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COMPARISON OF EXTREME WEATHER INDICATORS ELABORATED FROM HETEROGENEOUS AGROMETEOROLOGICAL SOURCES

CONFRONTO DI INDICATORI DI CONDIZIONI METEOROLOGICHE ESTREME ELABORATI DA FONTI DI DATI AGROMETEOROLOGICI ETEROGENEE

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Abstract

In the current study, the sensitivity of extreme weather indicators related to temperature and rainfall has been assessed in relation to different sources of agrometeorological data: the weather stations that belong to the Piedmont Regional service (RAM) and the proximity sensors deployed in the production area of Moscato d'Asti (SISAV). Indicators assessment has been conducted between 2021 and 2023 in five locations with twin stations for RAM and SISAV (<2 km distance). Results show varying sensitivity of the indicators to data sources, depending on the considered weather factor, the location, and year. For instance, the yearly number of frozen days (ID0, i.e., days without thaw) is similar for both the sources, while the yearly number of tropical nights (TR20, i.e., days with minimum temperature >20°C) varies among sensor, with about 4 to 6 days of difference between the two sources of data. Discrepancies in indicators highlight the key role of the data provider to understand climate changes and trends over time.

Keywords:
Internet of Things, wireless sensor networks, agrometeorological platforms, proximal monitoring, public agrometeorological networks
Parole chiave:
Internet of Things, reti di sensori senza fili, piattaforme agrometeorologiche, monitoraggio di prossimità, reti pubbliche di sensori agrometeorologici

Introduction

Meteorological data are fundamental to numerous purposes, including the study of climate change (CC). The knowledge on current and past weather is mandatory when trying to identify and estimate CC impacts. While simulation models help to project future climate scenarios, the monitoring of weather variables and their application to meteorological indicators allows the understanding of CC in last decades and ongoing trends.

Recently, several meteorological indicators have been proposed based on mean data on different time scale and distributions of temporal series of weather data. However, indicators based on extreme values seem to better depict the magnitude of CC and are particularly relevant also in relation to the impact of extreme events on the environment and human health.

Particularly, extreme temperature and rainfall events play a key role in agriculture due to their influence on hydro-geological aspects, availability of water resources, yield and harvest quality, as well as the occurrence of plant diseases and contamination of productions.

The study of extreme events and the application of extreme weather indicators is more difficult than studying average distributions. In fact, extreme events are often unpredictable, with a point or patchy distribution over a geographical area. It therefore becomes essential to have a complete series of weather data with a high temporal and spatial resolution. These characteristics often depend on weather data providers, which may have networks of stations differently deployed on a territory, mounting diverse sensor types, and operating with distinctive timesteps. In this context, variability in extreme indicator values, result interpretation, and CC effect estimation may be found in relation to the choice of weather data provider.

The aim of the current work is therefore to assess the sensitivity of extreme weather indicators related to temperature and rainfall in relation to different sources of agrometeorological data. For this purpose, the production area of Moscato d'Asti has been selected as a case study, and the weather stations that belong to the Piedmont Regional service (RAM) and the SISAV network of proximity sensors provided by iXemWine were considered. Thus, indicators assessment has been conducted using weather data between 2021 and 2023 from five locations with twin stations (i.e., close stations belonging to the two networks).

Materials e Methods

Weather stations

In this paper two different agrometeorological networks have been exploited: the Piedmont agrometeorological network (RAM) and iXemWine. These two networks are different both in technology and deployment strategy.

The RAM network, initially started in 1998, is currently composed of 120 agrometeorological stations, deployed in places selected to respect metrological constraints, hence outside crops. The technology used to transmit data is GPRS, therefore only places served by cellular coverage can be monitored. Data is transmitted daily on a remote server that collects and stores all the measurements sampled hourly. Validation is applied on the server side and possible missing samples are reconstructed. The result is a valuable archive of historical data ready to be used in different agronomic applications. In addition, the RAM network allows users to visualize the last 30 days of measurements by means of a web application.

The SISAV proximity sensors are 18 proximal agrometeorological weather stations deployed in the area pf production of Moscato d'Asti. Figure 1 shows the location of RAM and SISAV stations in the area of study.

The stations have been implemented in the framework of the SISAV project and data are collected by means of the the iXemWine platform, developed by the iXemLabs at Politecnico di Torino. Regarding the transmission technology, a Low Power-Wide Area Network (LP-WAN) system has been chosen, with LoRa radios, a LoRaWAN network protocol, and the network server from The Things Network (TTN). Finally, data is collected and stored by the iXemWine application server that enables users to visualize and share the measured data.

Sensors are connected by wire to a LoRaWAN end-node that has been designed for this specific project. A custom Printed Circuit Board (PCB), as shown in Figure 2, has been developed for collecting and transmitting data from the sensors, using a Murata module (type 1SJ) that integrates a microcontroller from the STM32L0 family (by STMicroelectronics) and the SX1262 radio chip (by Semtech) into a single component, powered by 2 AA alkaline batteries in series. This choice allows for a miniaturized and optimized device suitable for field installations. A boost converter has been inserted for compatibility with both 3.3V sensors and 5V sensors. To improve network converage, an external dipole antenna has been connected through an RF pigtail to the PCB.

The system supports different sensor types, but for this project, to compare measures with the RAM network, we have considered only the following types:

- Temperature and relative humidity of the air sensor (Sensirion SHT31), protected by a Stevenson shelter in plastic;
- Rain gauge (Pronamic Tower Rain Gauge 1 mm);
- Double-sided capacitive electronic leaf wetness sensor, specifically designed for this project to be low power and low cost (Filipescu *et al.*, 2024), exploiting a capacitance-to-digital converter (FDC2112).

Table 1 shows the resolution and accuracy for each sensor is reported.

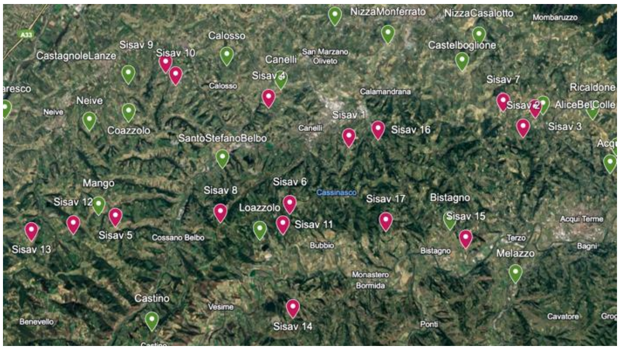

Fig. 1 – RAM (green) and SISAV (bordeaux) stations in the area of study

Fig. 1 – Posizione delle stazioni RAM e delle stazioni SISAV nell'area di studio

Fig. 2 - PCB integrating microcontroller and LoRa radio

Fig. 2 - PCB che include microcontrollore e radio LoRa

Tab.1 – Technical characteristics of the proximal sensors

Tab.1 – Caratteristiche tecniche dei sensori di prossimità

Sensor	**Resolution**	**Accuracy**
Sensirion SHT31	T: 0.1 °C RH: 0.1%	T: ±0.3 °C RH: ±2%
iXem Leaf Wetness	1%	±5%
Pronamic Tower Rain Gauge	1 mm	±5%

Differently from the RAM network, the weather stations have been installed within the crops, as shown in Figure 3, in locations to be as more representative as possible of the entire vineyard.

Regarding the locations, this study has been conducted in the region of Piedmont where the Moscato grape is cultivated: a large area that includes the provinces of Asti, Alessandria and Cuneo. All these locations have different features for altitude, exposure to the sun and slope inclination. Consequently, in the area climate conditions are not uniform, therefore neither is the vegetative development. To provide an idea of the size of the Moscato area, table 2 reports the vineyard surface and the number of municipalities for each province.

Fig. 3 - Weather stations were installed inside the vineyard
Fig. 3 - Stazione meteo installata all'interno del vigneto

Tab.2 - Details of the Moscato area in Piedmont
Tab. 2 - Informazioni relative all'area di coltivazione del Moscato in Piemonte

Province	Vineyard surface (ha)	Number of municipalities
Alessandria	1.540	9
Asti	4.116	28
Cuneo	4.210	15

Finally, devices have been programmed to take one measurement per sensor at 10-minute intervals, providing 144 daily updates. The transmitted data has been received by LoRaWAN gateways deployed in strategic locations from the perspective of the electromagnetic coverage, with easy accessibility for maintenance operations.

Extreme weather indicators

A total of 13 extreme weather indicators have been selected, based on their relevance and significance, according to Fioravanti et al. (2013). Eight of them are related to temperature and calculated based on minimum and maximum daily temperature (in °C). The other five indicators are related to rainfall and calculated using daily rain data (in mm). The list of selected indicators and their description is listed in Table 3. Calculation of extreme weather indicators have been performed using the R software (R Core Team. R: A Language and Environment for Statistical Computing 2023; available at https://www.r-project.org/). Daily data have been obtained from the hourly weather data provided by the stations. Then, each indicator has been calculated as defined in Table 1 for five locations hosting twin weather stations by RAM and SISAV networks between 2021 and 2023. Weather stations from the two networks have been considered as twins when their distance is within 2 km. The twin stations are fairly distributed in the production area of Moscato d'Asti (Table 4). Indicators have been compared for their consistency among different years and locations and for their sensitivity to the source of weather data.

Tab.3 - List of extreme weather indicators related to temperature and rainfall, their acronym, and description. Tmin=minimum daily temperature; Tmax=maximum daily temperature; R=daily rainfall.
Tab.3 - Lista degli indicatori meteorologici estremi in relazione a temperatura e pioggia, loro acronimi e descrizione. Tmin= temperatura minima giornaliera; Tmax=temperatura massima giornaliera; R=pioggia giornaliera.

Code	Indicator	Description
FD0	Frozen days	N. of days in a year with Tmin < 0 °C
SU25	Summer days	N. of days in a year with Tmax > 25 °C
ID0	Days without thaw	N. of days in a year with Tmax < 0 °C
TR20	Tropical nights	N. of days in a year with Tmin > 20 ºC
TN10p	Cool nights	% of days with Tmin < 10th percentile
TX10p	Cool days	% of days with Tmax < 10th percentile
TN90p	Warm nights	% of days with Tmin > 90th percentile
TX90p	Warm days	% of days with Tmax > 90th percentile
SDII	Daily rainfall intensity	Ratio between the total R in a year and the N. days with R ≥ 1 mm)
R10	Number of days with intense rainfall	N. of days with R ≥ 10mm in a year
R20	Number of days with very intense rainfall	N. days with R ≥ 20mm in a year
R95p	Rainfall in intense rainy days	Sum of R > 95th percentile in a year
R99p	Rainfall in very intense rainy days	Sum of R > 99th percentile in a year

Results and Discussion

Varying sensitivity of the indicators to data sources, depending on the considered weather factor, the location, and year has been analyzed. Particularly, indicators as FD0, SU25, TR20, and R10 show great differences in their values depending on the weather station network (Figure 4). For instance, the yearly number of tropical nights (TR20, i.e., days with minimum temperature >20°C) varies among sensor locations, with about 4 to 6 days of difference in the mean value between the two sources of data, but the range of variation is significantly wider for SISAV data source. High variance has been also observed for the yearly number of frozen days (FD0, i.e., days with minimum temperature <

0 °C), which shows an average of 17 more days when based on RAM data sources.

Tab.4 - List of RAM and corresponding twin SISAV weather stations selected for the calculation of extreme weather indicators between 2021 and 2023, their geographical coordinates (latitude; longitude), and altitude.
Tab. 4 - Elenco delle stazioni meteorologiche RAM e delle corrispondenti stazioni gemelle SISAV selezionate per il calcolo degli indicatori meteorologici estremi tra il 2021 e il 2023, le relative coordinate geografiche (latitudine; longitudine) e altitudine.

Twins	Weather station	Location	Altitude
1	RAM Alice Bel Colle	44°43'31.2"N 8°26'26.6"E	257 m
	proximal Sisav 3	44°43'25.2"N 8°26'08.5"E	285 m
2	RAM Bistagno	44°40'16.2"N 8°22'44.2"E	275 m
	proximal Sisav 15	44°39'44.2"N 8°23'22.1"E	211m
3	RAM Loazzolo	44°40'00.1"N 8°15'08.6"E	403 m
	proximal Sisav 11	44°40'09.0"N 8°16'03.8"E	382 m
4	RAM Canelli	44°44'14.6"N 8°15'59.6"E	281 m
	proximal Sisav 4	44°43'43.1"N 8°15'30.2"E	299 m
5	RAM Mango	44°40'41.6"N 8°08'44.8"E	468 m
	proximal Sisav 5	44°40'22.2"N 8°09'25.2"E	504 m

On the other hand, some indicators seem to be less affected by the data source. For example, the yearly number of days without thaw (ID0, i.e., days with maximum temperature < 0 °C) is similar for both the sources. Similarly, indicators related to very intense rainfall events such as R20 (i.e., days with daily rainfall ≥ 20 mm) or R99p (i.e., the sum of daily rain higher than the 99th percentile in a year) poorly varies among weather stations. For daily rainfall intensity (SDII, i.e., the ratio between precipitation amounts and rainy days), instead, a tendency towards underestimation has been observed for RAM compared to SISAV.

Trends could also be identified for some indicators in relation to the year, although different values have been obtained for the two sources of weather data. For instance, TR20 increases over the three years in all the locations, while FD0 values decreases, indicating a tendency in the increase of minimum temperature from 2021 to 2023. However, values differ depending on the weather station network. For example, at Alice Bel Colle, calculations using RAM data result in TR20 equal to 2, 10, 18 days from 2021 to 2023; however, values for the corresponding SISAV3 station are lower (i.e., TR20 was 0, 4, and 16 in 2021, 2022, and 2023, respectively). On the contrary, FD0 decreases over time in all the locations.

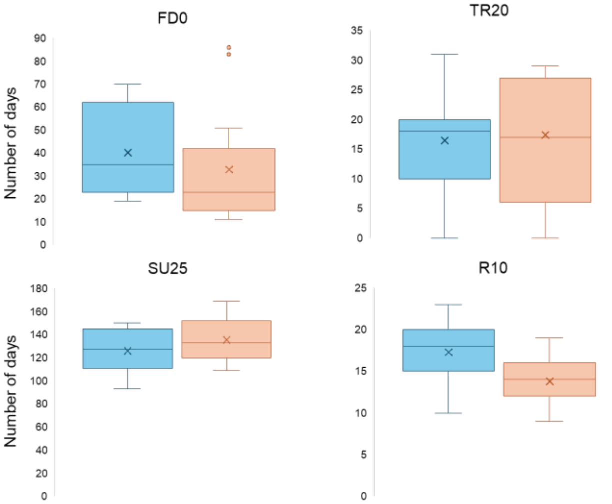

Fig.4 - Boxplot showing the variation of the following indicators: yearly number of frozen days (FD0, i.e., days with minimum temperature < 0 °C); yearly number of summer days (SU25, i.e., days with maximum temperature > 25 °C); yearly number of tropical nights (TR20, i.e., days with minimum temperature >20°C); and yearly number of days with intense rainfall (R10, i.e., days with daily rainfall ≥ 10mm). Boxes represent values calculated based on data provided by RAM (blue) and SISAV (orange) weather stations; the line in the boxes is the median; the x is the average value; the lowest value in each box represents the 1st quartile (25th percentile); the top part of each box represents the 3rd quartile (75th percentile); whiskers extend from minimum to maximum.
Fig. 4 - Boxplot che mostrano la variazione dei seguenti indicatori: numero annuo di giorni di gelo (FD0, ovvero giorni con temperatura minima < 0 °C); numero annuo di giorni estivi (SU25, ovvero giorni con temperatura massima > 25 °C); numero annuo di notti tropicali (TR20, ovvero giorni con temperatura minima > 20 °C); e numero annuo di giorni con precipitazioni intense (R10, ovvero giorni con precipitazioni giornaliere ≥ 10 mm). I riquadri rappresentano i valori calcolati sulla base dei dati forniti dalle stazioni meteorologiche RAM (blu) e SISAV (arancione); la linea nei riquadri è la mediana; la x è il valore medio; il valore più basso in ciascun riquadro rappresenta il 1° quartile (25° percentile); la parte superiore di ciascun riquadro rappresenta il 3° quartile (75° percentile); i baffi si estendono dal minimo al massimo.

Although only three years have been considered, indicators for temperature show a tendency towards warmer weather from 2012 to 2023, with more evident trends observed for indicators related to an increase in warm extremes than those associated to a reduction of cool conditions. This agrees with broader observations on temperature trends made by Fioravanti et al. (2013) in Italy between 1961 and 1981. They have also pointed out a lower consistency in rain trends, also related to spatial variability. According to their results, only R95 e SDII indicate a slight increase for intense precipitation.

However, similar trends have not been observed in the current study, likely due to the lower number of weather stations and years considered.

It is worth noting that indicators often show different values between the two weather station networks, despite the closeness of weather stations compared. These discrepancies highlight the key role of the data provider, the technology implemented on weather stations, and deployment strategy.

Conclusions

Climate is changing quickly, leading to the need for indicators to evaluate past and current weather, especially for extreme temperature and rainfall events that strongly affect viticulture. The study of extreme weather, however, is difficult because it requires weather data series with good resolution at spatial and temporal level. A packed weather station network providing accurate and reliable data becomes fundamental to depict weather conditions and to understand weather changes and trends over time.

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