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ORIGINAL ARTICLE

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Weather impacts on respiratory infections in Athens, Greece

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Abstract In this study the contribution of meteorological parameters to the total variability of respiratory infections (RI) is analysed. For this purpose, data on the daily numbers of general practitioner (GP) consultations for RI during the year 2002 were used. This dataset has been compiled by the Local Health Service in the surroundings of Athens, Greece (Acharnes city). The meteorological data obtained by the Meteorological Station of the National Observatory of Athens comprise daily values of mean, maximum, and minimum air temperature, air temperature range, relative humidity, absolute humidity, sunshine, surface atmospheric pressure, wind speed, as well as day-to-day changes of these parameters. Furthermore, the following biometeorological parameters and thermal indices were also evaluated: mean radiant temperature (T_{mrt}), predicted mean vote (PMV), physiologically equivalent temperature (PET) and standard effective temperature (SET*) as well as their day-to-day changes. First, the relationship between every meteorological-biometeorological parameter and consultations for RI was examined by applying the Pearson Chi-Square Test (χ^2) to the data of the 25 compiled contingency tables. In the second stage, the application of generalised linear models (GLM) with Poisson distribution to the data revealed how much the weather variability leads to statistically important changes in consultations for RI. The results of this study contribute to the evidence that there is an association between weather conditions and the number of GP consultations for RI. More specifically, the influence of air temperature and absolute humidity on consultations on the same day is weaker than the lag effect (~2 weeks) related to cold existence and absolute humidity, while a strong wind during the preceding 3 days drives a peak in GP consultations.

Keywords Respiratory infections · Weather · Biometeorology · Thermal indices · Athens/Greece

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Introduction

Since the era of Hippocrates (430 BC), it is well known that meteorological changes influence human health. The effect of weather-climate changes, and also of the atmospheric environment in general, on human health has been studied by numerous scientists (Katsouyanni et al. 1988; Kalkstein 1993; Kalkstein and Smoyer 1993; McMichaels et al. 1996; Colwell et al. 1998; Panagiotakos et al. 2004; Bartzokas et al. 2003; McGregor 2005). More specifically, an estimate of the influence of certain weather types or specified thresholds of meteorological variables on human health seems to be very important. The appearance of large meteo-pathological reactions found in native populations could be explained by the day-to-day change in weather patterns (Lecha 1998). Furthermore, the Intergovernmental Panel on Climate Change (IPCC) highlights that global climate change will have various impacts, some of which are positive, but mostly negative, on human health (IPCC 2001). Changes in the frequencies of extreme heat and cold, the frequencies of floods and droughts, and the degree of local air pollution and aeroallergens will directly affect population health.

Acute viral respiratory infections (RI) are a significant cause of morbidity worldwide. An association between low air temperatures and an increase in consultations made by elderly people (65+ years) for lower respiratory tract infections was observed in 16 locations in the United Kingdom over a 10 year period, 1992–2001 (Hajat et al. 2004). A remarkable increase in paediatric hospitalisations due to viral lower RI has also been observed in Buenos Aires, Argentina, during the winter months. A detailed 5-year retrospective analysis (1998–2002) of acute lower RI (viral aerobiology) in children under 5 years was performed. The findings highlight an inverse correlation between viral frequencies (RSV and IA) with mean air monthly temperature and UV-B radiation, while the correlation is positive when relative humidity is taken into account (Viegas et al. 2004). As noted by Goncalves et al. (2005), noticeable changes in synoptic conditions seem to have played an important role in regulating respiratory morbidity in Sao Paulo City, Brazil, during the summer months. These authors found that prefrontal (postfrontal), hot (cold) and dry (wet) days favoured the decrease (increase) of respiratory morbidity. Furthermore, respiratory syncytial virus and influenza infections have been observed mainly during the rainy seasons in Asian, African and South American countries (Shek and Lee 2003).

In Greece, hospital lower respiratory tract infections are associated with significant morbidity and mortality (Kofteridis et al. 2004), while environmental pollution was found to have a detrimental effect on the respiratory system of children, due mainly to the occurrence of rhinitis and infectious bronchitis (Sichletidis et al. 2005). In addition, weather conditions are a significant driver for RI (Danielides et al. 2002; Bartzokas et al. 2003).

The present study focuses on the possible quantitative effects of meteorological and biometeorological parameters on the emergence of RI in the wider region of Athens.

Materials and methods

The medical data used in this study, concerning 1,212 general practitioner (GP) consultations made by people for RI, were filed by the Local Health Service in Acharnes city in the Northwest suburbs of Athens, Greece, during the year 2002. RI includes the following diseases: bronchitis, tracheiobronchitis, respiratory infections, farygitis, tonsillitis, laryngitis, the common cold and flu, and pneumonia. The analysed meteorological data, recorded by the meteorological station of the National Observatory of Athens, include the following parameters: mean temperature (T_{mean}); maximum tempera-

Table 1 Number of days with 0, 1, 2, 3, 4 and 5 or more cases of respiratory infection (RI) in the Health Unit for each quintile of mean air temperature (T) and absolute humidity (e), and for each class of physiological equivalent temperature (PET) and predicted mean vote (PMV)

		Consultations for RI					
		0	1	2	3	4	≥5
Quintiles T (°C)							
1	$T \leq 12.5$	36	7	1	5	3	23
2	$12.5 < T \leq 16.1$	25	4	2	2	5	34
3	$16.1 < T \leq 21.4$	27	4	2	8	7	26
4	$21.4 < T \leq 26.1$	29	5	6	6	8	17
5	$T > 26.1$	37	5	3	7	3	18
Quintiles of e (g m^{-3})							
1	$e \leq 7.6$	33	9		4	3	24
2	$7.6 < e \leq 9.2$	28	2	1	5	5	33
3	$9.2 < e \leq 11.2$	33	4	5	3	5	22
4	$11.2 < e \leq 13.5$	26	6	2	12	4	23
5	$e > 13.5$	34	4	6	4	9	16
Classes of PET (°C)							
1	PET≤0	3	1		1		
2	0< PET≤4	2	1		1	1	3
3	4< PET≤8	13	2		1	1	4
4	8< PET≤13	23	3	2	3	2	20
5	13< PET≤18	25	5	1	3	6	34
6	18< PET≤23	23	3	2	5	3	21
7	23< PET≤29	26	5	5	8	8	18
8	29< PET≤35	23	3	4	4	4	12
9	35< PET≤41	16	2		2	1	6
Classes of PMV							
1	PMV ≤ −3.5	6	2		2	1	3
2	−3.5< PMV ≤ −2.5	18	3	1	1	1	10
3	−2.5< PMV ≤ −1.5	21	3	1	3	2	21
4	−1.5< PMV ≤ −0.5	22	5	2	3	6	29
5	−0.5< PMV ≤ 0.5	25	2	2	5	5	21
6	0.5< PMV ≤ 1.5	24	5	5	8	8	17
7	1.5< PMV ≤ 2.5	22	3	3	4	2	12
8	2.5< PMV ≤ 3.5	16	2		2	1	5

ture (T_{max}); minimum temperature (T_{min}); diurnal temperature range (T_{range}=T_{max}−T_{min}); day-to-day change in mean temperature (ΔT_{mean}); day-to-day change in maximum temperature (ΔT_{max}); day-to-day change in minimum temperature (ΔT_{min}); day-to-day change in diurnal temperature range (ΔT_{range}); mean relative humidity (RH); day-to-day change in mean relative humidity (ΔRH); absolute humidity (e); day-to-day change in mean absolute humidity (Δe); mean sunshine (S); day-to-day change in mean sunshine (ΔS); mean atmospheric pressure at sea level (P); day-to-day change in mean atmospheric pressure (ΔP); mean wind speed (v) and day-to-day change in mean wind speed (Δv).

The following biometeorological parameters were also evaluated: mean radiant temperature (T_{mrt}), predicted mean vote (PMV), physiologically equivalent temperature (PET) and standard effective temperature (SET*) as well as their day-to-day changes (VDI 1998; Matzarakis et al. 2000). The relative humidity reveals the percentage of saturation of water vapour in the atmosphere and not the total sum of water vapour contained in it. The vapour pressure is considered as the most important parameter for the estimate of the effect of humidity on the human body (Fiedler 1989). The calculated thermal indices are based on the human energy balance and describe the combined effects of thermal environments on the human body (Gagge et al. 1986; VDI 1998; Höppe 1999; Matzarakis et al. 1999). The thermal indices and the T_{mrt} were calculated using the RayMan model (Matzarakis et al. 2000).

The relationship between RI and the aforementioned meteorological parameters was calculated through: (1) Pearson χ^2 test, the most widely used method of independence control of groups in lines and columns in a table of frequencies, and (2) generalised linear models (GLM) with Poisson distribution, (Nastos et al. 2005; Danielides et al. 2004). In the first stage of the statistical analysis, the values of each meteorological variable were grouped in five quintiles. The values of each biometeorological variable were grouped in well defined thermo-physiological strain classes of the thermal indices PMV and PET (Matzarakis and Mayer 1996). Accordingly, the first quintile (first class) contained the lowest 20% (lowest thermal sensation) and the fifth quintile (last class) the highest 20% (highest thermal sensation) of all values. In this process, the number of days with 0, 1, 2, 3, 4 and 5 or more daily consultations for RI in the Local Health Service was calculated for each quintile. The results of this step were assembled in a contingency table for every parameter. Table 1 shows the contingency tables for mean air temperature, absolute humidity, PET and PMV. The Pearson χ^2 test was applied for each of the 25 contingency tables, testing the null hypothesis that the quintiles (classes) of each meteorological parameter are not related to (and hence are independent of) the number of RI. The use of contingency tables instead of Pearson correlation is considered to be more accurate, since the medical data show a high dissimilarity to a Gaussian (regular) distribution. In the second step of the analysis, the statistical importance of the correlation between RI frequency and the meteorological parameters was examined through GLM with Poisson distribution as described by McGullagh and Nelder (1997).

The class of models known as GLMs was introduced by Nedler and Wedderburn (1972). According to their theory, the link function establishes the connection between the linear predictor, n, and the mean of the distribution, μ. There is a so-called ‘natural link’ for each distribution. It is important to note that, although the link function is in some senses similar to a transformation function, it only establishes a mathematical connection between the mean and the response variables. A transformation function may be used to simplify the connection between the mean and the response variables. It may also stabilise the variance. The natural link for the Poisson distribution is the log link: $n=\log(\mu)$, $\mu=e^n$, the variance function is $\upsilon(\mu)=\mu$ and, as in

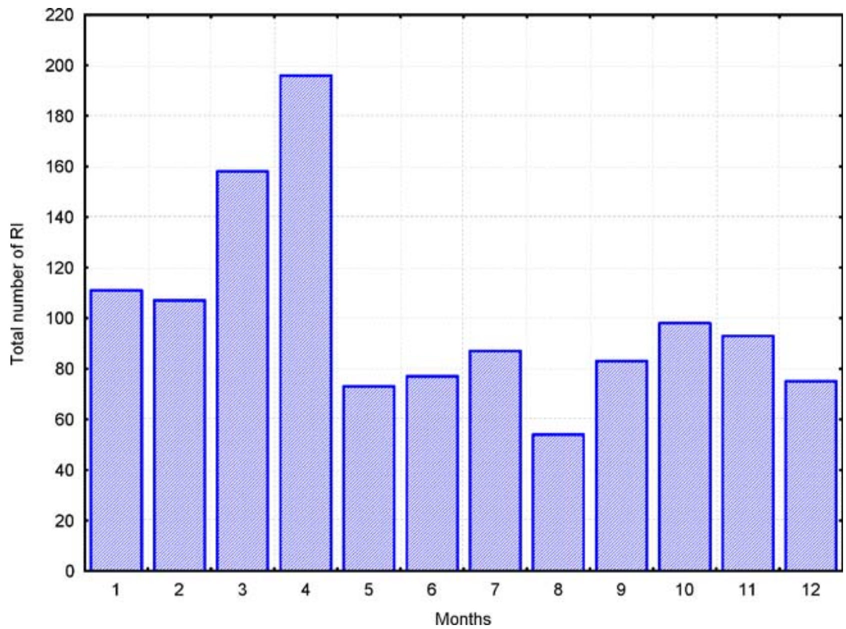


Fig. 1 Monthly distribution of general practitioner (GP) consultations for respiratory infections (RI) for the year 2002

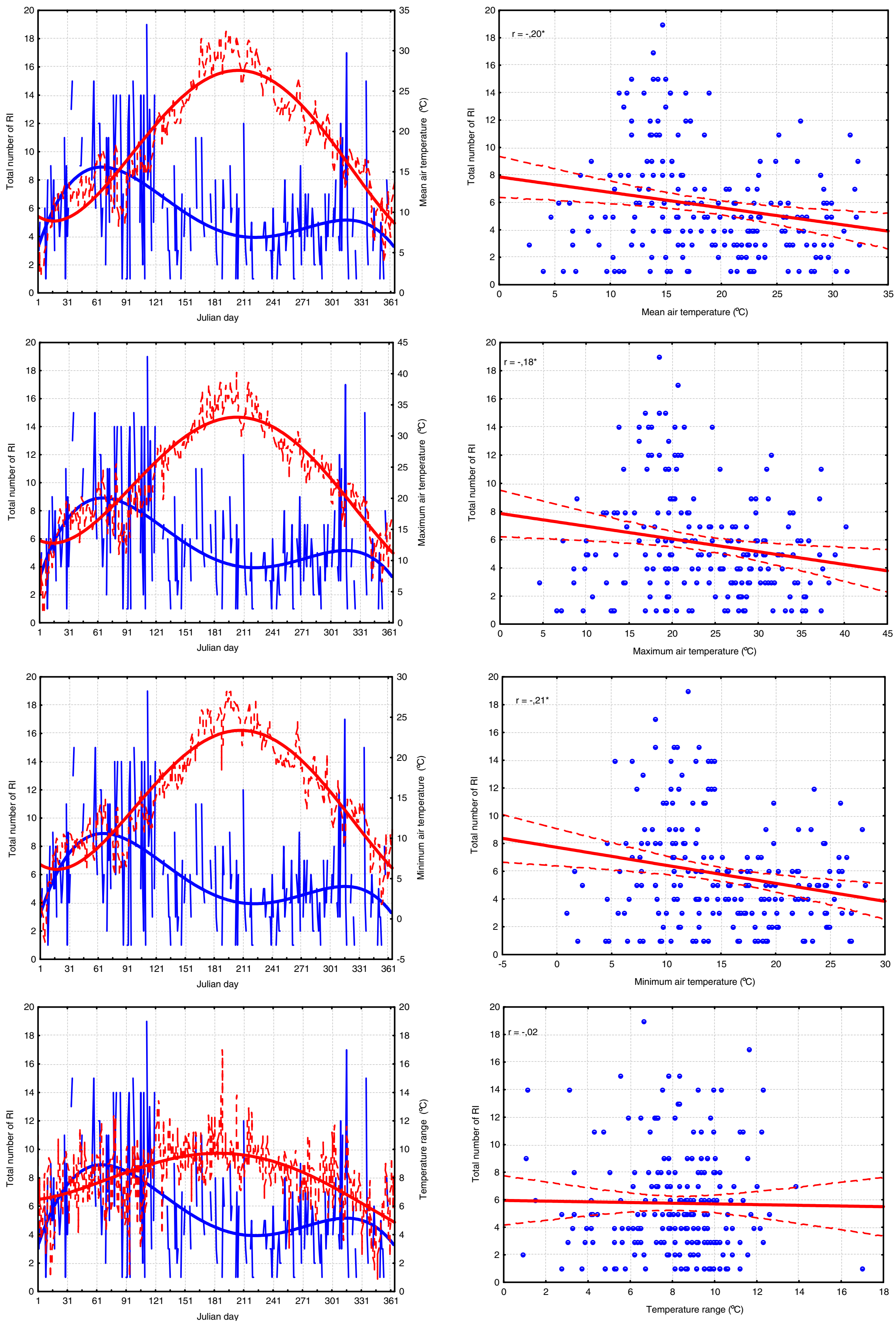


Fig. 2 The intra-annual variation in the daily number of GP consultations for RI and the daily mean, maximum, minimum air temperature and the daily air temperature range, along with 4th degree polynomial fitting, as well as the correlations between them

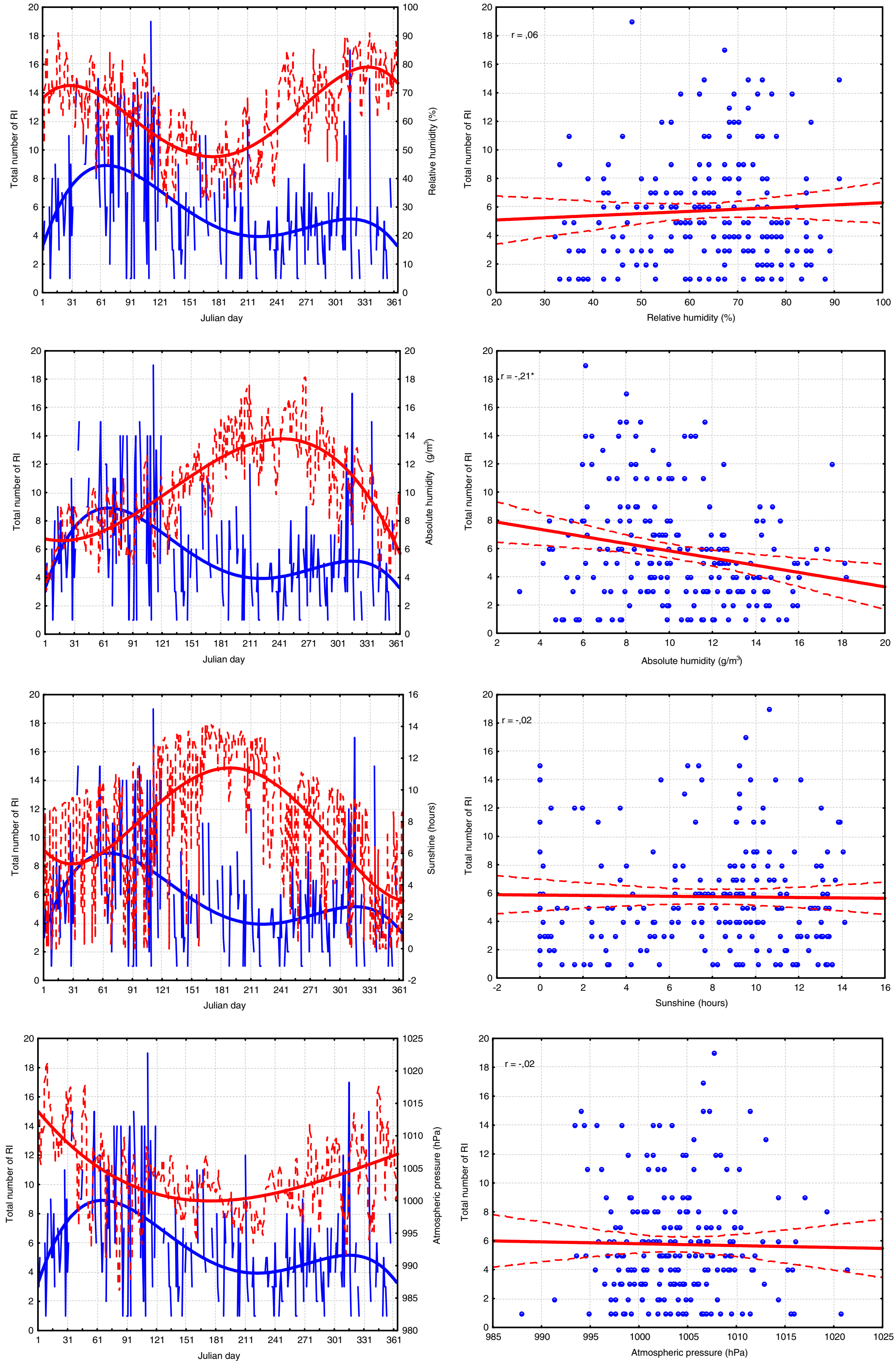


Fig. 3 The intra-annual variation in the daily number of GP consultations for RI and the daily mean relative humidity, the mean absolute humidity, the total sunshine and the mean atmospheric pressure along with 4th degree polynomial fitting, as well as the correlations between them

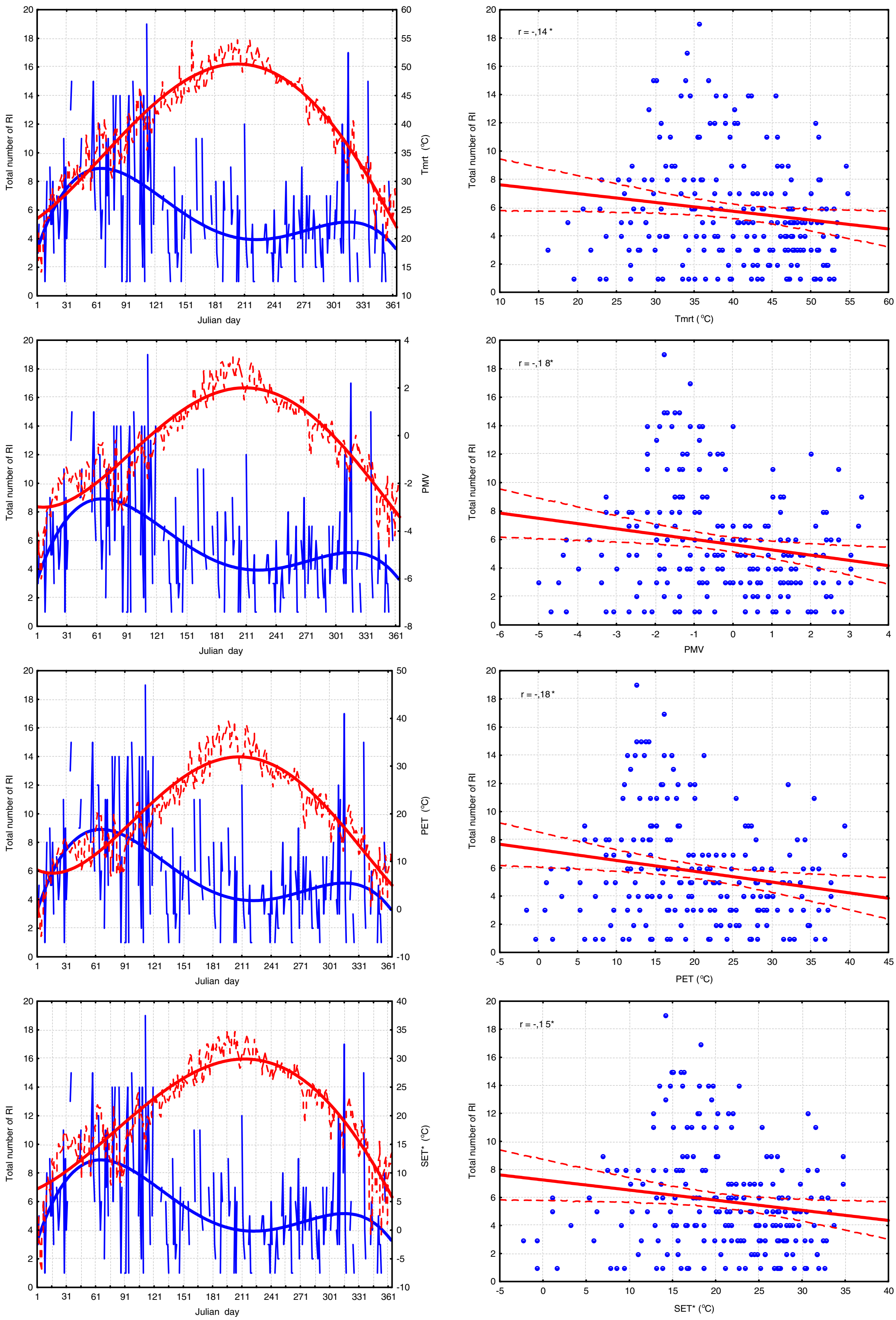


Fig. 4 The intra-annual variation in the daily number of GP consultations for RI and the corresponding biometeorological parameters mean radiant temperature (T_{mrt}), predicted mean vote (PMV), physiologically equivalent temperature (PET) and standard effective temperature (SET*) along with 4th degree polynomial fitting, as well as the correlations between them

Table 2 Results of the application of generalised linear models (GLM) with Poisson distribution, (dependent variable is the daily number of GP consultations for RI, while independent covariates are the aforementioned meteorological and biometeorological parameters); variables in *bold* indicate statistically significant relationship (P<0.002) after Bonferroni adjustment

Variable	b Coefficient ± standard error	Significance level (P)	Variable	b Coefficient ± standard error	Significance level (P)
T_{mean} (°C)	−0.0198±0.0043	0.000004	**T_{mrt}(°C)**	−0.0107±0.0032	0.000995
T_{max} (°C)	−0.0157±0.0038	0.000035	**PMV**	−0.0636±0.0158	0.000054
T_{min} (°C)	−0.0228±0.0047	0.000001	**PET (°C)**	−0.0134±0.0032	0.000029
T_{range} (°C)	−0.0044±0.0117	0.708669	**SET* (°C)**	−0.0122±0.0036	0.000714
ΔT_{mean} (°C)	−0.0051±0.0194	0.792489	ΔT_{mrt} (°C)	0.0293±0.0140	0.036668
ΔT_{max} (°C)	−0.0039±0.0125	0.753191	ΔPMV	0.1096±0.0607	0.110926
ΔT_{min} (°C)	0.0185±0.0175	0.290997	ΔPET(°C)	0.0189±0.0119	0.070945
ΔT_{range} (°C)	−0.0119±0.3139	0.313891	ΔSET*(°C)	0.0226±0.0115	0.050114
RH (%)	0.0026±0.0021	0.204845			
ΔRH (%)	0.0093±0.0032	0.004096			
e (g.m $^{-3}$)	−0.0449±0.0092	0.000001			
Δe (g.m $^{-3}$)	0.0372±0.0191	0.052247			
S (h)	−0.0024±0.0070	0.727909			
ΔS (h)	0.0014±0.0082	0.859683			
P (hPa)	−0.0023±0.0052	0.663452			
ΔP (hPa)	−0.0072±0.0088	0.414669			
v (m/sec)	−0.0642±0.0064	0.006450			
Δv (m/sec)	−0.0328±0.1126	0.112574			

T_{mean} Mean temperature, T_{max} maximum temperature, T_{min} minimum temperature, T_{range} ($=T_{max}-T_{min}$) diurnal temperature range, *RH* mean relative humidity, *e* absolute humidity, *S* mean sunshine, *P* mean atmospheric pressure at sea level, *v* mean wind speed, T_{mrt} mean radiant temperature, *PMV* predicted mean vote, *PET* physiologically equivalent temperature, *SET** standard effective temperature

the case of the binomial distribution, the scale parameter is 1. Poisson models with log links are often called log-linear models and are used for frequency data.

In the model-fitting procedure we used as dependent variable the daily GP consultations made by patients for RI, filed by the Local Health Service, while as independent covariates the aforementioned meteorological and biometeorological parameters were included. Goodness-of-fit of the model was evaluated through deviance residuals (McGullagh and Nelder 1997). A simple way of keeping the experiment error rate to a specified level (usually α=0.05) is to divide the acceptable α-level by the number of comparisons we intend to make (Bonferroni adjustment). In our study, if 25 pairwise comparisons are to be made and we want to keep the overall experimental error rate to 5% we will evaluate each of our pairwise comparisons against 0.05 divided by 25. That is, for any comparison to be considered significant, the obtained P-value would have to be less than 0.002 (0.05/25=0.002) and not 0.05.

Results

The intra-annual distribution of monthly consultations for RI during the year 2002 is presented in Fig. 1. A clear peak of cases of RI is observed in April and a minimum in August.

The intra-annual variation of the daily number of consultations for RI and the corresponding meteorological parameters along with 4th degree polynomial fitting, as well as the correlations between them, are presented in Figs. 2 and 3. The intra-annual variation of the biometeorological variables is presented in Fig. 4. The correlation coefficients of the relationship between the numbers of consultations for RI, the air temperature variables and the absolute humidity are small but statistically significant (P<0.05). As mentioned before, the medical data do not follow a normal distribution but rather a Poisson distribution. Therefore, the application of GLM with Poisson distribution and the Pearson χ^2 test were considered as appropriate methods with which to analyse these data.

The intra-annual variation in the number of consultations for RI reveals a double oscillation during the year, with the main maximum in early spring and a secondary maximum in early winter, while the characteristic minimum occurs during August and almost coincides with the maxima of the air temperature, absolute humidity and sunshine variables. The relative humidity shows a similar pattern to that of RI, but a delay of 1 month is apparent, while the atmospheric pressure is lowest during summer.

The application of the Pearson χ^2 test to the 25 contingency tables of the meteorological-biometeorological parameters shows a statistically significant correlation (confidence level 95%) between the number of consultations for RI, the absolute humidity, and the day-to-day change in atmospheric pressure. The number of consultations for RI seems to be higher during negative changes of atmospheric pressure (first quintiles of the contingency table). Additionally, there is a statistically significant correlation (confidence level 90%) between the daily number of consultations for RI, the maximum air temperature and the day-to-day change in sunshine. More precisely, an increase in the maximum air temperature and number of hours of sunshine results in a decrease in the daily number of consultations for RI.

Concerning the biometeorological parameters, a statistically significant relationship (confidence level 95%) exists between the daily number of consultations for RI and the day-to-day changes in T_{mrt}, while in a lower confidence level (90%), a significant correlation exists between RI, PET, ΔPET and ΔSET.

The results of the application of GLM are presented in Table 2. Interpretation of these findings leads to the conclusion that a statistically significant correlation ($P<0.002$) exists between the number of cases of consultations for RI and T_{mean}, T_{max}, and T_{min}, as well as the absolute humidity. Concretely, a decrease of 10°C in T_{mean} leads to an increase of 18% in the probability of people suffering from RI, while a decrease of 10°C in T_{max} is related to an increase of 14% in the probability of the appearance of RI, and finally a decrease of 10°C in T_{min} is linked to an increase of 20% in the probability of having an RI event. It is also worth noting that an increase of 10 g/m^3 in absolute humidity leads to a 36% decrease in the probability of the appearance of RI and vice versa.

In the analysis, we examined if there are delays between cold weather and GP consultations; such delays gave rise to the highest regression coefficients (statistically significant at P=0.05). We found a 15-day lag between the T_{min} trough of air temperature and the peak of GP consultations; a decrease of 10°C in T_{min} is associated with a lagging increase of 28% in GP consultations. It is noteworthy that a lag of 3 days is also revealed but with a lower regression coefficient than that of the 15-day lag. As far as the other meteorological parameters are concerned, a lag of 3 days can be discerned between the occurrence of strong wind and a peak in GP consultations, (an increase of 1 m/s on lagged wind speed is linked to a 7% increase in GP consultations) while a delay of 12 days and a minor delay of 3 days is observed between the minimum of absolute humidity and the maximum of GP consultations. An increase of 10 g/m^3 in absolute humidity leads, with a 12-day lag, to a 47% decrease in GP consultations and vice versa.

Taking into account the influence of the biometeorological regime, a statistically significant correlation ($P<0.002$) appears between the number of consultations for RI and T_{mrt}, PMV, PET and SET*. A decrease of 10°C in T_{mrt} leads to an increase of 10% in the probability of suffering from RI, while a decrease of 10 units in PMV is related to an increase of 47% in the probability of the appearance of RI. Also, a decrease of 10°C in PET, SET is linked to an increase of 12% and 11% in the probability of having an RI event.

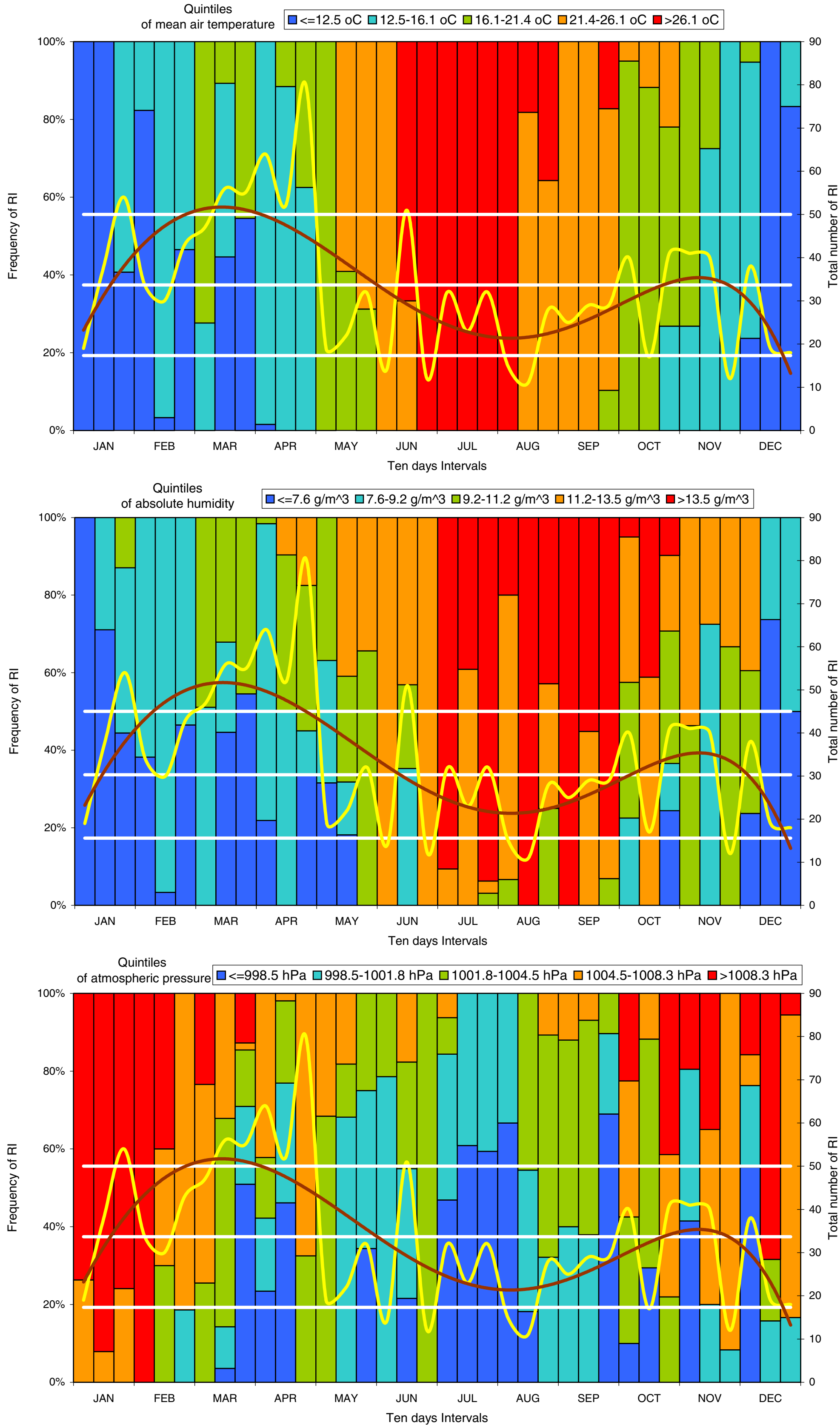
In order to illustrate the relationship between GP consultations for RI and the meteorological-biometeorological variables more descriptively, the original consultation data were transformed from daily values to 10-day interval values. The frequencies of GP consultations for RI were analysed as a function of the meteorological and biometeorological variables' percentiles and classes, respectively. Three reference lines representing the mean, the mean+SD and the mean−SD are also depicted (Figs. 5, 6). Regarding the meteorological conditions, high pressure patterns (higher percentiles) associated with low air temperature and low absolute humidity (lower percentiles) seem to be responsible for peaks in RI consultations, especially during the cold period of the year (November–March). On the other hand, the minimum in RI consultations is related to the higher percentiles of air temperature and absolute humidity as well as the lower percentiles of atmospheric pressure. In addition, from the biometeorological point of view, both the high classes of PET and PMV indices coincide with troughs in GP consultations for RI (Fig. 6).

Discussion

The results show that GP consultations for RI examined during the year 2002 demonstrate an intra-annual distribution, with a double oscillation during the year. The fall in consultations for RI in December compared to January may be due to the fact that the Local Health Service is closed for a few days before and after the Christmas period and that the schools are closed for the short Christmas holidays. The abrupt increase in consultations in early spring is possibly explained by the fact that, during this period, the weather conditions show great variability and allergenic pollen are widespread in the atmosphere. Gioulekas et al. (2004) studied the 15-year allergenic pollen records and sensitisation in patients with respiratory allergy in Thessaloniki, Greece, and found that the highest concentrations of pollen were observed from the beginning of March until the start of June. The period from January to April is characterised by an increased number of GP consultations for RI. The predominant causes are usually atmospheric changes, i.e. sudden weather changes, which often occur in spring and fall and increase the likelihood of common colds. These findings are fairly similar to the results presented by Danielides et al. (2002) and Bartzokas et al. (2003), who analysed the influence of meteorological parameters on acute laryngitis in the region of Ioannina in north-western Greece, and on respiratory problems in Athens, respectively. This pattern of distribution is also similar to the seasonality of asthma admissions in Malta (Grech et al. 2002), where admissions show a peak in January and a trough in August and a second smaller peak in spring, while in Ankara, Turkey, the number of asthma emergency room visits is higher in the winter months, April and September. The first peak is related to allergic pollens during April and the second peak is probably due to opening of schools during September–October (Berktas and Bircan 2003). Furthermore, Avendano et al. (1999) found that lower ambient temperature coincides with higher detection of respiratory syncytial virus at week 28, in an area of Metropolitan Santiago, Chile.

According to the application of GLM, low air temperature and low absolute humidity regimes are associated with high numbers of consultations for RI. These results

Fig. 5 Frequency of GP consultations for RI per 10-day interval as a function of meteorological variable percentiles together with the variation of the total number of GP consultations for RI per 10-day interval (*yellow line*) and the polynomial fitting (*brown line*). Three reference lines (*white lines*) represent the mean, the mean+SD and the mean−SD



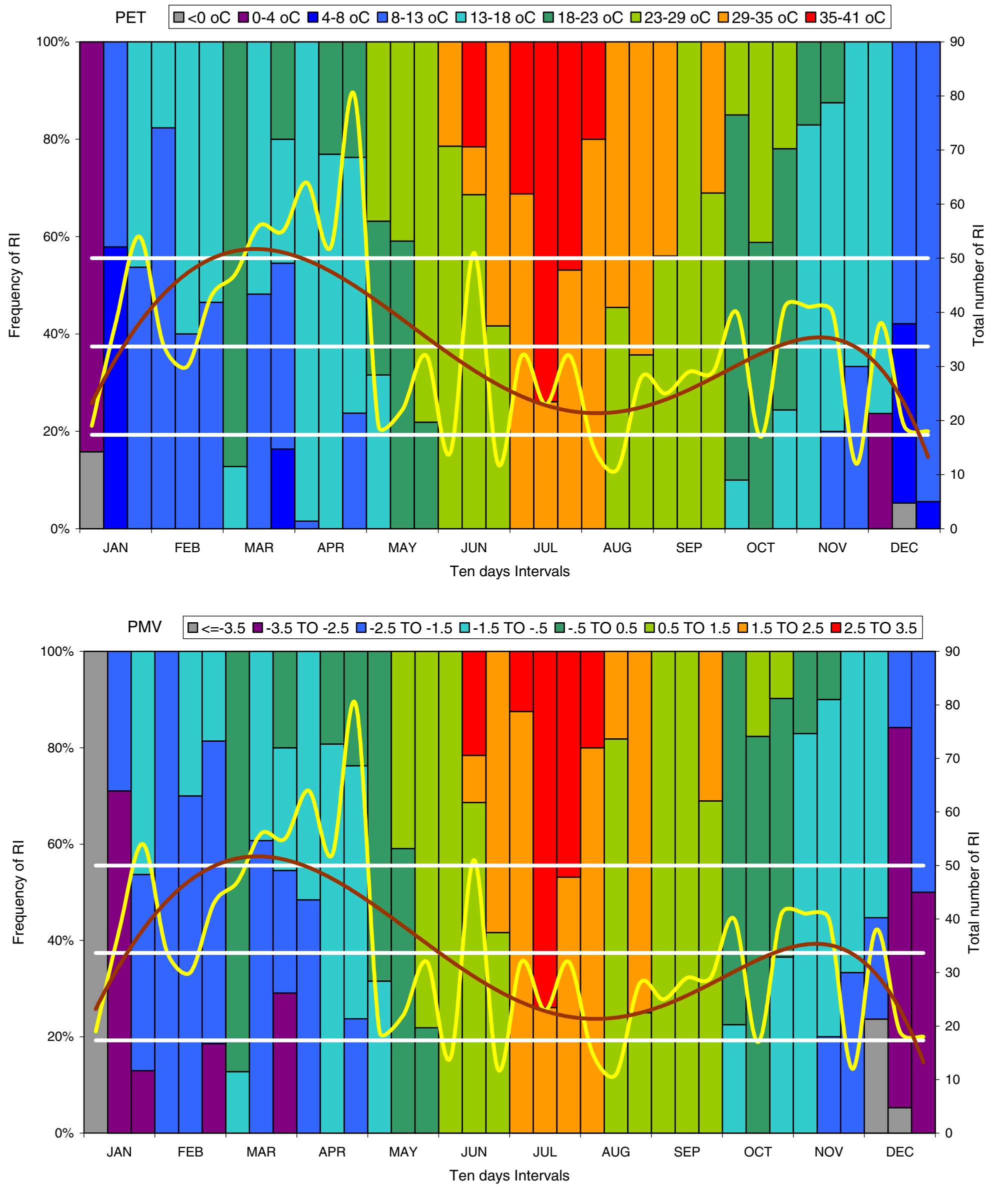


Fig. 6 Frequency of GP consultations for RI per 10-day interval as a function of biometeorological variables percentiles together with the variation of the total number of GP consultations for RI per 10-day interval (*yellow line*), and the polynomial fitting (*brown line*). Three reference lines (*white lines*) represent the mean, the mean+SD and the mean−SD

are in agreement with the findings of Weiland et al. (2004), who investigated the association between climate and prevalence of symptoms of asthma, allergic rhinitis, and atopic eczema, using worldwide data from 146 centres of the International Study of Asthma and Allergies in Childhood (ISAAC). Berktas and Bircan (2003) also found that emergency room admissions for asthma were negatively correlated with ambient temperature.

On the other hand, the increases in GP consultations for RI were maximal at 15 days (12 days) after a trough in air temperature (absolute humidity). There are studies determining such relationships between either consultations or mortalities for RI with lagged air temperature. Hajat et al. (2004), studying the effect of cold weather and GP consultations for respiratory conditions in the United Kingdom, found that a 19.0% increase in lower respiratory tract infections consultations was associated with a 1°C drop in mean temperature below 5°C observed 0–20 days prior to the day of consultation. Respiratory mortality also increases at 12 days after the peak in cold (Donaldson and Keatinge 1997). The secondary assessed lag of 3 days between cold peak and peak in consultations, although of lower importance, may be explained by delays because the patient did not get an appointment quickly, and there might be an incubation period as the virus replicates and symptoms worsen—normally 3 days for a rhinovirus (common cold).

The link between peak in GP consultations for RI and high wind speed in the preceding 3 days is also mentioned by Berktas and Bircan (2003). The negative relationship between consultations and wind speed on the same day, which however is not statistically significant [P>0.002 (Bonferroni adjustment), Table 2], may be attributed to the presence of air temperature inversions near the ground, under the cold anticyclonic conditions that occur during winter and early spring. Among others, Hashimoto et al.

(2004) suggest that childhood asthma increases when climate conditions show a rapid decrease from higher barometric pressure, from higher air temperature and from higher humidity, as well as lower wind speed, while the presence of mist and fog exacerbates asthma in children (Kashiwabara et al. 2002).

Biometeorological thermal indices are used to quantify the integral effects of the thermal environment of humans. The results of the analysis show that the thermal index PMV (which is a predictor of the thermal environment, especially for thermal comfort and cold conditions) is strongly associated with RI. Nevertheless, thermal indices and T_{mrt} can be relevant indicators for the relationship between weather and RI.

Conclusions

This analysis provides clear evidence that variations in weather, as represented by changes in the 25 parameters examined, including day-to-day changes, influence the number of GP consultations for RI in the wider region of Athens. Air temperature and humidity parameters have the highest influence on the variability of the number of GP consultations for RI. The effect of air temperature and absolute humidity on consultations on the same day is weaker than the lag effect (~2 weeks) associated with cold and absolute humidity. The application of GLM showed that not only meteorological parameters but also thermal indices provided by human-biometeorological methods can explain the relationship existing between respiratory diseases and weather more clearly. The human-biometeorological variables used (PET, PMV, T_{mrt} and SET*) are statistically associated with RI in the same way. For instance, a change of 1 unit in PMV corresponds to about 5 units in PET or SET*. Further research is required to detect the influence of weather patterns on the seasonality of consultations for RI on a local scale.

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