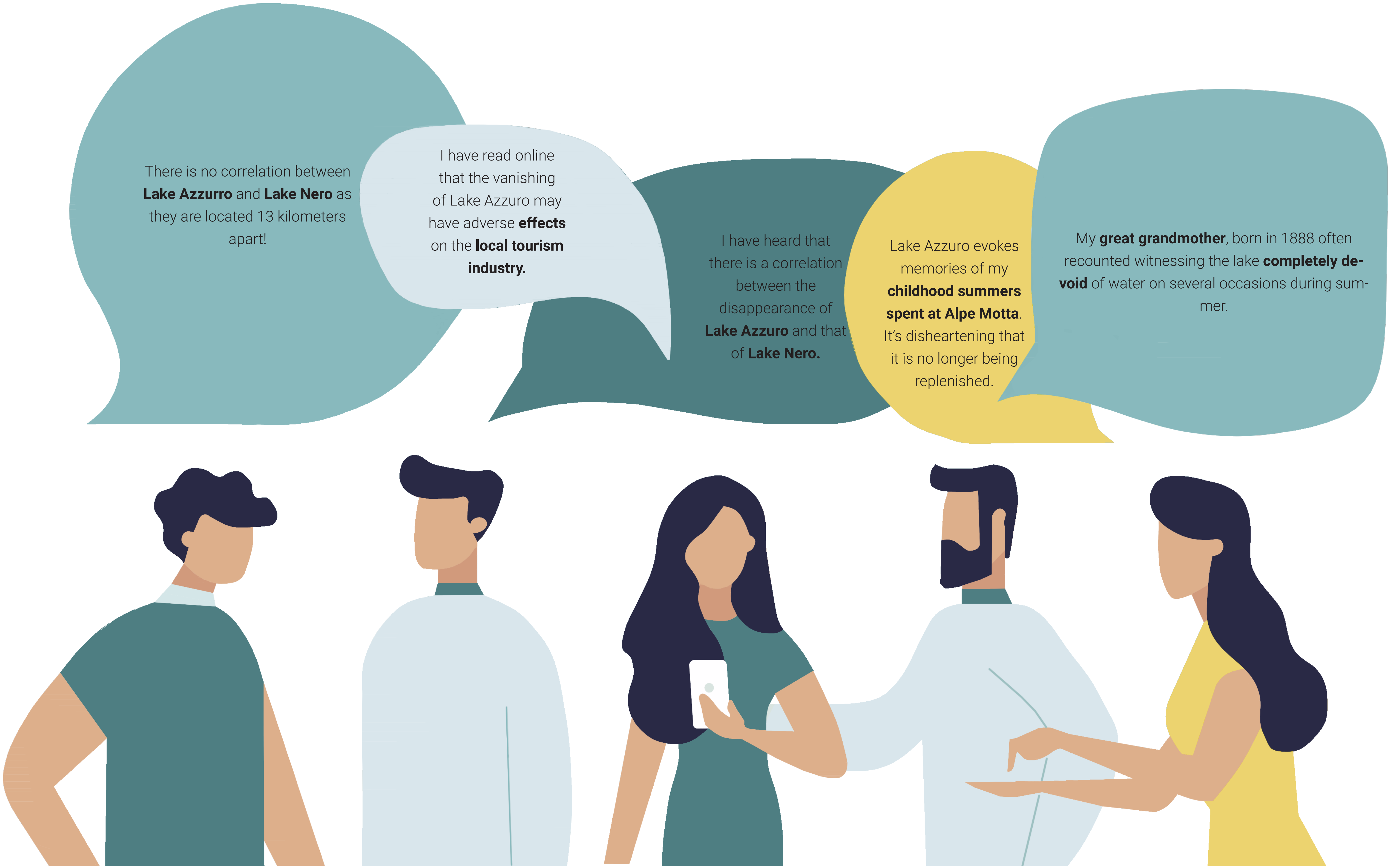
3.5 Climate change and its impact on Ecosystems

Climate change is profoundly affecting Alpine ecosystems and the invaluable services they offer. These ecosystems play a vital role in providing essential services like water supply, carbon storage, and biodiversity habitats. However, climate change is introducing various alterations to these ecosystems and their services. The most significant impact stems from the melting of glaciers and snowpack, which reduces water availability and poses risks of flooding and landslides. Moreover, shifting temperatures are influencing the distribution and abundance of plant and animal species, disrupting the region's biodiversity and important services like pollination and seed dispersal. Changes in the timing of biological events further disturb species interactions and ecosystem services. The increasing frequency and intensity of extreme weather events, such as heatwaves, droughts, and storms, cause substantial damage, including forest fires and soil erosion. Additionally, climate change affects the carbon cycle by accelerating the decomposition of organic matter and releasing more carbon into the atmosphere, impacting the region's carbon storage capacity. Furthermore, changes in resource availability like timber and pasture have economic implications for the region and the livelihoods dependent on them. The tourism industry, a significant source of income, is also affected as rising temperatures reduce snow cover and the length of the skiing season. Lastly, the cultural heritage tied to the natural environment faces challenges, as the changing ecosystems may jeopardize the cultural significance of the region's resources and landscapes, impacting the well-being and identity of its residents (Pyke et al., 2010).

3.6 Public opinion on Lake Azzurro

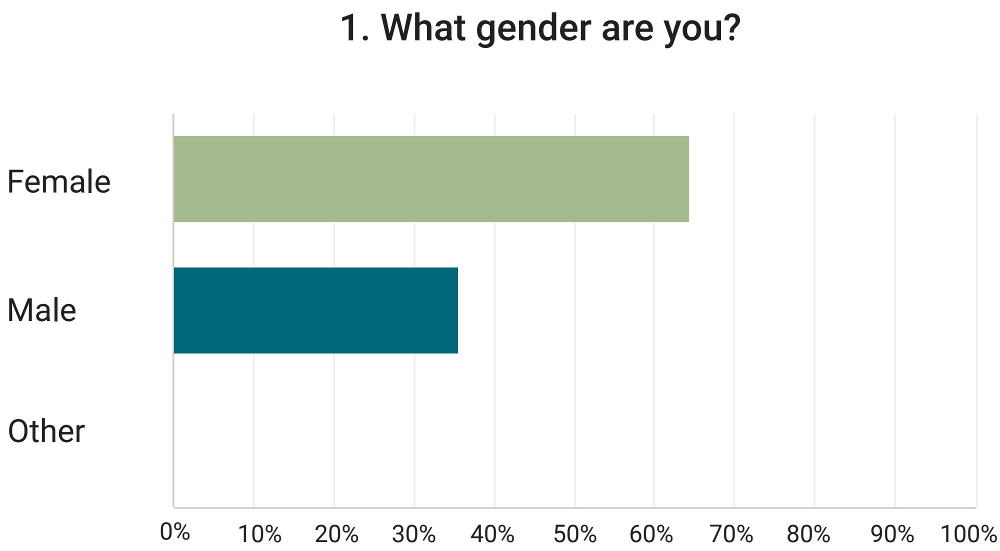
In order to gain a comprehensive understanding of the ecosystem services associated with Lake Azzurro, two distinct analyses were undertaken. These analyses aimed to explore public per-ceptions and attitudes towards the lake's disappearance and the importance of preserving its environment. The first analysis (Fig. 59) took a more superficial approach, utilizing social me-dia platforms such as Facebook. Several posts were created on pages followed by residents of Valchiavenna, encouraging them to share their thoughts on Lake Azzurro's disappearance and the significance of protecting such a natural environment.Engaging with the community throu-gh Facebook proved to be an effective means of gathering initial insights and public sentiment. Despite the relatively informal nature of this approach, it provided valuable preliminary informa-tion about people's opinions and concerns related to the lake. The responses received throu-gh these posts helped lay the foundation for understanding the local community's perspectives. Concurrently, a more detailed and extensive survey titled "I Laghi Alpini della Valchiavenna" was conducted (Fig. 60-Fig. 66). This survey was designed to comprehensively explore people's care for the lake environment and the underlying reasons behind their sentiments. Surpassing expecta-tions, both surveys generated a significant amount of interest and participation from the public. The second survey, "I laghi alpini della Valchiavenna," specifically targeted individuals who had visited the Valchiavenna area. It aimed to gather in-depth data and opinions from a larger sample size. Sur-prisingly, the survey received responses from an impressive 528 people, further amplifying the level of community engagement in the research.The unexpected level of interest and participation in both analyses clearly demonstrated the community's strong connection to Lake Azzurro. It underscored the significance of the lake and its environment to the local residents. The combined findings from these two analyses provide a comprehensive understanding of the ecosystem services associated with Lake Azzurro and offer valuable insights for future conservation and management efforts.The-se analyses not only contribute to expanding knowledge about the ecosystem services provided by Lake Azzurro but also serve to raise awareness among the public about the lake's importance. The community's active involvement in these surveys highlights their desire to have their voices heard and to actively participate in the preservation of their natural surroundings. The gathered data from the-se analyses will serve as a valuable resource for policymakers, researchers, and stakeholders invol-ved in the protection and sustainable management of Lake Azzurro and its surrounding ecosystem.

Figure 59. People's opinion on Lake Azzurro



2.6.1 *Survey titled "I laghi alpini della Valchiavenna"*

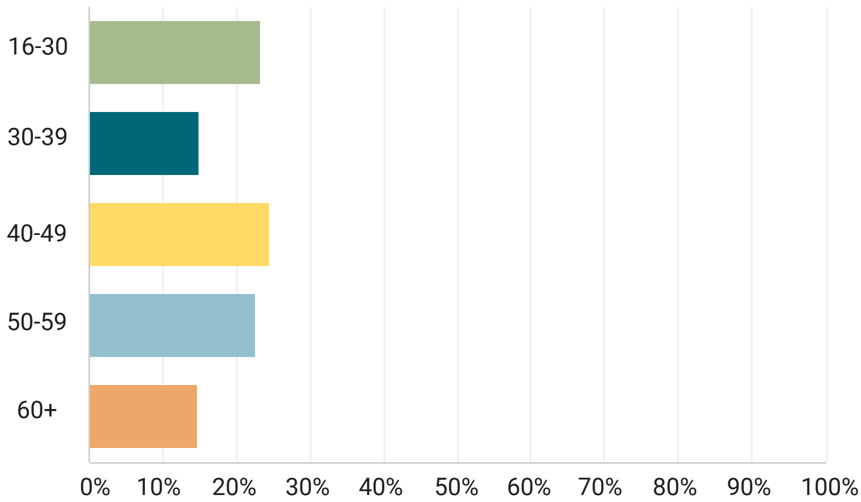
Figure 60.



Answers options	Answers	
Female	64.39%	340
Male	35.61%	188
Other	0.00%	0
Total		528

Figure 61.

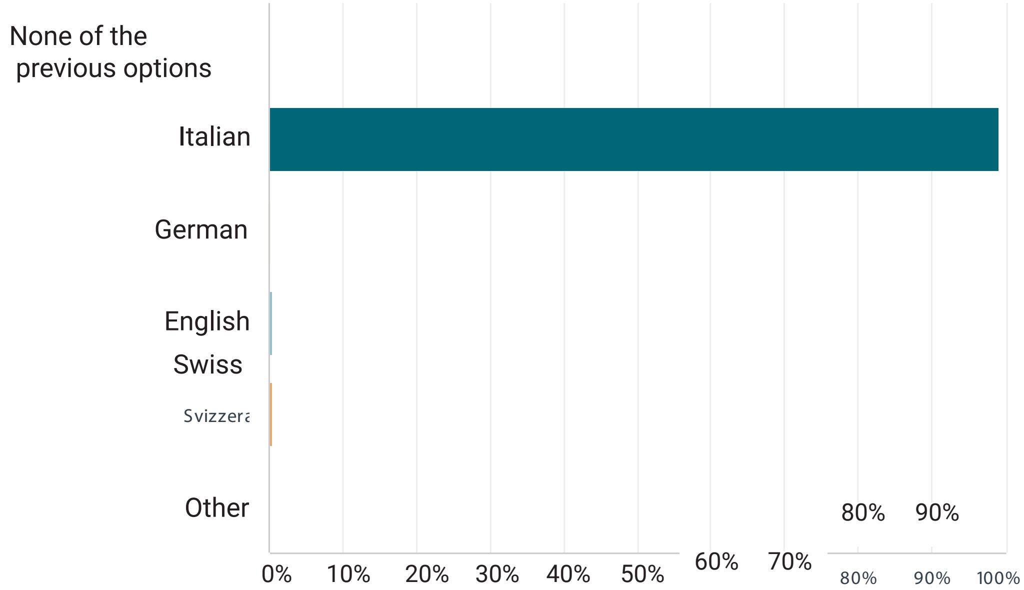
2. How old are you?



Answers options	Answers	
16-30	23.30%	123
30-39	14.96%	79
40-49	24.43%	129
50-59	22.54%	119
60+	14.77%	78
Total	100%	528

Figure 62.

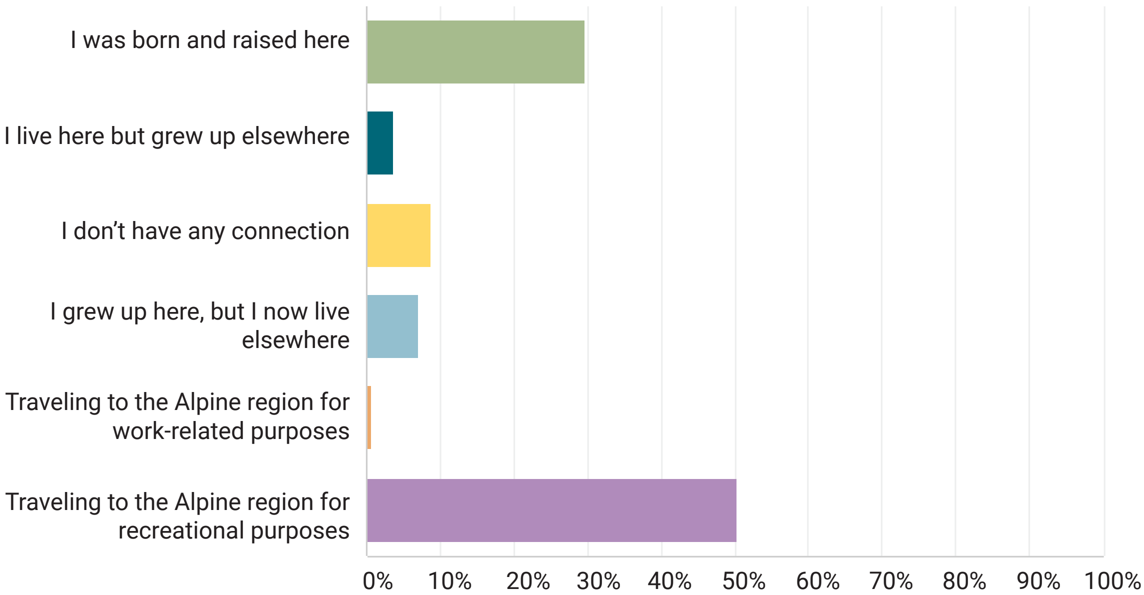
3. What is your nationality?



Answers options	Answers	
None of the previous options	0.00%	0
Italian	99.05%	522
German	0.19%	1
English	0.38%	2
Swiss	0.38%	2
Other	0.00%	0
Total	100%	527

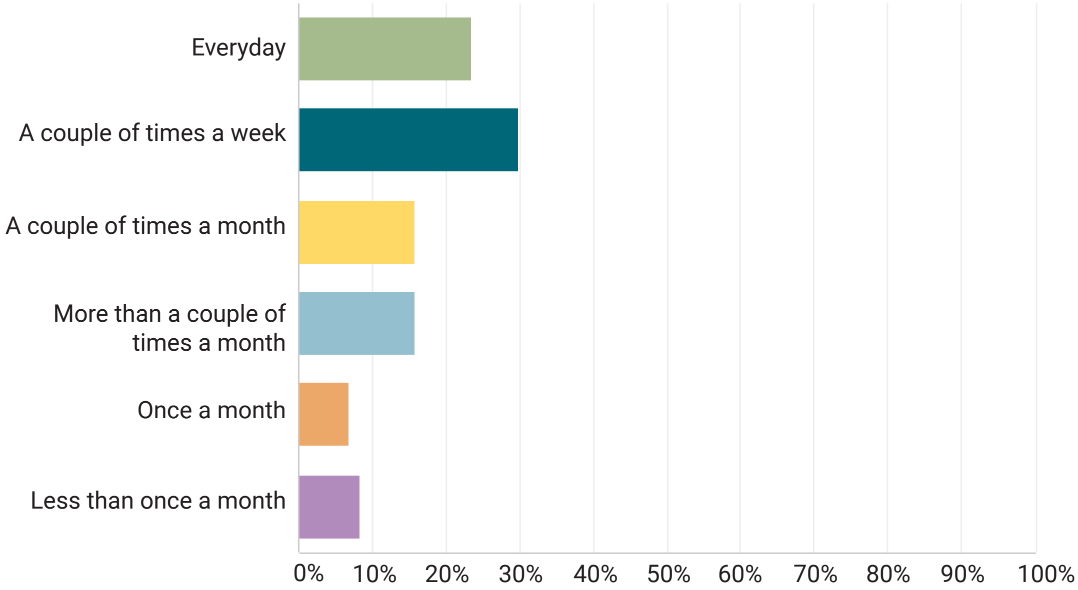
Figure 63.

4. What is your connection to Valchiavenna?



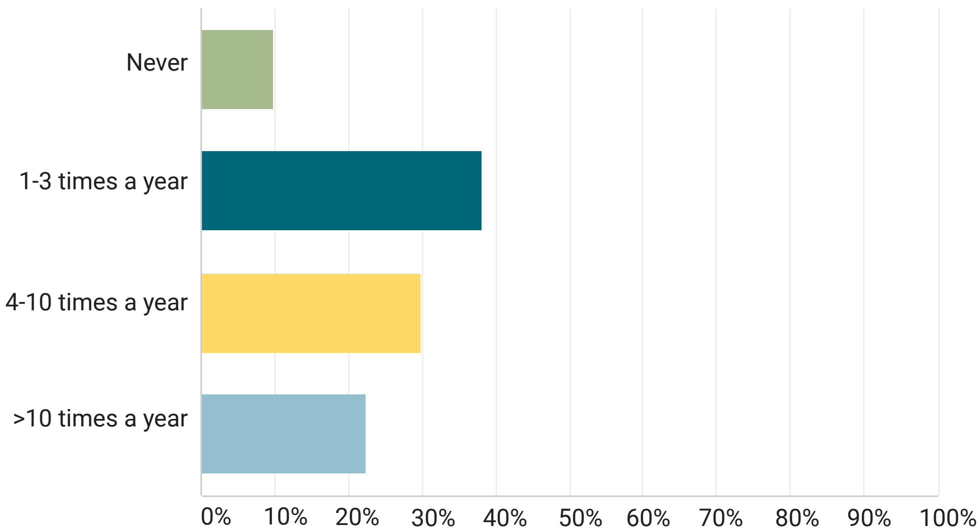
Answers options	Answers	
I was born and raised here	29.71%	156
I live here but grew up elsewhere	3.62%	19
I don't have any connection	8.76%	46
I grew up here, but I now live elsewhere	7.05%	37
Traveling to the Alpine region for work-related purposes	0.57%	3
Traveling to the Alpine region for recreational purposes	50.29%	264
Total	100%	525

Figure 64. 5. How much time do you spend surrounded by nature?



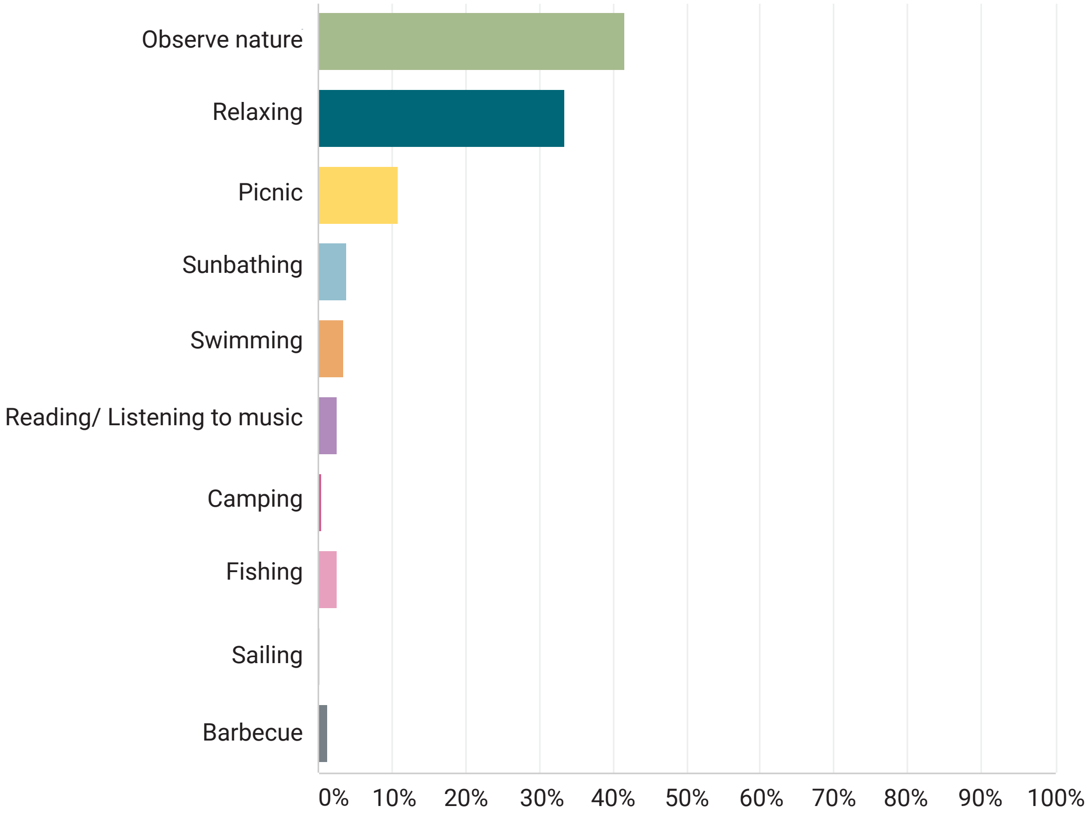
Answers options	Answers	
Everyday	23.53%	124
A couple of times a week	29.79%	157
A couple of times a month	15.75%	83
More than a couple of times a month	15.75%	83
Once a month	6.83%	36
Less than once a month	8.35%	44
Total	100%	527

Figure 65. 6. How often do you visit the Alpine lakes of Valchiavenna?



Answers options	Answers	
Never	9.71%	51
1-3 times a year	38.10%	200
4-10 times a year	29.90%	157
>10 times a year	22.29%	117
Total	100%	525

Figure 66. **7.What activities do you do once you are at the lake?**



Answers options	Answers	
Observe nature	41.49%	217
Relaxing	33.46%	175
Picnic	10.90%	57
Sunbathing	3.87%	20
Swimming	3.44%	18
Reading/ Listening to music	2.49%	13
Camping	0.38%	2
Fishing	0.49%	13
Sailing	0.19%	1
Barbecue	1.34%	7
Total	100%	523

The survey conducted has provided valuable insights into the perception and significance of alpine lakes (Fig. 67-Fig. 71) among both local residents and tourists of Valchiavenna. It revealed that alpine lakes, including Lake Azzurro, hold a special place in the hearts of people residing in the area as well as those visiting as tourists. The survey results highlighted that both groups deeply care about the preservation and conservation of these natural environments. Interestingly, the survey findings indicated that certain age groups displayed a particularly strong interest in alpine lakes. Young people aged 16 to 30 years old showed a significant level of engagement and concern for these ecological treasures. Their enthusiasm and active involvement in advocating for the protection of alpine lakes emphasize the importance of environmental education and awareness-raising initiatives targeted towards this demographic. Moreover, the survey results also revealed that individuals between the ages of 40 and 49 years old exhibited a notable interest in alpine lakes. This age group demonstrated a strong connection to nature and a deep appreciation for the ecological value and beauty of these pristine environments. Their engagement in preserving alpine lakes suggests the presence of a generation that understands the urgency of sustainable practices and the need to safeguard these natural resources for future generations. Overall, the survey provided valuable insights into the broad support and concern for alpine lakes among both local residents and tourists. It emphasized the importance of engaging and empowering younger generations to take an active role in environmental conservation efforts. Additionally, it highlighted the influential role of individuals aged 40 to 49 years old in championing the cause of preserving alpine lakes. By targeting these age groups, efforts can be focused on fostering a sense of responsibility and inspiring collective action to protect and preserve these invaluable ecosystems.

Figure 67.

Lake Truzzo, source: Danilo Ferrario, 2016

Figure 68.

Lake Angeloga, source: Mara Cislaghi, 2022

Figure 69.

Lake Andossi, source: www.orobie.it

Figure 70.

Lake Nero, source: www.paesidivaltellina.it, 2020

Figure 71.

Lake Acquafraggia , source:Naike Sangiorgio, 2023

2.7 Lake Azzurro ecosystem services

Lake Azzurro plays a crucial role in providing a diverse range of ecosystem services (Fig. 72, Tab 7.) that are vital for both the environment and the local community's well-being. These services can be categorized into three main groups: provisioning, regulating, and cultural. The provisioning ecosystem services of Lake Azzurro extend beyond providing food for various wildlife. The vegetation surrounding the lake offers medicinal plants and resources for traditional practices, such as the *Achillea moscata* herbal infusion. Furthermore, the lake's surroundings, characterized by a lush wooded area, create a favorable microclimate that not only helps regulate temperatures but also enhances local biodiversity. The diverse plant and animal species thriving in this habitat contribute to the overall ecological balance, promoting a healthy and resilient ecosystem. In addition to its ecological importance, Lake Azzurro continues to be a cherished cultural landmark. The lake's natural beauty and recreational opportunities attract tourists from far and wide. Visitors can engage in a multitude of activities, such as trekking, sunbathing, swimming, and picnic, allowing them to connect with nature and appreciate the lake's scenic splendor. Moreover, the presence of a chapel near the lake adds a spiritual and religious dimension, attracting pilgrims seeking solace and reflection. Lastly, Lake Azzurro's allure extends beyond its physical attributes, as it has served as a profound source of inspiration for renowned poets, like Giosuè Carducci. Its serene waters, picturesque surroundings, and captivating ambiance have stirred the creative minds of artists throughout the ages, leaving an indelible mark on the realm of literature and artistic expression.

Figure 72.

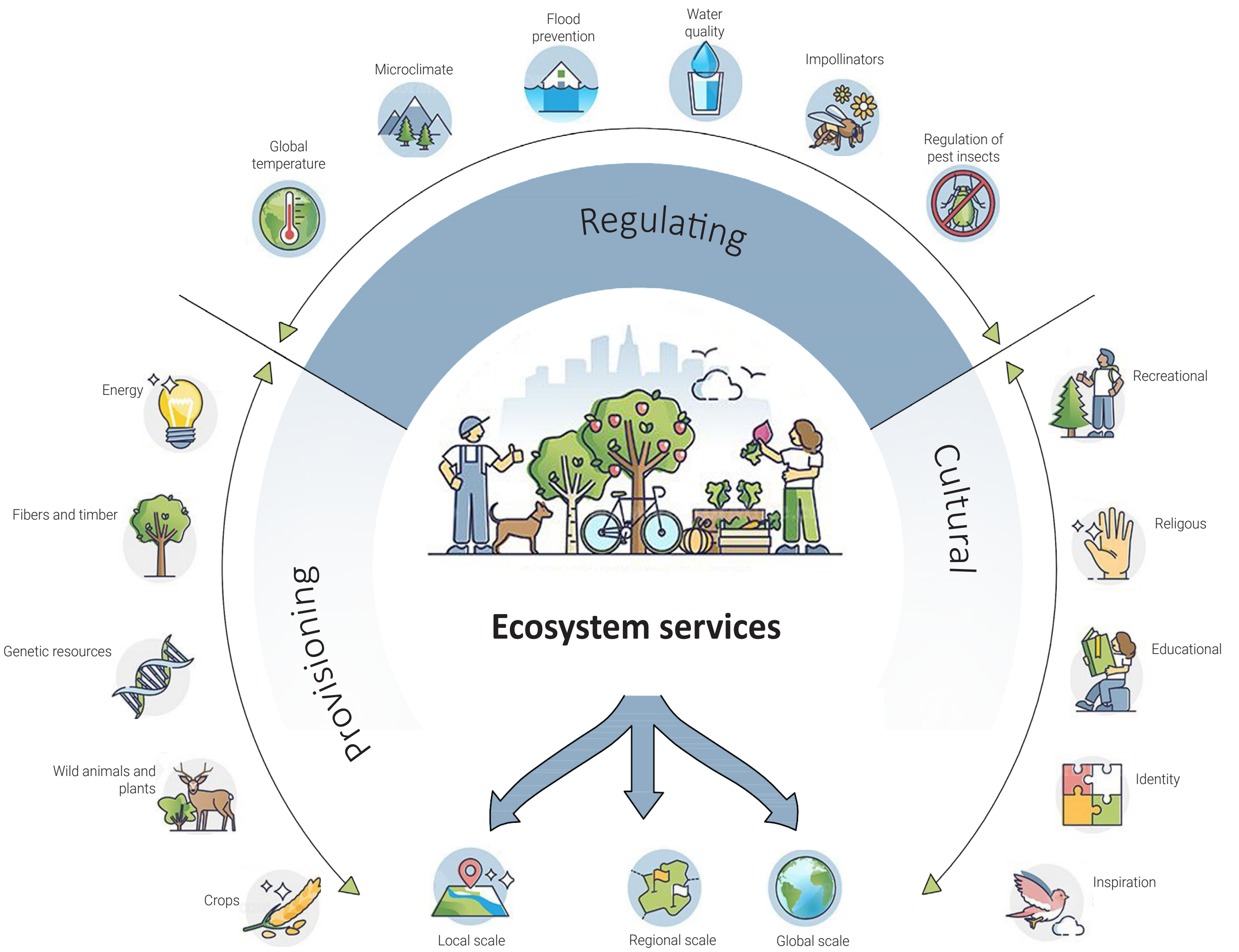


Table 7. Lake Azzurro Ecosystem services

Provisioning	Regulating	Cultural
Providing food for wildlife	Microclimate	Recreational
Providing medicinal plants	Impollinators	Religious
		Educational

Figure 73.

Lake Azzurro, source: Enrico Caprio, 2020

04

LAKE AZZURRO FUTURE

Possible scenarios

4.1 Two main scenarios

The future of Lake Azzurro hinges on the management of the increasing drying rate, which necessitates a closer examination of potential scenarios. Below, I will delve into two distinct scenarios, each highlighting different dynamics that may unfold.

Scenario 1: Sustainable Management and Conservation

In this optimistic scenario (Fig 74.), proactive and sustainable management practices take center stage to safeguard the future of Lake Azzurro. A comprehensive set of environmental policies and regulations is implemented, prioritizing the protection of the lake's fragile ecosystem. These measures emphasize sustainable water management strategies and responsible land use practices within the surrounding area. The collaborative efforts of local communities, government agencies, and conservation organizations yield fruitful results, leading to effective monitoring programs and targeted restoration initiatives. Under this scenario, Lake Azzurro thrives as a biodiverse ecosystem, teeming with vibrant plant and animal life. The successful conservation efforts not only ensure the preservation of the lake's ecological integrity but also enhance its aesthetic appeal. Visitors, both local and from afar, are drawn to the lake's natural beauty and recognize its profound ecological value. Sustainable tourism practices and educational programs further promote the appreciation and understanding of Lake Azzurro's significance, fostering a sense of stewardship among visitors and locals alike.

Scenario 2: Climate Change Impact and Adaptation

In this alternative scenario (Fig. 74,Fig 75), the impacts of climate change on Lake Azzurro become increasingly evident. Rising temperatures and changing precipitation patterns contribute to fluctuating water levels and ecological disruptions within the lake's ecosystem. These changes necessitate a strategic focus on adaptation measures to mitigate the challenges posed by a shifting climate. Efforts primarily revolve around enhancing the lake's resilience and promoting adaptation through ecosystem-based approaches. Scientists, policymakers, and local communities collaborate closely to devise innovative strategies and interventions. This includes initiatives such as restoring wetlands, implementing sustainable water management practices, and enhancing the connectivity of the surrounding landscape. By adopting a proactive approach to adaptation, Lake Azzurro's ecosystem becomes more robust and adaptable to the changing climate conditions. The lake's ecological dynamics are carefully monitored and managed, allowing for the preservation of vital habitats and the promotion of species resilience. These concerted efforts also aim to maintain the overall health and functionality of the lake's ecosystem services, ensuring its long-term survival in the face of climate uncertainties.

In both scenarios, the collective actions taken by various stakeholders play a pivotal role in shaping the future of Lake Azzurro. By prioritizing sustainable management, conservation, and adaptation strategies, the lake can continue to provide invaluable ecological services while remaining a cherished natural treasure for generations to come.

Figure 74.

Lake Azzurro, source: Alessandro Cabella, 2020

Figure 75.

Lake Azzurro, 2022

CONCLUSION

In conclusion, this thesis has provided a comprehensive analysis of the impacts of climate change on Lago Azzurro, an ecologically significant lake located in Motta. The evidence presented throughout this study unequivocally points to a distressing future scenario: the disappearance of the lake itself. Furthermore, this loss will not only affect the lake but also result in the irreversible disappearance of its vital ecosystem services. Urgent and decisive action is crucial to mitigate the risks posed by climate change and secure the long-term survival of this unique ecosystem.
The examination of historical climate data has highlighted an alarming trend of rising temperatures in the region, accompanied by shifting precipitation patterns. These changes have already begun to exert immense pressure on Lago Azzurro, leading to dwindling water levels and altering the lake's hydrological dynamics. Consequently, the ecological consequences are far-reaching, impacting the interconnected web of life that relies on the lake's ecosystem services for their existence and sustenance.
Projections of future climate scenarios paint a stark and troubling picture for Lake Azzurro, as the risks and challenges are set to intensify. The projected increases in temperature, coupled with potential shifts in rainfall patterns, will exacerbate the precarious situation of the lake. The accelerated melting of glaciers, which contribute to the lake's water supply, combined with altered rainfall patterns, may result in prolonged droughts or intense rainfall events, further destabilizing the lake and ultimately leading to its disappearance.
To address these risks and protect the invaluable ecosystem services provided by Lake Azzurro, immediate and collaborative action is imperative. A comprehensive adaptation strategy must be developed, integrating measures to enhance water resource management, conserve biodiversity, and promote sustainable land-use practices within the lake's catchment area. The involvement of governmental bodies, scientific institutions, local communities, and stakeholders is vital for the successful implementation, monitoring, and ongoing evaluation of these measures.
Moreover, it is paramount to raise public awareness about the vulnerable state of Lake Azzurro and the urgent need for climate change mitigation. Educational campaigns and outreach initiatives should be employed to foster a sense of responsibility and drive behavioural changes that contribute to the preservation of this unique ecosystem and its associated services.
In conclusion, the future scenario of Lake Azzurro is one of its impending disappearance (Fig 49.). This sobering reality underscores the urgency of our collective responsibility to act now. The potential loss of the lake, along with its crucial ecosystem services, would have profound consequences. The disappearance of Lake Azzurro would disrupt the delicate balance of the surrounding ecosystem, depriving local communities and future generations of its numerous benefits, including clean water, habitat provision, climate regulation, and recreational opportunities.
The future of Lake Azzurro hangs in the balance, demanding immediate action and a resolute commitment to climate change mitigation. It is crucial to implement sustainable strategies and policies that preserve the lake's ecosystem and ensure its continued existence. Only through concerted efforts Lago Azzurro and its ecosystem services can be safeguard, leaving a legacy of ecological integrity and resilience for generations to come.

Figure 76.

Lake Azzurro, Alessandro Ceppi, 2023

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APPENDIX

CHAPTER1: Valchiavenna climatic framework further analysis

1.1 Yearly mean temperature at Madesimo Spluga (1915m a.s.l)

1.2 Yearly mean precipitation at Madesimo Spluga (1915m a.s.l)

1.3 Yearly mean temperature at Chiavenna (333 m a.s.l)

1.4 Yearly mean precipitation at Chiavenna (333m a.s.l)

1.5 Yearly mean temperature at Gordona (1362m a.s.l)

1.6 Yearly mean precipitation at Gordona (1362m a.s.l)

1.7 Yearly mean temperature at Prata Camportaccio (1035m a.s.l)

1.8 Yearly mean temperature at Samolaco (206m a.s.l)

1.9 Yearly mean precipitation from at Samolaco (206m a.s.l)

1.10 Yearly mean temperature at San Giacomo Filippo (2064m a.s.l)

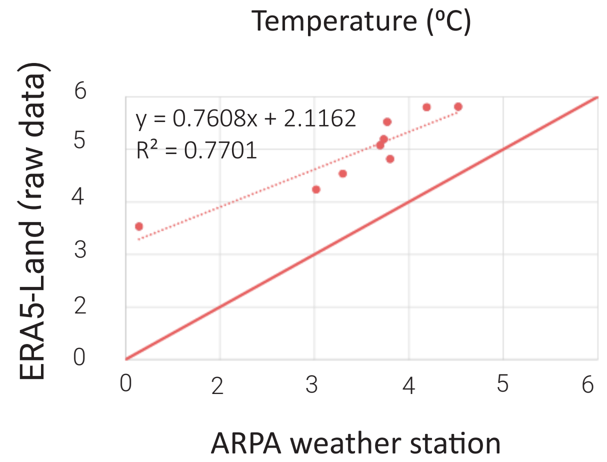
1.11 Yearly mean precipitation from 1950 to 2022 in San Giacomo Filippo (2064m a.s.l)

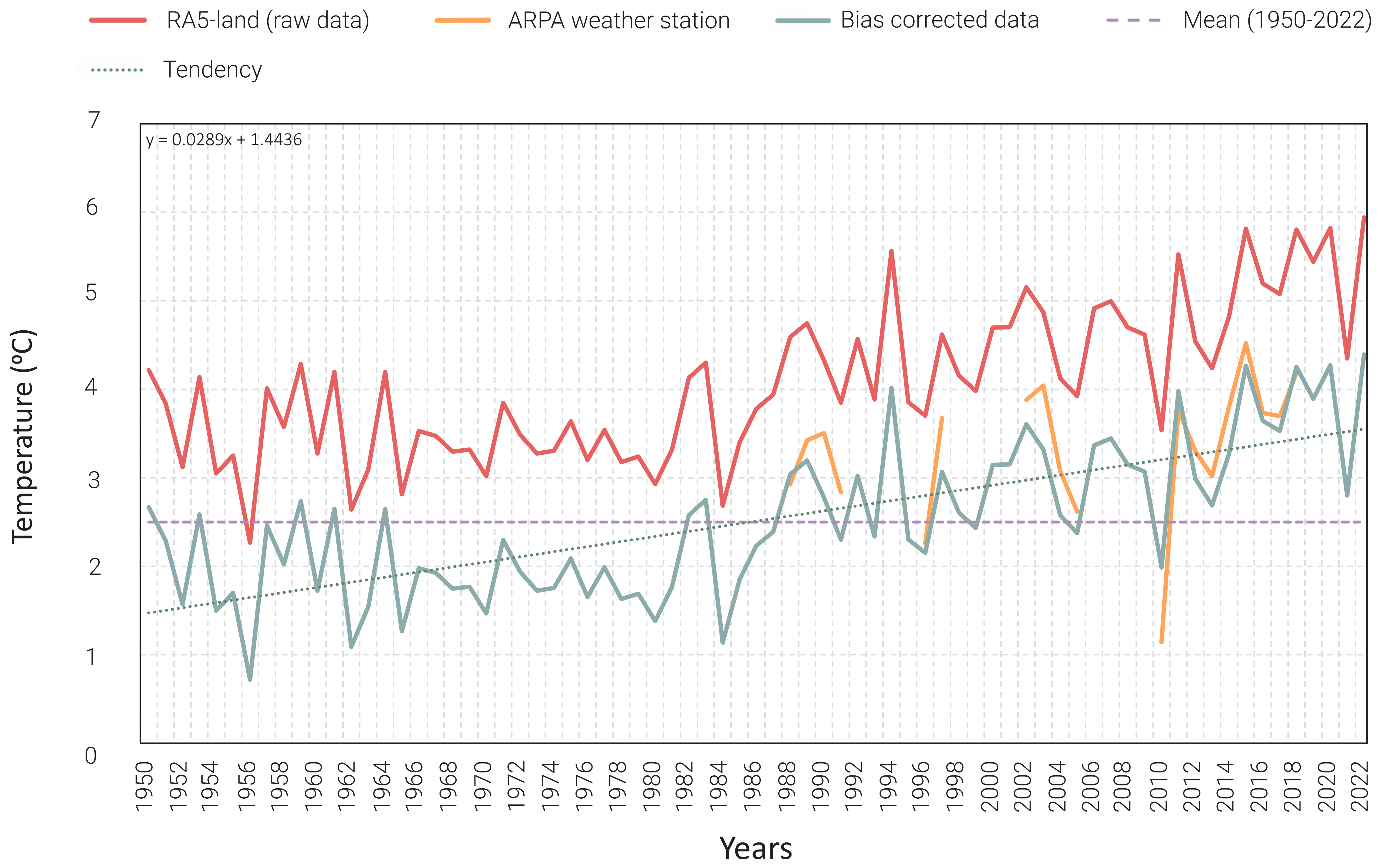
1.12 Yearly mean precipitation at San Giacomo Filippo (2064m a.s.l)

1.13 Yearly mean temperature at Villa di Chiavenna (665m a.s.l)

1.14 Yearly mean precipitation at Villa di Chiavenna (665m a.s.l)

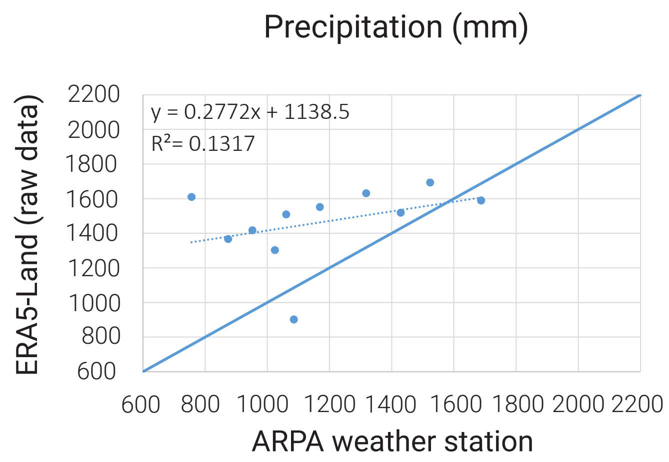
1.1 Yearly mean temperature at Madesimo Spluga (1915m a.s.l)

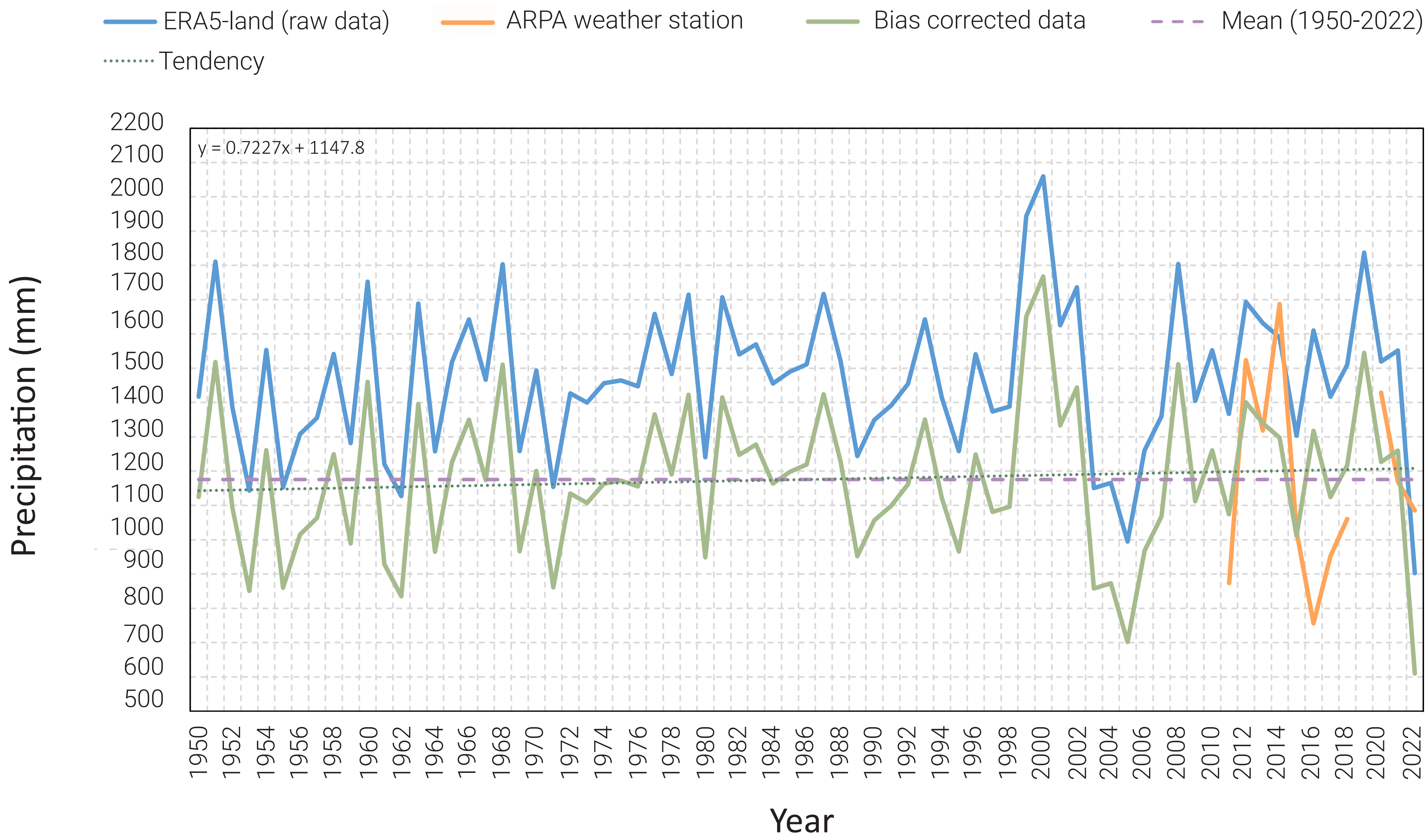




1.2 Yearly mean precipitation at Madesimo Spluga (1915m a.s.l)

Unheated rain gauge





1.3 Yearly mean temperature at Chiavenna (333 m a.s.l)

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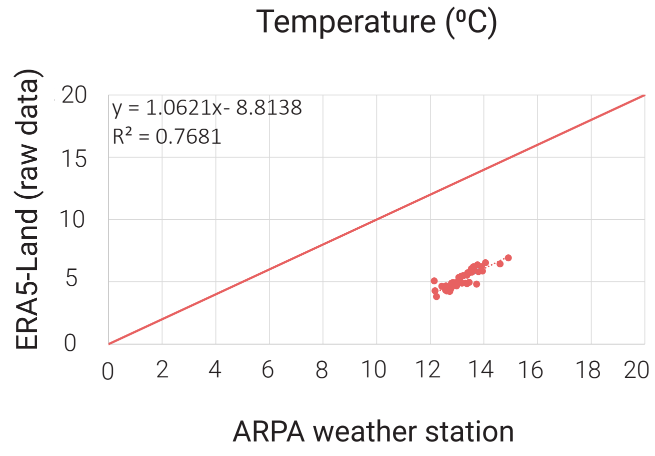
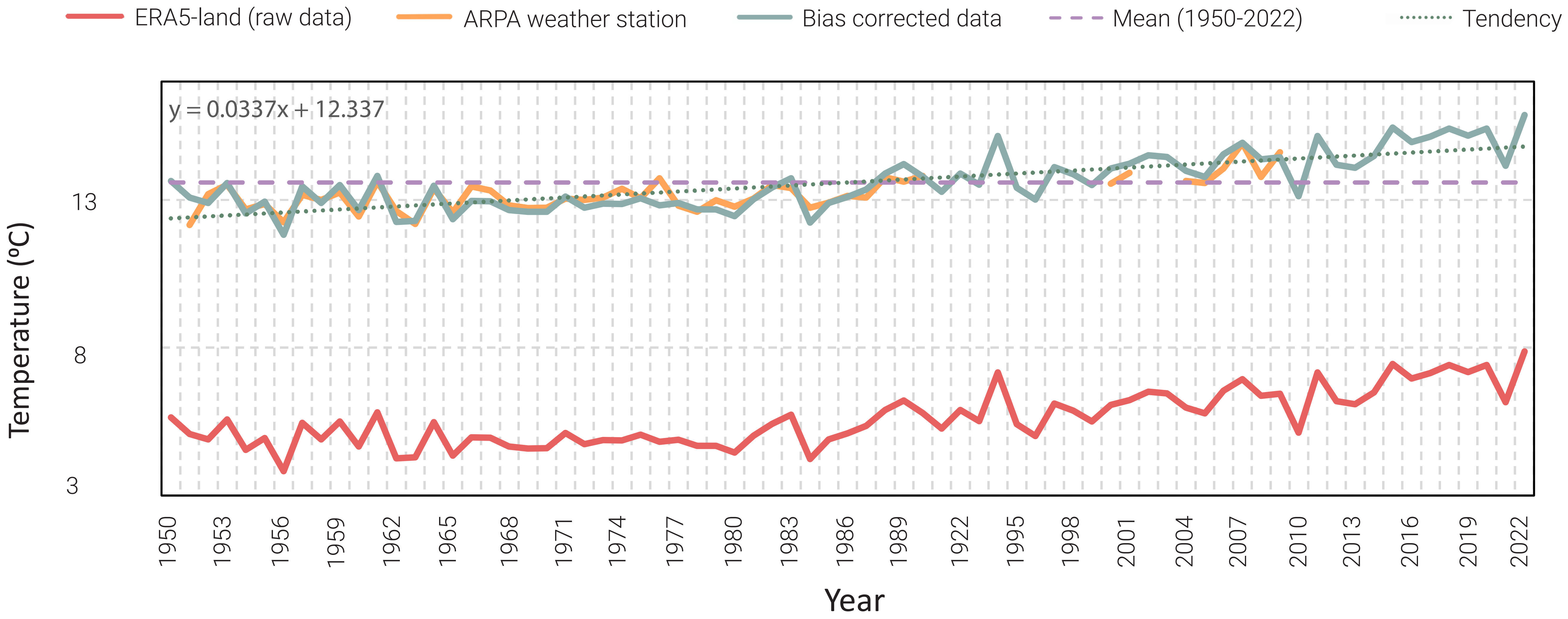
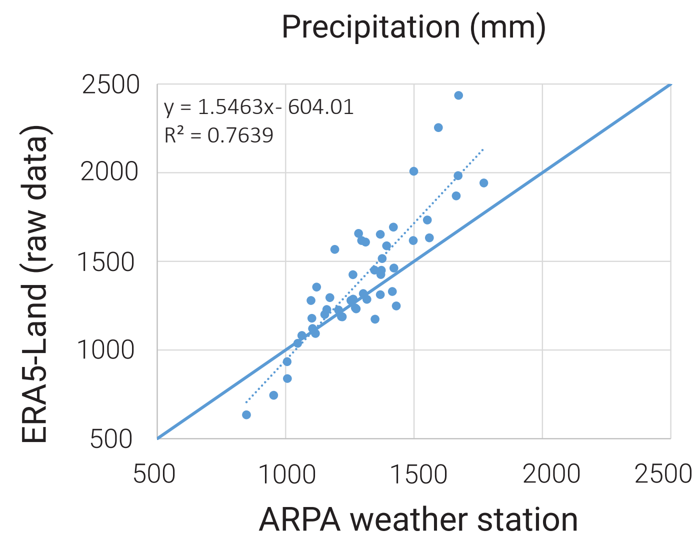


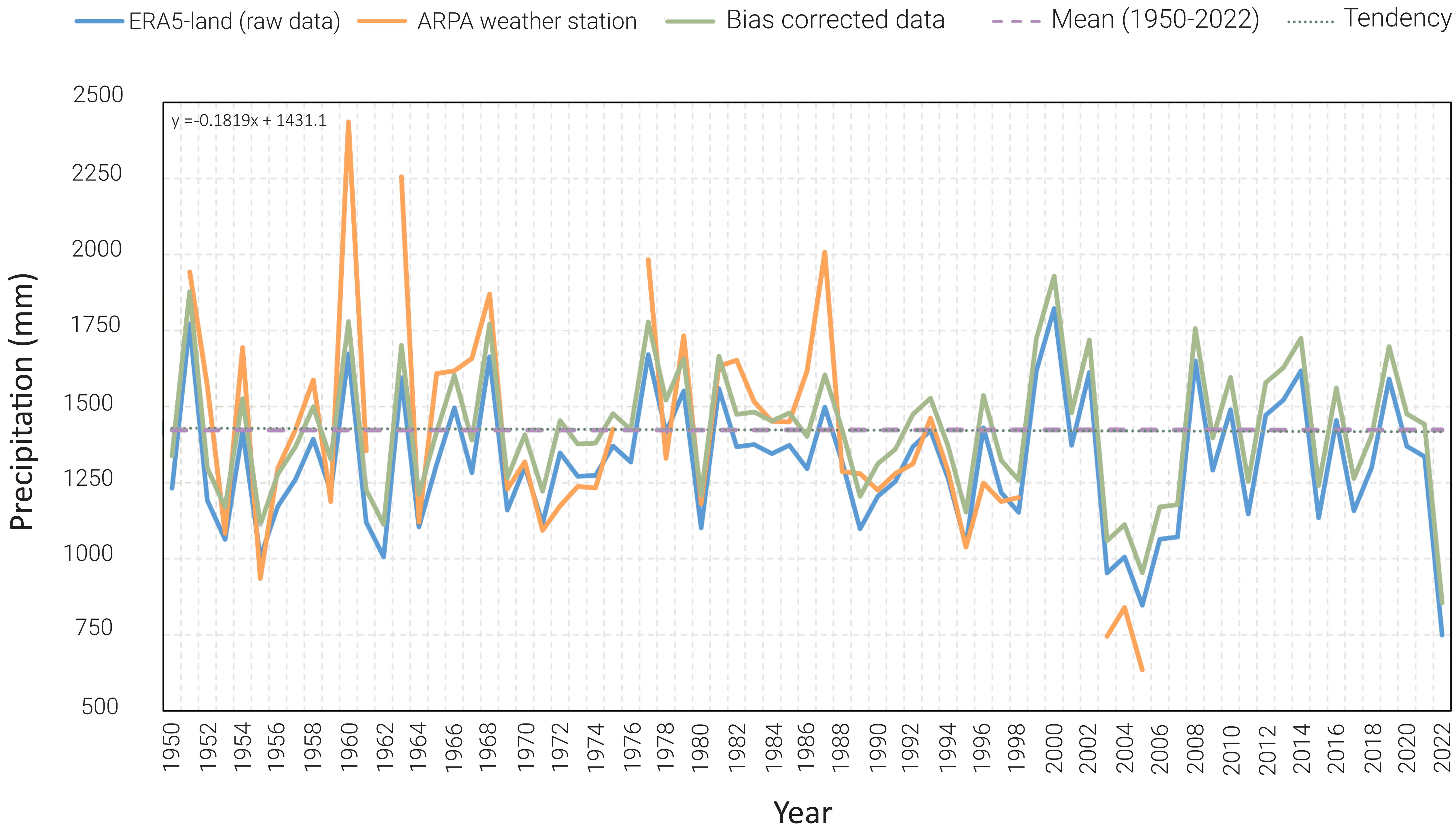


1.4 *Yearly mean precipitation at Chiavenna (333m a.s.l)*

Unheated rain gauge

Università Statale di Milano is thanked for the homogenized historic data series.





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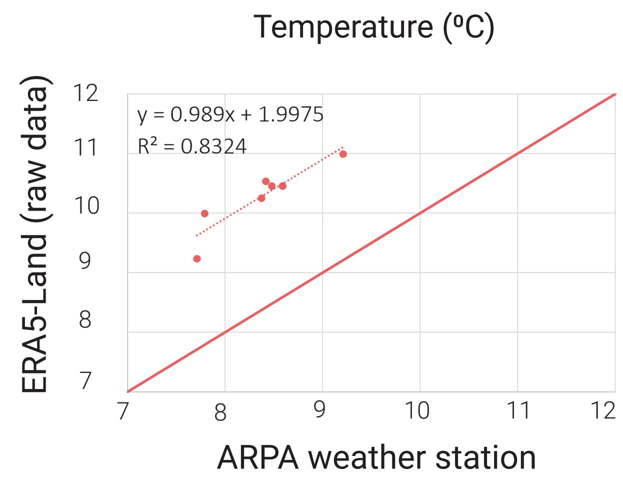
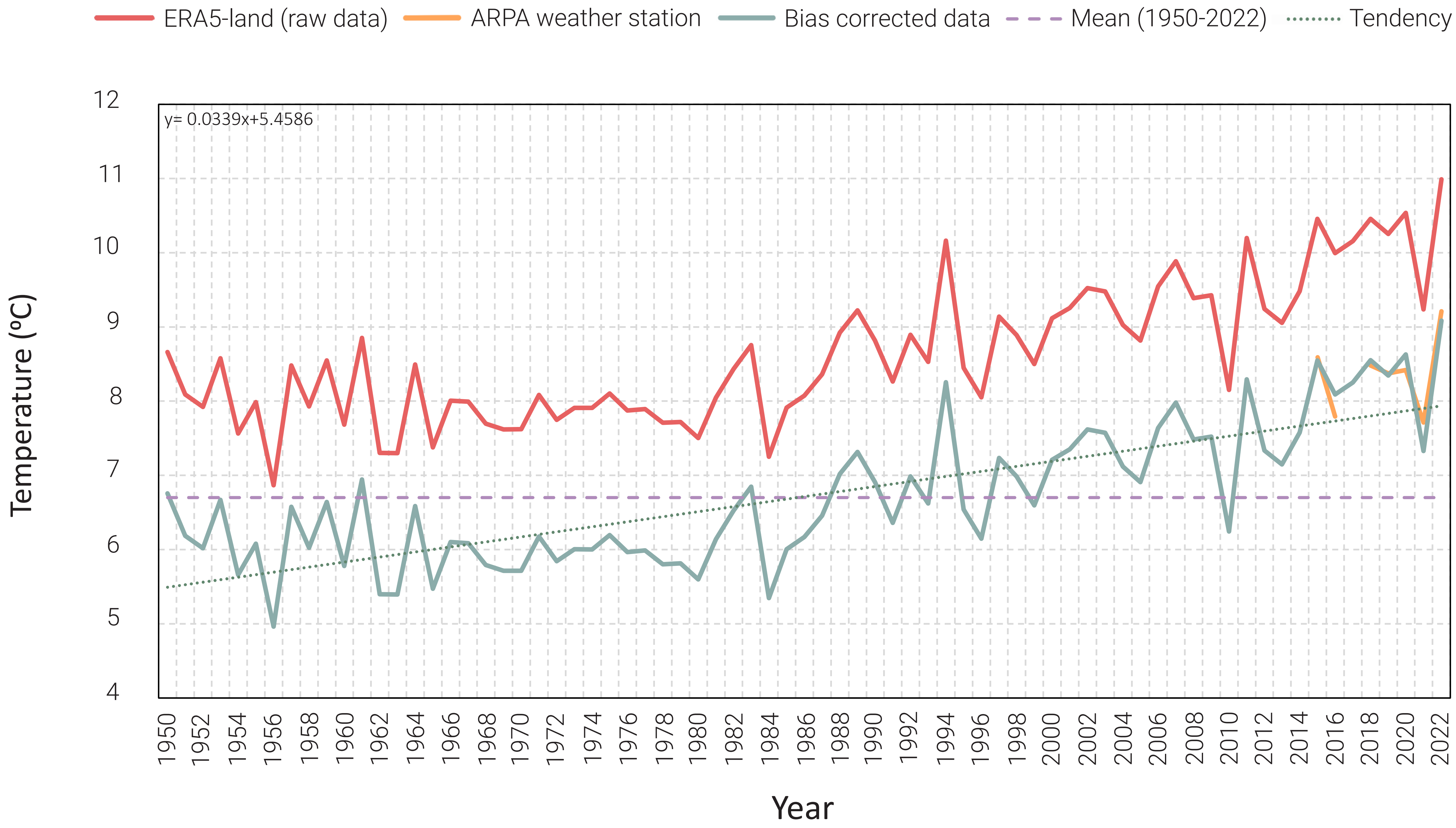
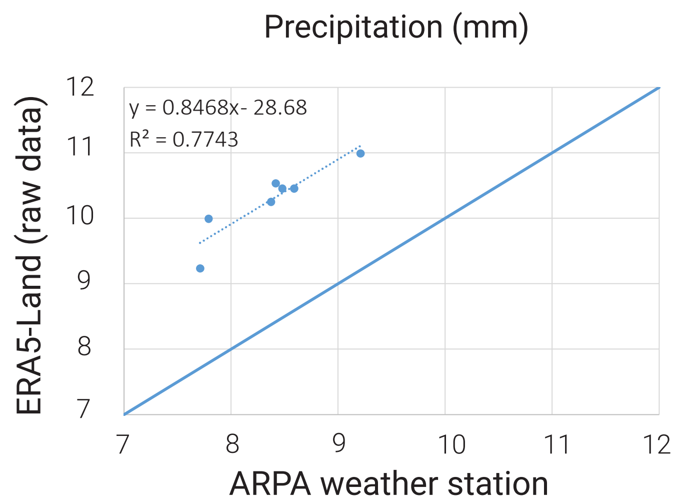
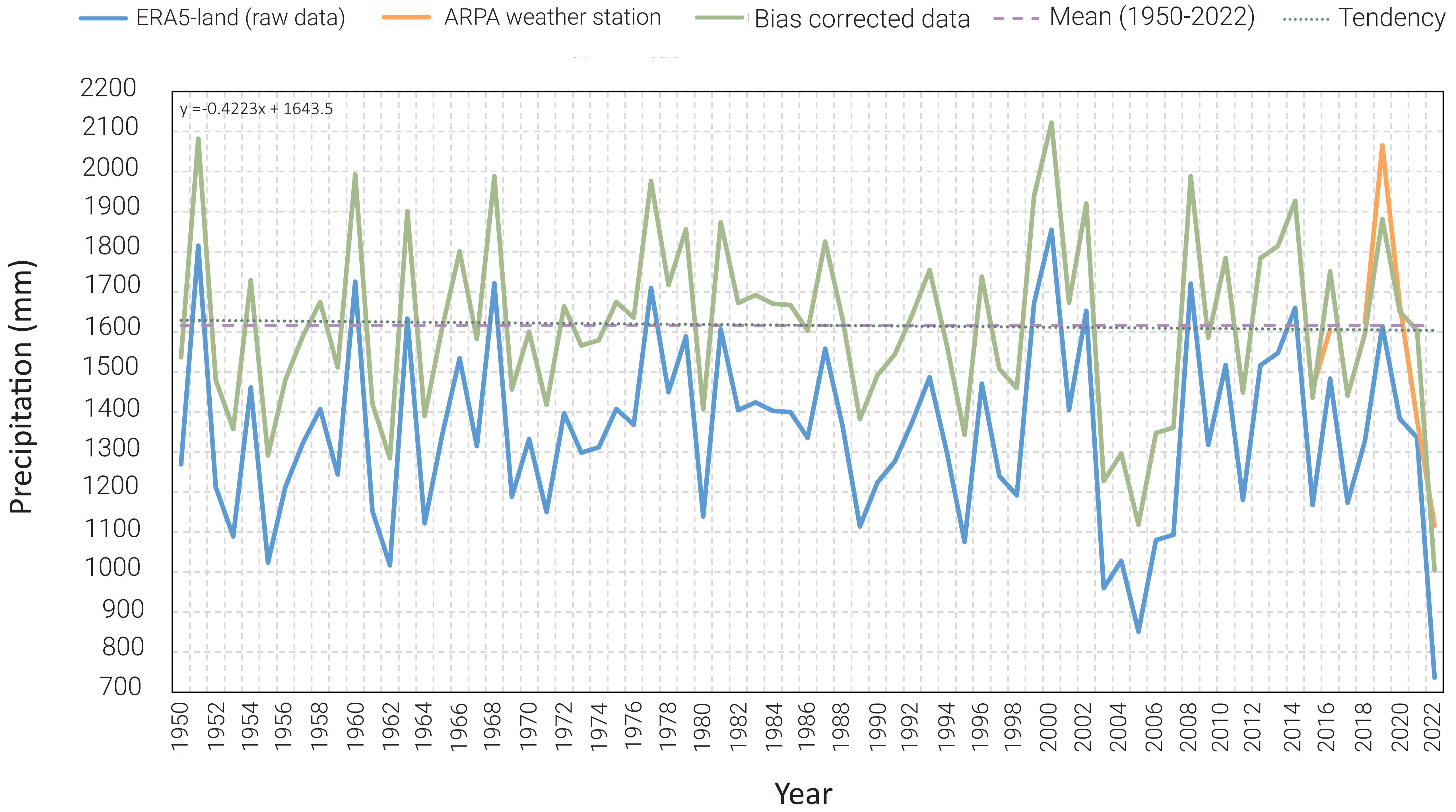




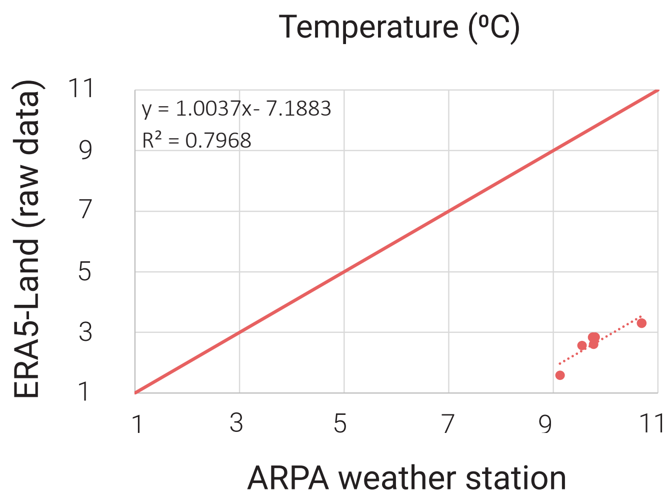
1.6 Yearly mean precipitation at Gordona (1362m a.s.l)

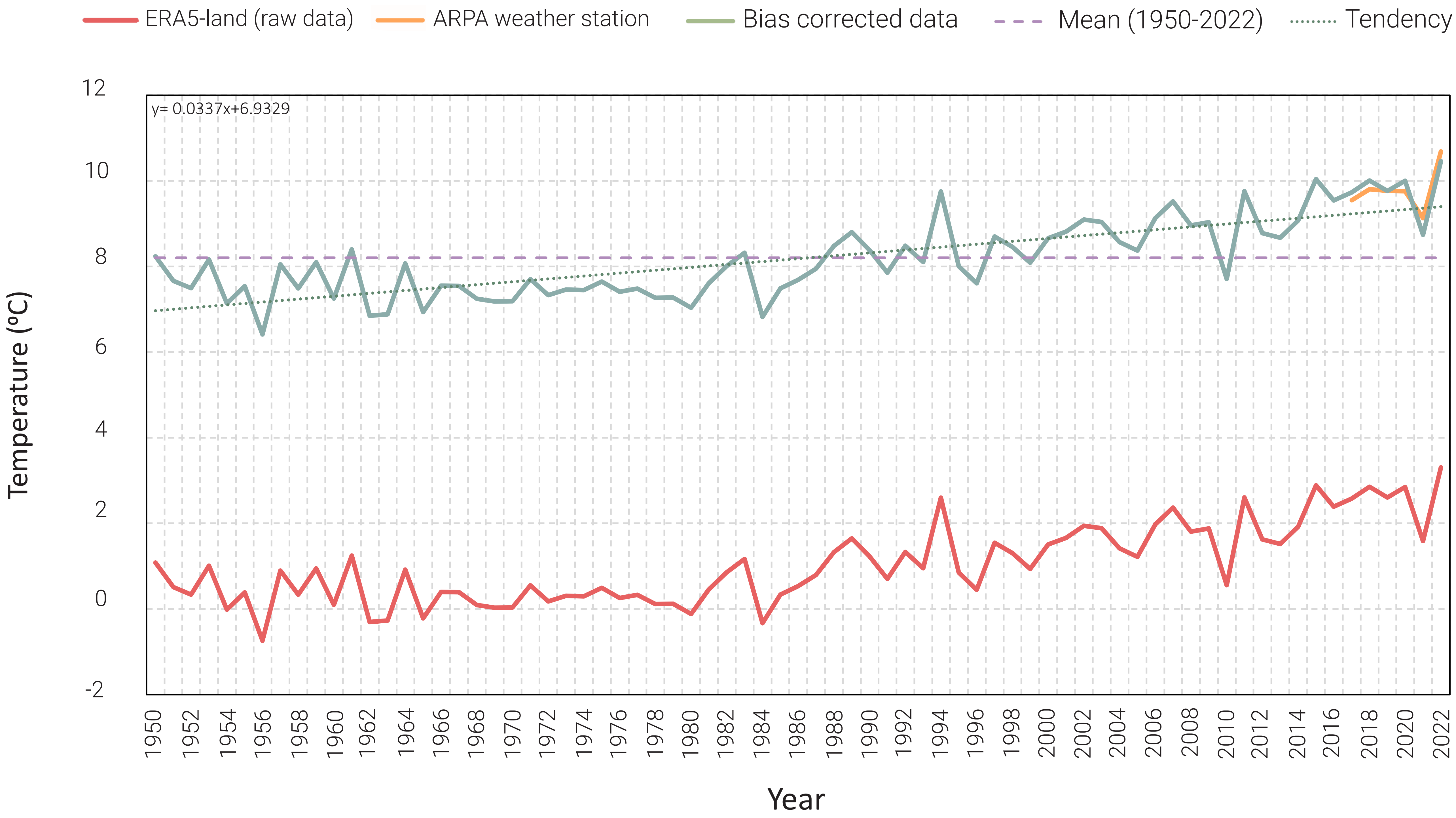
Heated rain gauge





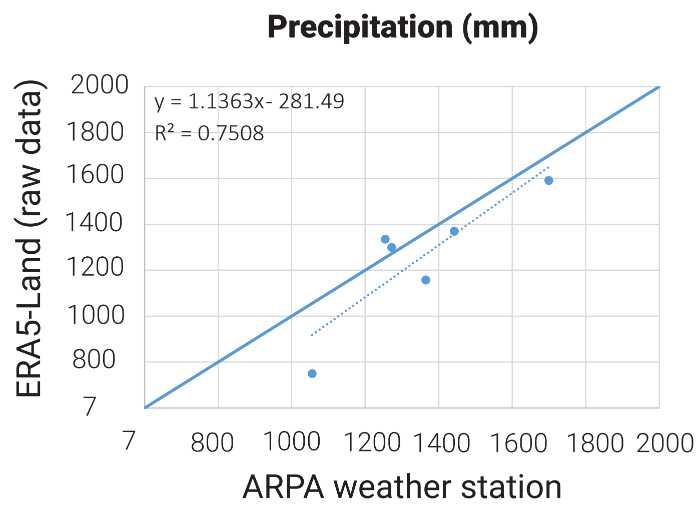
1.7 *Yearly mean temperature at Prata Camportaccio (1035m a.s.l)*

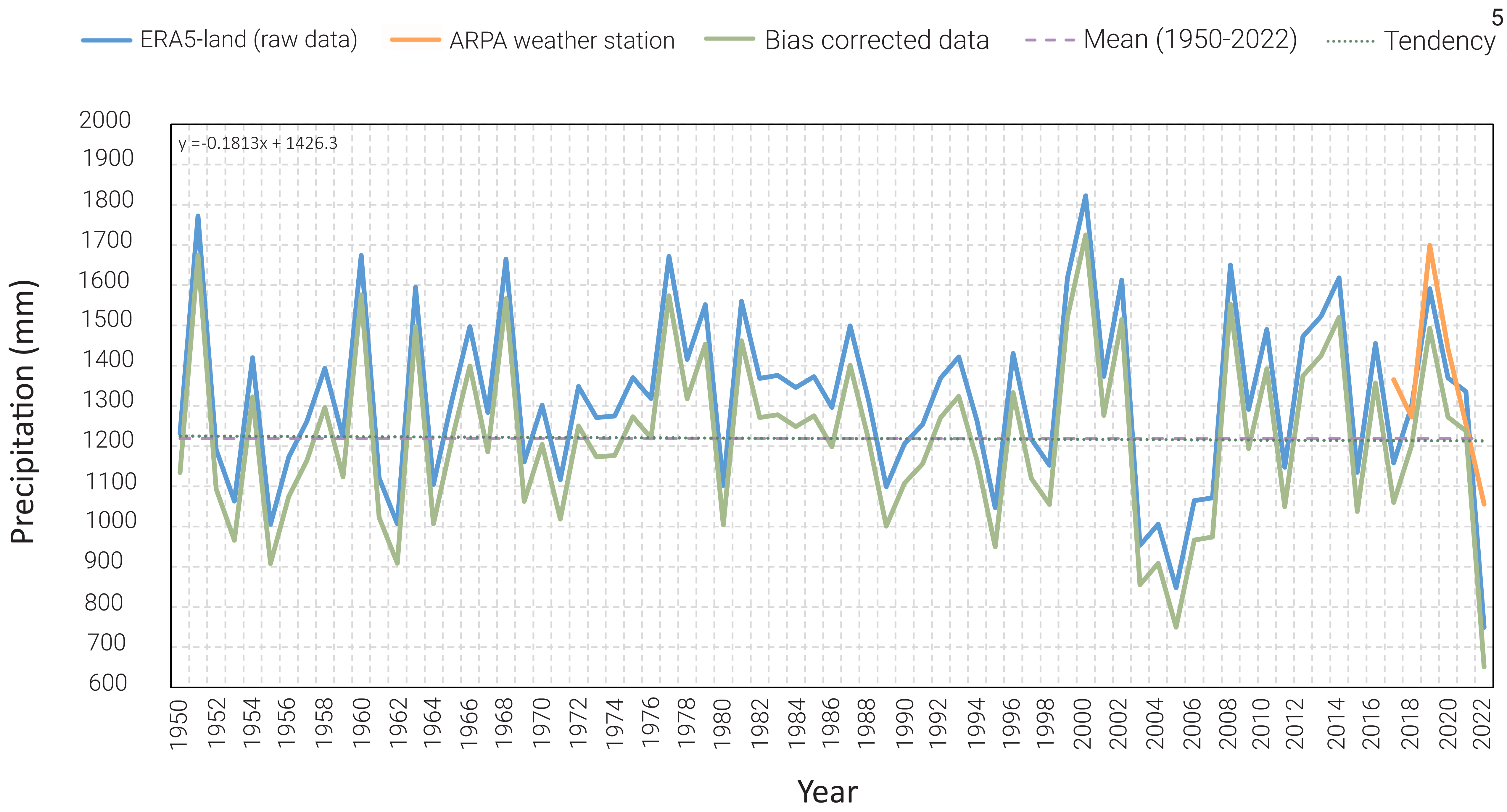




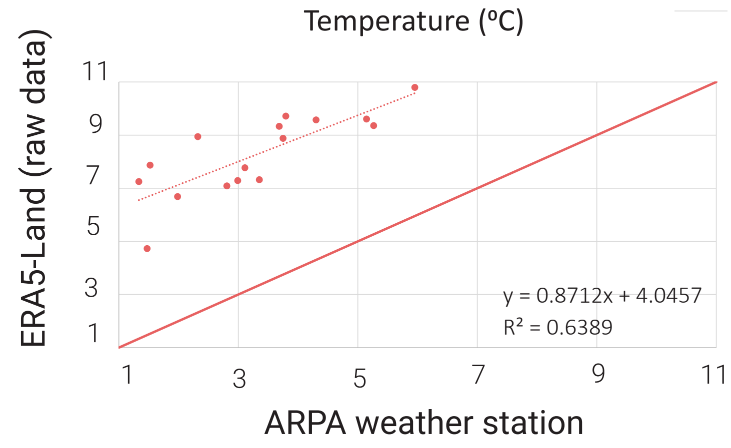
1.8 *Yearly mean precipitation at Prata Camportaccio (1035m a.s.l)*

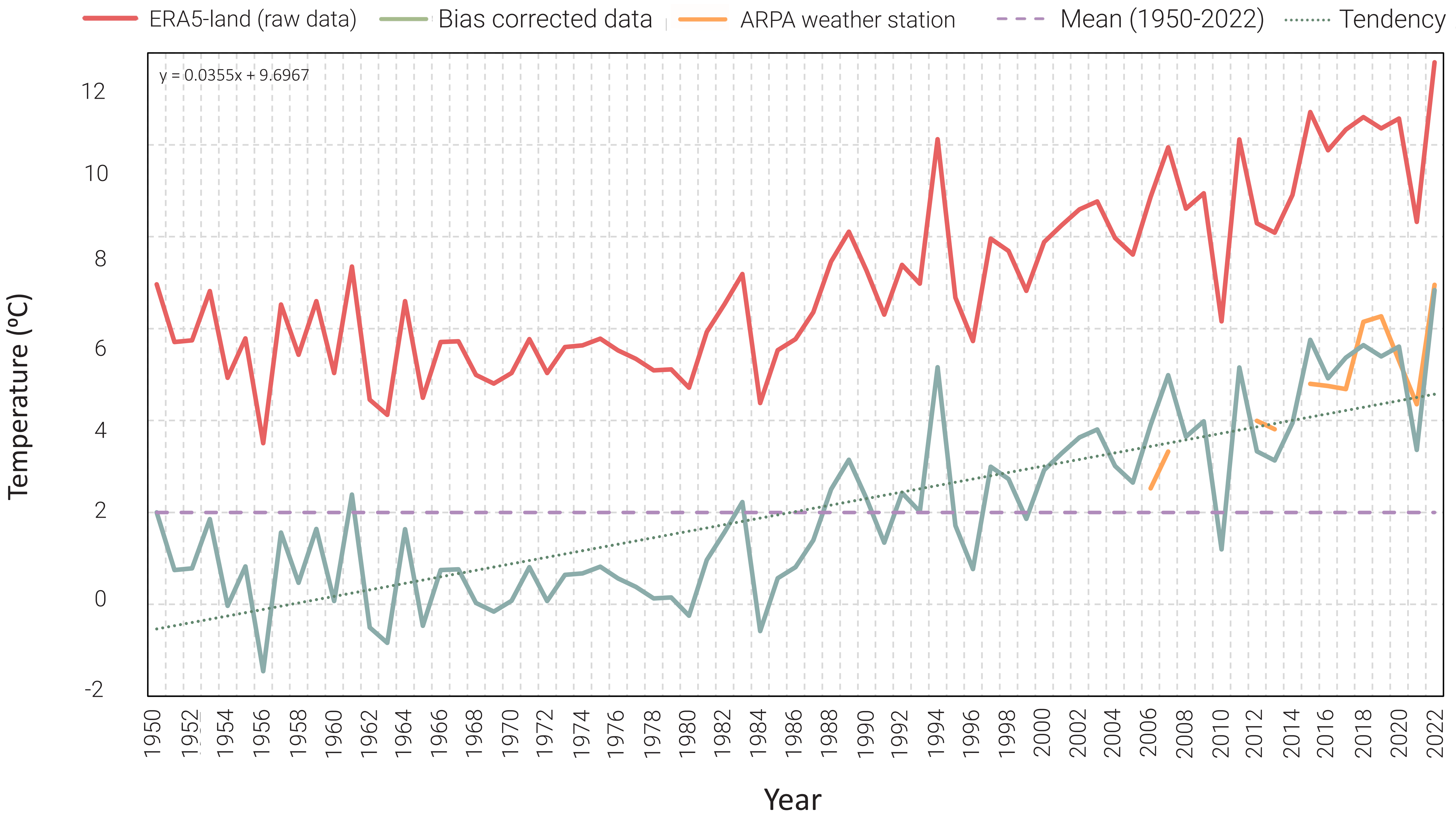
Unheated rain gauge





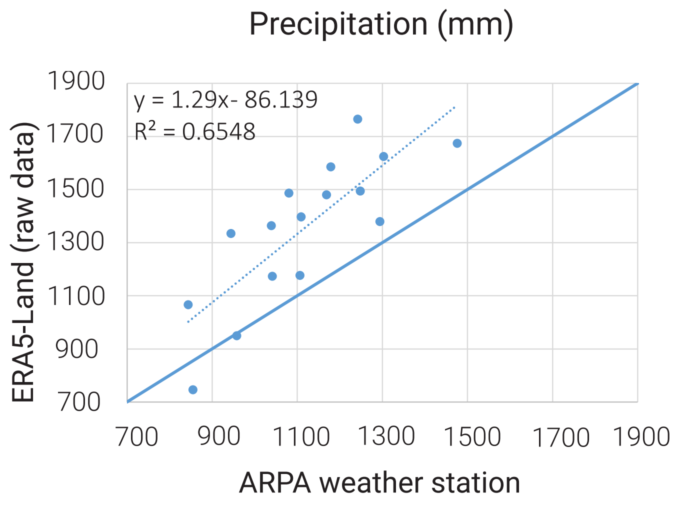
1.9 *Yearly mean temperature at Samolaco (206m a.s.l)*

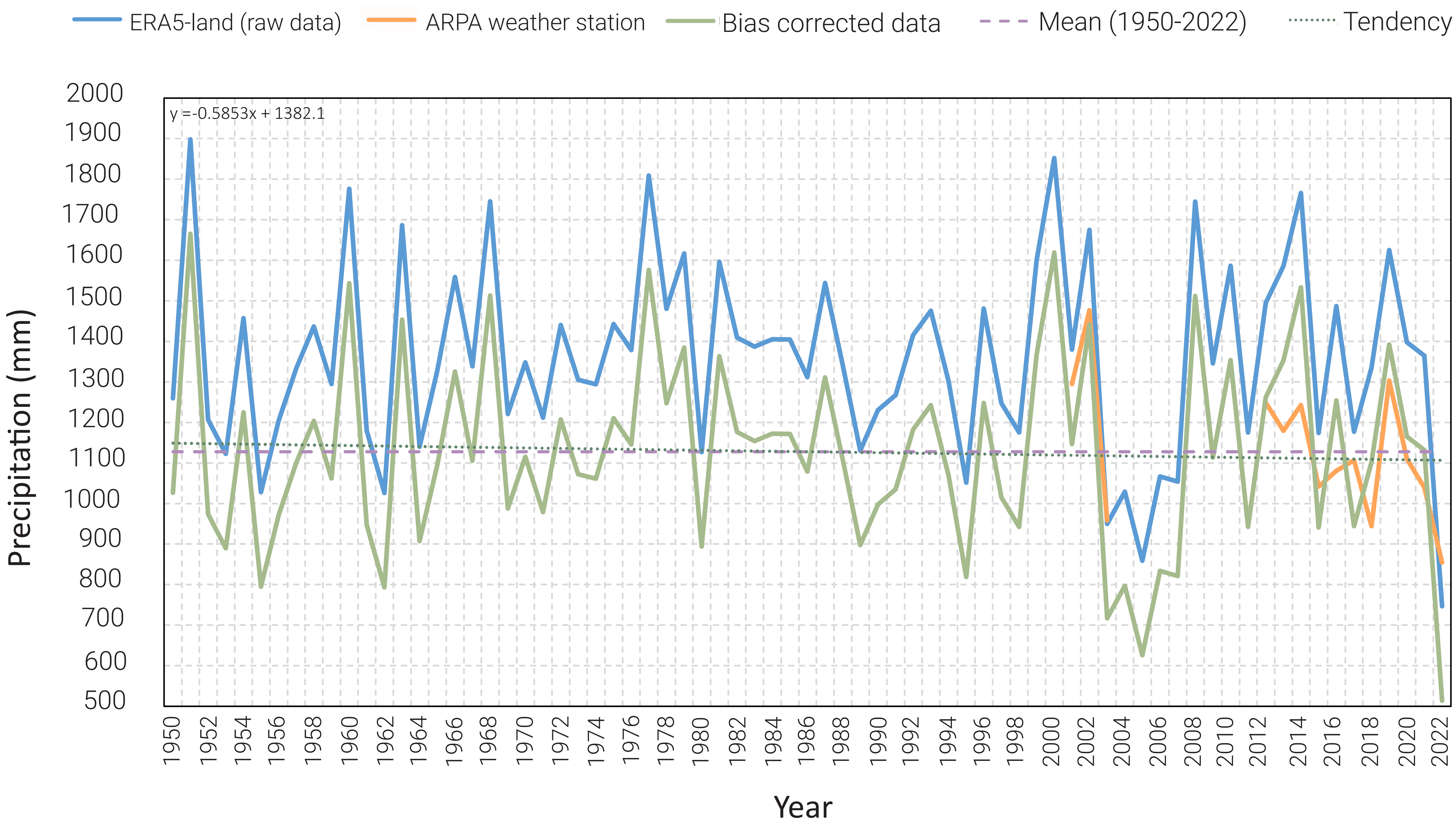




1.10 *Yearly mean precipitation from at Samolaco (206m a.s.l)*

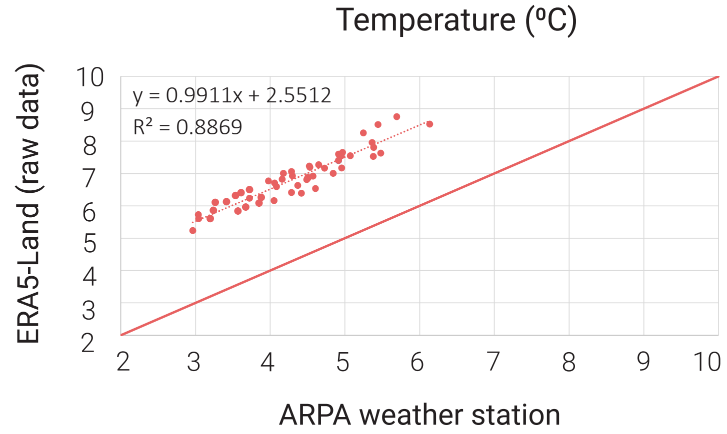
Unheated rain gauge

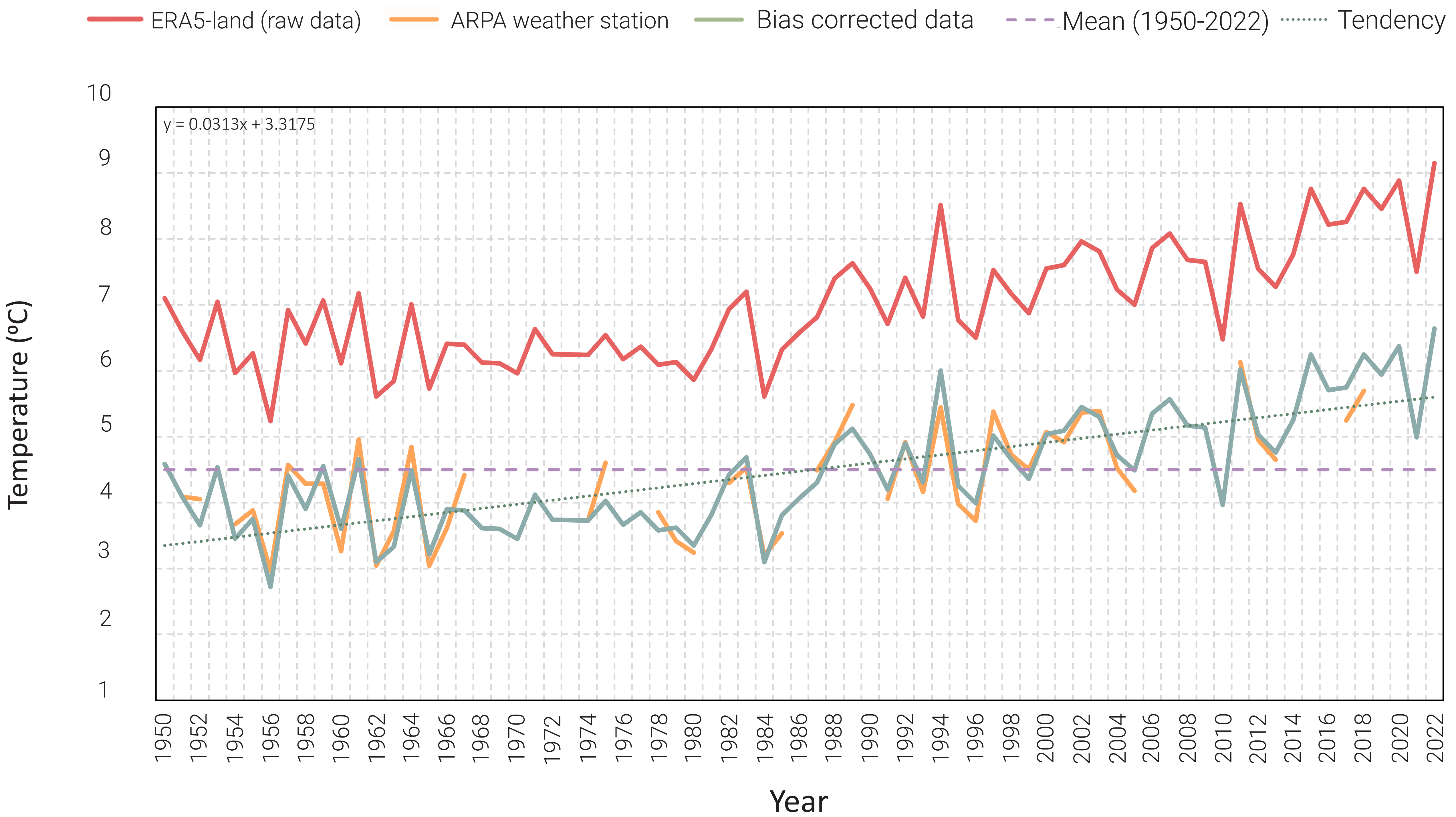




1.11 *Yearly mean temperature at San Giacomo Filippo (2064m a.s.l)*

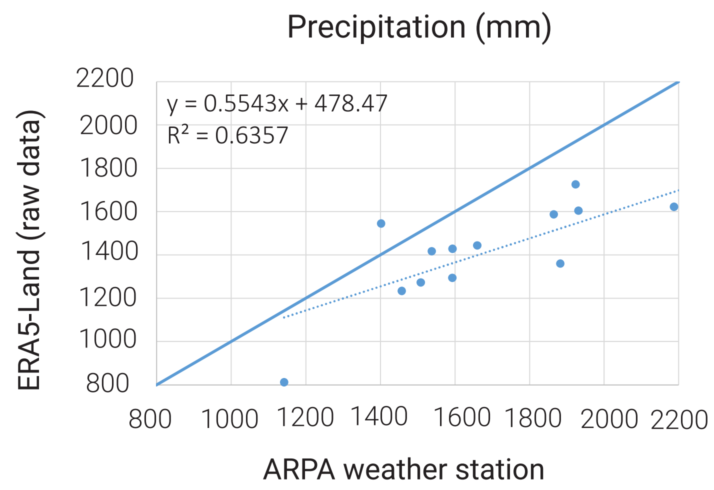
CNR-ISAC is thanked for the homogenized historic data series.

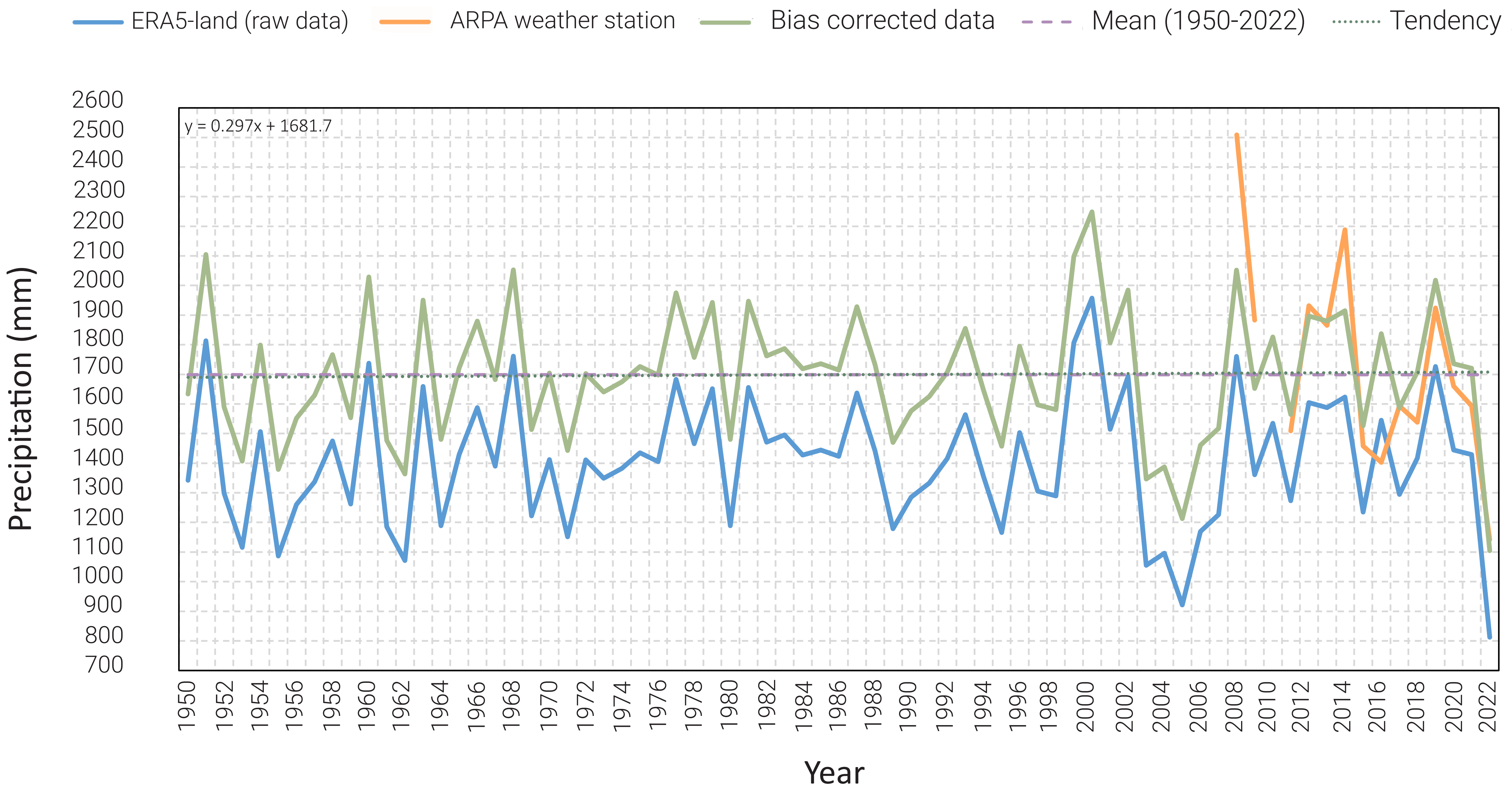




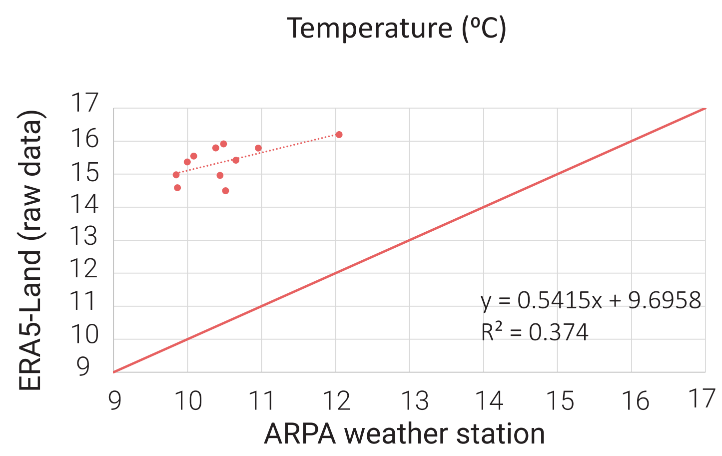
1.12 *Yearly mean precipitation at San Giacomo Filippo (2064m a.s.l)*

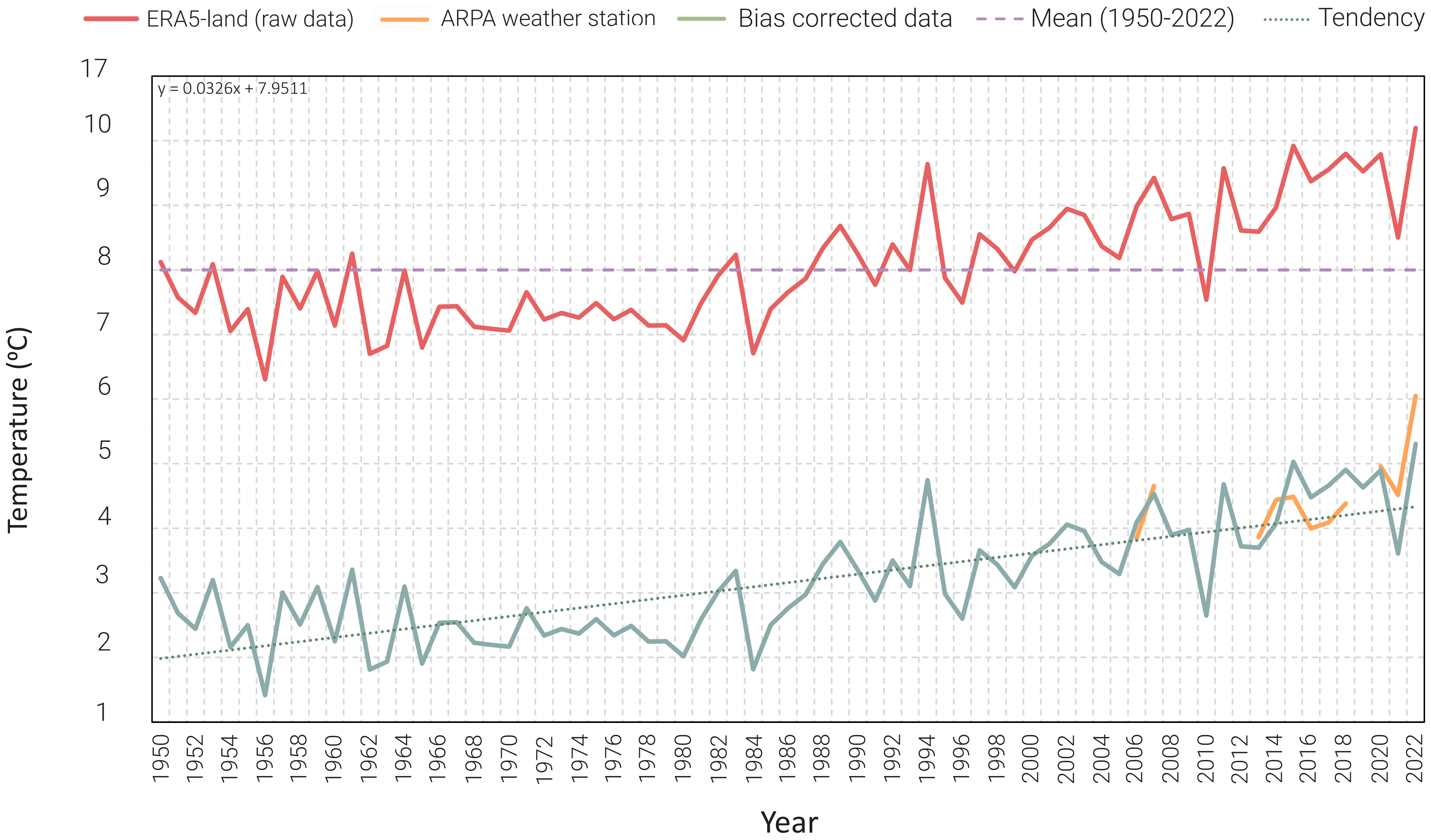
Heated rain gauge





1.13 *Yearly mean temperature at Villa di Chiavenna (665m a.s.l)*





1.14 *Yearly mean precipitation at Villa di Chiavenna (665m a.s.l)*

Unheated rain gauge