LIFE TERRACESCAPE

“Employing Land Stewardship to transform terraced landscapes into green infrastructures to better adapt to climate change”

Report on the micro-climate of the pilot areas before and after project interventions

Deliverable 2

Version 1 - October 2022

The LIFE16 CCA/GR/000050 project is implemented by the University of the Aegean, Municipality of Andros, Green Fund, National and Kapodistrian University of Athens, Hellenic Agricultural Organization – DEMETER and National Observatory of Athens with the financial support of the European Union.

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CLIMADAPT Group

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EXECUTIVE SUMMARY

This report is the second deliverable of action C.5, entitled «**Report on the micro-climate of the pilot areas before and after project interventions** ». Action C.5 is undertaken (solely) by the National Observatory of Athens (NOA) and took place from July 2018 until October 2022. The Aegean islands, characterized by strong relief and low vegetation cover, are a region of high desertification risk. Impacts of climate change are expected to affect significantly the local economy, including the agricultural sector.

The main goal of this report is to assess, at the demonstration areas that experienced project interventions (renewed cultivation of abandoned terraces), if the anticipated improvement of air humidity (i.e. increase compared to non-intervention sites) and air temperature (i.e. decrease compared to non-intervention sites) is detectable. To this end, changes in temperature and humidity between weather sensors at locations that did (not) experience project interventions were examined. Using the observational meteorological data collected, an in-depth time-series analysis for the study areas was performed.

In the framework of the LIFE Terracescape project, NOA assessed the island's vulnerability to climate change and analyzed micro-climatic changes at demonstration sites. A network of fourteen meteorological stations (12 small autonomous stations and 2 automated) were installed on Andros Island by NOA at selected project plots. Recorded meteorological parameters were used in this micro-climate assessment of pilot areas, with and without project interventions. Six of the terraces/plots with meteorological stations experienced interventions that concern cultivation of the abandoned terraces with barley for (some of) the 4 growing seasons (October -June).

Data for the microclimate assessment were generated by: [1] the meteorological station of Moustakeio that is fully automated and provides online (https://www.iersd.noa.gr/WeatherOnLine/s_Andros1/meteo_tableGR.html) data in 1-min time steps (air temperature & relative humidity, wind speed & direction, air pressure, precipitation and solar radiation intensity), and [2] 12 small autonomous stations that record daily air temperature & relative humidity fluctuations. Data from the new online automated Panachrantou station (installed in July 2022) have been excluded from the microclimate analysis, due to the short time of recordings (2 months); this station will be mainly used for the needs of after LIFE activities. Up to October2022, NOA recorded 8 data-series with a total length of 39 months, and 5 data-series with a total length of 51 months.

Daily (or monthly) mean air temperature recordings ranged from a minimum of 5 (or 12)^{0}C to a maximum of more than 35^{0}C (or 27 ^{0}C, respectively) over the period June 2018 – September 2022 at the Moustakeio online station. For definition of heatwaves, days with very high temperature (Tmax>35^{0}C) were extracted from the Moustakeio data-series. Only few days with Tmax>35^{0}C were detected:3 days in 2019, 10 days in 2021 and 1 day in 2022. Relative humidity shows the opposite behavior of air temperature (as expected) with monthly values raging from 55% (July) to 80% (November- February). Wind speed (WS) daily values are about 15 -20 km/h for almost the whole 2018-2022 period, with maximum WS being around 50 km/h, showing the high winds and wind gusts that characterize the Island. Wind direction is mainly from the North East and North West. Total annual precipitation (PR) from the automated online station in Moustakeio station ranged from the (very) wet year of 2019 (800 mm) to the (very) dry year of 2021 when a total PR was recorded of about 300mm, indicating the large variation from one year to another. Extreme precipitation events were detected by estimating number of days with PR>10mm (high precipitation days) and PR>20mm (very high precipitation day); showing 11 days /year with high precipitation

(reaching 21 days in 2019) and around 10 days with very high precipitation in 2019 and 2020. Monthly solar radiation ranges from minimum values in December (of about 180 W/m^2) to maximum values in July (about 230 W/m^2) and are similar for each year over the recording period.

Data from the network of 12 small meteorological stations show that yearly average air temperature is >19°C at the Korthi bay stations and around 17°C at the other stations that are located at higher altitudes or in Northern areas of the island. The average winter temperature ranges from 7.5 °C (Gianiseo) to 12.8 °C (Korthi-Ladorfos); spring air temperatures are from 13°C (Gianiseo) to 16.8 °C (Korthi-Ladorfos). Summer air temperatures are close to 25°C for almost all stations, with the highest temperature at Korthi Glynou (27°C) and the lowest of 23.5°C at Gianiseo and Kastro Kohylou. Autumn air temperatures are around 20°C for all 12 stations. Yearly average relative humidity is ~68 %, with the highest annual value in Gianiseo (72.7%) and the lowest in Korthi-Glynou (63.7%). Relative humidity shows the highest values during winter (from 72 %, Korthi Ladorfos to 87 %, Gianiseo); in autumn RH remains quite high (67% Korthi-Glynou to 77% Gianiseo). In summer are the lowest RH average values (53% Korthi-Glynou-66 % North Glaras), followed by spring (62% Korthi Landrorfos-73% Gianiseo).
NOA examined the (preliminary) changes in temperature, as well as relative humidity, between meteorological sensors on sites that did /did not experience renewed terrace cultivation. For this reason, detailed analyses of daily air temperature and relative humidity evolution were performed for the plots/stations which experienced barley cultivation over growing seasons; these were compared to nearby stations which remained uncultivated. Representative days with Tmax>35°C were selected (23/6/2022 and 8-10/7/2019). Uncultivated stations in Korthi Bay experienced higher daytime Tmax and lower nighttime Tmin compared to cultivated areas. This effect is visible during hot days (T>30°C); local factors explain temperatures during cooler days (e.g. wind, topography).

The preliminary data and analyses suggest that terraces may help decrease the negative (direct) impacts of climate change, through decreasing local temperatures during heatwaves. Heatwaves will become more frequent in the future, rendering this a key finding supporting the use of terraces as green infrastructure to combat the impacts of climate change. The benefits of terrace restoration are likely felt progressively over time, depending on the total extent of restored areas. The meteorological network will continue to provide base-line meteorological information that will be of crucial importance for future monitoring in the context of the “after-LIFE” program.

1. INTRODUCTION

This report is the second deliverable of action C.5, entitled « Report on the micro-climate of the pilot areas before and after project interventions». This action solely undertaken by the National Observatory of Athens (*hereafter*: NOA).

Fourteen meteorological stations (12 small autonomous stations and 2 automated) were installed on Andros Island by NOA at selected project plots. These record the meteorological parameters that were used in this assessment of the micro-climate of the pilot areas before and after project interventions.

Specifically, data contained within this report were generated by: [1] the meteorological station of Moustakeio that is fully automated and provides multiple data in 1-min time steps (air temperature & relative humidity, wind speed & direction, air pressure, precipitation and solar radiation intensity), and [2] 12 small autonomous stations that record daily air temperature & relative humidity fluctuations. Data from the new online automated Panachrantou station (installed in July 2022) have been excluded from the microclimate analysis, due to the short time of recordings (2 months) and they will be mainly used for the needs of after LIFE activities.

Up to the end of the reporting period (September 2022), NOA recorded 8 data-series with a length of 39 months, and 5 data-series with a length of 51 months. There are more stations and longer data-series than foreseen in the original "LIFE Terracescape" proposal, which promised data-series with a length of 39 months from ten stations. Meteorological data are therefore in line with the project's requirements.

1.1 Scientific rationale & hypothesis

Climate change is becoming increasingly evident in the Mediterranean (IPCC 2012; MedECC 2020; IPCC 2021). The region is warming and shows significant increases in the frequency, intensity and duration of heat waves (Kuglitsch et al. 2010), a decrease in the total amount of precipitation, and changes in rainfall patterns, extreme events and soil dryness (Alpert et al. 2002; Gubanova and Li 2007). During the 21st century, climate change is projected to intensify throughout the region. Air and sea temperature and their extremes (notably heat waves) are likely (60%-100%) to continue to increase more than the global average (Ali et al., 2022, https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_CCP4.pdf).

The Aegean islands, characterized by strong relief and low vegetation cover, are listed as a region of high desertification risk (Giorgi 2006; Zanis et al. 2008; Giannakopoulos et al., 2009). Impacts of climate change are expected to affect significantly agricultural production and the local economy (JRC 2014). The future vegetation cover and composition is likely to change under influence of the projected declining annual precipitation, rising temperatures and the increasing length of dry spells in Aegean Islands (Kitsara et al., 2021).

Due to anthropogenic emissions of greenhouse gases, climate is changing in the Mediterranean Basin faster than global trends, both historically and as projected by climate models (Cherif et al., 2020, MedECC). Annual mean temperatures on land and sea across the Mediterranean Basin are 1.5°C higher than during pre-industrial times and they are projected to rise until 2100 by an additional 3.8 to 6.5°C for a high greenhouse gas concentration scenario (RCP8.5) and 0.5 to 2.0°C for a scenario compatible with the long-term goal of the UNFCCC Paris Agreement to keep the global temperature well below +2°C above the pre-industrial level (RCP2.6). On land and in the sea, heat waves will intensify in duration and peak temperatures. Despite strong regional variations, summer rainfall will likely be reduced by 10 to 30% in some regions, increasing existing water shortages, desertification and decreasing agricultural productivity (MedECC 2020).

Most impacts of climate change in the Mediterranean are exacerbated by other environmental challenges such as changing land use, increasing urbanization and tourism, agricultural intensification, overfishing, land degradation, desertification, and pollution (MedECC 2020). The impacts of climate change are expected to affect significantly agricultural production, biodiversity, soil structure, and, as a result, local economic activities (JRC 2014).

The Terracescape project aims to demonstrate, at the Aegean island of Andros, the use of drystone terraces (a prominent element of the Mediterranean landscape) as green infrastructures resilient to climate change impacts. Drystone terraces allowed for millennia the cultivation of marginal island areas with poor and particularly dry soils, thus supporting local farming communities by improving the rainwater percolation, reducing the soil erosion and wildfire risk, as well as favoring local biodiversity.

The present report aims to pinpointing the role of drystone terraces in limiting climatic extremities. It will explore the hypothesis that air temperature and humidity at sites without project interventions are expected to be higher and lower, respectively. Project interventions are expected to reduce the amount of solar radiation reaching the ground, as it will be mostly absorbed and reflected by the vegetation on newly cultivated fields. Therefore, lower temperatures will prevail, as perennial and annual crops will decrease the warming of the ground surface by shading it from direct sunlight. Moreover, as crops will transpire water through their leaves, they will increase the ambient air humidity and cool the air by evaporating water.

1.2 Objective

The main goal of this report is to assess at the demonstration areas that experienced project interventions if the anticipated improvement of air humidity (i.e. increase compared to non-intervention sites) and air temperature (i.e. decrease compared to non-intervention sites) is detectable.

To this end, (preliminary) changes in temperature and humidity between weather sensors at locations that did (not) experience project interventions were examined. Using the observational meteorological data collected, an in-depth time-series analysis for the study areas was performed. A trend analysis of temperature, precipitation, humidity and wind with a focus on extreme events such as heatwaves, floods and storms in terms of duration, frequency and intensity is also provided.

This assessment will further provide base-line meteorological information that will be of crucial importance for future monitoring that will be part of the "after-LIFE" program. Base-line meteorological data are essential for evaluating future climate forecasts and will provide useful information for e.g.agriculture, flood analyses, erosion studies

1.3 Report structure

The structure of the remainder of this report is as follows:

- Chapter 2 presents a description of the study area and the local climate of Andros Island.
- Chapter 3 summarizes the meteorological data from the diverse meteorological stations, and presents an analysis of the results that focusses on the differences between non-intervention and intervention sites;
- Chapter 4 discusses the results and analyses and provides the main conclusions for this assessment;

2. Description of the study area & local climate

2.1 Island of Andros

Andros is the northern most island of the Greek Cyclades archipelago. It is for the most part mountainous, with many fruitful and well-watered valleys. The municipality, which includes the island Andros and several small, uninhabited islands, has an area of 380 km^2 (146.719 sq mi).The largest towns are Andros (town), Gavrio, Batsi, and Ormos Korthiou.

The climate of Andros, as an Aegean Island, is displaying the basic characteristics of the Mediterranean climate such as winter rainfall, summer drought, large inter-annual variations in total rainfall, hot summers (with intense sunlight) and relatively cool winters. Strong northerly winds occur over all months. The island has rich geographical contrasts and combines the dry Cycladic landscape with rich vegetation and abundant waters.

The Aegean islands, characterized by strong relief and low vegetation cover, are listed as a region of high desertification risk. Impacts of climate change are expected to significantly affect agricultural production and the local economy. For millennia, terraces allowed the cultivation of island regions with poor and dry soils, supporting local farming communities, reducing soil erosion & fire risk, and favoring local biodiversity.

Climate change poses significant challenges to the islands and is expected to worsen already acute situations such as the environmental problems that have arisen from the abandonment of traditional uses of land (terrace farming), such as erosion leading to loss of fertile soils and increasing fire risk. Essential resources like fresh water, soil, and agricultural production are threatened, while ecosystems will be challenged by increased physical risks. The agricultural sector is crucial for minimizing the island's dependence on food imports and is an important source of revenues through the export of agricultural products. In the long term, most islands will be facing decreased crop production and higher costs for water irrigation (Sauter et al. 2013).

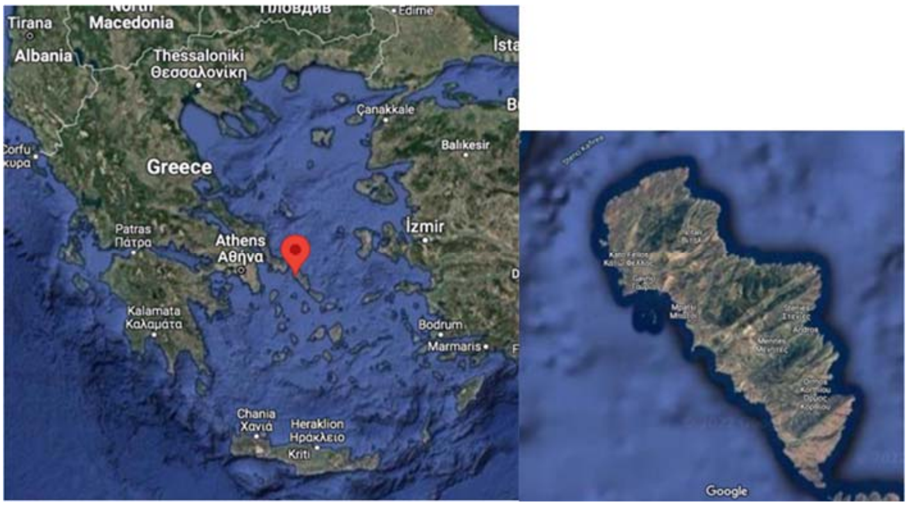


Figure 1 Right: Map of Greece, showing the location of Andros Island. Left: Map of Andros showing the location of Gavrio meteorological station.

2.2 Local climate of Andros Island (based on data from the Gavrio-Andros meteorological station)

Climate is the average weather in a given area over a longer period of time (https://www.climateurope.eu/what-is-climate-and-climate-change/). The usual period for describing climate is 30 years, as defined by the World Meteorological Organization (WMO), although shorter time periods (spanning at least 10-15 years) may be used if no long-term records are available. However, many Aegean islands have no long-term meteorological data-series at all; furthermore, spatial coverage is not good enough to look at micro-climatic variability within islands.

In the framework of the LIFE Terracescape project, the climate situation in Andros was analyzed by NOA, based on the 10 years records of the meteorological station in Gavrio (part of the https://www.meteo.gr/Gmap.cfm weather stations network of the National Observatory of Athens (NOANN), Lagouvardos et al. 2017). This is the only available station with a longer-term meteorological record that may be used to evaluate local climate. There is no meteorological station installed by the Hellenic National Meteorological Service (HNMS) on the Island of Andros.

This section starts with the analysis of basic climate parameters from the meteorological station "Gavrio-Andros" (record spanning 2011-2021) and the assessment of selected climate indices related to agriculture and weather extremes.

Daily measurements of mean, maximum &minimum air temperature and precipitation were obtained for the "Gavrio-Andros" station, covering the period 2011-2021.The Andros meteorological station is located at the port of Gavrio (Liopesi) on the top of a building (**Lon:** 24.739, **Lat:** 37.880, **Alt:** 16m), at the mouth of a deep valley in the mountainous east-coast of the island. Figure 1 shows the location of the meteorological station of ''Andros-Gavrio''. The station is located close to the seashore (Fig. 1), directly east of the mainland and its climate is subjected to continental influences. The data-set from "Gavrio-Andros" station has a length of 10 years and, although not considered accurate for climate analyses, is used to describe the climate situation in Andros as it is the only available longer term data record (over a decade).

Figure 2 shows the annual and monthly average air temperatures (mean, maximum, minimum) in "Gavrio-Andros" for the period 2011-2021. The average values of annual mean (TG), maximum (TX) and minimum (TN) air temperature are about 19.4^{0}C, 22.5^{0}C and 16.7^{0}C, respectively, for the analysed period.

Seasonal average TG, TX, TN temperatures and their trends were also estimated from daily data, shown in Figure 3. Winter temperatures were calculated as an average of December, January, February; spring temperature from March, April, May; summer from June, July, August; and autumn from September, October, November. The pattern of average monthly mean (TG), maximum (TX) and minimum (TN) air temperature is typical of the Mediterranean climate with the higher temperatures recorded in summer months and the lowest in wintertime. The difference between highest (warmest month) and lowest (coldest month) values is close to 16^{0}C, 17^{0}C, and 15^{0}C for TG, TX and TN, respectively. The difference between mean annual TX and TN is 2.7^{0}C, indicating the mild winter and the quite high minimum temperatures in the Aegean islands affected by the sea surface temperature. High temperatures in Andros Island, occur in summer (30.3^{0}C TX, 26.6 ^{0}C TG, 23.5^{0}C TN) and autumn (23.3 ^{0}C TX, 20.4^{0}C TG, 18.1^{0}C TN). Spring (20.8^{0}C TX, 17.2^{0}C TG, 14.3 ^{0}C TN), is characterized by lower temperatures than autumn, and winter temperatures are close to 15.2^{0}C for TX, 12.5^{0}C for TG, and 10.4^{0}C for TN (Fig 3). The 10-year maximum and mean temperature record from Andros-Gavrio station (Fig. 3) indicates small steady increases, for all seasons over the period 2011-2021. There is no change in TN.
Figures 4 and 5 shows the annual and monthly precipitation patterns in Andros island, based on the daily data records of "Gavrio-Andros" station. Overall, Andros Island appears to experience a drying trend; however, this is a very tentative observation as there are only 10 years of Precipitation (PR) recording. There are clear seasonal differences in precipitation: most rain falls in winter, followed by autumn and spring, while summer rainfall is very low to non-existent over most years (Fig. 5). There are no clear changes in long-term rainfall, but inter-annual variation is large. The average total precipitation is around 500mm/year for the period of measurements (2011-2021). The month with the highest mean precipitation amount (Fig. 5) is December (125mm), followed by February (122mm). Figure 5 also presents the maximum monthly averages for the 2011 2021 period, indicating values over 200mm during the three winter months, which are almost the double from the mean monthly ones. Mean annual relative humidity is 66.4% for the period 2011- 2021.

Mean Annual Cycle

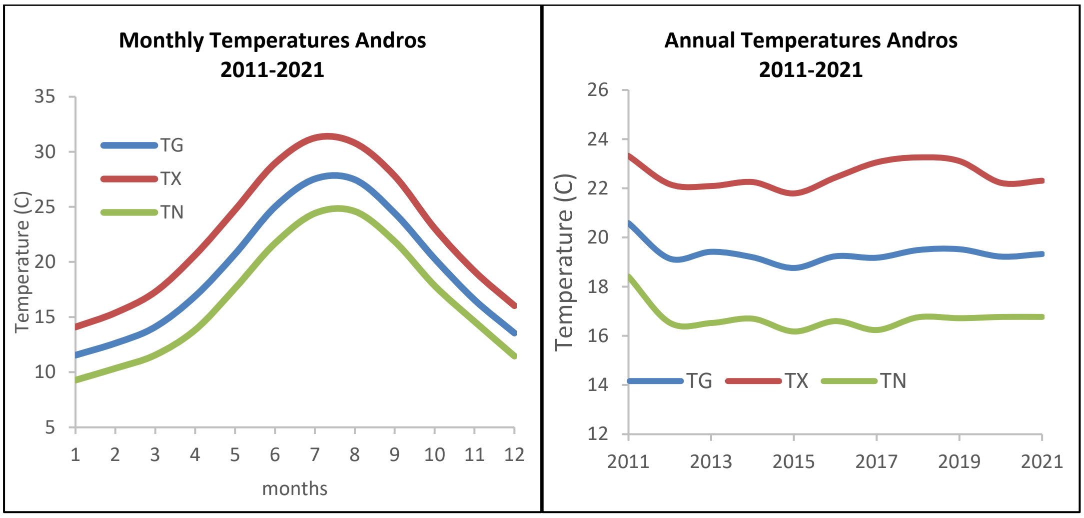
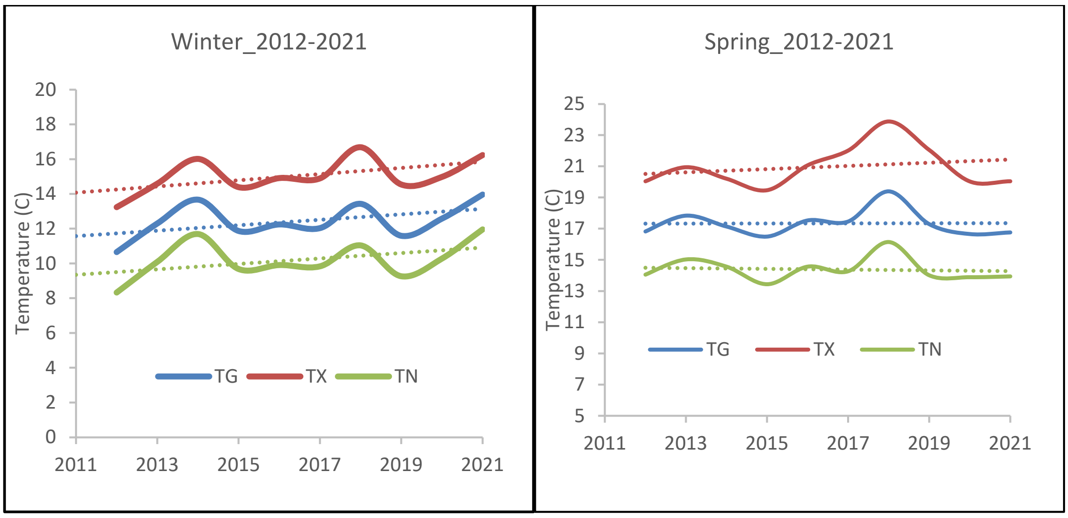


Figure 2 Observed annual and monthly average air temperatures in Gavrio-Andros station for the period 2011-2021, respectively. Red, blue and green curves depict the maximum, mean and minimum temperature, respectively.

Seasonal Trends



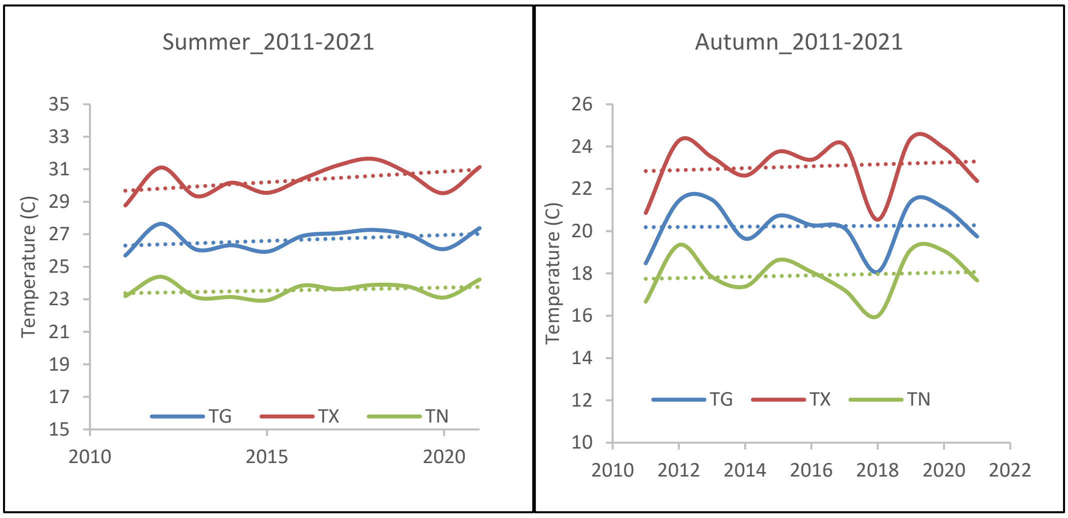


Figure 3.Average seasonal temperatures at Gavrio-Andros station during the period 2011-2021. Red, blue and green curves depict the maximum, mean and minimum temperature, respectively

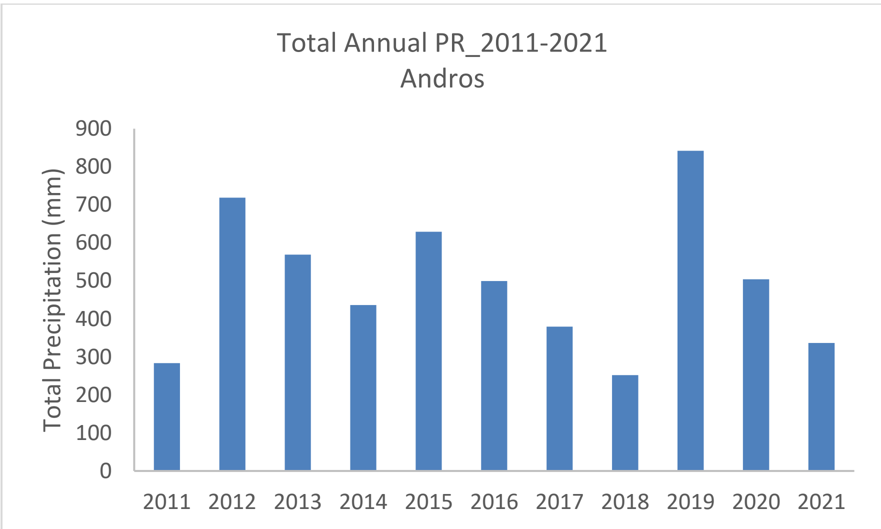


Figure 4.Average Total annual Precipitation at Gavrio-Andros station during the period 2011-2021.

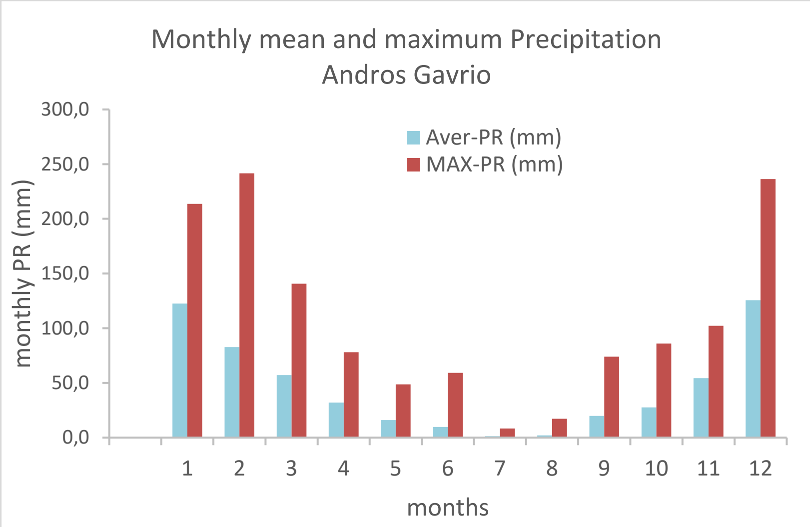


Figure 5.Average Mean monthly and Maximum Precipitation at Gavrio-Andros station during the period 2011-2021.

3. Data from the installed meteorological network on Andros island

To record the meteorological conditions prevailing in the selected study areas (terraces /plots), 12 small autonomous and 2 automatic meteorological station were installed on the island of Andros. The plots for the installation of the stations were selected in collaboration with the Municipality of Andros and the local community. The meteorological data series in Andros provide:

- baseline data to define the main characteristics of the microclimate in Andros (before the project only one station was operating in Gavrio-Andros since May 2011; see https://www.meteo.gr);
- essential weather station measurements for evaluating future climate forecasts & projections;
- data for examining the preliminary changes in temperature and humidity between meteorological sensors at locations with(out) terrace cultivation.

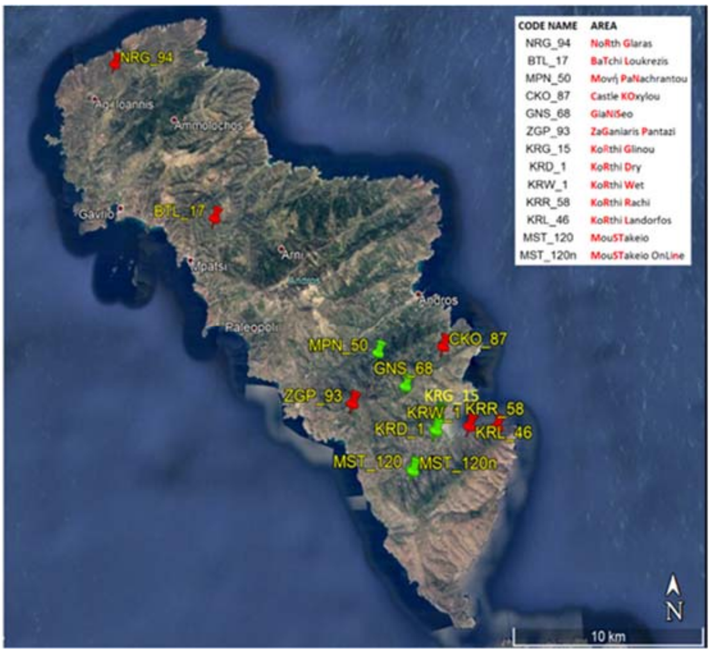


Figure 6.Map of Andros, with the locations of the meteorological stations installed by NOA (noted with :green the stations recording from June 2018; red, the stations recording from June 2019).

Table 1. List of the installed meteorological stations on Andros, providing the cultivated crop type for those plots chosen for land-use modifications.

α/α	Station	Cultivated Crop type
1	NRG_94	
2	BLT_17	
3	MNP_50	
4	CKO_87	Barley
5	GNS_68	Barley/lupin
6	ZGP_93	Peas/Barley
7	KRL_46	Barley
8	KRG_15	Barley
9	KRD_1	
10	KRW_1	
11	KRR_58	Barley
12	MST120	
13	MST120n	
14	Panachrantou_n	

Seven of the small autonomous meteorological stations were installed in June 2018 (green points in Fig. 6), while six more were installed in May 2019 (red points in Fig. 6). The 12 small autonomous stations are covering air temperature and relative humidity and are installed throughout Andros, from the north part of the Island to the Korthi bay. The first automatic online meteorological station was installed in June 2018 on the roof of the Moustakeio building (Korthi, SE Andros), recording air temperature, relative humidity, precipitation, wind speed / direction, atmospheric pressure and solar radiation. Data from the new (second) online automated station (installed in July 2022at Panachrantou monastery) have been excluded from the microclimate analysis, due to the short time of recordings (2 months);this station will be mainly used for the needs of after LIFE activities.

For the small autonomous and automatic weather stations, the following equipment has been used:

1) Digital data loggers which record, after calibration, the basic meteorological parameters at the specific point (terraces/plots) at regular timescales;
2) Air temperature and relative humidity sensors, placed on a metal mesh at a height of 1.5-2.0 meters above the ground, on a free field for better ventilation.

The automatic (online) stations have the following additional sensors installed:

3) Wind speed and direction sensor, placed on top of a metal mesh, as far as possible from high obstacles (e.g. buildings, trees);
4) Sensor for recording precipitation (rainfall, snow or hail which is measured as water equivalent), placed on a suitable support base on the ground away from obstacles that may "shadow" the collection of rain (rain screen);
5) Sensor for recording intensity of solar radiation.

Five of the 12 small, automated stations are located at sites that did not experience land-use change. Data from these stations will be used as base-line data, to assess the impacts of land-use changes against. Seven stations were installed at selected project plots chosen for land-use modifications (Table 1). Data from the 12 small autonomous stations (providing air temperature and relative humidity) were downloaded manually during visits.

The automatic weather station in Moustakeio building (Korthi) provides measurements of air temperature, relative humidity, precipitation, wind speed / direction and solar radiation. The station is remotely-accessed and all data are available online to the project stakeholders and the general public through NOA's (https://www.iersd.noa.gr/WeatherOnLine/s_Andros1/meteo_tableGR.html) or Life-Terracescape's (http://www.lifeterracescape.aegean.gr) websites.

In June 2022, an additional automated on-line meteorological station at the area near the Panachrantou monastery on Andros island, was installed from the NOA team (Fig. 7, Table 1). Due to strong wind gusts that prevail in the area the 10-meter mast of the station was supported on a rock. The station records: wind speed and direction; air temperature and relative humidity; precipitation. A website has already been developed, in order to provide online the data/ measurements of the Panachrantou station. The webpage is under operational testing and will be soon available, at the following link:
https://www.iersd.noa.gr/WeatherOnLine/s_Andros2/meteo_tableGR.html.

Figure 7.The new automated meteorological station at Panachradou Monastery, installed in July 2022.

3.1 Data from the automatic online meteorological station in Moustakeio-Andros

The automatic online meteorological station on the roof of the Moustakeio building in Korthi (South East Andros) has been equipped with sensors recording air temperature, relative humidity, precipitation, wind speed / direction, atmospheric pressure and solar radiation.

Observations collected from the automatic meteorological station in Moustakeio-Andros are available online through the NOA website at the following link: https://www.iersd.noa.gr/WeatherOnLine/s_Andros1/meteo_tableGR.html(Fig.8).

Figure 8.NOA webpage with available online weather data from Moustakeio-Andros meteorological station , installed in the frame of LIFE-Terracescape.

Meteorological data (2018-2022) from Moustakeio Andros are used for a full in-depth time series analysis of essential parameters. The analysis of air temperature (T), relative humidity (RH), precipitation (PR), wind speed (WS)/direction (WD), air pressure and solar radiation was based on daily values, monthly estimations and the growing season (October -June for barley).

Daily air temperature ranges from a minimum 2 ^{0}C to a maximum 35 ^{0}C over the period 2018 -2022 of recordings. Ten days were recorded with temperatures less than 5 ^{0}C and the summer of 2021 was the warmest, with the most days over 30 ^{0}C (Fig 9a). Relative humidity has the opposite evolution from air temperature (as expected) with daily values ranging from 30% to 90% (Fig 9a). Monthly mean, maximum and minimum air temperature is presented in Fig 10a. Monthly mean air temperature is ranging from 12^{0}C (winter months) - 27^{0}C (July, August), maximum temperature from 17^{0}C (January) to 37 ^{0}C (July, August) and minimum temperature from 3^{0}C (January) to 22^{0}C (August). Monthly relative humidity (Fig. 10a) is quite high during the year, ranging from 55% (July) to 80% (November- February).

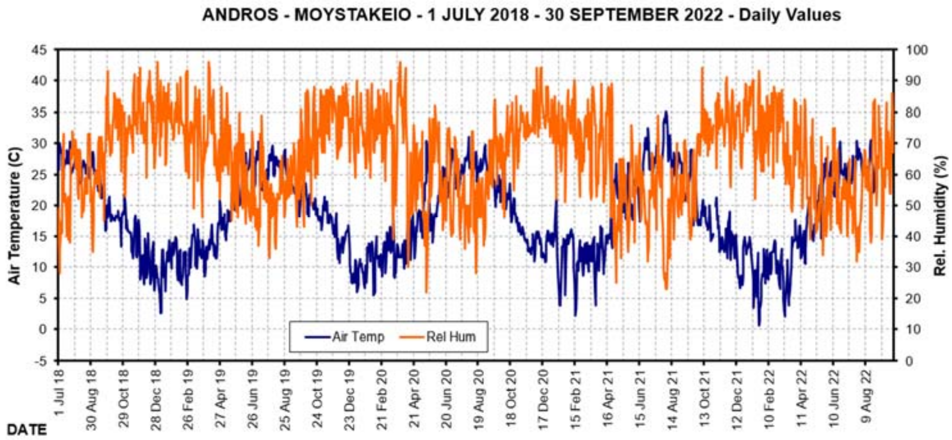
Total (cumulative) precipitation, presented in Fig. 9b, was considerably higher in 2019 (greater than 800 mm) compared to the long-term mean (~500mm from Gavrio station), while the lowest total PR was recorded in2021, of about 300mm, indicating the large variation from one year to another. Monthly estimated total PR (Fig. 10b) show January 2019 with the highest total monthly PR (about 240mm), a value close to the annual total PR of 2021. During summer months (JJA), almost no PR amounts were recorded for the 2018-2022 period (Figure 10b). Extreme precipitation events (Fig. 10b) were detected by estimating number of days with PR>10mm (high precipitation days) and PR>20mm (very high precipitation days); showing on average 11 days /year with high precipitation (reaching

21 days in 2019) and around 10 days with very high precipitation in 2019 and 2020 (with only 2 days in 2018 and 2021).

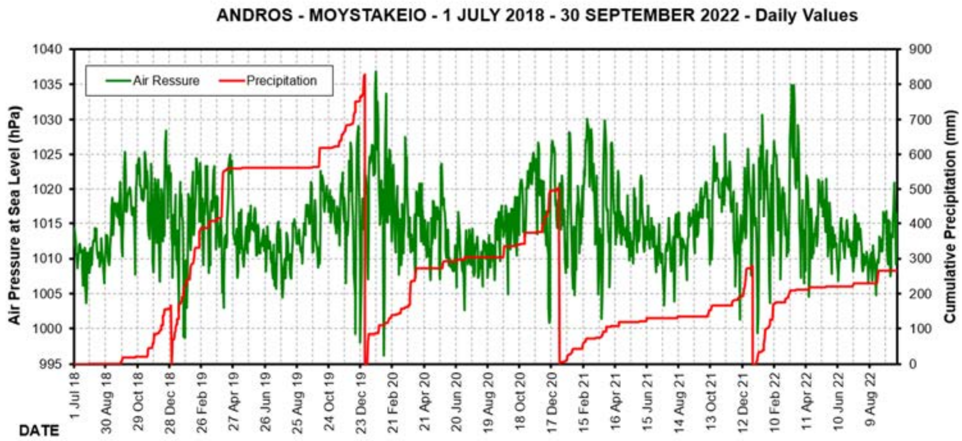
Wind speed daily values are about 15 -20 km/h for almost the whole 2018-2022 period (Fig 9c), with maximum average WS being around 50 km/h, showing the high winds and wind gusts that characterize the Island. Wind direction (Fig. 9c) is for all years (2018 -2022) mainly North East and North West, corresponding to the main axis of the Korthi valley. Monthly estimates of mean wind speed (Fig 10c) show high values, over 20km/h, for the winter months and July to August (due to the etesian winds), while monthly maximum wind speed (Fig 10c) is greater than 80km/h for almost all months of the years of recording.
Solar radiation series shows normal inter-annual variation, with low values in winter and high intensities in summer, following the same pattern without inter-annual differences over the 4 years of the recording period (Fig.9d). Monthly solar radiation (Fig 10d) ranges from minimum values in December (of about 180 W/m^2) to maximum values in July (about 230 W/m^2) for each year of the recording period.

Daily

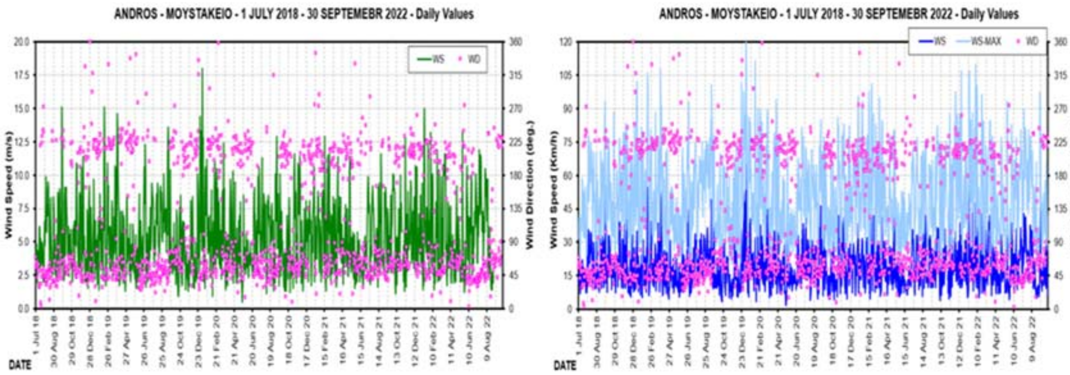
(a)



(b)



(c)



(d)

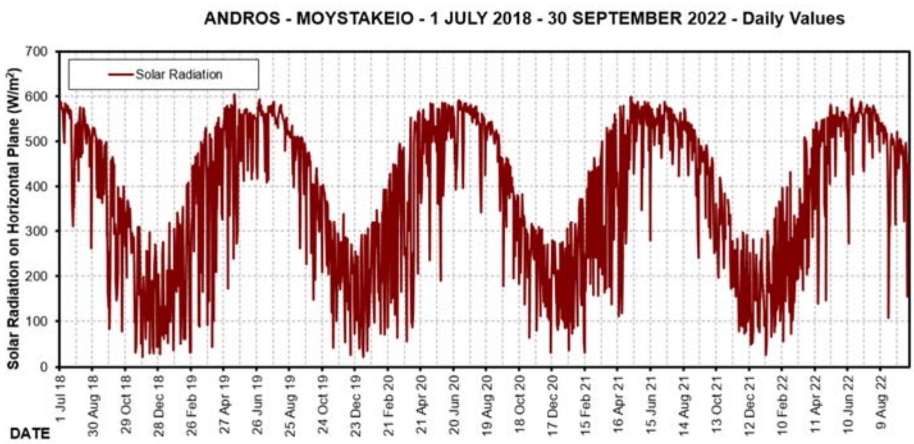
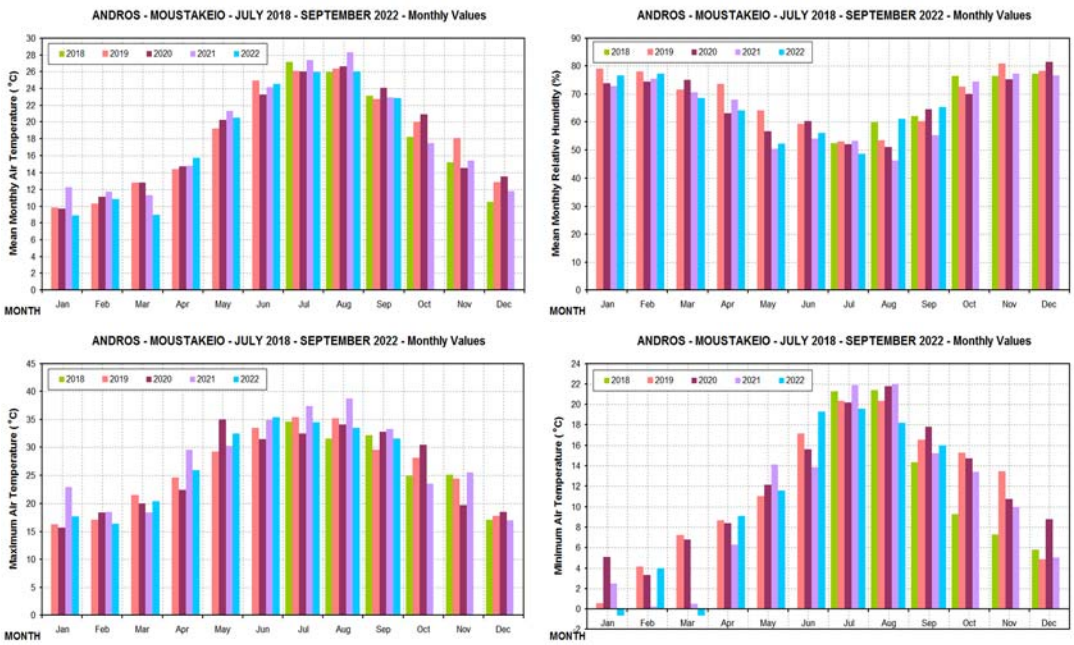


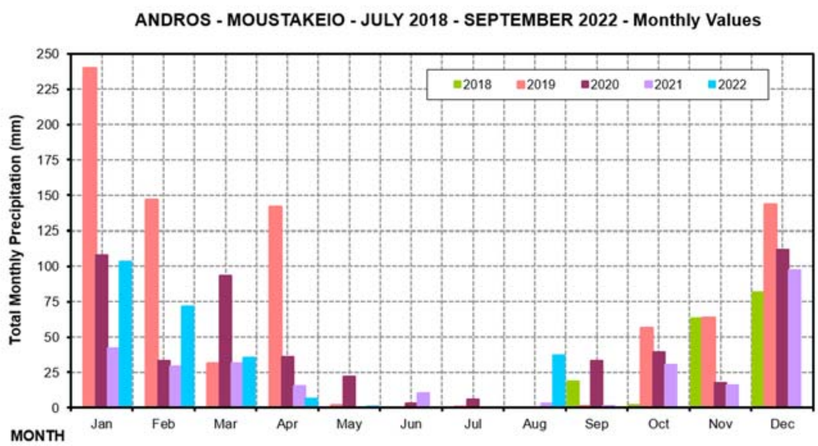
Figure 9.Daily values of : (a) air temperature [^{0}C] and relative humidity [%], (b) precipitation [mm] and air pressure [hPa], (c) wind speed [km/h] and wind direction (^{0}) , (d) solar radiation [W/m^2] over the period 2018-2022.

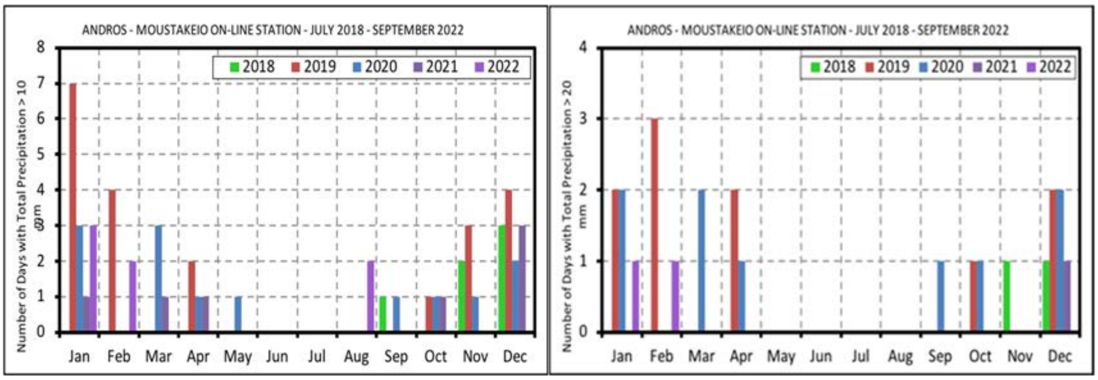
Monthly

(a)

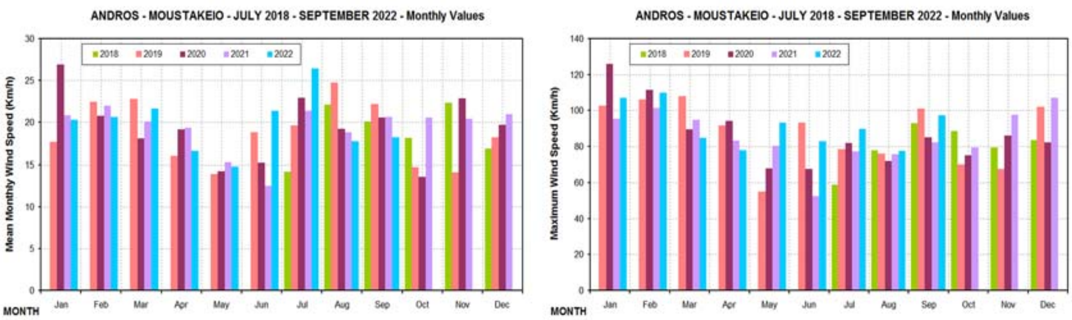

ANDROS - MOUSTAKEIO - JULY 2018 - SEPTEMBER 2022 - Monthly Values
2018 2019 2020 2021 2022
Mean Monthly Air Temperature (°C)
Mean Monthly Relative Humidity (%)
Maximum Air Temperature (°C)
Minimum Air Temperature (°C)
MONTH
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

(b)


ANDROS - MOUSTAKEIO - JULY 2018 - SEPTEMBER 2022 - Monthly Values
2018 2019 2020 2021 2022
Total Monthly Precipitation (mm)
MONTH
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec



(c)



(d)

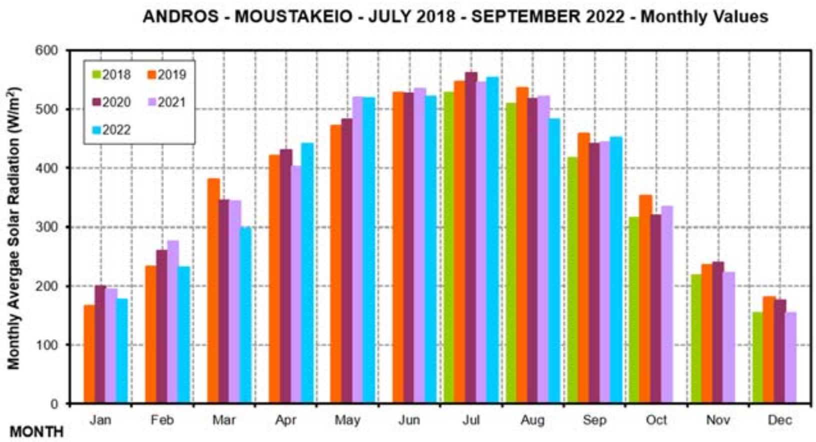
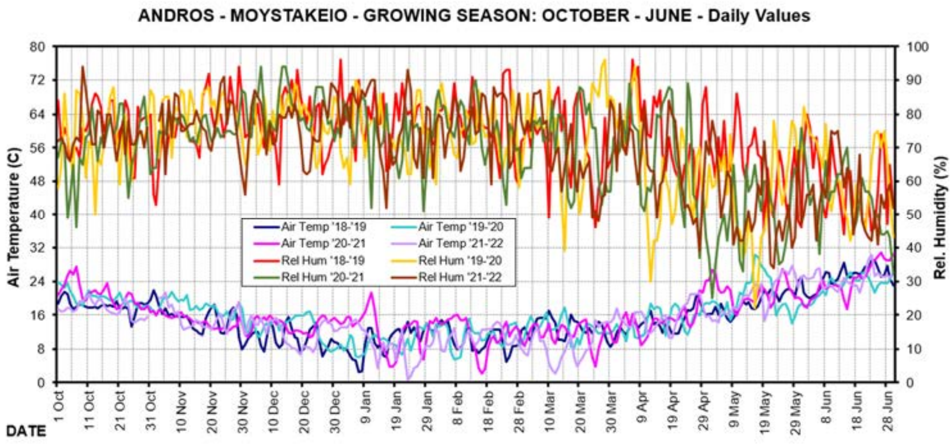


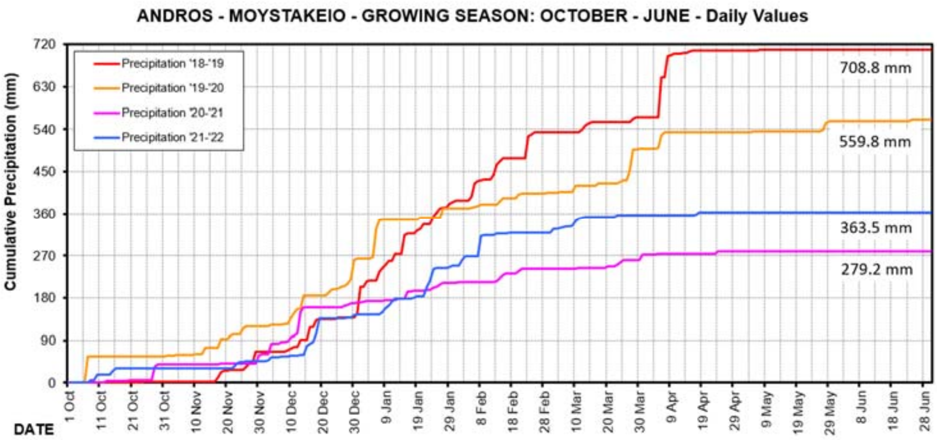
Figure 10.Monthly :(a) Mean, maximum, Minimum Temperature and relative humidity, (b) total precipitation and number of days with high and very high precipitation average, (c) wind speed and maximum wind speed, (d) solar radiation (bottom) for the period 2018- 2022 from Moustakeio online station.

Growing season

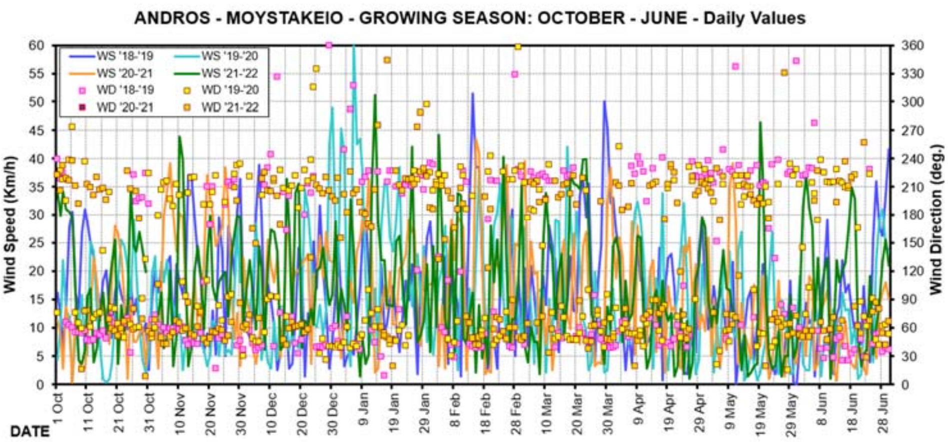
(a)



(b)



(c)



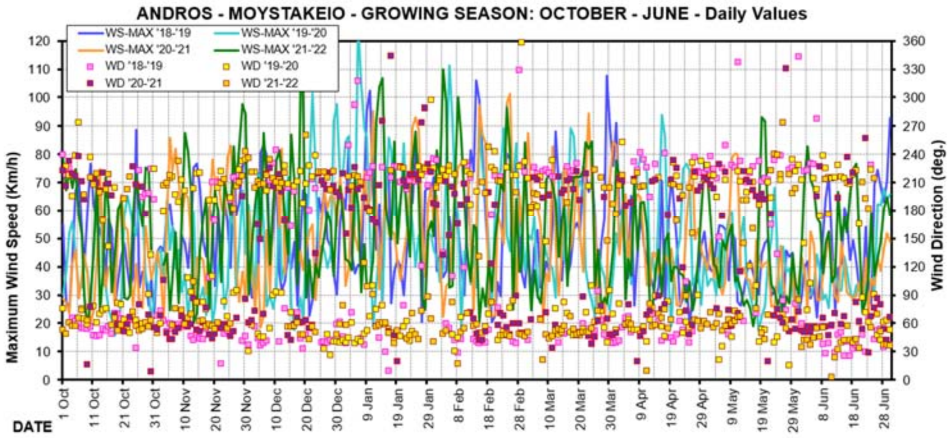


Figure 11.Growing season (October-June): (a) air temperature and relative humidity, (b) cumulative precipitation, (c)wind speed, maximum wind speed and wind direction, for the period2018-2022.

Project interventions in six of the terraces/plots (part of the meteorological station network) concern cultivation of the abandoned terraces, mainly with barley (Table 1). To capture the cultivation period, Figure 11 shows the basic meteorological parameters from Moustakeio station over the 4 growing seasons (October 2018 -June 2022). The sowing period for barley is from the end of October to the end of December, depending on rainfall, and the harvest period is around June. Air temperature is higher for the 2020-2021 growing season (October-June) reaching close to 30^{0}C, while lowest values are for the 2021-2022 growing season (Fig. 11a). There are only small differences in air temperature between the 4 growing seasons (October 2018 -June 2022).

Figure 11b shows the cumulative precipitation during the growing seasons, with the total PR amount for ‘18-‘19 growing season being 708mm. Total PR amount for ‘19-‘20 growing season remains close to 500mm, while the two last growing season are dry with PR amounts of less than 370mm. Wind speed shows variations (from 5-30km/h) for all 4 growing seasons, reaching up to 60 km/h in ‘19-‘20, while the main wind directions are NE and NW (Fig. 11c).

3.2 Meteorological sensor data from the 12 small autonomous stations on Andros

NOA has also installed a network of 12 small autonomous stations, recording air temperature and relative humidity, in selected locations on Andros Island to establish the (micro-) climate conditions of plots that did / did not experience project interventions. Our analyses focused on identifying extreme weather events (heat waves) and detecting possible differences in climate parameters between cultivated- and uncultivated demonstration sites over the project period. Terraces are theoretically expected to modify such events (see chapter 1). The collected data will also provide solid base-line data to evaluate future projected climate changes.

Figure 12 presents the statistical data on air temperature and relative humidity of the 12 meteorological stations over the period June 2018 to September 2022. Extreme maximum and minimum values are marked by the bars; the average value is noted with a red diamond; the rectangle contains 50% of the values. Stations in higher altitude areas of the island exhibit the lowest average annual air temperature (15°C), as opposed to the stations in Korthi bay that display the highest annual air temperature of around 20°C (Korthi-Landorfos, Korthi-Glynou) (Figure 12). Regarding relative humidity, Gianiseo has the highest annual mean value 72.7%, while the lowest value of 63.7% is registered in Korthi-Glynou.

Figure 13 shows the seasonal air temperature variability during the recording period. The stations at higher altitude (Panachrandou Monastery, Gianniseo, KastroKoxylou) show the lowest seasonal temperatures, while low-lying stations in Korthi bay (Korthi stations) register the highest seasonal temperatures. The average winter temperature is ranging from 7.5 °C (Gianiseo) to 12.8 °C (Korthi-Ladorfos); spring air temperatures are between 13°C (Gianiseo) to 16.8 °C (Korthi-Ladorfos);summer air temperatures are close to 25°C, with Korthi-Glynou recording the highest summer temperature of 27°C and lowest 23.5°C at Gianiseo and Kastro Kohylou; autumn air temperatures are around 20°C for all stations (and are thus higher than spring values). During winter, relative humidity (Fig. 14) shows the highest values (from 72 % at Korthi-Ladorfos to 87 % at Gianiseo); in autumn RH remains quite high (from 67% at Korthi-Glynou to77% at Gianiseo). In summer, the lowest RH average values are observed (53% at Korthi-Glynou to 66 % at North Glaras), while values are slightly higher in spring (from 62% at Korthi-Landrorfos to 73% at Gianiseo).

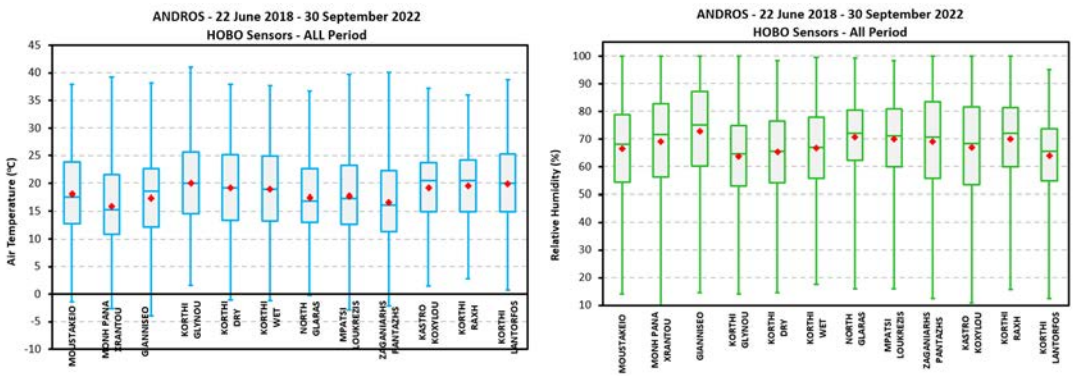


Figure 12.Statistical presentation of air temperature (left) and relative humidity (right) observations of the 12 small autonomous meteorological stations for all period of recordings (June2018-Sepempber 2022). Extreme maximum and minimum values are marked by the bars; the average value is noted with a red diamond; the rectangle consists 50% of the values.

Seasonal

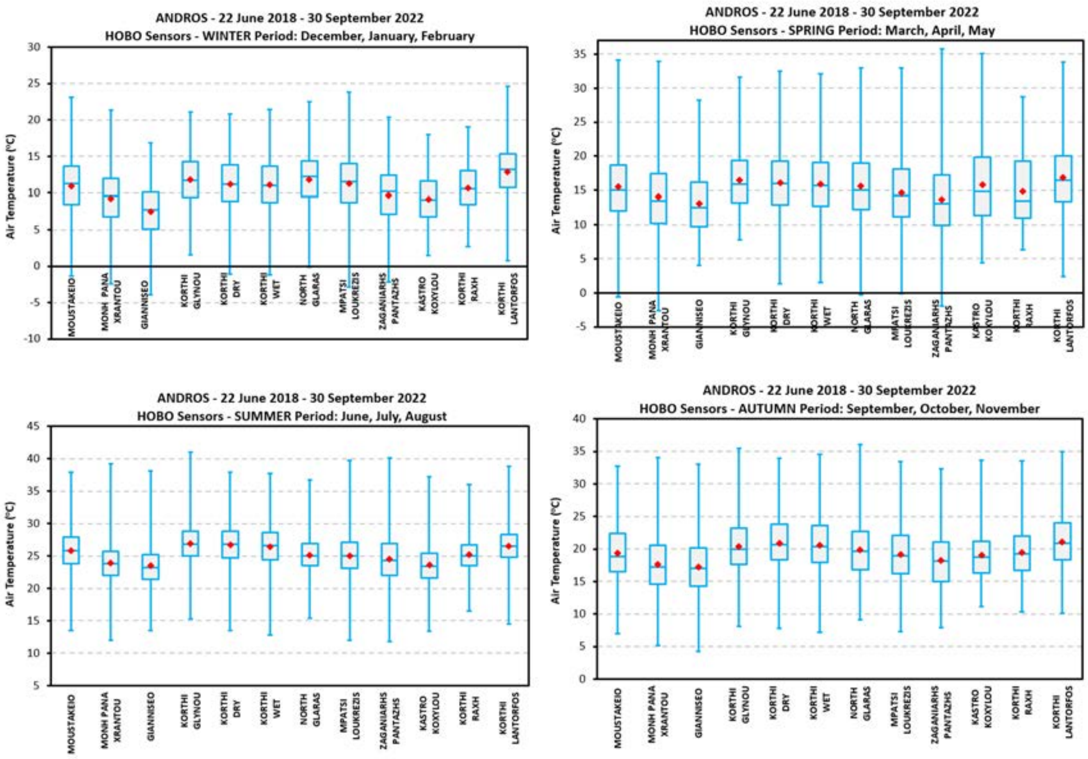
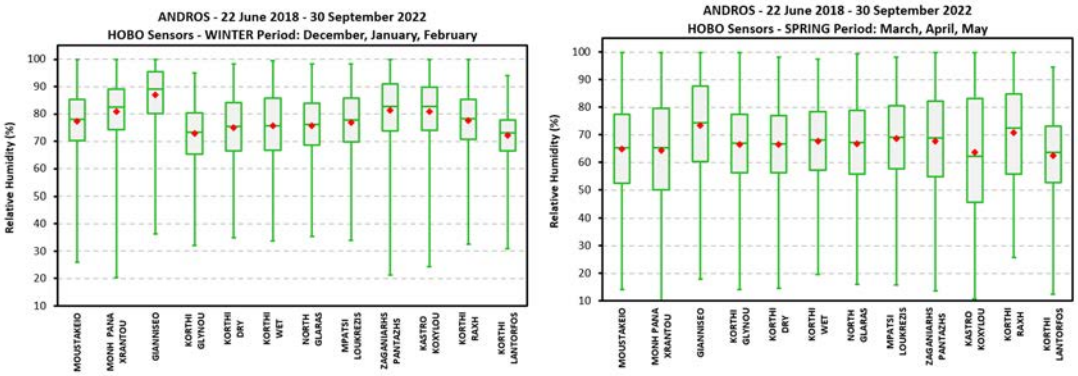


Figure 13.Seasonal statistical presentation of air temperature observations of the 12 small autonomous meteorological stations for 2018-2022. Extreme maximum and minimum values are marked by the bars; the average value is noted with a red diamond; the rectangle consists 50% of the values.



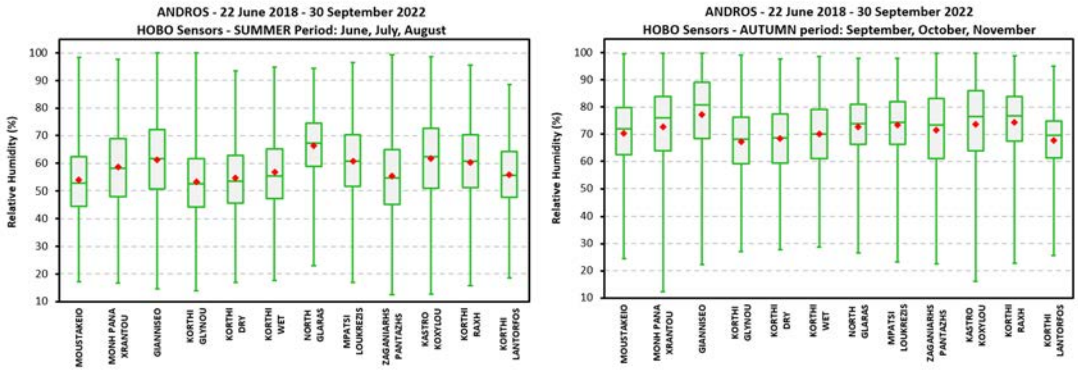


Figure 14.Seasonal statistical presentation of relative humidity observations of the 12 small autonomous meteorological stations for 2018-2022. Extreme maximum and minimum values are marked by the bars; the average value is noted with a red diamond; the rectangle consists 50% of the values.

Growing season

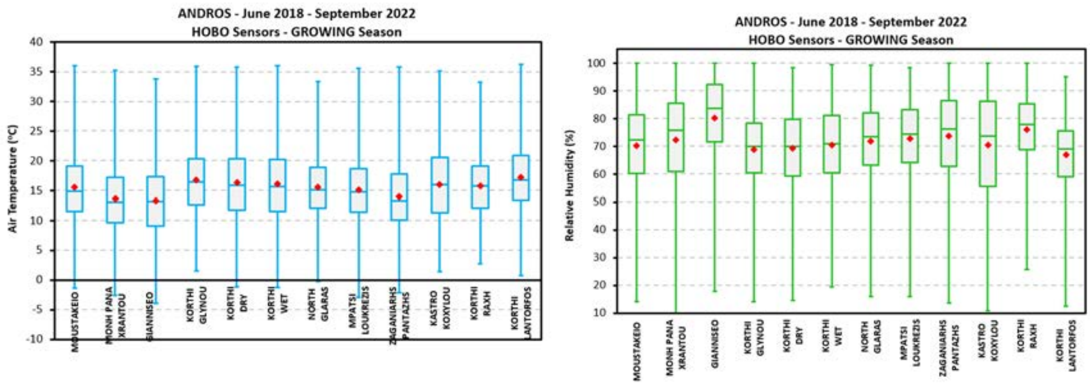


Figure 15.Growing season (October-June) statistical presentation of air temperature (left) and relative humidity (right) observations of the 12 small autonomous meteorological stations, average for 2018-2022. Extreme maximum and minimum values are marked by the bars; the average value is noted with a red diamond; the rectangle consists 50% of the values.

During the growing season (October to June), which incorporates the wet period for the Island (Oct-Apr), average air temperature was around 15^{0}C; Gianniseo and Panachradou stations are 2^{0}C lower, due to their location at higher altitudes.
Almost all stations record relative humidity at 70% during growing season (October to June), except for Gianniseo that reaches 80%. All stations in Korthi bay show the same average temperature and relative humidity over the growth seasons for the period June 2018-September2022, whether they were cultivated with barley or not.

Monthly

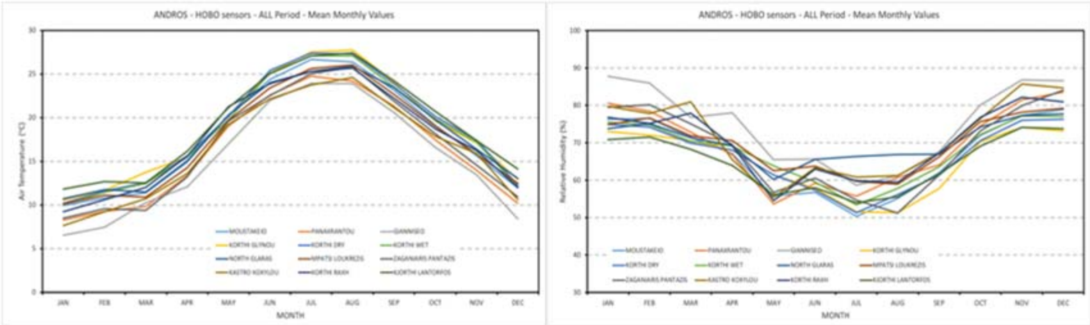


Figure 16.Monthly mean air temperature (left) and relative humidity (right) observations of the 12 small autonomous meteorological stations for June2018-Sempember 2022 period.

On a monthly basis (Fig. 16) all stations show the same air temperature pattern, increasing from January to August and subsequently decreasing until the end of the year. Gianiseo has the lowest mean monthly temperatures values and Korthi-Glynoy, Korthi-Landorfou the highest monthly temperature values.

Station/fields that have larger temperature amplitudes (i.e.,monthly Tmax-Tmin difference), are in the low-altitude Korthi valley area (e.g. KorthiDry, Korthi wet- both not cultivated- and Korthi-Glynou -cultivated). However, cultivated fields in Korthi-Landorfos have some of the smallest monthly temperature amplitudes, probably because of its location close to the sea.

Small temperature differences are also noted for the stations at higher altitudes, and at northern part of the island that is most affected by strong winds. Monthly evolution of relative humidity (Fig. 16, left) shows the opposite pattern from air temperature, with the larger RH amplitudes (over 20%) in mainland stations and the smallest in seaside stations (around 16%).

3.3 Analyses of meteorological station data

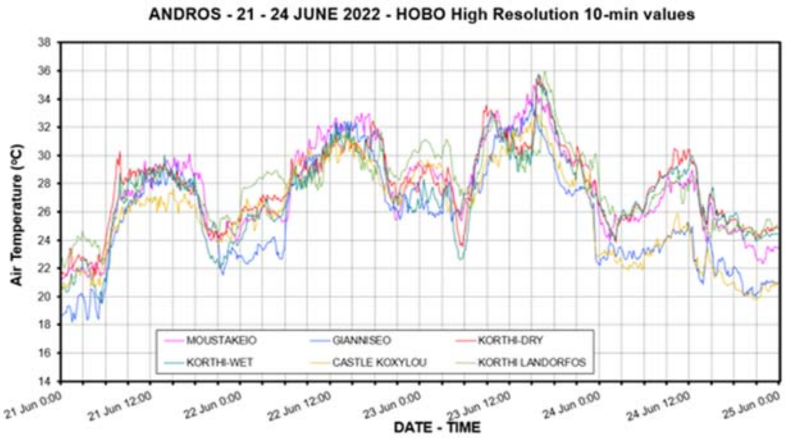
NOA looked at the differences in temperature and relative humidity between meteorological sensors on sites that did /did not experience renewed terrace cultivation. A detailed analysis of daily air temperature and relative humidity evolution was performed for the plots/stations which experienced cultivation during growing seasons, in comparison with nearby stations which remained uncultivated.

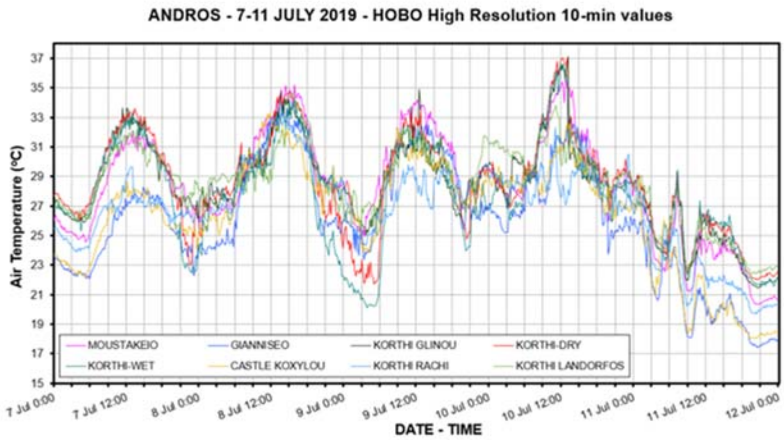
Terraces are expected to exert the greatest influence on air temperature during heatwaves (chapter 1). Therefore, data from the automated online station in Moustakeio were used to define days with very high temperatures (days with Tmax>35^{0}C). The results showed 3 days in 2019, 10 days in 2021 and 1 day in 2022. Such days will, however, become more common in the future (see Report Action C5, deliverable 1).

Analyses focused on representative days with very high temperatures to determine the effect of terrace cultivation on extreme temperatures. For example, on 23rdJune 2022 (at midday), uncultivated stations in Korthi (Moustakeio small station, Korthi wet, Korthi dry)

showed the highest air temperature values in comparison with the rest cultivated stations in Korthi bay (Gianiseo, KorthiGlinou, KorthiRachi) (Fig. 17 upper). Similar observations were noted for the 8th of July 2019, when Moustakeio small station, Korthi Wet, Korthi Dry (all 3 uncultivated during project) reached the highest midday air temperature values, while the cultivated Korthi sites recorded lower midday temperatures (Fig.17).During the 10th of July 2019 (also a day with Tmax>35^{0}C), the uncultivated stations (Korthi dry, Korthi Wet and Moustakeio small) had clearly the highest midday temperatures (ranging from 35-37^{0}C), while cultivated Korthi sites (Landorfos, Rachi, Gianiseo) registered much lower temperatures at the same time (32^{0}C -33.5^{0}C).
It is notable that the Moustakeio station reaches the highest maximum daily values during extreme temperature days, while the (multi-)monthly averages showed that Moustakeio is not one of the stations with the highest average summer temperatures (Fig 13, Fig 16). Regarding minimum temperatures, during the night of 9/7/2019 (a representative hot night), the uncultivated Korthi stations (Korthi Wet, Korti Dry) recorded the lowest temperatures (20^{0}C and 22^{0}C, respectively), while the cultivated stations in Korthi registered night temperatures of around 24^{0}C -25^{0}C. Along with the cultivation, the location of the stations and topography, altitude and wind affect configure the local climate conditions in an area (Fig.17 middle). For the 3rd of August 2019 (another day with Tmax>35^{0}C), all stations in Korthi bay (cultivated or not) recorded high temperatures from 33^{0}C (Castle Koxylou) to 37^{0}C (Korthi-Landorfos), which is probably expected since till early of August, harvest activities have finished and all field (with/without project's interventions have a bare soil and are not covered with crops (Fig.17 down). As regards minimum night temperatures for the same day , the non cultivated fields of Korthi dry and Korthi wet recorded the lowest values 22^{0}C, while the cultivated ones (Korthi-Glynou , Korthi-Landorfou, Korthi Rachi) had around 27 ^{0}C.
Figure 18 presents the analysis of daily relative humidity evolution for the same selected days with very high temperatures. Thus, during 23 of June 2022, Moustakeio and Korthi dry uncultivated stations recorded the lowest relative humidity values (noon), but really close to the cultivated ones of Castle Kohylou or Gianiseo. For 8th of July 2019, no significant differences were noticed between the stations, with Korthi wet recording the highest values sometimes during the day. For 10th of July 2019 (Fig 18, middle), although Moustakeio and Korthi dry show the lowest middlay relative humidity, their recordings had small difference in the relative humidity records of the cultivated ones. During 3rd of August, the stations at higher altitudes (cultivated) do not show relative humidity amplitude, while the ones close to the seaside (Korthi-Landorfos, Korthi-Glynou) along with the uncultivated Korthi wet and dry seem to have an amplitude of 20% during the day. Terrace cultivation does not appear to influence air humidity, which appears strongly controlled by air masses (wind), altitude and local irrigation / water presence.

Selected days with Extreme Temperatures





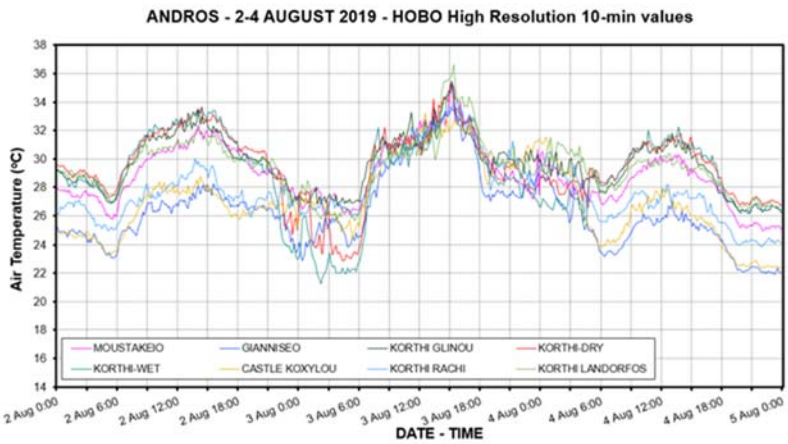


Figure 17.High resolution 10-minute air temperaturesrecorded in Korthi bay stations [(non cultivated:Kothi Wet, Korthi Dry,Moustakeio) and (cultivated: KorthiGlynou,KorthiLandorfou, KorthiRachi, Gianiseo,CastleKohylou, KorthiGlynou) in selected days with extreme temperatures (Tmax>35).

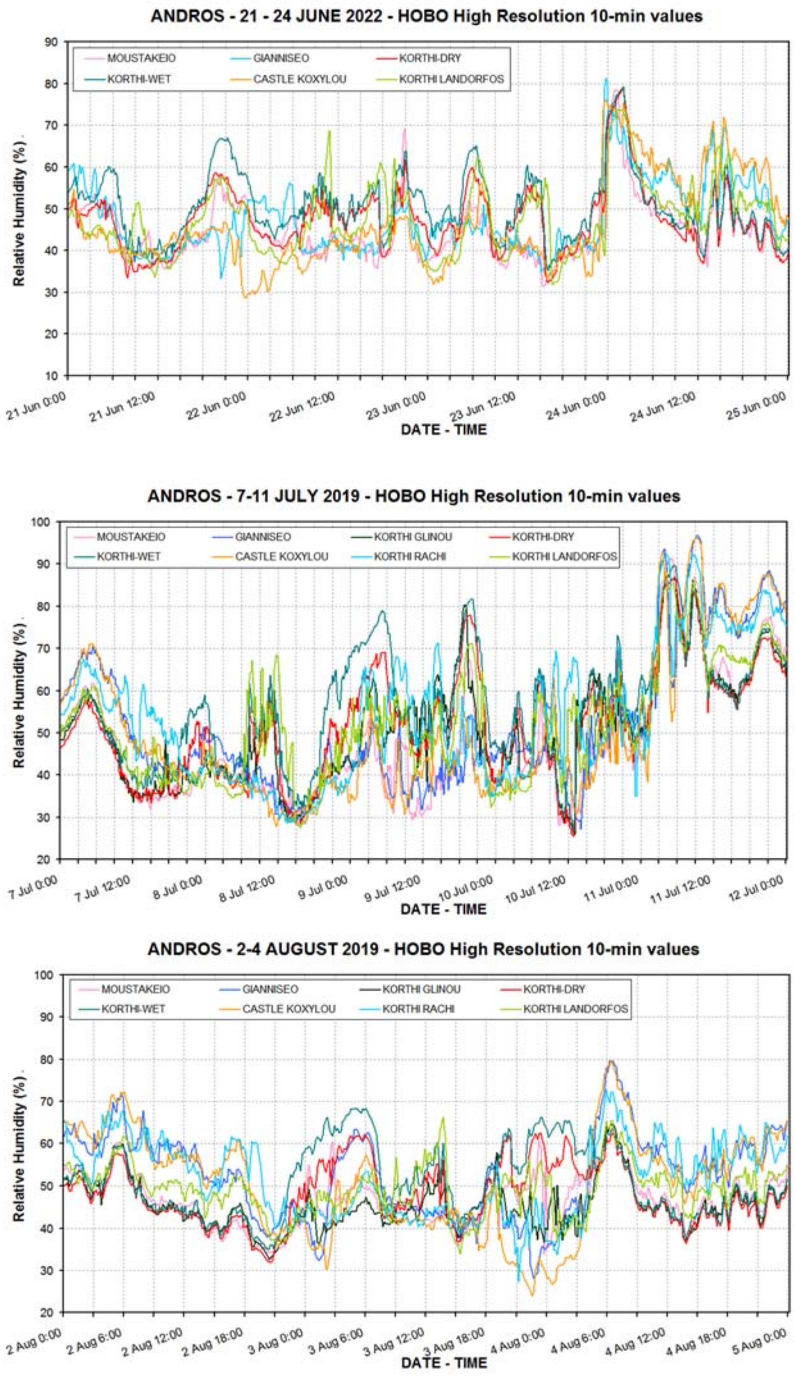


Figure 18.High resolution 10-minute Relative Humidity recorded in Korthi bay stations [(non cultivated:Kothi Wet, Korthi Dry,Moustakeio) and (cultivated: KorthiGlynou,KorthiLandorfou, KorthiRachi, Gianiseo,CastleKohylou, KorthiGlynou) in selected days with extreme temperatures (Tmax>35).

4 Discussion & conclusions

The main goal of this report is to assess the role of renewed drystone terrace cultivation in limiting extreme air temperatures and increasing humidity at selected demonstration sites of Andros Island (Greece).To this end, we examined changes in temperature and humidity between weather sensors at [1] locations that did experience project interventions and [2] nearby areas not experiencing any change. Using the observational meteorological data collected, an in-depth time-series analysis for the study areas was performed. Trend analyses of temperature and humidity, with a focus on extreme heatwave events, was performed on a (multi-)annual, seasonal, growth-season and daily basis.

Analyses of averaged mean-maximum-minimum temperatures (on annual, monthly and growth-seasonal basis) did not show any differences between cultivated- and uncultivated plots. On these timescales, factors dominating local temperature include altitude, proximity to the sea, topography and wind-exposure. However, studies (e.g. Founda et al. 2019) show that heatwaves override such local factors. We therefore focused on warm to hot days (T> 30°C and T>35°C, respectively), to assess whether there are temperature differences between cultivated and uncultivated sites.

An important preliminary finding, based on available data, is that restoration of drystone terraces, followed by agricultural cultivation, directly influences micro-climate through lowering air temperature during heatwaves. This effect is visible on days with maximum temperatures above 30°C. Such days will become increasingly frequent in the future climate. Project interventions likely reduce the amount of solar radiation reaching the ground, as perennial and annual crops decrease the warming of the ground surface by shading it from direct sunlight and cooling the air through water evaporation.

Analyses of averaged mean-maximum-minimum humidity (on annual, monthly and growth-seasonal basis) did not show any differences between cultivated- and uncultivated plots. Neither heatwaves show any systematic difference in air humidity (as measured at the meteorological stations) between cultivated- and uncultivated plots. Any increase in humidity related to cultivation may be visible below crop-level, as crops are expected to transpire water through their leaves, thus increasing the ambient air humidity. The effects of terrace cultivation on temperature and humidity are likely greater near/at ground level. Measurements at ground level were however not a component of action C5, which is the subject of this report.

Terraces may furthermore decrease the negative (indirect) impacts of climate change, through decreasing erosion, increasing infiltration, help storage and slow release of groundwater, decreasing flood peaks, creating fire-breaks and preserving soil (and vegetation). The benefits of terrace restoration are becoming progressively more significant, with increasing the total aerial extent of restored terraces. Finally, this assessment provides base-line meteorological information that will be of crucial importance for the future monitoring that is part of the “after-LIFE” program. Base-line meteorological data are essential for evaluating future climate forecasts.

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