

*Research Article*

## Potential future climatic conditions on tourists: A case study focusing on Malta and Venice

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**Abstract.** The main purpose of this study is to quantify important climatic shifts that took place over Malta and Venice that could be considered as a determining factor on their choice as two prime tourist destinations. Rather than making use of traditional tourist climate indices, this study identifies long-term trends in weather variables and their derived bioclimatic indices. These climate derivatives are based on a set of high temporal observations (some of which are collected every 30 minutes) and are thus able to capture valuable information that traditional monthly distribution cannot provide. The derivatives obtained from the elementary meteorological observations showed that the level of comfort experienced by visiting tourists over the long term is deteriorating due to increased heat stress. Nonetheless, the increased occurrence of optimal wind speed conditions, as well as a reduced occurrence of gale storms and wind chill events is making these destinations more attractive. A careful study of the output of IPCC climate model projections sheds light on a critical future bioclimate condition during current peak visiting months (July and August) at both destinations. This may imply a required shift, as a form of adaptation, of the visiting periods at these two destinations. This study should allow tourist planners to determine which weather element is a likely future obstacle to the overall bioclimatic suitability of outdoor tourism activities.

**Keywords:** Climate change, climate trends, thermal bioclimate indices, Climate projections, adaptation measures, Mediterranean

### 1 Introduction

The opportunity for tourists to enjoy themselves and relax by participating in outdoor activities that differ

from their daily routine and surroundings, defines the selection of particular destinations (Dann, 1981). These activities are affected by their intrinsic climatic nature (Becken & Wilson, 2013) or other temporal factors such as seasonality (Gartner, 1986). In the tourism sector, a ‘favourable climate’ can be regarded as a resource, and destinations with climate resources of a better quality than others always enjoy a competitive advantage. Indeed, optimal variations in temperature, humidity or snow depth (as in the case of high altitude places) favour outdoor activities at specific times of the year.

Economically, a strong link has developed between these destination-based activities and the employment generated, which however could be disrupted in the face of a changing climate (Olsen, 2009). Thus there is a pertinent need to assess and evaluate the suitability of the destinations’ climate for tourism, in order to aid decision-making by tourists as well as the tourism industry itself in better assessing the state of the destination for tourism development, identify any significant trends, and incorporate adaptation strategies in tourism infrastructure planning and programming.

Many investigators looked at the possibility of using an index-based approach that considers the multifaceted nature of weather and the complex ways in which the weather variables come together to give meaning to local climatology for tourism (Mieczkowski, 1985; de Freitas, Scott & McBoyle, 2008). The formulation of such climate indices have evolved from the more general development of climate indices in sectors such as health (e.g. Wind Chill, Humidex, etc.) and agriculture (e.g. various drought indices). A key issue in their construction is the selection of the right weather variables. Smith (1993), and Matzarakis and Moya (2002) suggested that the weather parameters affecting tourists’ comfort and safety should include air temperature, hu-

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midity, radiation intensity, wind, cloud cover, sunshine duration and precipitation. de Freitas (2003) classified climate according to its thermal, physical and aesthetic aspects, where the thermal aspect incorporates air temperature, humidity, wind and solar radiation; the physical aspect includes rain and wind; and the aesthetic aspect relates to sunshine or cloud conditions.

Tourist-related climatic indices range from single facet indices (e.g. Becker, 2000) to other more elaborated ones (e.g. Mieczkowski, 1985; Morgan et al., 2000). One of the most comprehensive schemes proposed so far is that by Mieczkowski (1985) who developed a Tourist Climate Index (TCI) that merges seven features of climate into a single climate index for general tourism activities. However, the application of such indices must be carried out with caution since the level of visitors' perception to these variables, coupled to any behavioural adaptation makes their preference and experience even more complicated (de Freitas et al., 2008). Moreover, such indices have not necessarily been validated against tourists' preferences or visitation data, and thus lack any objective rating and weighting schemes used for individual climate variables. Other weaknesses stem from their failure to address the essential requirements of a comprehensive index as highlighted by the study conducted by de Freitas et al. (2008).

Kovacs and Unger (2014) have recently slightly modified Mieczkowski's TCI by including a more realistic index that is related to thermal comfort conditions, in order to look at the suitability of Hungarian climate for general tourism purposes (such as sightseeing, shopping, and other light outdoor activities). They also managed to adjust the TCI to a ten-day scale rather than the original monthly averages of the climatic parameters, making it more relevant to tourism. This shows that research on tourist climate indices is ongoing so as to make them more relevant to the tourism sector.

This study does not make use of the original Mieczkowski's index or any of its most recent derivatives, which is beyond the scope of this article, but rather identifies long-term trends in weather variables and makes use of published bioclimatic indices that could point to the prevalence of less favourable weather conditions at selected tourist destinations, and which could potentially favour a shift in the visitation patterns. The method presented here analysed a wide range of weather variables collected from two tourist destinations at high temporal resolution, thereby addressing the weather conditions that tourists actually experience during their stay in these locations.

The main purpose of this study was to identify any localised current and future trends of weather variables as a quantitative approach for measuring the state of such a tourism resource. Its scope was to expose any

statistically significant, long-term changes in weather trends as potential outcomes due to a changing climate, and to see if they can be termed as critical to the touristic experience. This study also looked at how these weather parameters and related bioclimatic indices are expected to deteriorate at both destinations by 2070.

Important studies have shown that climate change can substantially redistribute climate resources across regions and between seasons, with particular reference to well-established and emerging Mediterranean destinations (e.g. Lanquar, 2011). In this respect, this study is a step forward towards the needed quantification of the statements published by IPCC (2014) that Mediterranean tourism is likely to be impacted by climate change.

This paper examined whether two popular destinations – Malta and Venice – are and will be experiencing any shifts in those climatic factors considered to be important factors influencing the travelling choice. The selection of these two locations is based on both practical and geographical reasons, namely: (1) the availability of consistent and long-term weather observations at high temporal resolution and (2) the different climatologies owing to the difference in latitudinal positions of the two locations, thus offering two independent scenarios for the study.

#### *Destination 1: Malta*

In Malta tourism is one of the main economic pillars. In 2010, British, Italian, German, French and Spanish tourists accounted for 68% of all visitors (European Commission, 2014). The success of the tourism sector, which generates 8.3% of the total Maltese employment (compared to the 1% in other EU countries; EUROSTAT, 2008), originates mainly from its Mediterranean climate (Galdies, 2011), which provides an ideal year-round destination.

According to the Malta Tourism Authority, in 2013, a total of 1,582,153 inbound tourists visited Malta with an average length of stay of 8 days. During that year, the total tourist expenditure per capita amounted to 910 Euros. The three most popular tourist months were July, August and September. The three main motivations for choosing Malta in 2013 was the agreeable climate (57%), new destination (46.7%) and history and culture (39.2%). During that year swimming, walking and hiking constituted 95% in terms of tourist participation in sport and outdoor activities. Sightseeing was the highest activity registered in 2013, followed by visits to historical sites and churches.

A total of 97.2% of tourists travelled to Malta by air, while the remaining tourists arrived by sea. The total number of cruise passengers in 2013 was 431,397.

Future climate change policies to mitigate the emissions of greenhouse gases however may result in problems of connectivity to Malta, both by air as well as by sea (European Commission, 2013; Roson & Sartori, 2014).

### *Destination 2: Venice Lagoon, Italy*

As to Venice Lagoon, art and culture are the main touristic attractions and many tourists visit Venice lagoon because of its unique location as well as its cultural history. It has a major port, which is the most important in the Mediterranean for cruise tourism and ranks 10th worldwide in terms of the number of passengers it receives. In 2011, the total arrivals reached almost 5 million. During that year, the US accounted for the most inbound tourists to such a destination, whereas the traditional European markets were constituted of French, British and German tourists (Euromonitor International, 2012).

During the month of August 2013, international visitors to Venice lagoon amounted to 1,515,956 (Sezione Sistema Statistico Regionale on Istat: Regione Veneto, 2014), while domestic tourist arrival amounted to 8,240,596 during the same year. The least popular month is January, with a total of 201,394 of total arrivals.

Tourism will continue to be one of the most important economic activities at both locations, and to remain sustained by market-driven forces. Their tourist type is composed of a 'residential' and 'day-tripper/cruise-tourists' type, where the latter category is also becoming popular in Malta in view of its developing cruise-liner tourism.

## **2 Methodology**

### **2.1 Identification of Current Climatic Trends**

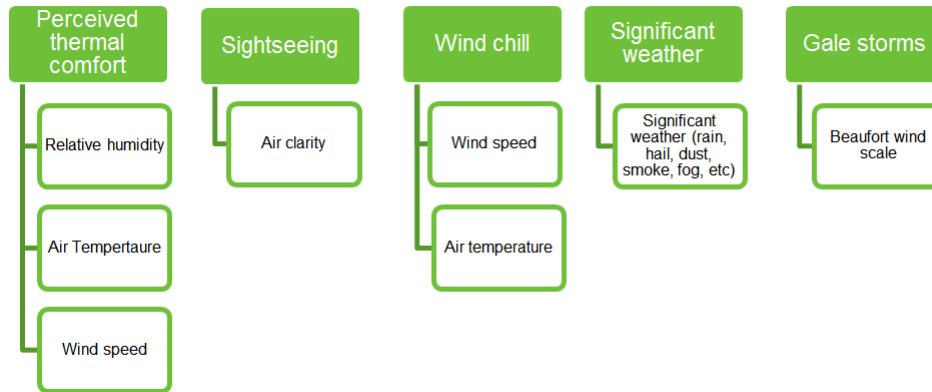
Rather than applying climate indices for tourism, this study considers (1) the identification of climatic trends of the main weather parameters, such as air temperature (maximum and minimum temperature; air pressure; occurrence of heat waves) that are good indicators of a changing climate within the Mediterranean region, and (2) essential characteristics that defines an optimal outdoor recreation environmental setting. This approach seeks to integrate the factors that influence the body-atmosphere thermal state by considering ambient air temperature, relative humidity, vapour pressure and wind speed. It also provides perceptive indices produced and used by international weather services (such as NWS/NOAA and Environment Canada, where both indices are applied by Malta Meteorological Office during the summer period (<http://Maltairport.com/weather>) and by ARPA (Franco & Gabriele, 2001)). These were chosen because of their relation to the net thermal con-

tent of the human body. Variables studied included rain and wind speed. Aesthetic facets such as sunshine or cloud cover were not included here due to the overall mild Mediterranean weather.

In addition to elementary weather parameters such as precipitation, humidity, wind speed and temperature maxima, minima and anomalies from the climate norm of the two destinations (based on the 1961–1990 climate normal), the present study adopts a three-level climatic approach similar to the one published by Yu, Schwartz and Walsh (2009) using a mix of elementary and bioclimatic approaches. In their study, they (1) combined high temporal weather observations that are more relevant to tourism, (2) addressed the overriding nature of individual weather elements (instead of arbitrarily assigning weights, as in the case of the Tourist Climate Index), and (3) integrated multiple weather elements that affect the quality and suitability of weather conditions for outdoor tourism (Matzarakis & Moya, 2002). Regarding point (1) above, it is important to note that frequent weather observations contain more valuable information than statistical daily or monthly data since weather elements with high temporal variation such as rain, thunderstorms and visibility are closely related to the viability of outdoor tourism activities and so cannot be ignored. The use of sub-hourly weather observations provides a greater chance of capturing the weather variability that could be of specific relevance to different outdoor tourism activities. Moreover, based on a survey to gauge tourist perception, Hamilton and Lau (2005) found that there are more than one significant tourism-related climate attributions in addition to ambient air temperature. de Freitas (2004) showed that, within a broad range of 'non-extreme' thermal conditions, several different factors are important in determining the pleasantness rating of given climate conditions. For example, the non-thermal elements of rain, high wind and low visibility were shown to have considerable impacts on tourists' satisfaction.

The three-level climatic approach used in this study was determined by the availability of weather variables in historical weather archives, which are based on the following three weather components: perceived temperature, wind and significant weather (the latter ultimately defining the overall visibility).

- Perceived temperature combines temperature, relative humidity and wind. It is represented by the Wind Chill Index in the winter (the combined physiological effect of air temperature and wind speed; National Weather Service, 2001) and by the Humidex during summer (Masterton & Richardson, 1979). Low or high perceived temperatures are uncomfortable and can be harmful to tourists.



**Figure 1:** Sub-indices starting from observed, high temporal elementary weather observations.

- Strong wind can considerably degrade tourist satisfaction and affect outdoor safety.
- Significant weather encompasses different weather conditions such as rain, hail, lightning, fog, visibility, smoke and dust storms.

A sub-index was created for each of these weather components representing perceived temperature in terms of Wind Chill and Humidex, Wind, and Significant Weather (Fig. 4). Each sub-index was scaled to three levels of suitability for outdoor tourism activities (1 = unsuitable conditions, 2 = critical conditions, and 3 = optimal conditions) indicated by upper and lower thresholds. The thresholds and sub-index categories are summarized in the Appendix. The criteria used to scale the sub-indices are flexible and can be modified to best fit the characteristics and requirements of specific activities, and their thresholds can be easily determined by tourist experts or from surveys of tourists. The thresholds can be modified to fit any activities for which reasonable weather-related thresholds for tourist involvement can be made available.

## 2.2 Thermal Bioclimate Indices

In support of the above approach, the analysis of thermal bioclimate is also of high interest to the health and recreation tourism sectors. The estimation of mod-

ern bioclimatic indices, based on human energy balance, presents an adequate method for the quantification of the human thermal bioclimate under different meteorological conditions (Matzarakis, 2006; Matzarakis, Rutz & Mayer, 2010).

This study thus analysed three thermal stress indices that highlight potential hazardous conditions to visitors. These include the following:

1. the **Thermal Sensation** (TSN) equation (Givoni & Noguchi, 2004);
2. Becker (2000) **Human Bioclimatic Comfort** (HBC), and
3. the shade **Apparent Temperature** ( $AT_{\text{shade}}$ ) equation (Morabito et al., 2014).

(1) the Thermal Sensation (TSN) equation can be calculated as follows,

$$TSN = 1.2 + 0.1115T_a + 0.0019S - 0.3185V, \quad (1)$$

where TSN is the thermal sensation scale ranging from 1 (very cold) to 7 (very hot), while 4 is neutral,  $T_a$  is the air temperature ( $^{\circ}\text{C}$ ),  $S$  is the solar radiation ( $\text{Wm}^{-2}$ ), and  $V$  represents the wind speed ( $\text{ms}^{-1}$ ).

Thus for an average person under an environmental condition with an air temperature of  $28^{\circ}\text{C}$ , solar radiation of  $150 \text{ Wm}^{-2}$ , a wind speed of  $1.9 \text{ ms}^{-1}$  over the

**Table 1:** Monthly average solar radiation over Malta and Venice in  $\text{Wm}^{-2}$ .

S ( $\text{Wm}^{-2}$ )	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
<b>Qrendi (Malta)</b>	116.67	145.83	208.33	242.50	305.42	322.92	322.92	295.42	232.08	172.92	132.50	95.83
<b>Venice Lagoon</b>	48.61	81.57	130.55	185.42	235.65	259.26	267.01	228.24	170.02	109.03	56.25	40.86

**Table 2:** Degree of cooling power of the Human Bioclimatic Comfort thresholds (Farajzadeh & Matzarakis, 2012).

HBC ( $\mu\text{cal cm}^{-2}\text{s}^{-1}$ )	Air situation	Type of bioclimatic stimulation
0 to 4	Hot-sultry – uncomfortable	Bioclimatic pressure
5 to 9	Warm-comfortable	Bioclimatic comfort
10 to 19	Mild-pleasant	Bioclimatic comfort
20 to 29	Cool	Moderate stimulation
30 to 39	Cold – slightly uncomfortable	Middle to intense stimulation
40 to 49	Moderate – very uncomfortable	Intense stimulation
50 to 59	Unpleasant – extremely cold	Intensive pressure

body would be needed in order for the person to remain in neutral, thermal sensation condition (Cheng & Ng, 2006).

For this study, the solar radiation over Malta was based on monthly values published by Farrugia, Fsadni, Yousif and Mallia (2005) and converted from  $\text{kWh m}^{-2}\text{day}^{-1}$  to  $\text{Wm}^{-2}$ . Values related to the Venice lagoon were derived from WMO standard normal for the period 1961–1990 and converted to  $\text{Wm}^{-2}$  (Table 1).

(2) the Human Bioclimatic comfort can be calculated as follows:

$$\text{HBC} = (0.26 + 0.34V^{0.632})(36.5 - T_a), \quad (2)$$

where, HBC is the human bioclimatic comfort in terms of cooling power of the environment at ( $\mu\text{cal cm}^{-2}\text{s}^{-1}$ ),  $V$  is 10 m wind speed ( $\text{m s}^{-1}$ ), and  $T_a$  is the air temperature ( $^{\circ}\text{C}$ ).

According to Becker (2000), when the HBC value is less than 5 or exceeds 20, then a bioclimatic pressure on the human body occurs. Table 2 shows the degree of cooling power of the Human Bioclimatic Comfort thresholds.

(3) the Apparent Shade Temperature ( $\text{AT}_{\text{shade}}$ ) can be calculated by taking into account the air temperature and humidity,

$$\text{AT}_{\text{shade}} = T_a + 0.33e - 0.70V - 4.00, \quad (3)$$

where,  $T_a$  is the air temperature ( $^{\circ}\text{C}$ ),  $V$  is 10 m wind speed ( $\text{m s}^{-1}$ ), and  $e$  represents the water vapor pressure (hPa).

### 2.3 Future Climate Projections Using the Latest CMIP5 Climate Data (IPCC, 2014) for the two Destinations.

In this study, CMIP5 future climate projections presented by IPCC (2014) 5<sup>th</sup> assessment report were used. Specifically, the modelled projections produced by the Met Office Hadley Centre HadGEM2-ES coupled Earth System Model (Collins et al., 2011) were assessed. The climate model comprises of an atmospheric GCM and an ocean GCM, the latter is deemed important for appropriate simulation of the future climate in parts of

the Mediterranean basin. Additional model components include terrestrial and ocean carbon cycle and tropospheric chemistry. According to Martin et al. (2011), the earth system components of HadGEM2-ES compared well with observations and with other models, and was considered to be a valuable tool for predicting future climate and for the understanding of the climate feedbacks within the earth system. HadGEM2-ES has been used to perform Hadley Centre's contribution to the CMIP5 modelling activity for IPCC's 5<sup>th</sup> Assessment Report.

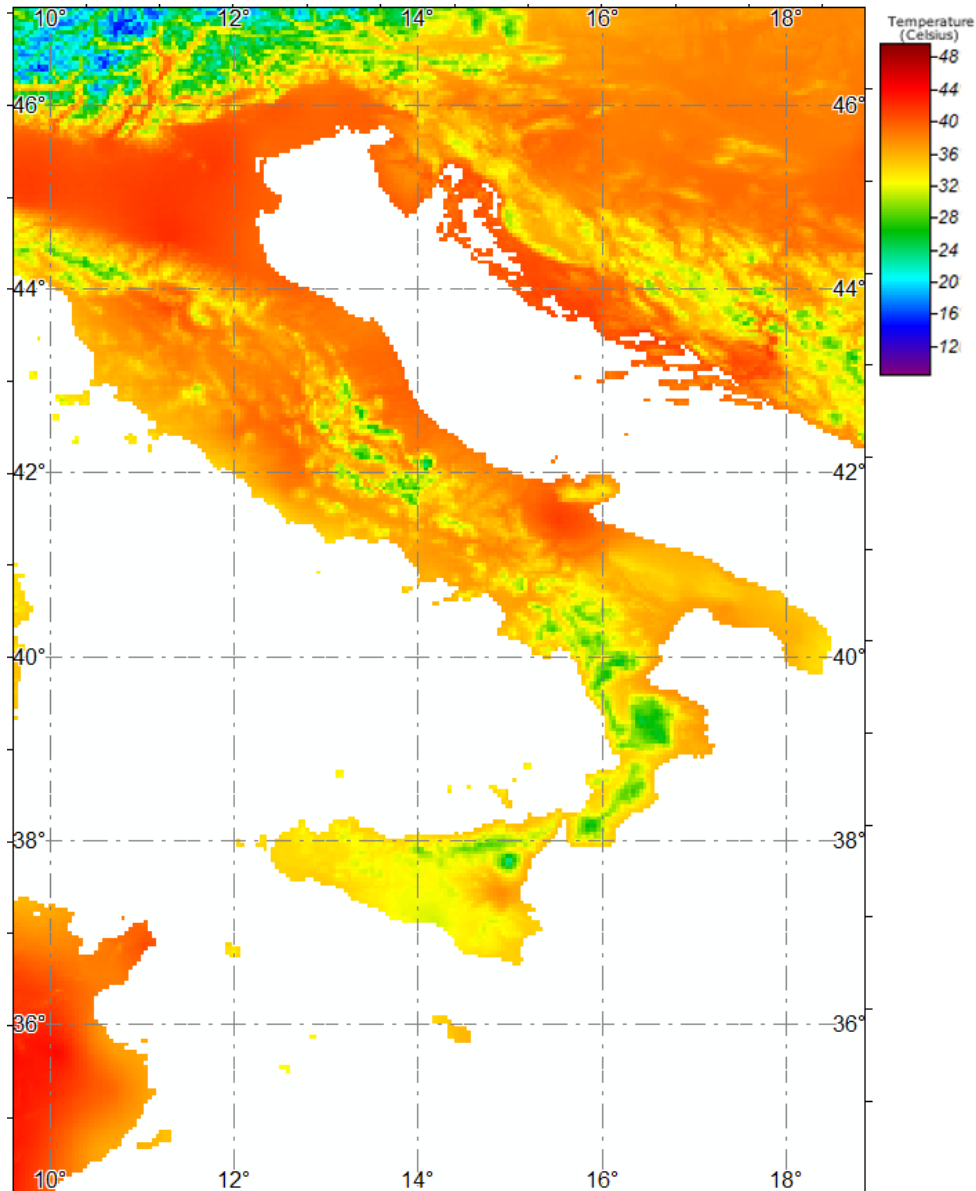
Global gridded monthly values of the 2-m minimum and maximum temperature and precipitation were analysed (Fig. 2). These datasets were downscaled to reflect local impacts by means of established techniques in order for managers to interpret global climate projection information at the local scale. Detailed quality assurance information of downscaled CMIP5 have been published (Brekke, Thrasher, Maurer & Pruitt, 2013). The monthly values were extracted over the two areas of interest for the four pathways. The Human Bioclimatic Comfort was calculated on the basis of these projected values taking into account the detected trends in wind speed over the two geographical locations.

### 2.4 Data analysis

Weather observations from two WMO climate stations, i.e. Malta (WMO 16597 Latitude: 35:51N Longitude: 014:29E) and Venice (WMO 161050 Latitude: 45:30N Longitude: 012:20E) were collected for this study.

From these observations, a normalised yearly analysis was carried on the data measured during the observation periods. The correlation between the elementary annual observations (such as wind speed, air temperature, humidity, etc.) and the frequency of a particular condition (i.e. unsuitable, critical and optimal conditions) at each of these destinations provides a measure of the potential sensitivity of tourism-related climate attributes to changes in that weather conditions (such as changes that are expected to be driven by global warming).

Temperature anomalies were derived to provide an accurate description of climatic variability and allow data comparison from different climatological areas. WMO recommends 30 years as a standard period for the ana-



**Figure 2:** Subset example of the HadGEM-ES RCP 8.5 climate model projection showing distribution of maximum temperature for July 2070.

lysis of climate anomalies (Folland, Karl & Vinnikov, 1990), and the climate period between 1961 and 1990 compiled for the two destinations is used as a typical baseline in conformity with the IPCC and other official climate centres.

In addition to ambient air temperature, dew point temperature, wind speed and atmospheric pressure, the following climatic parameters were calculated as shown in Table 3.

### 3 Results

#### 3.1 Climatic Indices Over Time

Weather observations from the two destinations, Luqa - Malta (1967–2013 except 1971, 1972 and 1973; average completeness throughout: 82%) and Venice - Italy (1973–2013; average completeness throughout: 84%) were used to illustrate how the elementary weather parameters as well as sub-indices could be applied to measure how climate, as a resource for tourism, has changed with time.

**Table 3:** Computation of the various climatic indicators based on published equations.

Climatic parameter	Reference
<b>Heat Index</b>	Masterton and Richardson (1979)
<b>Wind Chill Index</b> (°C)	National Weather Service (2001)
<b>Presence of Heatwave</b>	WMO; UK Met Office (2014b)
<b>Relative Humidity</b> (%)	Alduchov and Eskridge (1996)
<b>Windy conditions</b>	Yu, Schwartz and Walsh (2009)
<b>Gale storms</b>	The Beaufort scale (UK Met Office (2014a))
<b>Adverse weather</b>	World Meteorological Organization (2014)
<b>Precipitation (specific)</b>	World Meteorological Organization (2014)
<b>Visibility</b>	World Meteorological Organization (2014)
<b>Thermal Sensation Index</b>	Givoni and Noguchi (2004)
<b>Human Bioclimatic Comfort</b>	Becker (2000), Farajzadeh and Matzarakis (2012)
<b>Apparent Shade Temperature</b>	Morabito et al. (2014)

(i) *Trends over time: elementary weather parameters (annual minimum and maximum temperature, heat-wave events, and anomalies from the climate norm).*

Results show localised warming trends of the annual highest maximum temperature at both destinations, with +0.09 °C of +0.63 °C (per annum) in Malta and Venice respectively (Fig. 3). The Mann–Kendall test shows that the positive trends observed in both cases are significant at the 99% confidence level.

Results also show similar warming trends in the annual lowest minimum temperatures of +0.02 °C and +0.04 °C per annum in Malta and Venice respectively (Fig. 4). The Mann–Kendall test shows that the positive trend observed over Malta is significant at the 99% confidence level. This shows that throughout the years the incidence of warmer nights has become increasingly common with time.

Figures 5(a) and 5(b) show the annual mean air temperature anomalies registered in Malta and Venice compared to the climate norm of 1961–1990. In both cases, the Mann–Kendall test confirmed that the positive trends observed are significant at the 95% confidence level. Venice seems to have been impacted by a positive temperature anomaly since 1985, unlike Malta. In a previous study (Galdies, 2012) showed that the rate of temperature increase over Malta for a longer period of 1951–2010 was 0.2 °C per decade and already falls midway within the range of 0.1 °C and 0.4 °C as described by Hertig and Jacobeit (2008) for the predicted annual warming for the period 2020–2030 over southern Europe using IPCC-approved models.

The occurrence of conditions throughout the entire observation period, linked to the onset of heat-wave events at the two destinations, is shown in Figure 6. Results show that summer heat-waves are a more common feature in Malta than in Venice, implying a higher

impact on utility infrastructure and tourist activities, among others, especially in Malta. In spite of the lower frequency of occurrence observed in Venice during the study period, both trends are statistically significant at 95% confidence level. The severity and frequency of heat wave events are a representation of the larger regional climate patterns in the Mediterranean and may be related to the overall changing climatic conditions at both sites, to the detriment of visiting tourists.

(ii) *Climate suitability over time: 3-level sub-indices (wind speed, wind chill index, heat stress and Gale storms).*

In the following sections, the results for the occurrence of “suitable” days derived according to Table 3 are presented. These are based on the consolidation of three- and half-hourly weather reports. The annual frequency or number of occurrences within each of the three categories (Unsuitable – Critical – Optimal weather conditions) varied over time and across the two sites.

Results obtained from Malta (Fig. 7(a), 7(b), 7(c)) provided some strong evidence regarding the general trends. Less windy conditions are increasingly becoming more common (Fig. 7(a)), and this is shown by the statistically positive and significant increasing trend at the 95% confidence level. During the same long period of time, both critical and unsuitable conditions (that is windier conditions) show a negative statistically significant trend. This a classical example demonstrating that the optimal weather (in terms of wind speed) is increasing at the expense of the other two conditions. The above relationship also holds for the occurrence of Gale storms (Fig. 7(c)). All trends are statistical significant at the 95% confidence limit, and only the trend shown by the optimal conditions is positive.

With regards to the frequency of occurrences of wind

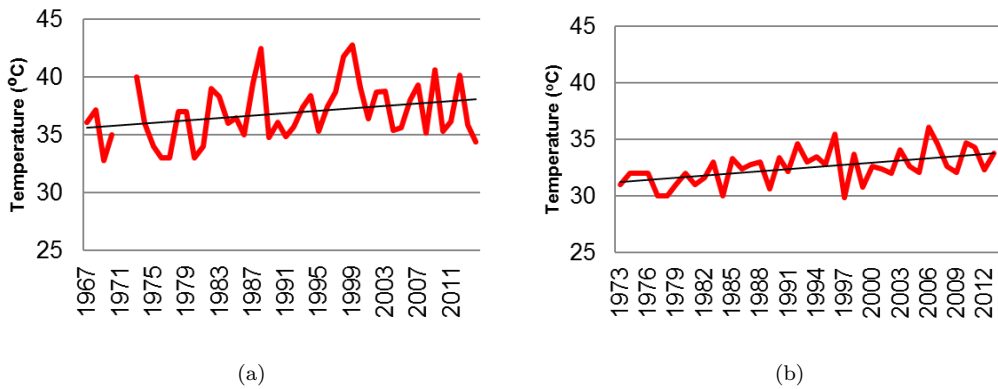


Figure 3: Annual highest maximum temperature trends over (a) Malta (1967-2013) and (b) Venice (1973-2013).

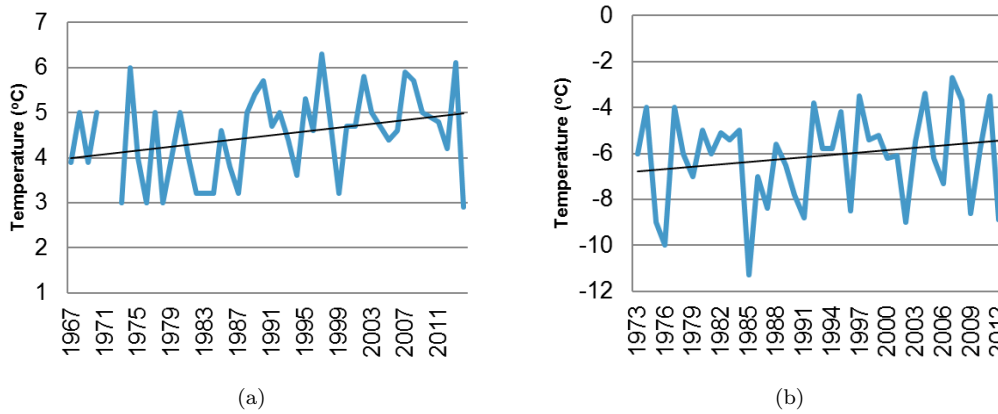


Figure 4: Annual lowest minimum temperature trends over Malta (a) (1967-2013) and (b) Venice (1973-2013).

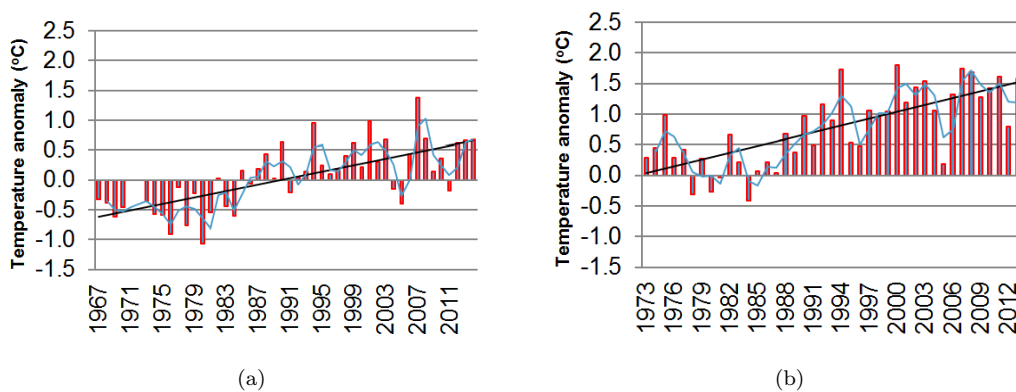
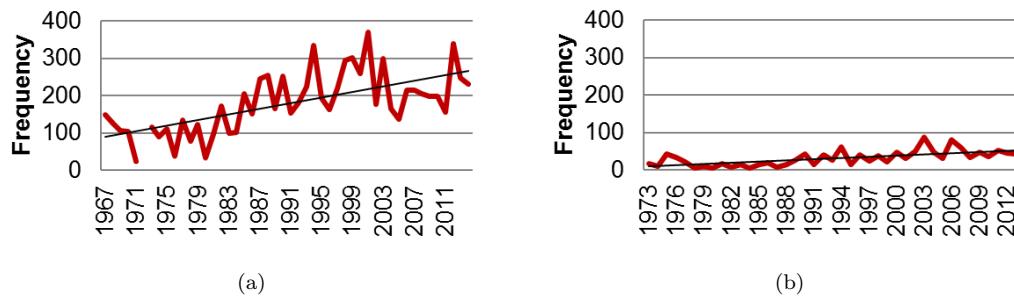
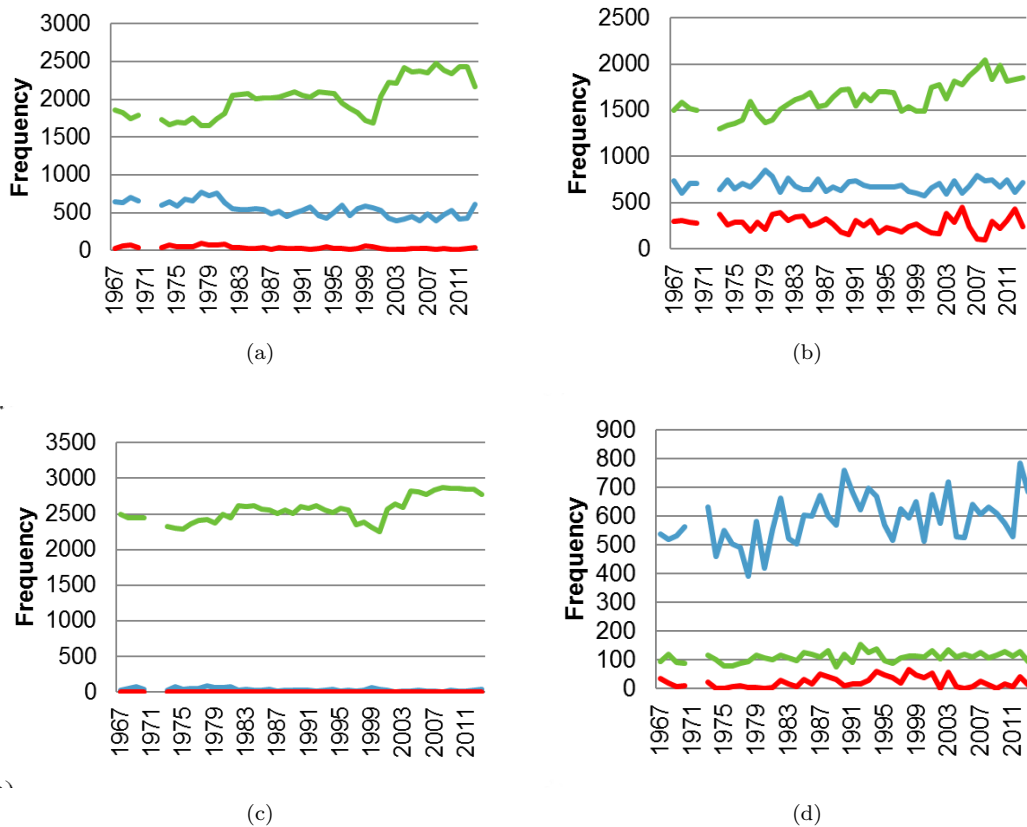


Figure 5: (a) Malta and (b) Venice annual mean air temperature anomalies for the period 1967-2013 and 1973-2013 respectively. Two-year running average shown in blue. Anomaly is based on Malta's and Venice's 30-year climatology of the annual mean air temperature observed during the climate norm 1961-1990.





**Figure 6:** Total number of occurrences (annual frequencies) when the maximum temperature exceeded the climate mean monthly maximum temperature by an additional 5 °C in (a) Malta and (b) Venice for the period 1967–2013 and 1973–2013 respectively. The climate norm of Malta and Venice is based on the 1961–1990 period.

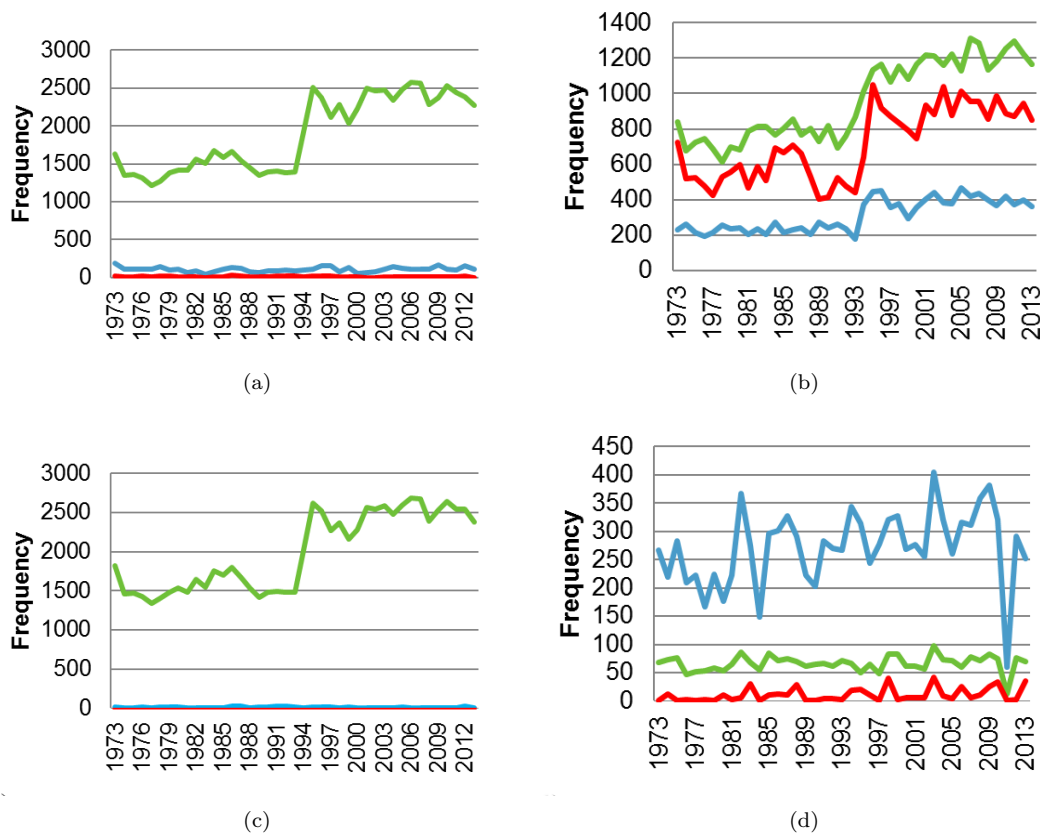


**Figure 7:** Annual frequency of the optimal (green), critical (blue) and unsuitable (red) conditions (blue) for (a) wind speed, (b) wind chill, (c) gales and (d) heat stress, based on the computation of elementary observations taken from Malta during the period 1967–2013.

chill events, only the trend for the optimal conditions (i.e. occurrence of minimal wind chill) is statistically significant and positive (Fig. 7(b)). The negative trends of the other two conditions proved not to be significant at the 95% confidence level.

Of high concern is the temporal trend of the heat stress index, for which positive trends exist for both the

occurrence of the critical and to a lesser extent that for optimal conditions (Fig. 7(d)). This trend of increased critical conditions was statistically significant at the 95% confidence limit. The trend for the frequency of occurrence of unsuitable (i.e. worst) heat stress conditions is not significant, although it is definitely a negative one which is especially evident during the latter part of the



**Figure 8:** Annual frequency of the optimal (green), critical (blue) and unsuitable (red) conditions (blue) for (a) wind speed, (b) wind chill, (c) gales and (d) heat stress, based on the computation of elementary observations taken from Venice during the period 1973–2013.

observation period.

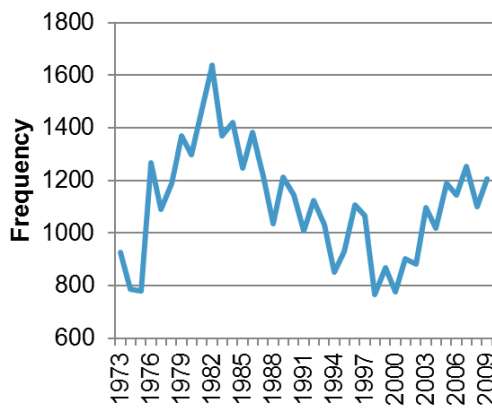
In the case of Venice, Fig. 8(a), 8(b) and 8(c) showed that the occurrence of less windy days (falling within the range of the defined optimal conditions) has a strong positive and statistically significant trend, while the other two trends have very low occurrence and are not statistically significant. The same pattern is seen for the frequency of gale storms (Fig. 8(c)), which exhibited a positive statistically significant trend for optimal conditions (i.e. less occurrence of gale events).

As to the occurrence of wind chill (Fig. 8(b)) results show that the trends of the three conditions exhibited a jump in the frequency of observations after 1993. This could be due to a change in observation methods or instrument sensitivity, the details of which are not available. However, what is important here is the relative difference between the three trends, which seems to be quite constant throughout the observation period. Analysis of only the post-1994 data showed that the trend of the occurrence of optimal conditions is the only statistically significant one at the 95% confidence level.

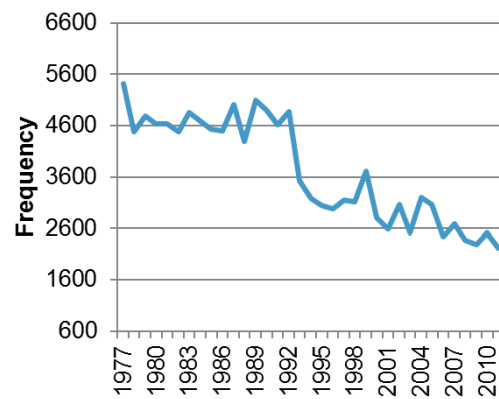
The frequency of three conditions dictated by the heat

stress index (Fig. 8(d)) produced statistically significant trends for the critical and unsuitable heat stress conditions and both of these trends are significantly correlated with each other at the 95% confidence level (Pearson's correlation). However, the trend obtained for the occurrence of optimal conditions is not statistically significant at the 95% confidence level indicating that the critical condition for the heat stress is becoming a real concern.

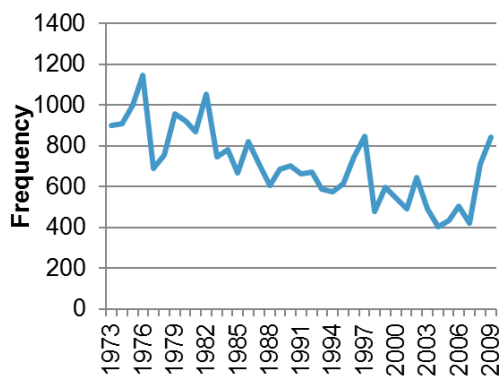
Results show that the negative precipitation trend over Malta (Fig. 9(c)) is statistically significant at 95% confidence level. Both adverse weather conditions (Fig. 9(a)) and increased incidence of reduced visibility (Fig. 9(e)) both have a negative, but statistically non-significant trend. As to Venice both the trend for the decreased occurrence of significant events and low visibility are statistically significant at the 95% confidence limit. However, the trend shown by the precipitation events over Venice is not statistically significant at the 95% confidence limit.



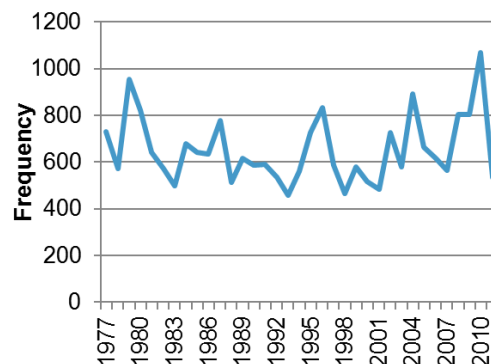
(a) Occurrence of significant (adverse) weather (Malta)



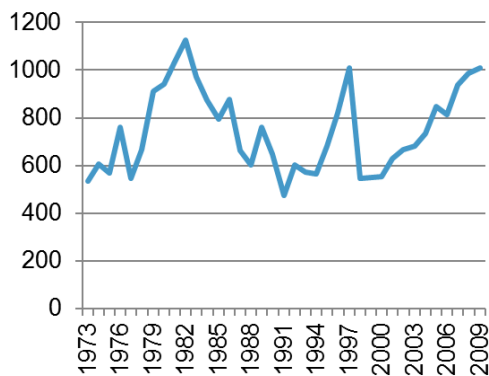
(b) Occurrence of significant (adverse) weather (Venice)



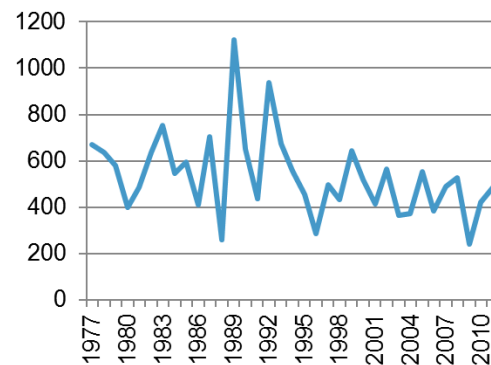
(c) Occurrence of precipitation events (Malta)



(d) Occurrence of precipitation events (Venice)



(e) Occurrence of low visibility (Malta)



(f) Occurrence of low visibility (Venice)

**Figure 9:** Annual frequency of (a) adverse weather events, (c) precipitation events and (e) poor visibility for Malta, and (b) adverse weather events, (d) precipitation events and (f) poor visibility for Venice, based on the computation of elementary observations.

### 3.2 Bioclimatic Indices Assessment

#### 3.2.1 Thermal Sensation Index

Figures 10(a) and 10(b) show an increasing positive trend of TSI at both locations, with Malta showing a

more pronounced and a statistically significant trend at the 95% confidence level. This index is based on a consideration of the effects of the following on the thermal resistance of the visitor: exercise, the respective effects of clothing on moisture loss and heat loss, ambient tem-

peratures, atmospheric water vapour, direct solar radiation, the degree of wind penetration into the clothing, and the effect of temperature on the thermal conductivity of the clothing (Steadman, 1979).

### 3.2.2 Apparent Shade Temperature

Both locations (Fig. 11(a), 11(b)) show an increasing positive trend in the apparent shade temperature. Only the trend observed over Malta was statistically significant at the 95% confidence level. This index considers all environmental and bodily conditions that affect human thermoregulation.

### 3.2.3 Human Bioclimatic Comfort Index

The use of this index was based on its simplicity and the combination of air temperature and wind speed. The temporal trends of the cooling power in relation to the two destinations are shown in Fig. 12(a) and 12(b). For both locations, the overall trend is a statistically significant, negative one indicating a deterioration in human

comfort was towards the warm side of the index spectrum.

### 3.3 Future Climate Projections HadGEM-ES Climate Model Output

Figures 13 and 14 present the annual cycle of the maximum and minimum temperature for each location for the years 2050 and 2070, compared to their climate baseline of 1961–1990. For both destinations, a significant rise in both monthly maximum and minimum temperatures from the baseline levels is evident, with a stronger signal for the RCP8.5 scenario. In the case of Malta, the peak tourist months are expected to experience an increase of around +1.9 °C (2050) and +2.0 °C (2070) for July and +2.1 °C (2050) and +2.2 °C (2070) for August for the least harmful scenario (RCP2.6). For the Venice lagoon, the increased temperatures will be more pronounced (Figs. 14(a) and 14(b)).

Based on the above projections, the future human bioclimatic comfort index, based on the worst case ra-

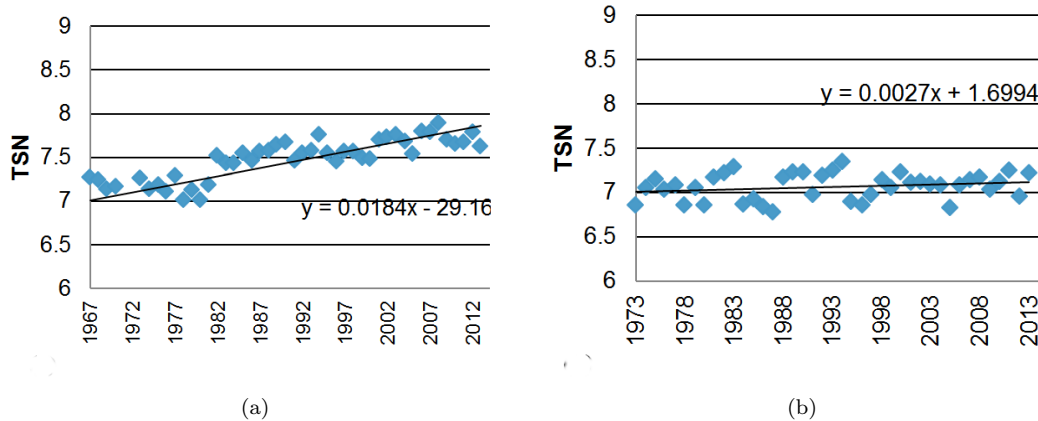


Figure 10: Trend of the thermal sensitivity index for (a) Malta (1967–2013) and (b) Venice (1973–2013).

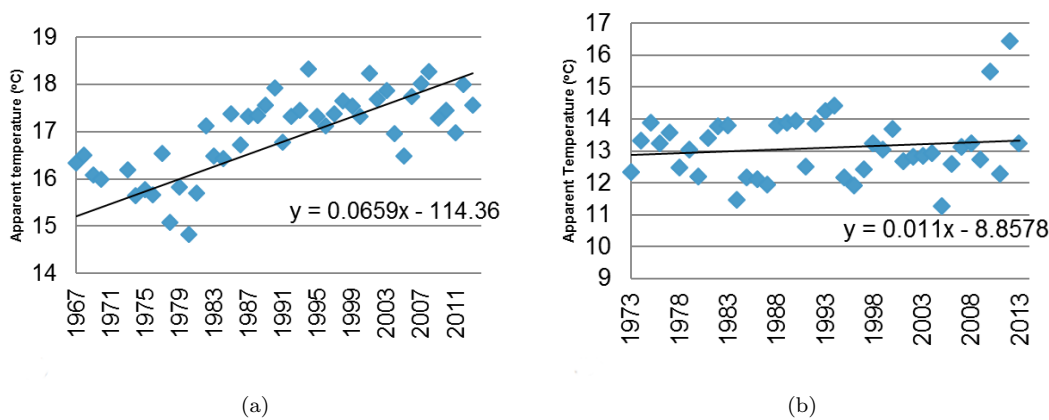
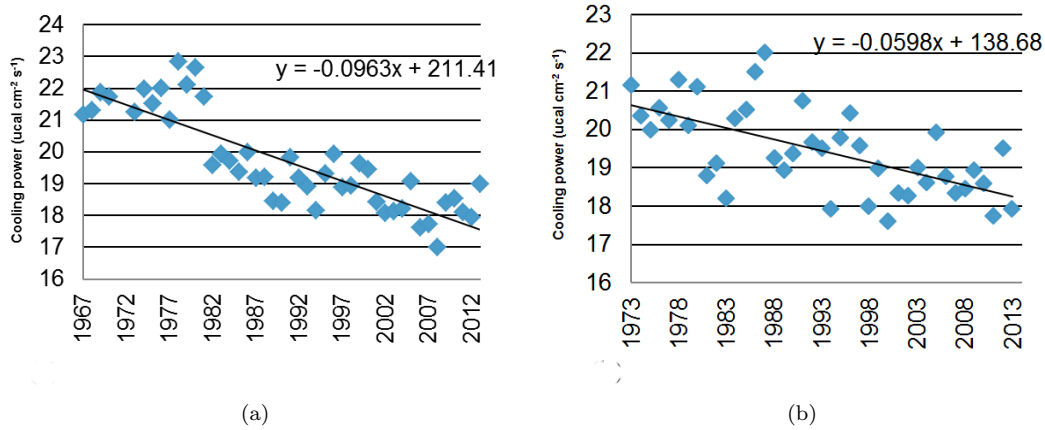
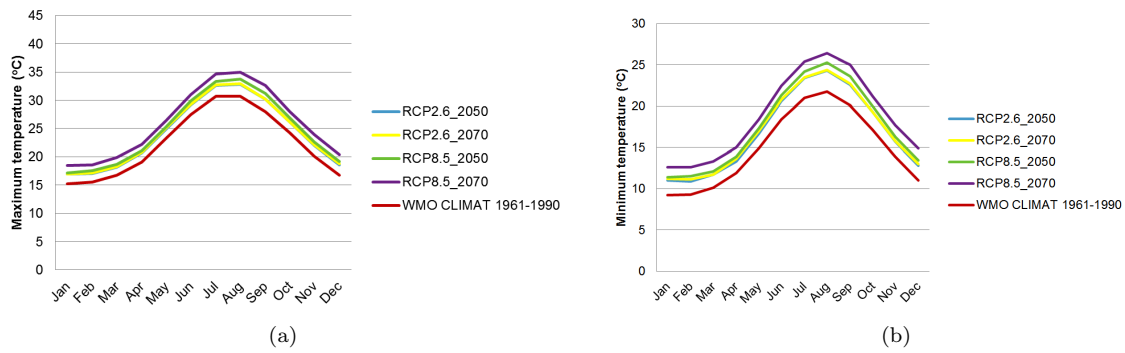


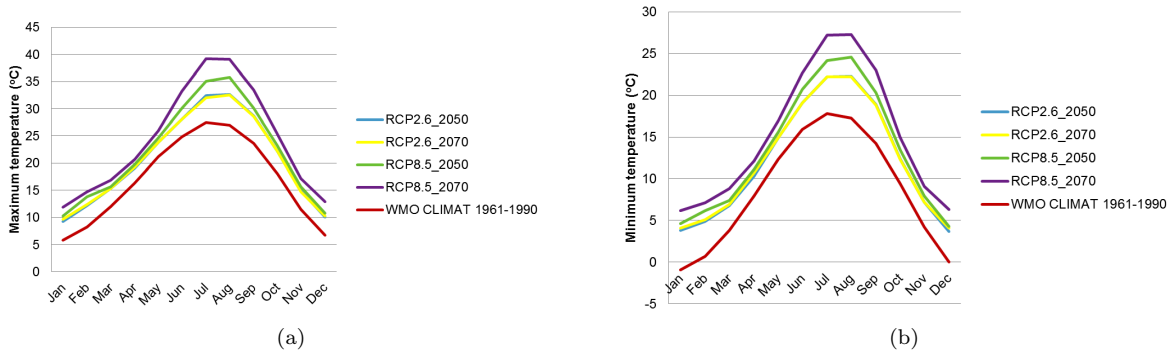
Figure 11: Shade apparent temperature index for (a) Malta (1967–2013) and (b) Venice (1973–2013).



**Figure 12:** Bioclimatic comfort index for (a) Malta (statistically significant at 95% confidence level) and (b) Venice.



**Figure 13:** Projected (a) maximum and (b) minimum monthly temperature over the Maltese islands in 2050 and 2070 against the 1961–1990 Climate Norm baseline.



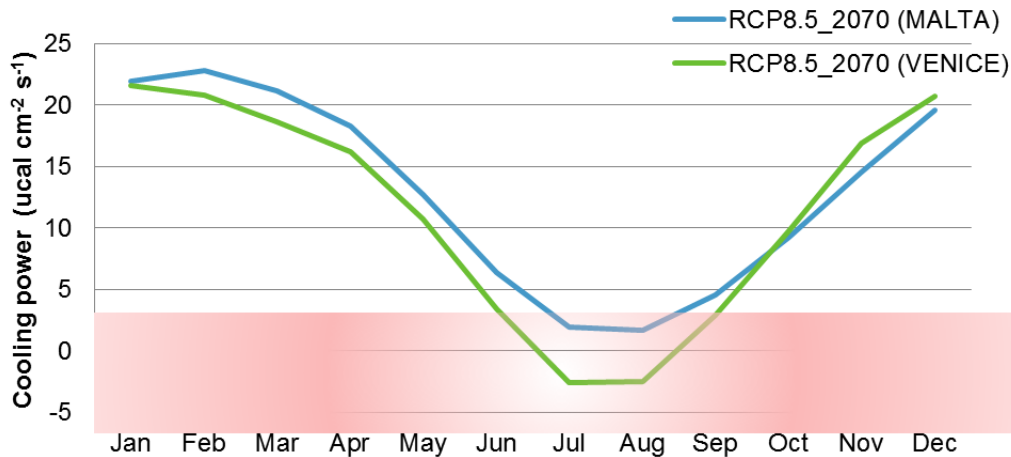
**Figure 14:** Projected (a) maximum and (b) minimum monthly temperature over Venice lagoon in 2050 and 2070 against the 1961–1990 Climate Norm baseline.

diative scenario modelled for 2070 (RCP8.5) shows critical situations during the peak visiting months (July and August) at both destinations (Fig. 15). This could imply a required shift, as a form of adaptation, of the visitation periods at these two destinations. The shaded area shows the worst bioclimatic conditions during the

peak tourist months (hot-sultry, uncomfortable; considerable bioclimatic pressure; Table 2).

## 4 Discussion

The study demonstrated a quantitative analysis of high temporal weather observations and their derivatives



**Figure 15:** Expected discomfort on the basis of the human bioclimatic comfort index for both destination by the year 2070. The shaded area shows worst conditions (hot-sultry, uncomfortable; considerable bioclimatic pressure; Table 2) at both sites during the months of July and August.

that can be further tuned to match the specificities of outdoor-related tourism activities. The study's main contributions to the emerging knowledge on this subject are highly relevant in order to assess the possible future touristic attractiveness of these two destinations. The statistically significant, long-term trends for some of the climatic variables and their derivatives studied here can be related to the level of increased comfort or otherwise that tourists have so far experienced at both destinations.

In particular, this study verified that a definitive shift in a number of weather patterns has been detected at the two destinations. These included an increased incidence of heat-wave episodes, increased occurrence of higher temperature maxima and minima, as well as an overall positive anomaly in the mean temperature at the two destinations. In an extended historical study, Galdies (2012) showed a higher incidence of heat-wave in recent years over the Maltese Islands.

The long-term positive anomaly trend of the mean air temperature observed over Malta up until 2014 corroborated previous studies that further delved into the varying rates of change of local weather variables (Galdies, 2011, 2012). These shifts were linked to the larger regional impact originating from a warmer climate. The rate of increase of the anomaly in the mean temperature is +1.1 °C while the positive trend observed for the maximum temperature recorded over the Maltese islands comes to +1.2 °C over the time period studied (46 years) which is equivalent to an increase of around 0.1 °C per year in the yearly maximum temperature. The observed decrease in precipitation events over Malta ( $P < 0.05^*$ ) implied an environment that is becoming increasingly dry, which was in line with the IPCC forecasts for this

part of the Mediterranean. Over Venice a similar situation was discerned, especially with regards to the increased occurrence of heat-waves, as well as to the significant positive trends of the maximum temperature and for the mean temperature anomaly against the climate norm (equivalent to +1.7 °C over 30 years). The number of sub-hourly occurrences of bad visibility and adverse weather (such as thunderstorms, precipitation, etc.) were also seen to decrease over Venice ( $P < 0.05^*$ ).

The indexed derivatives obtained from the elementary meteorological observations, such as wind chill and heat index, showed that the level of comfort experienced by visiting tourists (and equally by the local community) over the long term has deteriorated at both destination, especially with regards to the observed increase in heat stress. This is being balanced by increased occurrence of optimal wind speed conditions and lack of gale storms, as well as reduced occurrence of adverse wind chill events. These derivatives were based on a set of high temporal observations and are thus able to capture valuable information that traditional monthly distribution cannot provide. By applying this methodological framework one is also able to analyse important subsets of the day during which certain outdoor tourist activities become more relevant unlike those applied by other studies (such as the one conducted by Amelung and Nicholls, 2014).

However, the robustness of these derivatives to forecast the future visitation patterns to these two destinations is not straightforward, since attractiveness ultimately depends on a complex set of conditions related to economy, good marketing, investment (de Freitas, 2003) as well as tourist perception of a changing climate and related experiential behaviour, including their country

of origin (Morgan et al., 2000). Wall (2007) justifiably argued that it is extremely difficult to generalize concerning the possible implications of climate change for tourism. de Freitas et al. (2008), and Perch-Nielsen, Amelung and Knutti (2010) for example, addressed a number of deficiencies of the use of tourist climate indices by devising a theoretically and empirically sound method that integrated the various facets of climate and weather into a single index by means of a novel approach to explore the climate preferences of tourists in a detailed manner (Rutty & Scott, 2014). The testing of such indices with travellers is evidently an important area of inquiry in order to apply an 'objective' measure of quality of the climate at tourism destinations (Scott & McBoyle, 2001) by evaluating the appropriateness of the sub-index rating systems against stated tourist preferences. Moreover, it is worthwhile mentioning the excellent work of Goh (2012) who studied how travel motivation can be analysed using a socio-psychological framework in order to explore the impact of climate on tourism demand. Research is currently underway by the author to study related tourist perception and preferences of local climate.

Meanwhile, researchers are still resorting to the application of the tourist climate index that is a derivative of a mixture of climate variables like temperature, sunlight, precipitation, humidity and wind to forecast tourism flows (Amelung & Nicholls, 2014; Roson & Sartori, 2014).

#### 4.1 A Bioclimatic Approach

Such an approach was deemed necessary in order to steer away from presenting an analysis of weather trends. The high temperature preferences of beach tourists, for example, reveals that an analysis simply based on weather trends, without reference to the bioclimatic stress on the human body, would be problematic. What could be termed as 'critical' level index could actually be what beach users define as 'optimal'.

Thus including a series of published indices aimed at understanding the degree of physiological comfort with a changing environment provides further correlation with the weather trends that tourists have been witnessing since the early sixties/seventies at the two destinations.

These bioclimatic indices have significant implications for human adaptations to the physiological climate of the Mediterranean. Since the physiological climate affects not only human health and activity, but also physical and mental efficiency, it is important that bioclimatic knowledge are exploited for better technological and behavioural adaptations of potentially affected visitors. This could be translated into a set of adaptation measures (as defined by local policy- and decision-makers) to account for the predicted deterioration of the human bioclimatic comfort that is predicted by the

two extreme RCP scenarios as modelled by the CMIP-5 IPCC climate modelling.

Some areas in which knowledge of physiologic climate may prove to be useful include the use of appropriate clothing according to the prevailing physiologic climate and type of outdoor activities. For example, in locations where the apparent temperature exceeds 22 °C, vigorous sporting activities may be physiologically dangerous. The most recent information concerning tourist participation in sport and outdoor activities shows that 47.3% of total visitors engage in walking and hiking activities (Malta Tourism Authority, 2014). The rest engage in swimming and diving activities and therefore may not be affected as much by uncomfortable bioclimatic conditions during such practices. Specific segments of future tourists may thus find the results of this study useful in planning for the best period for their recreational activities.

#### 4.2 Future Climate

Results of this study show that the climate is already changing, and the intensity and frequency of extreme weather events, such as heat waves may change in the future. Recent extreme weather events caused serious health and social problems in Europe, particularly in urban areas (Christidis, Jones & Stott, 2015). This study looked at the likely future scenario with regards to both meteorological variables such as ambient temperature, and a monthly scenario of the human bioclimatic comfort at the two destinations (Amelung & Viner, 2006). Extreme events will pose additional challenges to the management of health risks to both public health and tourist sector alike. One hopes that the relevance of this information in light of current and future tourist visitation is taken on board by the respective authorities in Malta and Italy. The next step would be to focus local research on modelling the relation between climate and tourist preference as well as on the sustained competitive nature of the two destinations. The results of this study highlight the need for a proactive adaptation strategy by the main stakeholders.

In summary, the positive and negative impacts of a changing climate on visiting tourists at these two localities, as identified by this study are of practical importance to decision makers at the two tourism destinations analysed. In the case of Malta, such information has never been compiled.

Adaptation options exist for both destinations, but most of these options are likely to add costs and offer only short-term relief. Under the observed scenario of higher temperatures, questions exist as to whether adaptation is realistic, other than a possible shift in tourism peak seasons. These changes are likely to create opportunities at both destinations, including increased employment and income. However, non-climate factors

such as the dates of school holidays during summer might still influence families to keep their current visitation preferences.

The ability to analyse the past, current and future climate leads to a number of important benefits. The present findings show that there are distinct, significant climatological trends over a long period of observation. The ability to extrapolate possible future scenarios based on statistically sound climatic trends and future IPCC climate projections can benefit tourism planning regarding future options of outdoor activities at these two tourist destinations. Similar studies for a larger range of destinations with diverse climates can be carried out to extend the geographical scope of this study.

## 5 Conclusion

Climate change is a two-fold challenge for the tourism industry. One part of this challenge involves addressing the impacts of tourism in contributing to climate change. What is relevant for this study is the second part of this challenge, namely what tourism can and needs to adapt to climate change. This study provides basic knowledge that is needed to frame the right type of adaptation measures by highlighting to tourist planners which are those weather elements that are likely to present a future obstacle to the overall bioclimatic suitability for outdoor tourism activities at the two destinations.

The main findings of this study are summarised as follows:

- Climatic shifts in terms of an increased rate in the mean temperature anomaly, with respect to the climate norm, over Malta (+1.1 °C) and Venice (+1.7 °C) are linked to the larger regional and global impact originating from a warmer climate.
- The observed decrease in precipitation events over Malta (which is statistically significant at the 95% confidence level) points to an environment that is becoming increasingly dry. Over Venice, a similar situation can be discerned, especially with regards to the increased occurrence of heat-waves.
- The number of sub-hourly occurrences of bad visibility and adverse weather (such as thunderstorms, precipitation, etc.) were also seen to decrease over Venice (where such trends are statistically significant at the 95% confidence level).
- The derivatives obtained from the elementary meteorological observations show that the level of comfort experienced by visiting tourists over the long term is deteriorating when it comes to the increased heat stress. However, the increased occurrence of optimal wind speed conditions and lack of gale storms, as well as a reduced occurrence of adverse wind chill events, are making these destinations more attractive.
- All bioclimatic indices show a deterioration in the degree of comfort, which is particularly distinctive (statistically speaking) in Malta.
- IPCC climate model (in this case, by the HADGEM-ES) predictions show a significant increase in maximum and minimum temperature over both locations, with higher increases over Venice lagoon.
- In the case of Malta, the peak tourist months are expected to experience an increase of around +1.9 °C (2050) and by +2.0 °C (2070) for July and +2.1 °C (2050) and +2.2 °C (2070) for August for the least harmful scenario (RCP2.6). For the Venice lagoon, the increased temperatures are predicted to be more pronounced.
- The future human bioclimatic comfort index, based on the worst case radiative scenario modelled for 2070 (RCP8.5), is expected to reach critical conditions during the peak visiting months (July and August) at both destinations. This could imply a required shift, as a form of adaptation, of the visitation periods at these two destinations.

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## A Appendix

**Table A1:** Computation of the various climatic indicators based on published equations.

Three-level climatic approach		
Climatic parameter	Equation & Scoring	Reference
<b>Heat Index</b>	HEAT INDEX = AIR TEMPERATURE + (5/9)(VAPOUR PRESSURE - 10). If HI is between 30 and 39, then conditions are critical; if HI > 39, then conditions are unsuitable; else conditions are optimal.	Masterton and Richardson (1979)
<b>Wind Chill Index (°C)</b>	WIND CHILL = (((35.74 + (0.6215 × TEMPERATURE) - (35.75 × WIND SPEED <sup>0.16</sup> ) + (0.4275 × AIR TEMPERATURE × WIND SPEED <sup>0.16</sup> )) - 32) × 5)/9. If WCI is greater than 10, then critical; if WCI is less than 10, then conditions are unsuitable; else conditions are optimal.	National Weather Service (2001)
<b>Presence of Heatwave</b>	If temperature is greater than the climatic monthly average maximum temperature (climate normal period being 1961–1990) by five degrees then flag as unsuitable condition.	WMO; UK Met Office (2014b)
<b>Relative Humidity (%)</b>	Relative Humidity% = 100 × {exp[(17.625 × DEW POINT TEMPERATURE)/(243.04 + DEW POINT TEMPERATURE)]/exp[(17.625 × AIR TEMPERATURE)/(243.04 + AIR TEMPERATURE)]}	Alduchov and Eskridge (1996).
<b>Windy conditions</b>	If wind speed is between 14 and 25.5 knots, then conditions are critical; if wind speed is > 25.5 knots, then conditions are unsuitable. Else conditions are optimal.	Yu, Schwartz and Walsh (2009)
<b>Gale storms</b>	FORCE 8; mean wind speed 37 knots; 19 ms <sup>-1</sup> ; Limits of wind speed (knots) 34–40 knots; Probable wave height is 5.5 meters; Probable maximum wave height is 7.5 meters. If wind speed is between 22 and 33 knots, then moderate conditions; if wind speed is > 33 knots, then strong wind conditions. Else conditions are optimal.	The Beaufort scale UK Met Office (2014a)
<b>Adverse weather</b>	Occurrence of SH, TS, FZ, DZ, RA, SN, SG, IC, PL, GR, GS, UP, BR, FG, FU, VA, DU, SA, HZ, PY, PO, SQ, FC, and SS (see Annex 1 of WMO document)	World Meteorological Organization (2014)
<b>Precipitation (specific)</b>	Occurrence of SH, DZ, RA, SN, SG, GR, GS (see Annex 1 of WMO document)	World Meteorological Organization (2014)
<b>Visibility</b>	Occurrence of FG, FU, VA, DU, SA, HZ, PY, PO, SQ, FC, SS (see Annex 1 of WMO document)	World Meteorological Organization (2014)