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RESEARCH ARTICLE

REVISED Insights into climate variability of the meteorological records from a background monitoring station: the Giordan lighthouse, Gozo

[version 2; peer review: 2 approved, 2 approved with reservations]

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Abstract

Background

The Maltese islands are subject to substantial climate variability, with implications for ecosystems and human activities. This study leverages a 26-year dataset from the Giordan Lighthouse Background Monitoring Station (GL) on the island of Gozo to analyse short-term climate variability and its alignment with broader regional tendencies.

Methods

Hourly meteorological data collected from 1997 to 2022, including wind speed, wind direction, air temperature, relative humidity, and air pressure, were analysed. The study examined diurnal and annual cycles, probability distribution functions, and climate indices to characterise local climate dynamics. Qualitative comparisons were made to existing findings based in Malta to corroborate the results.

Results

The analysis revealed pronounced seasonal variability in all parameters. Rising air temperatures were detected, consistent with regional warming tendencies. Humidity and wind conditions showed

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seasonal shifts aligning with observations from other regional monitoring stations. The high-resolution dataset also captured fine-scale temporal patterns, reinforcing the critical value of localised, long-term meteorological monitoring for understanding climatic shifts.

Conclusions

This study underscores the value of long-term meteorological datasets in detecting climate variability, including a clear warming pattern and seasonal shifts in temperature, humidity, and wind conditions. Continuous monitoring and improved data reliability are essential for enhancing climate assessments and supporting effective adaptation strategies in the Maltese Islands.

Keywords
Short-Term Climate Variability, Meteorological Records, Background Monitoring Station, Giordan Lighthouse, Gozo

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REVISED **Amendments from Version 1**

This revised version incorporates substantial improvements based on the constructive feedback provided by all reviewers. Several clarifications were made to the methodology, including the rationale for data filtering thresholds, treatment of anomalous values, and a clearer explanation of the approach used in the calculation of climate indices. Additional extreme heat indicators (TX35, TXX, and TNN) were included, with expanded discussion of their implications. We also introduced seasonal and annual distributions for relative humidity and wind intensity (Figure 6 and Figure 7), enhancing the consistency of visual presentation across variables. The "Climate assessment" section was expanded to assess correlations between observed variables and major teleconnection indices, including NAO, MOI, and ENSO, addressing suggestions from multiple reviewers. While we explored annual trends, the high sensitivity of results to data availability thresholds led us to exclude quantified trend figures from the main text; however, the corresponding plots are included in the supplementary material, and relevant findings are discussed where appropriate. Figures were updated to improve clarity, with the inclusion of an elevation map, photo of the monitoring station, and adjustments to captions. Table 1 now includes details on instruments, observation periods, and uncertainties. Lastly, we added information on data calibration, maintenance practices, and clarified several points regarding data sampling and visualization. These revisions collectively strengthen the robustness and transparency of the study.

Any further responses from the reviewers can be found at the end of the article

Introduction

The Maltese Islands, situated in the heart of the Central Mediterranean, are characterised by a distinct climate with hot, dry summers and mild, wet winters. The climate of the Maltese Islands, shaped by its geographic location and proximity to the North African coast, has a history of scientific investigation (England *et al.*, 2010; Jahan *et al.*, 2022; Wadsworth, 1928). Notably, local research (Azzopardi, 2016; Galdies, 2010; Galdies, 2011; Galdies, 2012; Galdies, 2022; Hyde, 1955) has shed light on various aspects of Maltese climate. These studies contribute to a foundation of knowledge and understanding of the Maltese climate.

According to data collected between 1961 and 1990 from the Malta International Airport in Luqa, Malta (Galdies, 2010; Galdies, 2022), the seasonal cycle is defined by monthly averages of approximately 12 °C in January and February, and peak annual temperatures between July and August with averages above 25 °C. At their most extreme, temperatures have varied between 1.4 °C and above 43 °C (Galdies, 2011; Galdies, 2022). Over recent decades, the average temperature has been steadily increasing, reaching an anomaly of 1.5 °C higher than averages in 1952 (Galdies, 2022). Relative humidity (RH) also varies seasonally, with an average of ~79% in winter, and ~69% in summer (Galdies, 2011; Galdies, 2022). Furthermore, a recent report (Galdies, 2022) has noted a gradual decrease in average RH on the island of 0.8% per decade, a phenomenon that can be attributed to the observed warming, and also potentially to the aridification of the region (Doblas-Reyes *et al.*, 2021; Gutiérrez *et al.*, 2021; Ranasinghe *et al.*, 2021). The near-surface winds (measured at 10 m above ground) being predominantly north-westerly (centred at 315°), vary with a winter average of 5.25 m s-1 (10.2 knots) in winter to 3.54 m s-1 (6.9 knots) in summer (Galdies, 2022; Wadsworth, 1928). These studies also reveal that the Maltese islands may still be undergoing terrestrial stilling (McVicar *et al.*, 2012; Vautard *et al.*, 2010), a phenomenon which may be in the process of reversal (Zeng *et al.*, 2019).

However, there remains a need for continuous monitoring and analysis of climate variability, particularly in the face of ongoing global rapid climate change. The Giordan Lighthouse Background Monitoring Station (henceforth referred to as GL), established in 2000 and accredited as a Global Atmosphere Watch (GAW) station in 2005 (Ellul & Saliba, 2005), serves as a crucial site for this purpose. The station's suite of instruments, specifically chosen for their accuracy in harsh coastal environments, has been collecting high-resolution meteorological data for over two decades.

This study utilises the dataset from the GL to assess climate variability within this background monitoring station by comparing it with findings of existing research within the Maltese islands. While past research with GL data was primarily focused on wind and air quality (Azzopardi, 2016; Ellul & Saliba, 2005; Matasović *et al.*, 2023), we aim to provide a more comprehensive analysis of climate variability at the GL by:

- reporting on any missing data gaps and outliers within the time series;
- delving into meteorological parameters in addition to winds, allowing for a more holistic understanding of the climate system in the region;
- assessing climate variability within annual and diurnal cycles;
- exploring the variation of extreme indices derived from these parameters, providing insights into the frequency and intensity of extreme weather events at the GL.

The giordan lighthouse background monitoring station

History

The GL was constructed when the Maltese Archipelago was a British Colony. It started operating on 15 March 1853 (D'Amico *et al.*, 2024). The purpose of the GL was to act as a reference point for vessels crossing the Strait of Sicily and those approaching the Maltese islands, thus becoming an important landmark for navigation. As vessels were equipped with transponders and navigation devices, the physical presence of the GL was no longer needed for navigation.

After this time, the purpose of the GL shifted to provide a local and international scientific contribution. A joint Maltese-German atmospheric pollution research programme was launched on 7 December 1996 to monitor atmospheric pollution over the Maltese islands and in the Central Mediterranean (D'Amico *et al.*, 2024; Ellul & Saliba, 2005). Since the establishment of

this research programme, several meteorological parameters have been continuously measured and recorded, including wind speed and direction, air temperature, relative humidity, and atmospheric pressure. The resulting long-term dataset contributed to numerous air quality studies (Azzopardi *et al.*, 2013; Cristofanelli *et al.*, 2015; Kalabokas *et al.*, 2008; Nolle *et al.*, 2002; Saliba *et al.*, 2008; Saliba *et al.*, 2021; Sofen *et al.*, 2016; Tenkanen *et al.*, 2021; Tsuruta *et al.*, 2017), while the meteorological dataset forms the core of the study being reported here.

Instrument and data collection

The GL is located on Ġurdan Hill overlooking the village of Għasri on the northwest coast of the island of Gozo (Figure 1). Its base is 163 m above mean sea level and approximately setback by 800 m from the coastline. The Lighthouse is 21 m in height and has geographic coordinates 36° 04' 24" N and 14° 13' 08" E. The instruments used at the GL include a cup and vane anemometer (Lambrecht model 14512, replaced by Lufft model WS200 on 28th July 2021, installed at the top of the lighthouse) to measure wind speed and direction, a Vaisala HMP60 probe (installed approximately 4 m above the base level) to measure relative humidity and air temperature, and briefly, between 2002 and 2008, the Vaisala PTB110 was installed at approximately 167 m above mean sea level, to measure air pressure. All variables are recorded at one minute interval (instantaneous), and then averaged to an hourly resolution (Saliba & Micallef, 2025). This study provides an analysis of the meteorological data (variables and instrument information are summarised in Table 1) collected from this station over a 26-year period, ranging from 1997 to 2022, with an hourly temporal resolution.

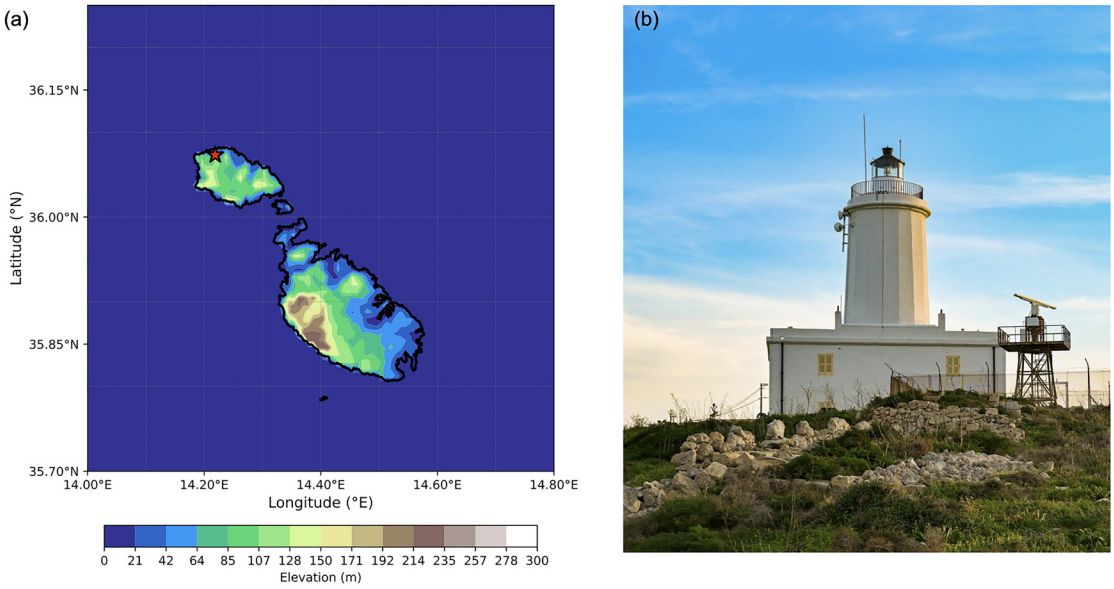

Figure 1. (**a**) Elevation of Malta and Gozo with the station position, and (**b**) a photo of the GL monitoring station.

Table 1. Abbreviations and descriptions of meteorological variables measured at the Giordan Lighthouse Background Monitoring Station. Lambrecht instrument for WS and WD was applicable up to 2017, and the Lufft instrument from 2020 onwards. FS = Full Scale (range provided in parenthesis), RMSE = Root Mean Square Error.

Abbreviation	Full Name	Units	Instrument	Uncertainty
WS	Wind Speed	m s^{-1}	Lambrecht 14512 Wind anemometer	± 2% FS (0 - 35 m/s)
			Lufft WS200 Smart weather sensor	±0.3 m/s
WD	Wind Direction	°	Lambrecht 14512 Wind anemometer	± 1% FS (0 - 360°)
			Lufft WS200 Smart weather sensor	<3° RMSE, >1.0m/s
RH	Relative Humidity	%	Vaisala HMP60 Probe	±3%
AT	Air Temperature	°C	Vaisala HMP60 Probe	±0.6 °C
DT	Dew Point Temperature	°C	*Calculated using Equation (8) in Lawrence (2005)*	*±5.7 °C*
AP	Air Pressure	hPa	Vaisala PTB110 Barometer	±0.3 hPa

The long-term nature of data collection inevitably leads to occasional technical issues. Data outside the sensor's measurement range is automatically flagged as invalid. The radiation shield housing the Vaisala probe is inspected every two weeks, and both the shield and probe are carefully cleaned when there is presence of light dust. Periodically, both the AT and RH readings are compared with those from nearby stations overseen by the Malta Meteorological Office. The Lambrecht wind anemometer was serviced once a year by putting three drops of fine oil in the head. No further calibration and maintenance was required as per the manufacturer's instructions (including for the Lufft anemometer).

Despite these regular checks, occasional irregular readings may still occur. Here, we discuss specific instances where data points were removed due to problems identified with the instruments. Notably, eight data points were identified where the pressure was around 750 hPa, with a change of well over 200 hPa from the previous and following time-steps. Additionally, a data gap occurred between September 2003 and December 2004 because the probe was not operational during that time.

A WS data gap is present between 26th September 2017, and 31st December 2020, which originated due to a malfunction in the original cup and vane anemometer (Lambrecht model 14512). To restore reliable data collection, the instrument was replaced with a Lufft model WS200 anemometer. Additionally, a separate period from 21:00 on 13th April 2017 to 06:00 on 5th July 2017 was excluded, as the values remained constant at 6.4 m s-1, due to a sensor malfunction, which was later resolved.

Although the Vaisala HMP60 probe is designed to measure RH within a 0–100% range, certain readings in this dataset fell outside this operational window. Notably, a value of 1766% was recorded at 01:00 of 13th April 2000 and a value of -462% recorded at 07:00 of 7th December 1999. All outliers exceeding the sensor's range were removed from the dataset. Additionally, instances where RH suddenly dropped to 0% (or close to it), such as at 04:00 on 3rd June 2019 and between 03:00 and 05:00 on 19th June 2019, were also excluded. In total, 1006 data points were removed due to these malfunctions.

Similarly, some AT readings were characterised by large and sudden deviations (e.g., 19°C to 47°C or above) in temperature compared to the nearest recorded values. The data points between the start and end of such activity were excluded from the dataset. The specific instances of these anomalous readings, which totalled 231 data points, included: 10:00 on 1st August 2016; 07:00 on 2nd August 2016; 09:00 to 18:00 on 15th June 2018; 21:00 on 2nd May to 01:00 on 16th May 2019; 16:00 on 24th May to 11:00 on 25th May 2019; 08:00 to 10:00 on 2nd June 2019; 05:00 to 07:00 on 3rd June 2019; 03:00 on 6th June 2019; and 08:00 on 11th June 2019. All these anomalous readings were removed from the analysis dataset but preserved separately in the Supplementary Material.

Data coverage

In this study, we begin by assessing the completeness of the dataset over the 25-year period. Specifically, we calculate the percentage of data available for each month across all six variables. This preliminary analysis is crucial for identifying periods of missing data, which could impact the validity of subsequent analyses and interpretations. The results of this initial assessment are visualised in Figure 2, which provide a clear overview of the data availability across different months and years.

Although the dataset starts in 1997, only WS and WD contain data within the first two years, as the GL station was still in the early stages of setup. All variables are missing data in 2009 and 2010 as the instruments room at GL was being restored in preparation for the arrival of new equipment funded by the European Regional Development Fund (ERDF 078 - Upgrading of Giordan Lighthouse GAW Research Station). When compared to the other variables, the AP records are available only for the span between 2002 and 2008 when the 21X logger was operating. Following the installation of the new equipment, the AP data was no longer recorded due to the limited analogue channel of the logger provided by the supplier. Taking into account measurement errors and system interruptions, each variable contains the following fractions of the 26-year dataset: 72.3% for AT; 70.86% for DT; 71.8% for RH; 18.5% for AP; 67.4% for WS; and 78.3% for WD. Given the small AP dataset, we have not explored the climatology of this parameter within the context of this study, however, analogous plots with this variable can be found together with the scripts (see Supplementary Images and Software availability).

Methods

The climate assessment of this meteorological dataset involves a comprehensive analysis using various tools and indices to capture the characteristics of the recorded variables. This section details the methodologies and indices employed to evaluate the climate conditions over the 26-year period.

To thoroughly analyse the dataset, a range of analytical tools was applied. Probability Distribution Functions (PDFs) were constructed from the hourly data to understand the distribution and variability of each meteorological variable. The means, standard deviation, maxima and minima for each of the daily 24-hours were used to construct diurnal cycles. The same statistics were obtained for every day of the year to create annual cycles, illustrating the seasonal tendencies and long-term variations throughout the year. These cycles are essential for identifying recurring patterns and potential anomalies in the data.

Seasonal Wind Roses were created to visualise the predominant wind patterns and variations across different seasons, aiding in understanding the local wind climatology. Finally, time series heat maps were prepared to represent the monthly means of each variable across the entire dataset. These

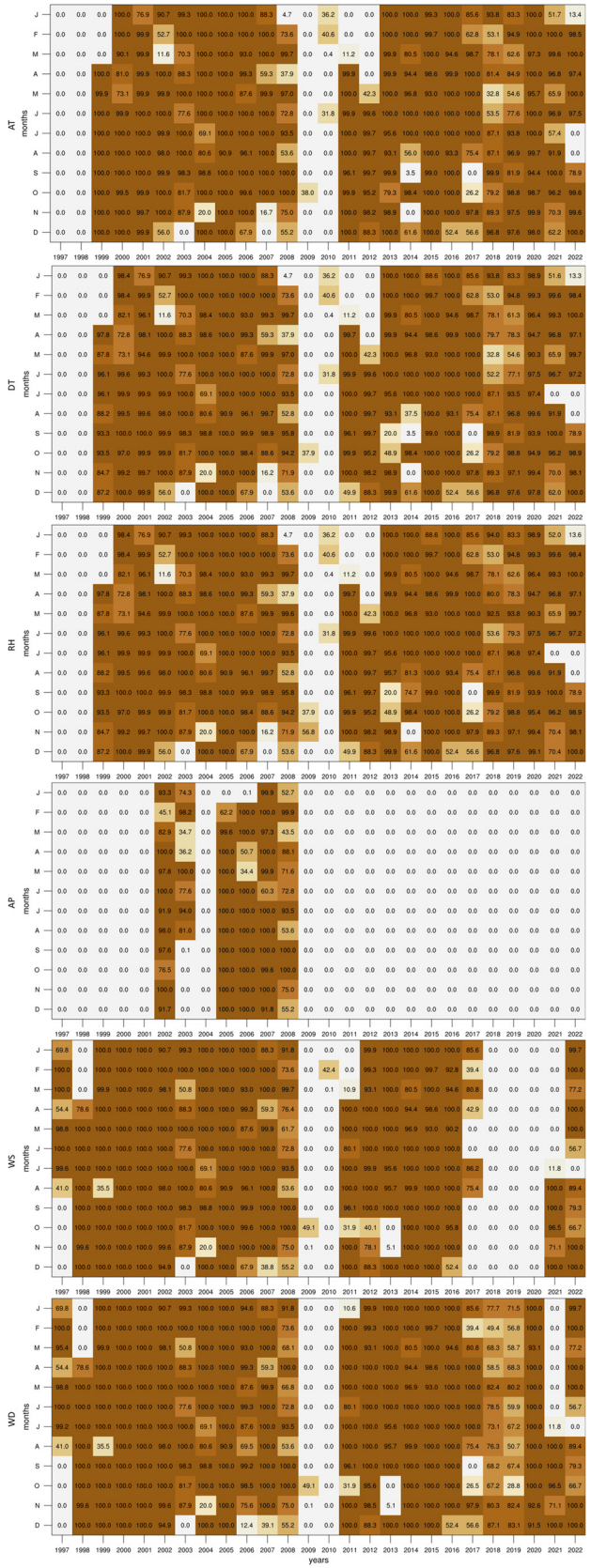

Figure 2. Percentage of valid data points for each month and variable in the dataset.

visualisations facilitate the identification of tendencies and anomalies in the data over extended periods, making it easier to spot changes in climate conditions.

To further describe the climatic conditions, we employed a few climate indices (Dunn *et al.*, 2020; Yu & Zhong, 2019) that provide a deeper understanding of specific weather patterns:

- Summer Days (SU), which accounts for the number of days in a month when the daily maximum temperature (TX) exceeds 25°C;
- Tropical Nights (TR), which measures the number of days in a month when the daily minimum temperature (TN) exceeds 20°C;
- Days exceeding 35°C (TX35), which quantifies the number of days in a month when TX exceeds 35°C;
- Monthly maximum for TX (TXX);
- Monthly minimum for TN (TNN);
- Windy Days (WI), which is a count of the number of days in a month when the mean WS is equal to or greater than Beaufort scale 6 (10.8 m/s or 22 knots).

The SU and TR are indicative of warm weather periods and are useful for assessing the frequency and distribution of hot days and nights over the years, which can have important implications for energy consumption, human comfort, and local ecosystems. TX35 complements these indices by quantifying the occurrence of extremely hot days within each month. Additionally, TXX and TNN provide insight into temperature extremes that stress the limits of the temperature at the station. Finally, the frequency of WI is crucial for understanding wind patterns and their potential impacts on local weather, infrastructure, and activities. The Supplementary Material also includes assessments for the following additional temperature indices: monthly mean for TX (TXm), monthly mean for TN (TNm), Diurnal Temperature Range (DTR; monthly average difference between TX and TN), and Extreme Temperature Range (ETR; difference between TXX and TNN).

To construct the annual cycles for these indices, the original monthly definition of each index was retained as "number of days per month", but a 30-day running mean (maximum and minimum for TXX and TNN respectively) was applied across the daily time axis. This corresponds to 336 overlapping 30-day windows per year, rather than 12 non-overlapping calendar months, and provides a smoother and more continuous representation of the annual cycle. This approach preserves the index definition and presents a result that is comparable to the other annual cycles presented, while offering enhanced interpretability and robustness.

To investigate long-term trends, we also constructed time series of annual means. However, due to the uneven data coverage across the full record (as shown in Figure 2), certain years may be misrepresented, particularly where seasonal gaps are present. To address this, we applied two filtering thresholds to the annual time series: one including only years with at least 60% data availability, and another using a stricter 80% threshold. The resulting trends proved highly sensitive to the chosen filter. For example, the heat maps reveal that missing summer data in 2014, 2017, and 2022 substantially affects indices such as SU and TR, which rely heavily on warm-season observations. Notably, the trend in TR appears negative when using the 60% filter, but becomes positive when applying the 80% filter. The latter outcome is consistent with broader European and Mediterranean trends in tropical nights (Correa *et al.*, 2024; Klok *et al.*, 2023; Yavaşlı & Erlat, 2024). Given these uncertainties, we have chosen not to present trend values in the main text, however, these annual time series plots are included in the Supplementary Material, and relevant observations are mentioned in the main discussion where appropriate. These tools and indices provide a robust framework for assessing the climate conditions represented in the dataset. The subsequent sections will present detailed analyses based on these methodologies, offering insights into the temporal and spatial variations in the recorded meteorological variables.

Climate assessment

In this section, we present a detailed analysis of the climate conditions captured in our meteorological dataset. The assessment focuses primarily on temperature, humidity, and winds. By examining these key variables separately, we aim to provide a comprehensive understanding of the climate described by the recorded data.

Similar plots and detailed analyses for all other variables, including AP, are available in the data repository alongside the dataset. These additional resources provide a more extensive view of the climate conditions at the station and support the findings discussed in this section.

To better understand the drivers of inter-annual variability influencing the GL station, we investigated correlations between monthly averages of the observed variables and a set of well-established large-scale climate indices. These included the El Niño–Southern Oscillation (ENSO; Kousky & Higgins, 2007; Rasmusson & Carpenter, 1982), the North Atlantic Oscillation (NAO; Barnston & Livezey, 1987; Chen & van den Dool, 2003; van den Dool *et al.*, 2000), and the Mediterranean Oscillation Index (MOI; Conte *et al.*, 1989; Palutikof, 2003; Palutikof *et al.*, 1996). These indices were obtained from the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI), the NOAA Climate Prediction Center (CPC), and the University of East Anglia (UEA) Climatic Research Unity (CRU) respectively.

The correlations, summarized in Table 2, reveal a clear link between the NAO and several climate parameters, most notably AT and WS, consistent with known effects of this teleconnection. The MOI also shows moderate correlations with WD, likely reflecting the influence of regional circulation patterns in the Mediterranean Basin. ENSO-related indices are generally

Table 2. Pearson correlation between GL variables and three teleconnection indices. ENSO is represented by NINO3.4, and MOI by MOI1. Bold values indicate correlations significant at the 95% confidence level. Correlations for air pressure (AP) are presented for completeness but should be interpreted cautiously due to limited data availability (see Figure 2).

	ENSO	NAO	MOI
WD	0.032121	-0.064030	**0.364481**
WS	**-0.223180**	**0.361187**	**-0.490180**
RH	-0.068790	0.056916	-0.063890
AT	0.003897	**-0.384720**	**0.455612**
DT	-0.027480	**-0.353610**	**0.423142**
AP	-0.018550	**0.243380**	0.038302

weakly correlated with the local variables, although WS exhibits some sensitivity.

Overall, this analysis supports previous findings in the literature (e.g., Brönnimann, 2007; Ciarlo` & Aquilina, 2015; Wallace & Gutzler, 1981) linking Central Mediterranean climate variability to large-scale atmospheric teleconnections. A more comprehensive treatment of this topic, including lagged effects and sub-seasonal dynamics, could be explored in future work. Full correlation matrices and variations of these indices are available in the Supplementary Material.

Temperature

Temperature is a fundamental climate variable, influencing many aspects of the environment and human activities. Figure 3 illustrates this variable at the Giordan Lighthouse in Gozo through a PDF, diurnal cycle, and annual cycle. The PDF (Figure 3a) shows a clear bimodal distribution for temperature, peaking at around 10 °C and 25 °C, which suggests that the climate in the region fluctuates predominantly between two

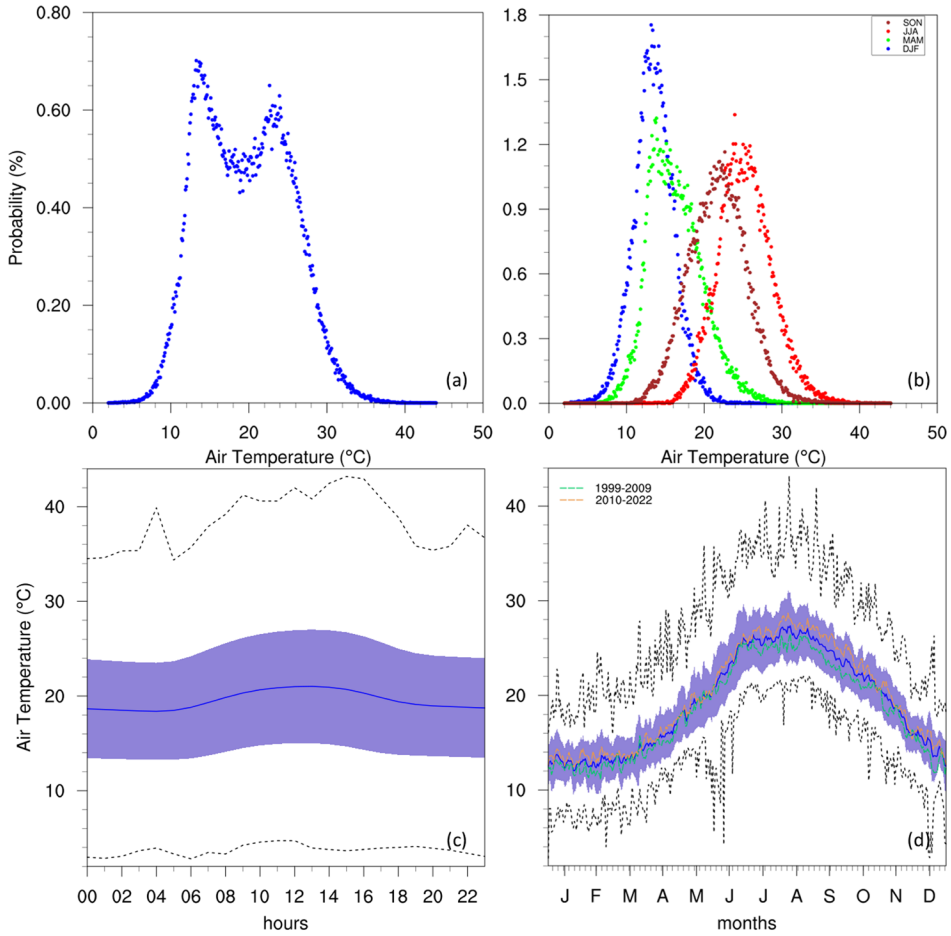

Figure 3. (**a**/**b**) Annual/seasonal PDFs, (**c**) diurnal and (**d**) annual cycles with data distribution for AT. For the seasonal PDFs (**b**), blue, green, red, brown-red dots represent DJF, MAM, JJA, SON respectively. For the diurnal (**c**) and annual cycles (**d**), the solid blue line represents the mean, the shaded area describes one standard deviation above and below the mean (2 sigma), and the dotted black line shows the upper and lower limits. The dashed lines in green and orange (**d**) represent the means for 1999–2009 and 2010–2022 respectively.

states: a cool period and a warmer period. This can be seen in more detail when assessing the PDFs of each season separately (Figure 3b), where DJF and MAM contribute to the low-temperature peak, while JJA and SON contribute to the warmer peak. This does not suggest that the local climate is made up of only two-seasons, as precipitation plays an important role in each season, and the GL data does not include this variable. The annual cycle (Figure 3d) also describes a typical Mediterranean seasonal cycle, with hot summers peaking in July and August, and cool winters around January and February. Furthermore, both the annual and diurnal cycles (Figure 3c) show that the minimum temperatures can come close to 0 °C but never reach it, while the most extreme warm temperatures can approach 40 °C in summer and on rare occasions exceed it.

The frequency of warmer and hotter events during the summer period is shown to be very high when looking at the annual cycle of extreme indices (Figure 4a–b). As the images shown

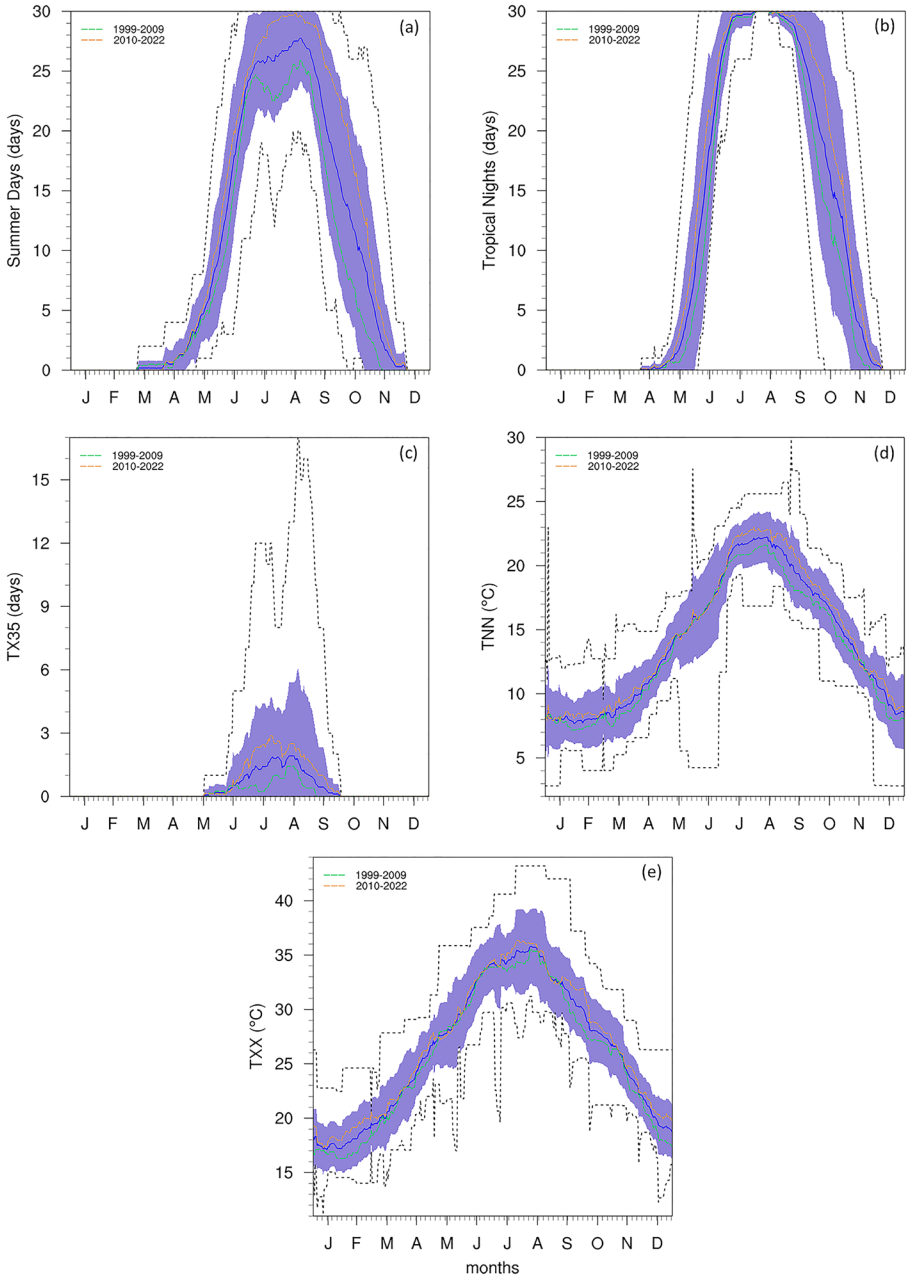

Figure 4. Annual cycle for (**a**) SU, (**b**) TR, (**c**) TX35, (**d**) TNN, and (**e**) TXX, TR at the Giordan Lighthouse in Gozo. The solid blue line represents the mean, the shaded area describes one standard deviation above and below the mean (2 sigma), and the dotted black line shows the upper and lower limits. The dashed lines in green and orange (**d**) represent the means for 1999–2009 and 2010–2022 respectively.

are making use of a 30-day running window for total events, the maximum possible value for SU and TR is 30 days. This maximal value is found within 1 standard deviation of the mean between July and August for SU, and between June and September for TR. This broader peak for TR could explain the rapid rise in temperature prior to the summer months and the slower rate of cooling after. Furthermore, between the end of July and beginning of August, TR is always maximal, indicating this as the most intense warming period of the year.

The TX35 (Figure 4c) displays a distinct seasonal pattern, with frequency peaking sharply in July and August, consistent with the climatological warmest period, and no occurrences prior to May or after September. Notably, TX35 indicates a recurring intensification of extreme heat events in September, suggesting a seasonal extension of summer-like conditions into early autumn. Furthermore, the upper bound of the distribution shows evidence of an anomalous event in which monthly counts exceeded 10 days (this is discussed in more detail in the section describing Figure 5). Complementing this, TXX (Figure 4e) and TNN (Figure 4d) highlight the seasonal variations recorded at the station. As expected, the highest TXX values occur in July and August, while the lowest TNN values are recorded between December and January.

Considering the gaps in the dataset, plotting annual means to follow the rate of warming detected by the station could be misleading. However, this can be circumvented with the use of time series heat maps describing monthly means (Figure 5). This reveals a clear difference between the two decades portrayed, as temperatures (especially summer) in the 2010s become visibly warmer than those in the 2000s. This can also be observed in the annual cycles (Figure 3 and Figure 4) which show the means for these two time periods. A similar rise in temperature can be seen in the time series of the data measured at the Malta International Airport Meteorological Office (Galdies, 2022), which shows a gradual rise in the 2000s, with more consistently high annual means after 2010.

Humidity

According to past studies (Galdies, 2011; Galdies, 2022), the RH of the Maltese islands is typically between 70 and 80%. The data from the Giordan Lighthouse (Figure 6) is in agreement with these past studies, as the PDF of hourly RH peaks just below the 80%, and dips during the warmest times of the day (as described in Galdies, 2011) as the capacity of air parcels to hold water increases. The PDF peaks for JJA and SON are very similar, each occurring above 70%, while those for DJF and MAM peak at a slightly higher RH, around 80%. This seasonal pattern aligns with the temperature variability (Figure 3b) and may also reflect underlying rainfall seasonality (although precipitation data is not available at the station to confirm this directly). A notable dip in average RH in summer can also be observed, however, the standard deviation and limits of RH during this time also broaden, reaching an absolute minimum close to 10%. This is possibly linked to the reduced precipitation of these months (noted by Galdies, 2011; Galdies, 2022). Although evaporation rates would theoretically increase during these periods, this likely does not compensate for the reduction in ambient moisture due to the lack of rainfall. As noted by Galdies (2022), the annual mean time series also show a gradual decrease in RH over time (refer to Supplementary Material, although the magnitude of this trend depends on the data completeness filter applied), a result consistent with expectations under increased warming.

Winds

The WS of the Maltese islands is documented (Galdies, 2011; Galdies, 2022) at an average of 5.14 m/s (10 knots), corresponding to the most frequent wind conditions at 5 m/s (Figure 7). The average however, noted more prominently in the diurnal and annual cycles, is shown to be closer to 7 m/s, even reaching 10 m/s during the winter seasons. This could be attributed to the position of the GL at the NW edge of the Maltese islands, combined with the direction of the prevailing winds (discussed below), sea or land breezes, and possibly thermal upslope winds. Another explanation could be related to the site's exposure to more frequent storms in the Sicily Channel (Alhammoud *et al.*, 2014; Nissen *et al.*, 2010) that tend to impact the GL more frequently, while the Luqa station would not be impacted by these events as often. The seasonal PDFs also show the probability of more intense wind activity increasing notably during MAM and DJF. However, attributing this feature to specific physical processes requires more targeted investigation beyond the scope of this study. The annual cycle reveals the lowest WS during summer months, with the highest values in winter. This corresponds to the peak of WI (Figure 8) at approximately 13 days/month in winter, which shows no notable changes in tendency throughout the time-period of the dataset. This high intensity of winds is also notable in the seasonal wind roses (Figure 9), where the strongest winds occur in the winter months, and the prevailing winds come from the W-NW direction. The frequency of WI may also be declining (see Supplementary Material), suggesting that terrestrial stilling persists on the Maltese Islands (Galdies, 2022; Wadsworth, 1928), but may also be linked to a decrease in the frequency of cyclonic storms in the region (Flaounas *et al.*, 2022).

Summary

This study provides a detailed analysis of the meteorological data collected from the GL in Gozo over a 26-year period from 1997 to 2022. The data includes six key variables: AT, DT, RH, AP, WS, and WD, all recorded with hourly resolution. The analysis aimed to assess the climate variability of the Maltese Islands, emphasising the completeness of the dataset, the characteristics of each variable, and the implications of observed tendencies.

Initially, the dataset's completeness was evaluated, revealing gaps and outliers primarily due to technical issues with the instruments. Notably, AP and WS data had subtantial gaps, and some anomalies were detected which were subsequently excluded from the analysis.

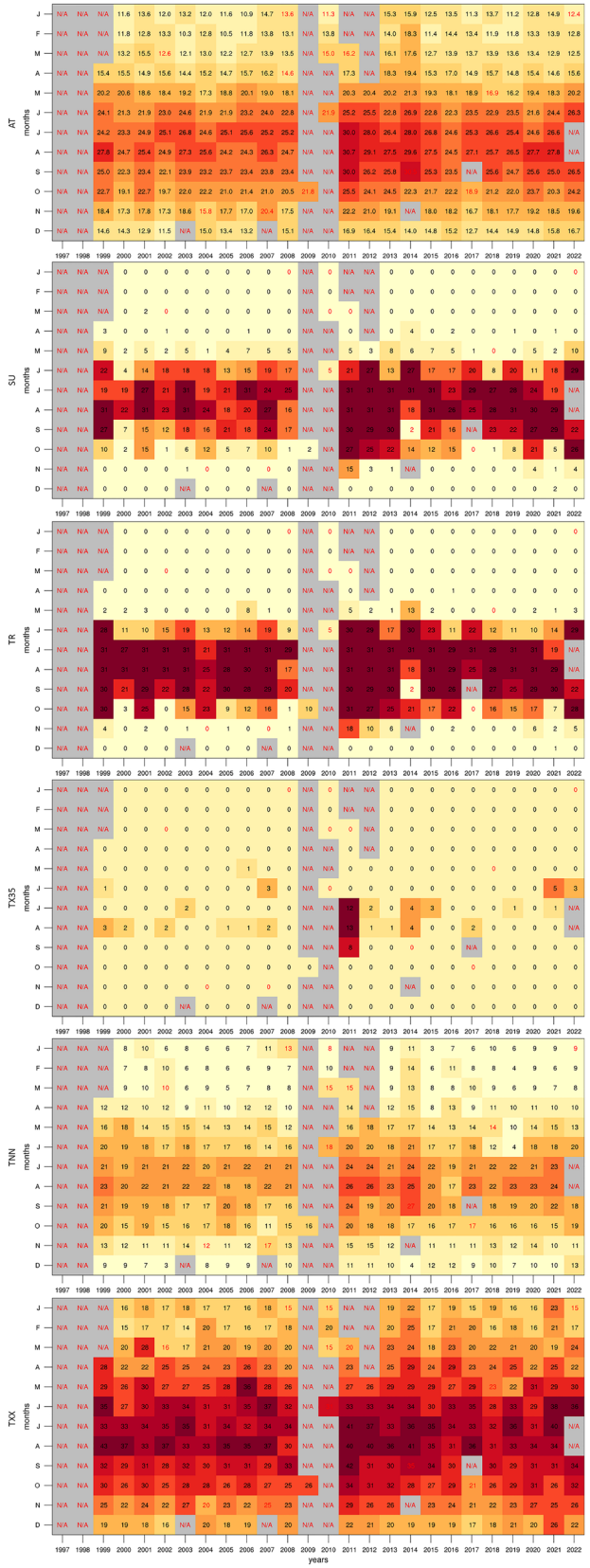

Figure 5. Monthly mean time series heat maps for AT, SU, TR, TX35, TNN, and TXX. The red text describes months with under 40% valid values.

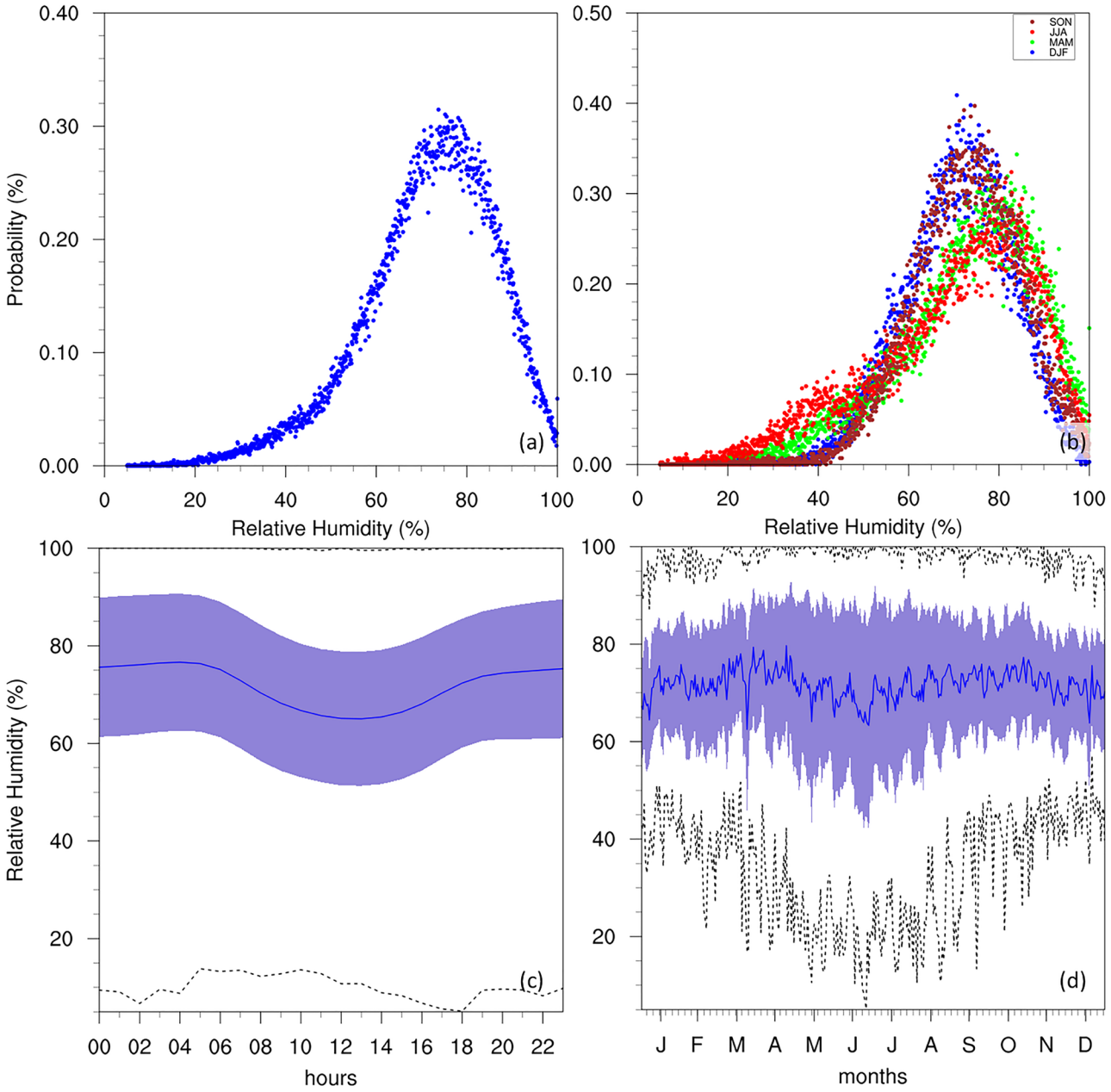

Figure 6. (**a**/**b**) Annual/seasonal PDFs, (**c**) diurnal and (**d**) annual cycles for RH at GL. For the seasonal PDFs (**b**), blue, green, red, brown-red dots represent DJF, MAM, JJA, SON respectively. For the diurnal (**c**) and annual cycles (**d**), the solid blue line represents the mean, the shaded area describes one standard deviation above and below the mean (2 sigma), and the dotted black line shows the upper and lower limits.

The analysis of temperature data indicated a clear bimodal distribution with peaks corresponding to winter and summer seasons. The annual cycle displayed a typical Mediterranean pattern with hot summers and mild winters. The frequency of warm events, as indicated by the SU and TR indices, showed a high occurrence during summer months, especially in the 2010s, suggesting a warming tendency over the study period.

RH data aligned with previous studies, showing typical values between 70% and 80%, with notable dips during summer months. The variability in humidity was attributed to seasonal changes in temperature and precipitation.

WS analysis revealed that the most frequent wind conditions were around 5 m/s, with a slight peak during midday possibly

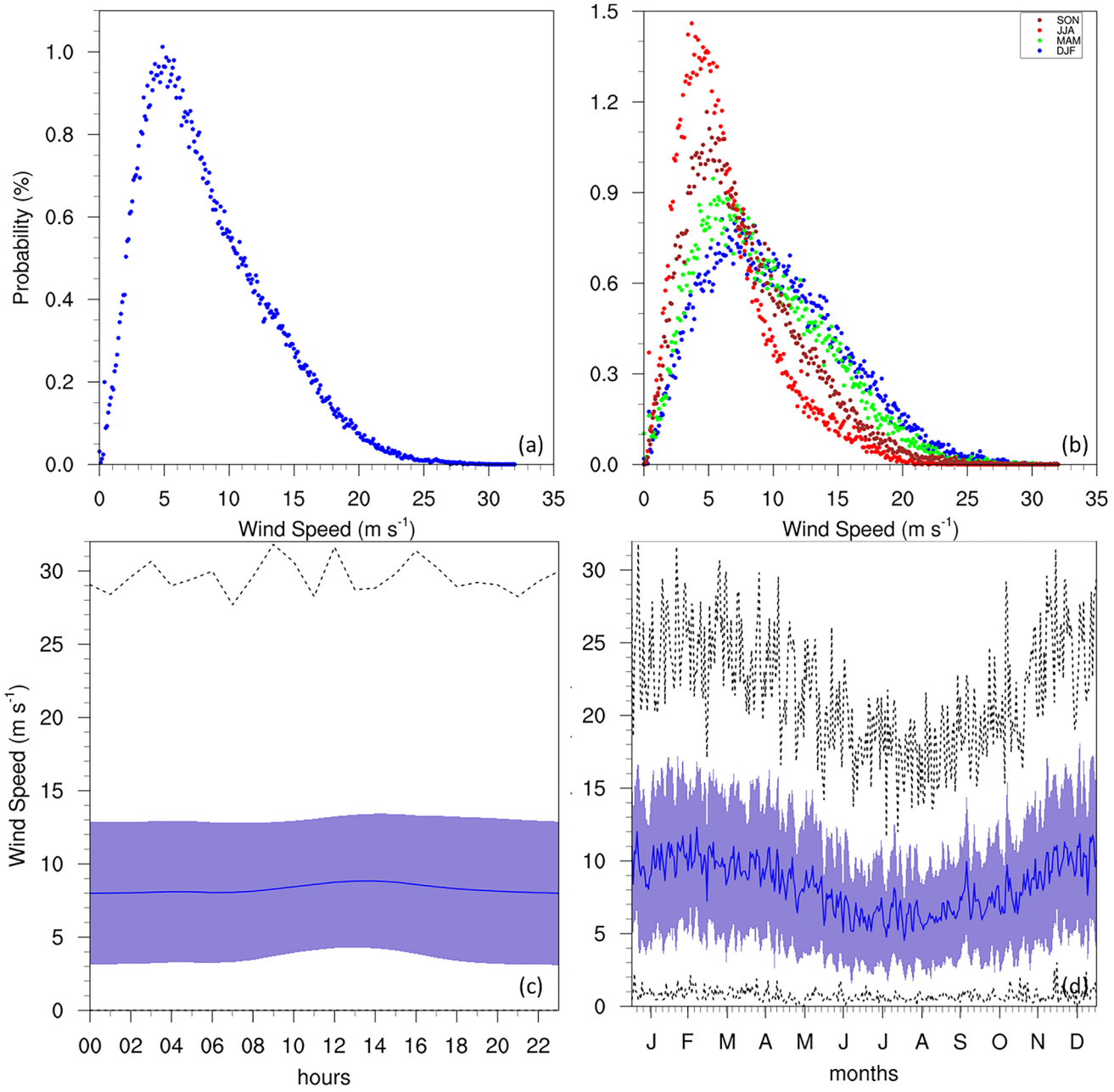

Figure 7. (**a**/**b**) Annual/seasonal PDFs, (**c**) diurnal and (**d**) annual cycles for WS at GL. For the seasonal PDFs (**b**), blue, green, red, brown-red dots represent DJF, MAM, JJA, SON respectively. For the diurnal (**c**) and annual cycles (**d**), the solid blue line represents the mean, the shaded area describes one standard deviation above and below the mean (2 sigma), and the dotted black line shows the upper and lower limits.

due to local topographical influences. The annual cycle showed higher WS during winter, consistent with the peak in the WI index. Seasonal wind roses highlighted the predominant wind direction from the W-NW and stronger winds in winter.

This comprehensive assessment of the GL meteorological dataset underscores the importance of long-term monitoring for understanding climate variability. The findings indicate the presence of seasonal patterns and tendencies in temperature,

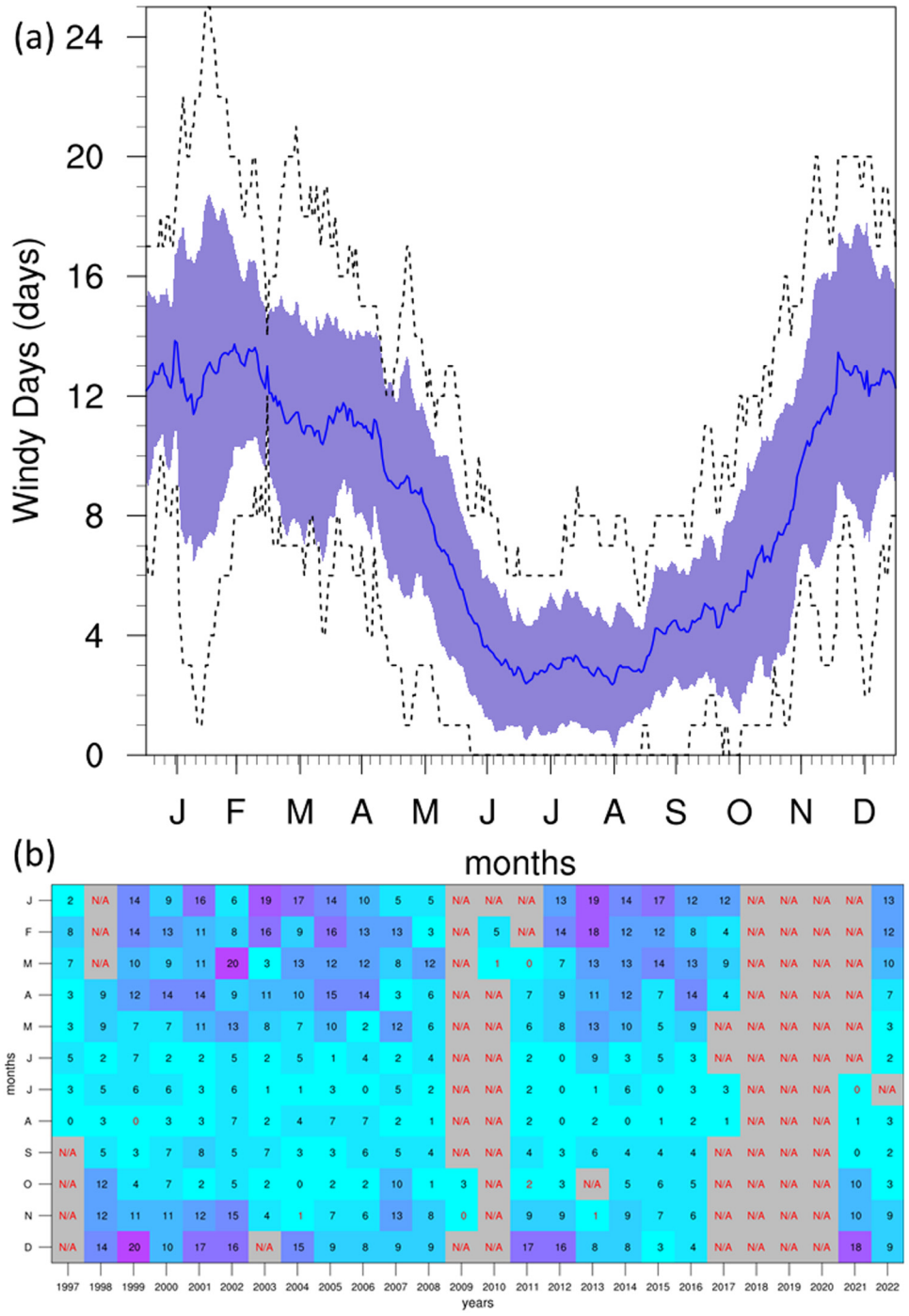

Figure 8. (**a**) Annual cycle and (**b**) monthly time series heat map for WI at GL. For the annual cycle (**a**), the solid blue line represents the mean, the shaded area describes one standard deviation above and below the mean (2 sigma), and the dotted black line shows the upper and lower limits. The red text in the time series heat map (**b**) describes months with under 40% valid values.

humidity, and wind characteristics over the 26-year period. Notably, the warming tendency observed in the frequency of hot days and nights during the summer months aligns with broader global climate change patterns.

This study highlights the need for continuous and accurate meteorological data collection to monitor and predict climatic changes. The insights gained from the GL dataset contribute to the broader understanding of the Maltese Islands' climate

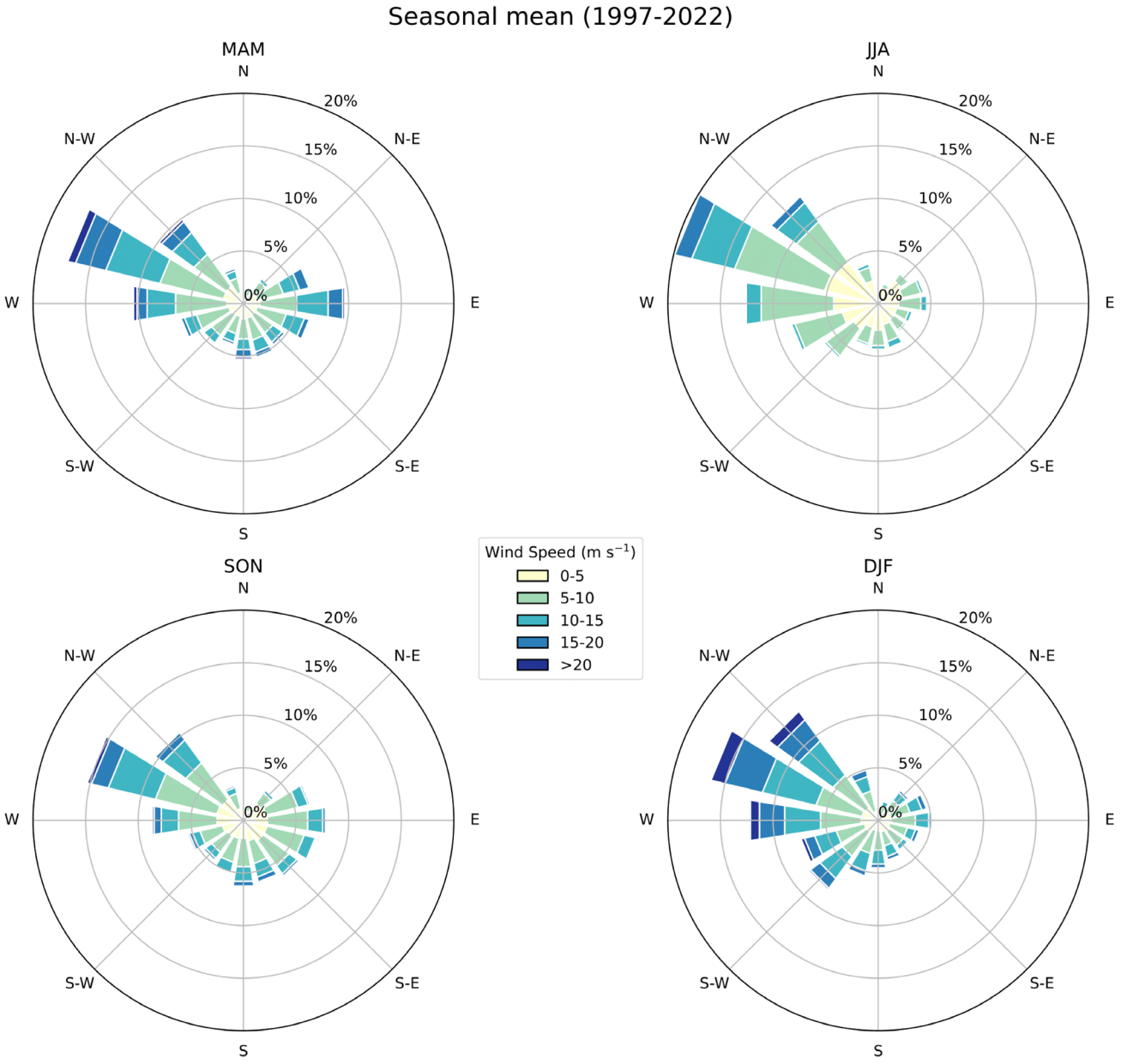

Figure 9. Seasonal wind rose showing WS distribution (m s-1) and frequency (%) at GL. The radial spokes indicate direction, while the length of each spoke corresponds to the frequency of winds coming from that direction. Different colours along the spokes represent varying WS ranges. Labels indicate the seasons: MAM, JJA, SON, DJF.

and underscore the value of background monitoring stations in climate research.

Future work should focus on improving instrument reliability (and hence reduce the occurrence of new data gaps), and expanding the analysis to compare to other datasets within the Maltese islands. This will enhance the robustness of climate assessments and support more effective climate adaptation and mitigation strategies for the region.

Ethics and consent

Ethical approval and consent were not required.

Data availability

Underlying data

Zenodo: Giordan Climate Assessment Data & SI, 10.5281/zenodo.14415659 (Ciarlo` *et al.*, 2024).

This study contains the following underlying data:

Giordan_data_hr.csv

The data is available under Creative Commons Zero v1.0 Universal.

Extended data

Zenodo: Giordan Climate Assessment Data & SI, 10.5281/zenodo.14415659 (Ciarlo` *et al.*, 2024).

This study contains the following underlying data:

Figure Legends - *For diurnal and annual cycles the solid blue line represents the mean, the shaded area describes one standard deviation above and below the mean (2 sigma), and the dotted black line shows the upper and lower limits. Dashed lines in green and orange represent the means for 1999–2009 and 2010–2022 respectively.*

For seasonal PDFs, blue, green, red, brown-red dots represent DJF, MAM, JJA, SON respectively.

Monthly mean time series heat maps use red text for months with under 40% valid values.

For wind rose, radial spokes indicate direction, while the length of each spoke corresponds to the frequency of winds coming from that direction. Different colours along the spokes represent varying WS ranges. Labels indicate the seasons: MAM, JJA, SON, DJF.

The data is available under Creative Commons Zero v1.0 Universal.

Software availability statement

- Source code available from: https://github.com/ciarloj/giordan-lighthouse-climate-assessment

  License: CC0 - 1.0

- Archived software available from: https://doi.org/10.5281/zenodo.14415659 (Ciarlo` *et al.*, 2024)

  License: Creative Commons Zero v1.0 Universal

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Current Peer Review Status: ? ✓ ✓ ?

Version 2

Reviewer Report 22 August 2025

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✓ **Pavlos Kalabokas**
Research Center for Atmospheric Physics and Climatology, Academy of Athens, Athens, Greece

I would like to inform you that the authors have addressed properly our remarks and introduced the requested changes, so we find that the manuscript is now ready for indexing.

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 18 August 2025

https://doi.org/10.21956/openreseurope.22677.r56745

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✓ **Paolo Cristofanelli**
Institute of Atmospheric Sciences and Climate (ISAC), Bologna, Italy

The authors addressed all my comments and I would recommend the indexing of the manuscript.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Atmospheric sciences

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 1

Reviewer Report 14 April 2025

https://doi.org/10.21956/openreseurope.20670.r51836

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Giandomenico Pace
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Virginia Ciardini
Department for Sustainability, ENEA National Agency for New Technologies Energy and Economic Sustainable Development, Rome, Italy

The manuscript of Ciarlò et al. presents and discusses a series of approximately 25 years (1997-2022) of meteorological data collected at the Jordan Lighthouse Background Monitoring Station that has been part of the Global Atmosphere Watch (GAW) since 2005.
After a brief description of the instrumentation and the data selection methodology, the metrics used to discuss the variability and patterns in the database are introduced. Due to several interruptions, the atmospheric pressure time series is not analysed, while temperature, relative humidity and wind behavior is discussed separately mainly in terms of probability distribution, daily and seasonal variability. The analysis also includes the discussion of three indices such as summer days, tropical nights and windy days. The conclusions, agree with other work on the Maltese Islands, show a bimodal annual distribution of daily temperatures, the increase in the average daily temperature during the 2020s decade compared to that measured in 2010s associated to an increase in the number of summer days and tropical nights. Relative humidity shows limited variability throughout the year and a daily minimum around the hottest hours of the day. The distribution of winds is dominated by a W-NW direction and a greater occurrence of winds around 7 m/s. An increase in the average daily value around the hottest hours is suggested to be due to anabatic winds connected with the location of the Station on the top of a hill.
The manuscript is clear in both description and purpose and the results are consistent with those of previous studies. The use of precipitation and atmospheric pressure data would certainly have extended the conclusions and expanded the authors' ability to provide a more original discussion. Overall, it provides a useful contribution to the climatological characterization of the central Mediterranean, even if the analysis would have been more complete, for example by trying to investigate the annual variability as a function of indices such as North Atlantic Oscillation, Mediterranean Oscillation or El Niño/Southern Oscillation.
In our opinion, the work would be more complete by clarifying and/or adding some information on the following points:
- In the 25 years of observations, the replacement of the anemometer and the use of the same humidity and temperature sensor is reported (p. 4). What is missing, however, is any information on the maintenance and recalibration of the instrumentation used during the period as well as more details in the description of the data quality control procedure. The authors stated that they removed data points due to problems identified with the instruments; we suggest to add

information about the whole data quality control procedure (e.g. control algorithm, manual check, etc.) and briefly reporting on maintenance and calibration checks.
- In the text it is clear that data are sampled every hour (first paragraph p. 5), but it is not specified whether the hourly data corresponds to instantaneous values or average values.
- p. 5 "To construct the annual cycles for these indices, a 30-day running average was used to obtain a "daily" frequency comparable to other annual cycles." Is it correct that this sentence only refers to the averages shown in Figures 4(a)-(b) and 8(a)? The other average behaviors (Figures 3 (c)-(d), 6 (b)-(c), 7(c)) are calculated by averaging the average values of each individual days of the year; is this correct?
- p.5 e 6.: On pp. 5 and 6, the authors report specific instances of outliers in the text; we suggest to collect them in a table providing a more schematic and readable information to the readers.
- p.8: Comment to figure 3 c, d : "Furthermore, both the annual and diurnal cycles (Figure 3c) show that the minimum temperatures often come close to 0 °C but never reach it, while the most extreme warm temperatures can approach 40 °C in summer and on rare occasions exceed it." Please replace "often" with "can"
- For the reader, it would be clearer the meaning of Figures 2, 5, 8 (b) if color scales linked to the occurrence of the event were shown.
- For greater uniformity of the results shown, similarly to figure 3 (temperature behavior), I would also show both the seasonal and annual distribution in figures 6 and 7, showing the seasonal distribution of RH and wind intensity respectively.
- Looking at figure (8)b one gets the impression that the number of windy days has slightly decreased over the years. Averaging over the number of windy days yearly, from June to June, is there any decrease? Although the wind measurement was extensively discontinued from 2017 to 2021, it would be interesting if there was a trace of this behaviour.
- Page 15 'The findings indicate significant seasonal patterns and trends in temperature, humidity, and wind characteristics over the 26-year period.' I would reformulate the sentence by removing the word trend since only temperature shows a clear increase in the database and no value was derived that could be associated with an annual trend (e.g. annual increase of the selected variable).
- Reference list: please check links to "Reference Source" (www.um.edu.mt) that do not seem to work.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and does the work have academic merit?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: data analysis, interaction between meteorological parameters, aerosols, clouds and short- and long-wave radiation

We confirm that we have read this submission and believe that we have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however we have significant reservations, as outlined above.

Author Response 11 Jul 2025

James Ciarlo

We are sincerely grateful to the team of reviewers for taking the time to carefully evaluate our manuscript and provide thoughtful, constructive feedback. We are confident that their input has significantly improved the quality and clarity of the paper. Please find our detailed responses to each of the comments below.

In response to the comment, "The use of precipitation and atmospheric pressure data would certainly have extended the conclusions and expanded the authors' ability to provide a more original discussion.":

We agree that including additional variables would have enhanced the analysis. However, we note that the Giordan station does not collect precipitation data. Moreover, due to the limited temporal coverage of the atmospheric pressure dataset, analysis with this data would be less robust than the other variables analysed in the main text. Nevertheless, for completeness and transparency, we have included the corresponding atmospheric pressure plots in the Supplementary Material.

In response to the comment, "Overall, it provides a useful contribution to the climatological characterization of the central Mediterranean, even if the analysis would have been more complete, for example by trying to investigate the annual variability as a function of indices such as North Atlantic Oscillation, Mediterranean Oscillation or El Niño/Southern Oscillation.":

We appreciate the reviewer's suggestion to further explore the role of large-scale climate modes. In response, we have added a new subsection to the beginning of the "Climate Assessment" section that evaluates the correlation between observed climate variables and teleconnection indices. We agree that further exploration of lagged and nonlinear responses would be valuable and hope to address this in future work. The remaining points presented below are addressed in the same order in which they were raised by the reviewer, to facilitate clarity and ease of cross-referencing.

1. We have added information to the manuscript text describing the maintenance procedures and calibration practices applied throughout the observation period. In addition, Table 1 now includes updated information on the instruments used.
2. The data is sampled every minute and averaged to produce hourly values. This has been clarified in the manuscript.
3. Yes, this is the correct interpretation. In the new manuscript, we have revised and expanded this sentence to improve clarity.
4. These anomalous readings were collected in separate csv files and included with the

supplementary material.
5. Completed.
6. We appreciate the reviewer's suggestion. However, we would like to clarify that Figures 2, 5, and 8(b) are intended as time series heat maps using a linear colour scale applied independently to each panel. The colours are not linked to the occurrence of a specific event but instead serve to highlight the distribution of values. Since the actual values are printed directly on the plots, we opted not to include colour bars to avoid redundancy and to maximise the size and readability of the figures. To improve clarity for the reader, we now refer to these figures explicitly as time series heat maps in the manuscript and have added a clarifying note in the figure captions.
7. We have revised Figures 6 and 7 to include both seasonal and annual distributions of relative humidity and wind intensity, in line with the structure used in Figure 3. Corresponding adjustments have also been made in the text to reflect these changes.
8. Thank you for this observation. The annual mean time series for windy days does indicate a decreasing tendency. However, due to the data discontinuities and the sensitivity of the trend to data availability thresholds, we have not included a quantified trend in the main text. That said, this pattern is now discussed briefly in the manuscript, and the filtered time series plots are available in the supplementary material.
9. Given the issue with quantifying trends, we have changed the terms "trend" throughout the document.
10. All links to the "Reference Source" (www.um.edu.mt) were double-checked and confirmed to be working at the time of submission of the updated manuscript.

Competing Interests: No competing interests were disclosed.

Reviewer Report 09 April 2025

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Pavlos Kalabokas
Research Center for Atmospheric Physics and Climatology, Academy of Athens, Athens, Greece
John Kapsomenakis
Research Center for Atmospheric Physics and Climatology, Academy of Athens, Athens, Greece

The study "Insights into climate variability of the meteorological records from a background monitoring station: the Giordan lighthouse, Gozo," by Ciarlo et al. provides a valuable analysis of climatological conditions and trends based on data from WMO/GAW regional station at El Gozo (Malta). The manuscript is well-written and clear, though some minor revisions are needed before

final acceptance.

- Page 5 (Figure 1). Please add in the map the orography
- The analysis for extreme heat is based on the number of SU (summer days) and TR (tropical nights). I would suggest expanding the analysis including indices for more extreme conditions such as Tx35 (number of days with Tmax exceeding 35 oC).
- In addition, it would suggest investigating if there is a seasonality in the differences between the 2 periods particularly for extreme heat indices. For instance, it seems from figure 4 (but is not so clear) that is a significant increase of TR during transitional seasons indicating an expansion of summer conditions during Spring and Autumn.
- I think that it would be useful to add a paragraph where the climate trends observed in Gozo will be compared with those reported in other regions of the Mediterranean.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and does the work have academic merit?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

We confirm that we have read this submission and believe that we have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however we have significant reservations, as outlined above.

Author Response 11 Jul 2025

James Ciarlo

We are sincerely grateful to the team of reviewers for taking the time to carefully evaluate our manuscript and provide thoughtful, constructive feedback. We are confident that their input has significantly improved the quality and clarity of the paper. Please find our detailed responses to each of the comments below. All points below are addressed in the same order in which they were raised by the reviewer, to facilitate clarity and ease of cross-referencing.

1. *Response to Page 5 (Figure 1):* Figure 1 and the associated caption were updated to

include an elevation map. We have modified the image further by including a photo of the station as suggested by another reviewer. We have removed the map of the Mediterranean to allow for a more presentable image, while the location context is still present by showing latitude and longitude.

2. Thank you for this valuable suggestion. In response, we have expanded the analysis to include TX35, as well as the monthly maximum of daily maximum temperature (TXX) and the monthly minimum of daily minimum temperature (TNN). These additions provide a clearer picture of extreme temperature events and seasonal variability. The associated analysis and figures have been updated accordingly in the main text. Additional indices and detailed results are available in the supplementary material.
3. We have expanded the set of extreme heat indices as suggested, adding TX35, TXX, and TNN. These show a clearer intensification of heat extremes, particularly in September, which may influence patterns during the SON season. Additionally, seasonal PDFs have been added for RH and WI to further support the discussion of seasonal variability. These additions have been implemented and discussed in the revised text.
4. Thank you for the suggestion. While we prepared annual mean time series for key variables, the trends proved highly sensitive to data completeness thresholds and were therefore not included in the main text. Given this uncertainty, we opted not to draw direct comparisons with other Mediterranean regions. However, we have now included this explanation in the manuscript and the filtered plots are available in the supplementary material, and we refer to broader regional patterns where relevant in the discussion.

Competing Interests: No competing interests were disclosed.

Reviewer Report 26 March 2025

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Paolo Cristofanelli
Institute of Atmospheric Sciences and Climate (ISAC), Bologna, Italy

This paper by Ciarlo et al. presents an interesting study on the climate variability of the meteorological records of the WMO/GAW regional station of El Gozo (Malta).
This work can serve as an updated reference for the characterisation of the meteorological conditions at this important measurement site in the Mediterranean basin, a well-known hotspot for climate change and pollution export from Europe.
The manuscript is clear and well written, but some minor adjustments should be made before

final acceptance.

1) In the "Methods" section, the authors cite a comparison with results from Malta Airport. However, I could not find a direct comparison of the two datasets in the manuscript. I would suggest to the authors to provide evidence of this comparison or to revise the "Methods" section

2) page 5 (Figure 1). I would suggest adding an image of the station location

3) Table 1. It would be useful to add information about the instruments used, the observation periods and the measurement uncertainties

4) Page 6 (Methods). It's not clear to me why the authors applied a 30-day running mean to the number of SU and TR. According to the reported definitions of SU and TR, these descriptors are "number of days in a month", so how can a 30-day running mean be calculated from a monthly frequency?

5) Page 9 ("Winds"): To explain the diurnal WS variability, the authors refer to anabatic/katabatic winds. I'm reluctant to believe that the small hill on which the station is located can create the thermal gradient to trigger upslope winds. Besides thermal upslope winds, can sea/land breezes be considered?

Pag 15 (Summary): As no trend detection or quantification statistical analyses have been carried out, I recommend to avoid mentioning the existence of a "trend", but to talk about "tendencies". Also, when describing long-term trends, avoid terms that imply statistical analysis (i.e. use "apparent" instead of "significant").

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and does the work have academic merit?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Atmospheric sciences

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 11 Jul 2025

James Ciarlo

We are sincerely grateful to the team of reviewers for taking the time to carefully evaluate our manuscript and provide thoughtful, constructive feedback. We are confident that their input has significantly improved the quality and clarity of the paper. Please find our detailed responses to each of the comments below.

1. We are grateful to the reviewer for presenting this point. The “Methods” section in the Abstract was intended to describe a qualitative comparison to other studies (e.g. Galdies, 2022) and not a direct quantitative comparison using the Malta Airport dataset. This sentence was clarified in the manuscript.
2. Figure 1 and the associated caption were updated to include a photo of the station. We have modified the image further by including an elevation map as suggested by another reviewer. We have removed the map of the Mediterranean to allow for a more presentable image, while the location context is still present by showing latitude and longitude.
3. We have updated Table 1 to include these details.
4. To clarify, we maintained the standard definitions of SU and TR as “number of days per month,” but instead of using 12 discrete monthly values, we calculated a 30-day running mean over the daily time axis, resulting in 336 overlapping windows. This approach does not change the index definitions but provides a smoother depiction of the annual cycle, which is more suitable for comparison with other climatological fields. We have now revised the text in the Methods section to clarify this point.
5. We have revised the manuscript to acknowledge that land/sea breezes could also contribute to the observed diurnal variability in wind speed. These considerations have been added alongside mentions of thermal upslope winds to present a more balanced interpretation.
6. *Response to Summary:* We have changed the terms “trend” and “significant” throughout the document.

Competing Interests: No competing interests were disclosed.

Reviewer Report 25 March 2025

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Sultan Hameed
Stony Brook University, Stony Brook, USA

This paper is potentially a useful contribution by presenting a first analysis of a 26 year long meteorological data set at the Giordan lighthouse in Malta. The results of this analysis can be considered as preliminary because the data have not been subjected to quality testing and adjustment. The manuscript needs some corrections and further analysis, as suggested below, before it can be recommended.

1. The authors removed air pressure readings below 950 hPa without giving a justification for this cut-off. Data at Malta international airport which is only 30 miles away from Gozo can be used as a guide to estimate the lowest air pressure that is likely to be observed at Gozo. Similarly, the lower and upper limits of air temperature can be estimated from the temperature data at the airport.
2. It would be very useful to plot time trends in seasonally averaged temperatures, summer days and tropical nights for 1997-2022. Such trend figures will quantify the rate of climate warming in Malta.
3. It would also be very useful to calculate correlations between seasonal averages of all the variables in Table 1 with the North Atlantic Oscillation to see how much of the inter-annual variability in these variables can be explained by pressure variations over the North Atlantic.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and does the work have academic merit?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 11 Jul 2025

James Ciarlo

We are sincerely grateful to the team of reviewers for taking the time to carefully evaluate our manuscript and provide thoughtful, constructive feedback. We are confident that their input has significantly improved the quality and clarity of the paper. Please find our detailed responses to each of the comments below. We are very grateful for the reviewer's comment. Following the suggestions of all reviewers, we have applied the recommended changes, and believe this has helped to strengthen the overall quality and reliability of our study.

1. Pressure range from the Malta international airport (MIA) is between 1014.9 to 1018.3 hPa according to Galdies (2010) with no significant changes reported in Galdies (2022). Five instances were identified where the pressure was around 750 hPa, with a change of well over 200 hPa from the previous and following time-steps - the minimum, after excluding these values, was 967 hPa. To remove only the erroneous values, a filter of 950 hPa (an arbitrary value below 967 hPa) was applied. As filter itself is not of import, we have rephrased the explanation to include the specific values removed and why.
   Similarly, temperature ranges from 1.4 to 43.8 degrees Celsius, according to Galdies (2010), with no precise changes were mentioned in Galdies (2022). A few instances of sudden increases in temperature (a jump of around 20 degrees in the span of an hour) were removed leaving behind a range of 3 to 43 degrees. Once again the filter mentioned was arbitrary to resolve the issue, but does not explain the problem properly. This was corrected in the manuscript.
2. We agree that long-term trend analysis would provide useful insights. As part of our investigation, we prepared annual mean time series for key variables, however, given the variable data coverage across the observational record, we constructed time series using both 60% and 80% data availability thresholds per year. We found that trend values were highly sensitive to the applied filter. For instance, the trend in TR appears negative under a 60% threshold but turns positive under 80%, in line with broader regional trends. Due to this sensitivity and the potential for misrepresentation, we opted not to include quantified trends and figures in the main text. However, the plots are provided in the supplementary material, and relevant patterns are discussed in the manuscript where appropriate.
3. As recommended, we have carried out correlation analyses between our observed climate variables and the NAO index. Following suggestions from another reviewer, we have also extended the analysis to include other teleconnection indices, including the Mediterranean Oscillation Index and ENSO. A summary of these correlations is now included at the beginning of the "Climate Assessment" section (Table 2).

Competing Interests: No competing interests were disclosed.