Influence of Weather and Air Quality Conditions on the Physiological response to cold weather stress: Impact on Asthma exacerbation in Miami Dade, Florida

D. Quesada, A. Perez, Y. Davila, M. Generani, and L. Perez-Cernuda
School of Science, Technology and Engineering Management, St. Thomas University 16401 NW 37 Ave. Miami Gardens FL 33054

Abstract

Human Health is affected by a complex and coordinated action of many factors: Atmospheric, physiological, and behavioral; placing humans into different scenarios of sensible stress that immediately impacts the response of human to external forcing. Asthma, a respiratory disorder characterized by inflammation of the airways and shortness of breath is an example of a human response to adverse environmental conditions modulated by the genetic predisposition of each individual. Florida Asthma Consortium (FAC) provided the asthma database for Miami Dade and Broward from January 2005 to December 2011, showing the number of visits to Emergency Rooms. Additionally, a comprehensive weather database obtained from WeatherBug (Earth-network) including outdoor temperature (T), humidity (H), barometric pressure (P), wind direction (θ_w) and speed (v_w) has been created. Environmental Protection Agency stations in Miami Dade provided information about Ozone and Particulate Matter over the same time frame. As a result, a seasonal pattern emerged, with a maximum appearing around the middle of December and a minimum around the middle of March every year for five years of analysis. The inclusion of weather indexes facilitates the understanding of the obtained correlations and helps to predict possible outbreaks of asthma.

Keywords: Asthma, biometeorology, correlations, pollution, regression, weather conditions, ozone, particulate matter.

Corresponding Author: David Quesada, dquesada@stu.edu

1. Introduction

The high load in services and resources in megacities impacts the environmental quality mainly by the modification of the physical and chemical properties of the atmosphere and the covering of the soil surface. Additionally, the burning of fossil fuel and secondary pollution from automobiles and industries have placed into the atmosphere a considerable amount of Carbon Dioxide (CO_2), Nitrous Oxides (NO_x), Ozone (O_3), and Particulate Matter of different sizes ($PM_{2.5}$ and PM_{10}), which combined represent a serious problem for human health. Therefore, the study of the combined effect of weather parameters and air quality indicators in urban landscapes has an enormous value these days. In this sense, Biometeorology has emerged as an interdisciplinary science which studies the effects of weather, climate, and environmental quality on organisms' adaptation mechanisms and the consequences of human activities on the atmosphere and surrounding environment considering mutual feedback among systems in interaction. Roots to this branch of science go back to the 5th century BC by Hippocrates, when the possible links between health and weather were addressed.

Currently, asthma is considered to be one of the most common respiratory disorders affecting about 150 million people worldwide. Even though the full understanding of the inner working of asthma is still under debate, it is basically a bronco-constriction with airway inflammation emerging from a complex and coordinated multi-system and multi-cellular response. Episodes of breathlessness of different intensity and duration along with cough and wheeze are some of the common signatures of asthma that result from the airway hyper responsiveness and mucous hyper secretion. Bronchial asthma affects 5 % of adults and about 10 % of children worldwide, which constitutes a source of stress load on socioeconomically disadvantaged, inner city, and minority patients, not only in terms on disease incidence and severity but also in terms of the challenges these patients face avoiding allergens that are endemic in urban environments. Peaks of asthma hospitalizations within continental U.S. often occur in urban areas and for periods of time no longer than a month and concentrated mainly from the beginning of autumn to early winter (October – Early January), when polar masses move southward with a minimum, ranging from April to June. Besides that, the seasonal occurrence of these peaks are almost uniform across continental U.S. and in most part of the world, suggesting a connection between temperature homeostasis and some sort of environmental stress that may induce changes in the population of regulatory immune cells controlling the inhibition or exacerbations of asthma in predisposed individuals. It is noteworthy that socio-economic variables seem to fit also into this model of stress – induced deregulation. Asthma seasonality seems to be represented as a bi-modal asymmetric distribution on top of a homogeneous background, being the winter asthma the overwhelming contributor. Temperature and humidity effects seem to be the most important triggering mechanisms in South Florida, because both, $PM_{2.5}$ and O_3 peak after the asthma season, and become more important for the early spring – summer asthma subgroup. Even though direct correlations with temperature and humidity are at the level of moderate correlations, the small R^2 values and the outcomes from residual analysis are indicators that weather parameters should be accounted in a nonlinear fashion, therefore, the thermodynamic analysis of the heat exchange might be taken into consideration. In this sense, the Acclimatization Thermal Strain Index (ATSI) is explored as a predictor for the combined effect of temperature, speed and humidity. In our opinion, the rich diversity of possible triggering mechanisms might be mapped into geographically dependent stress – strain relationships that impact different components of the neuro – endocrine – immune system, which ultimately is the one responsible for the inflammation process and hyper-responsiveness during asthma episodes.

2. Health, Weather and Air Quality Data.

Overall Emergency Department (ED) daily counts (including all age groups) for Miami Dade County were obtained from the Florida Asthma Coalition for the period 2005 – 2011. The time series is included in **Fig. 1**(left), showing clear signs of seasonality, with peaks between December and February every year and a minimal number of cases between April and June. In **Fig. 1** (right) the time series of outdoor average temperature for the day ($T_{mean} = (T_{max} + T_{min})/2$) for the same period and with the same temporal resolution is included.

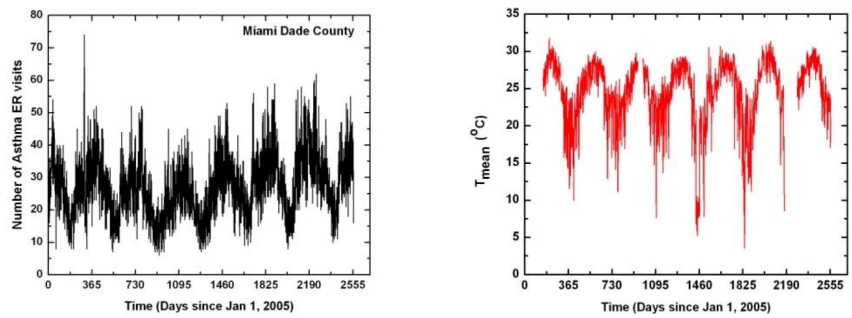

Fig. 1: Time series of (left) the number of daily counts at ED in Miami Dade, (right) the outdoor mean temperature. It is noteworthy the strong visual agreement with high counts and low vales of mean temperature.

A breakdown of the health data by zip codes shows some geographical distribution within the Metropolitan Miami, with a considerable group of patients coming from areas near highly crowded spots within expressways and certain microclimatic conditions. Air quality time series were obtained from Environmental Protection Agency (EPA) stations within the County (two stations measuring Ozone O_3, and two measuring Particulate Matter $PM_{2.5}$). Results are included in **Fig. 2**.

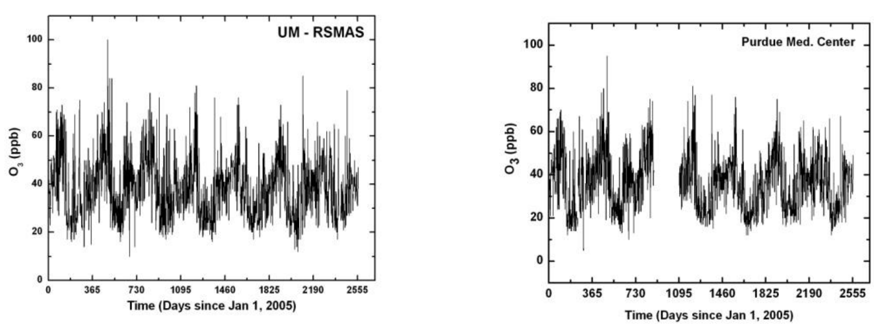

Fig. 2: Ozone time series from University of Miami Rosenstal School of Marine and Atmospheric Science (left) and Purdue Medical Center (right). They peak around March – April period.

The inclusion of Particulate Matter ($PM_{2.5}$) was done also and time series show peaks between April and May every year. In both cases, Ozone and Particulate Matter in Miami Dade remained below EPA standards of healthy values for these pollutants. Besides that, controlled sugarcane burning happening in Palm Beach and Martin Counties around the Lake Okeechobee was considered into the analysis, and no indications of any impact over Miami Dade conditions were found out. Conditions favorable for temperature inversions or shallow boundary layer were investigated through WRF Chem for December 2011 and no substantial effects were found. Correlation and analysis of residuals were performed for all variables of interest, being the mean temperature and humidity the ones with the largest Pearson correlation coefficient. Nevertheless, analysis of residuals and the R^2 values showed that only a small percentage of the observed variability could be explained by a direct proportion on these two variables. Further statistical indices indicated that temperature, humidity and wind speed should be considered in a nonlinear fashion. Even though the seasonality of Asthma in Miami Dade seems to be controlled mainly by thermal homeostasis rather than by Ozone and PM effects [1], these gases might be affecting indirectly the overall counts (closeness to highways observed distribution of cases).

Respiratory system is in charge for gas exchange, acid – base balance, phonation, pulmonary defense and metabolism. Often these effects are short term and are determined by the interactions of energy transfer, mass transfer, and metabolism. Essentially all of the physiological reactions are thermo chemical, so that, when reactants are available; their rates are determined largely by temperature. Central in this discussion are the body's core temperature (T_c) and the metabolic heat rate (M). The operating range of T_c has a central value, the set point (T_{c0}). The breathing process and its rate will determine the rates of oxygen and carbon dioxide exchange; rapid breathing increases the rate of cooling by taking cool air and exhaling (evaporation) from wet internal tissues. Any difference between T_c and T_{c0} of a healthy body (around 98.6 F (37 C)) acts as a strain factor. Then, a negative strain activates processes of shivering, while a positive one activates processes of sweating, at rates proportional to the size of the strain. Since the heat balance involves the hypothalamus, it seems that the influence of the weather on asthmatic people goes through a combined action of the hypothalamic axis, thermoregulation, and the immune system bias in favor of the T_{h2} subpopulation. This combined effect is responsible for the cytokine production and the pro-inflammatory response resulting in the obstruction of airways. It is noteworthy, that this picture may explain results from different geographical areas and climatic zones. Therefore, the combined action of temperature, humidity and wind speed will affect the pulmonary defense mechanisms facilitating external agents as bacteria, viruses, dust particles, toxic gases, and other pollutants interfere with the feedback mechanisms controlling the triggering of inflammation processes within the lung and then promote the appearance of asthma attacks. In order to explore such possibility, the Acclimatization Thermal Strain Index (ATSI) [2] is used. As a result, a better Pearson coefficient value was obtained ($r = 0.78$) as well as R^2 (0.64). Due to the complexity of asthma and the response of human body to temperature it is hard to obtain better values. The increase in correlation as well as in R^2 once the thermal exchange is considered is an evidence of a nonlinear response involving temperature, humidity and wind speed and also how strain – stress relationships might play a significant role in physiological responses to so called adverse environmental conditions (weather + seasonality + air quality). Even though, this work was mainly concerned with thermal homeostasis, the influence of polluting agents might be integrated through a couple of indices, one dedicated to the effect of aero-allergens (AASI) and another that focuses on the effect of toxic pollutants (TPSI). Using them, a phase diagram (ATSI, AASI, and TPSI) may be constructed pointing to parameters that potentially might exacerbate asthma episodes.

3. Conclusions

Miami Dade County and South Florida in general show a seasonal pattern of asthma ED visits most likely linked to thermal homeostasis rather than toxic pollutants as O_3 and $PM_{2.5}$. Even though, temperature, humidity, and wind speed seem to be the most important parameters, the nonlinear inclusion of them through heat exchange can account for observed correlations. The use of Thermal, Aero-Allergen, and Toxic-Pollutant Strain indices seem to offer a viable way to predict outbreak of asthma and crowed ED visits.

4. Bibliography

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