Thermoregulation and Periodically Forced SEIR model: Understanding asthma seasonality in South Florida

David Quesada
School of Science, Technology, and Engineering Management, St. Thomas University, Miami Gardens, FL 33054, USA

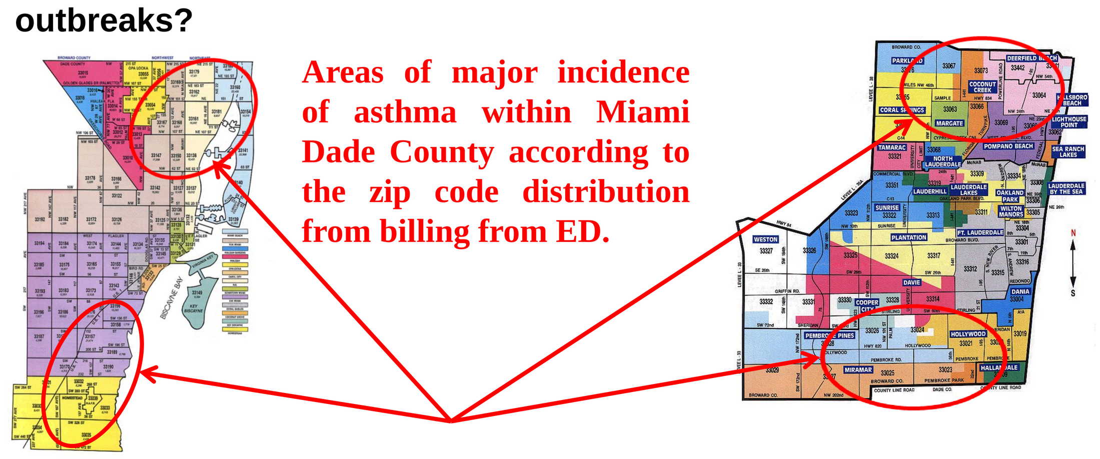
Abstract

The impact of changing weather and air quality conditions on cardio-respiratory diseases is very important. Epidemiological as well as biometeorology studies have documented the existence of exacerbating factors for asthma, different from often cited allergens. Economic conditions, educational backgrounds, stress, diets, along with weather and air quality conditions appear to compete and complement the allergen hypothesis. Motivated by these facts and aimed at understanding the inner working of asthma, time series of Emergency Department (ED) visits due to asthma in Miami Dade and Broward Counties were provided by the Florida Asthma Coalition for six years (2005-2011) with daily temporal resolution. They show a peak of attendance between the months of November and January and a minimum between the months of April and June every year.

The time series of weather parameters (Temperature, Humidity, Wind Speed and direction, Pressure, Diurnal range of both temperature and humidity, and extreme of both, temperature and humidity) were obtained from the Weatherbug mesonet in South Florida. Surface ozone, and particulate matter were obtained from EPA registered stations. Time series and correlation analyses between weather variables and the number of cases resulted in weak to moderate associations mainly with the minimum and mean temperature, the mean humidity, and some derived thermal indexes. Lagging effects were analyzed up to seven days previous to ED visit.

1. Motivations

- How far weather and air-quality conditions do affect the triggering of Asthma in South Florida (Miami Dade County)?
- What variables might serve as best predictors for Asthma outbreaks?



Features of Circled Areas
- Very close to highly transited roads and/or Expressways
- High motor load, due to connecting bridges
- Low income population
- Predominant ethnicity African – American

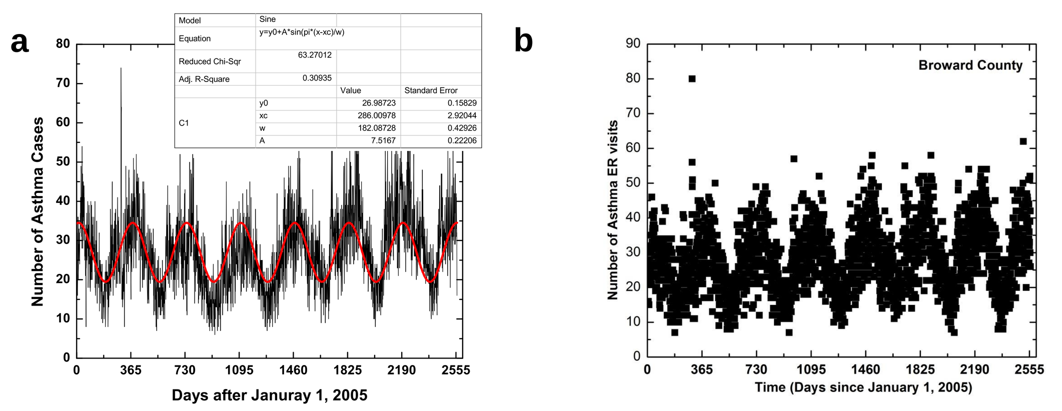


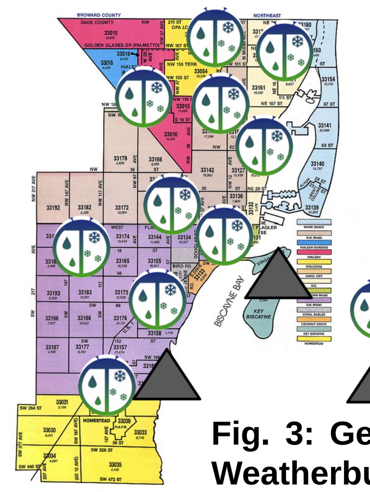
Fig. 2: Time series of the number of asthma cases at Emergency Departments (ED) in Miami Dade County (a) and Broward County (b). It is worth to notice the seasonality of the reported cases.

Year	Total	Mean	St. Dev.
2005	9686	26.54	9.27
2006	9591	26.27	8.84
2007	8122	22.25	8.51
2008	8763	23.94	8.30
2009	10293	28.20	8.39
2010	11373	31.16	10.80
2011	11219	30.73	9.18
Overall	69047	26.54	

Table I: Average daily number of ED visits due to asthma in Miami Dade.

BRACE project State of Florida Building Resilience Against Climate Effects

2. Miami Dade Weather and Climatology



M-D	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dic
T_{min}	59.6	60.5	64.0	67.6	72.0	75.2	76.5	76.5	75.7	72.2	67.5	62.2
T_{max}	76.5	77.7	80.7	83.8	87.2	89.5	90.9	90.6	89.0	85.4	81.2	77.5
T_{mean}	68.1	69.1	72.4	75.7	79.6	82.4	83.7	83.6	82.4	78.8	74.4	69.9
Prec	1.88	2.07	2.56	3.36	5.52	8.54	5.79	8.63	8.38	6.19	3.43	2.18

Miami Dade Climatology

Weatherbug station

Ozone measuring station

Fig. 3: Geographical locations of automated weather stations from Weatherbug Mesonet, as well as the two Ozone measuring stations from E.P.A. in Miami Dade County.

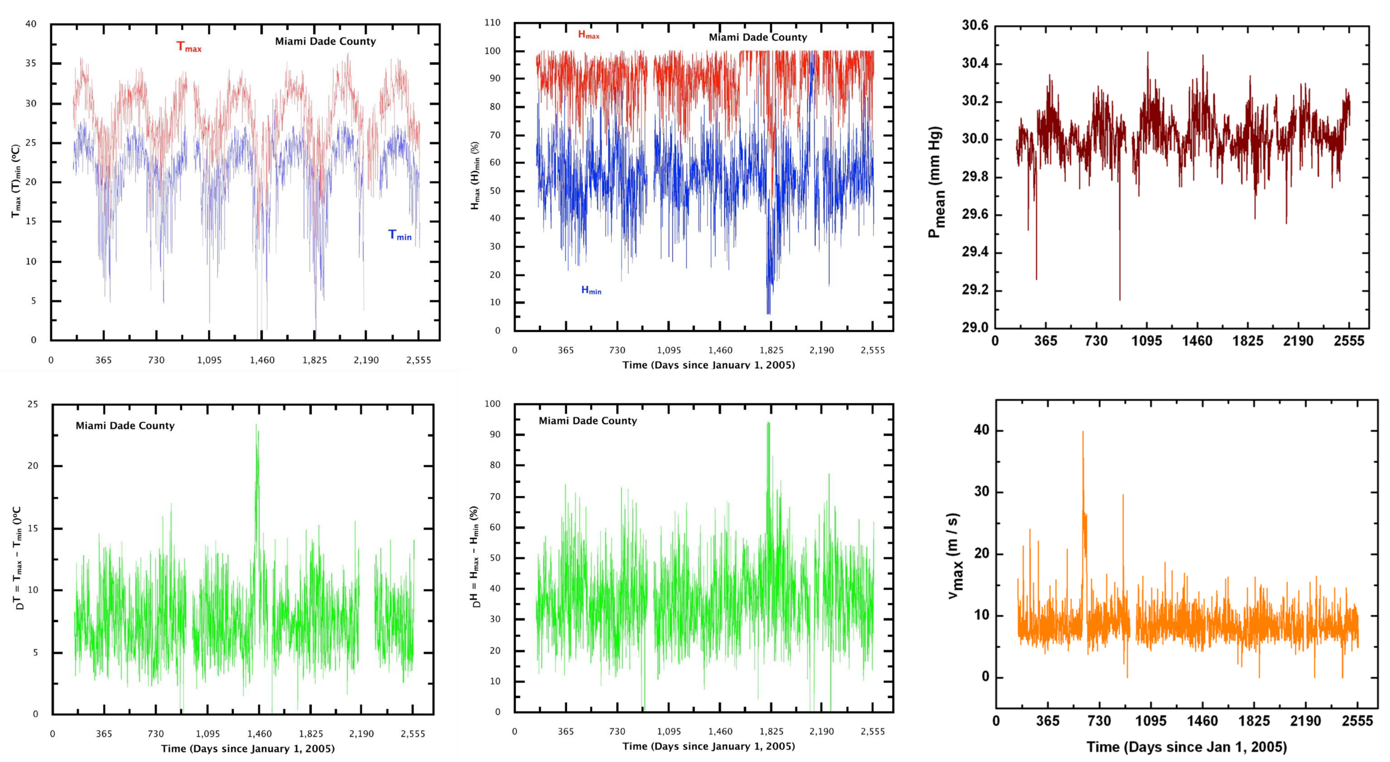


Fig. 4: Time series of: (Upper left panel) Ambient maximum and minimum temperature, (Bottom left panel) Diurnal temperature range, (Upper central panel) Relative Humidity maximum and minimum, (Bottom central panel) Humidity diurnal range, (Upper right panel) Mean values of the barometric pressure, and (Bottom right panel) Maximum wind speed.

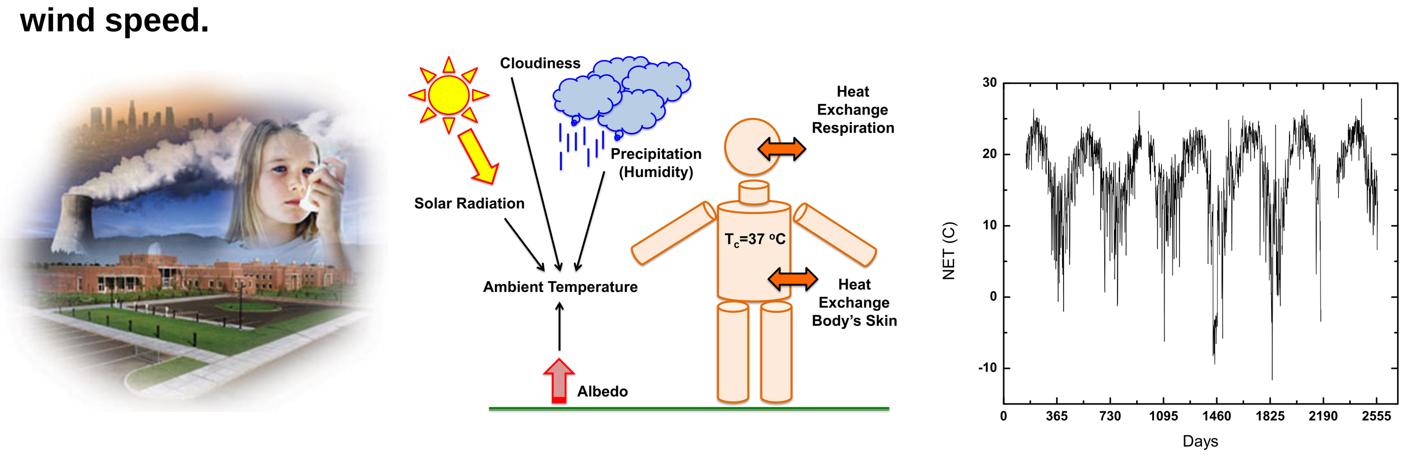
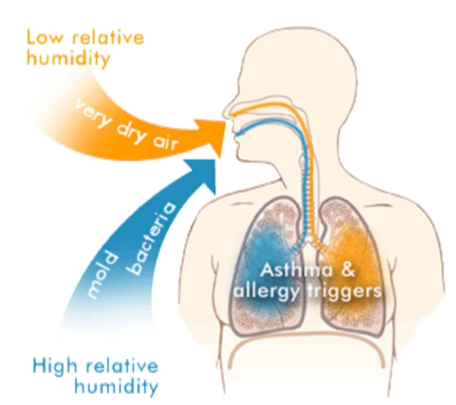


Fig. 5: (Left panel) Elements from the weather with direct impact on respiratory health, (Right panel) Net Effective Temperature, it incorporates the joined effect of the ambient temperature, humidity level and wind speed.

The respiratory organs are not protected and humans can do nothing to prevent the ambient air entering into the body's core area, the lungs, through airways



Why negative thermal loading is so relevant?

- Keystone in the etiology of acute respiratory diseases.
- Respiratory heat losses above the norm (15 W – effective heat loss) lead to high frequency of respiratory diseases in children.
- High heat losses from respiratory organs make it easier for pathogenic micro-flora to penetrate the protective barrier of lungs and may be the reason for increased morbidity.

$Q = C + E$

$C = 1.17 \times 10^{-3} M (T_{core} - T) A$

$E = 2.3 \times 10^{-3} M (e_a - e) A$

M – Metabolic heat rate (W / m^2)

A – DuBois body area (m^2)

T_{core} – Body core temperature (°C)

T – ambient air temperature (°C)

e – vapor pressure of ambient air (mm Hg)

e_a – vapor pressure of core air (mm Hg)

$M = 90\ W / m^2$ person standing relaxed

$e_a = 44$ mm Hg

$T_{core} = 37$ °C

3. Wind patterns and Air Quality

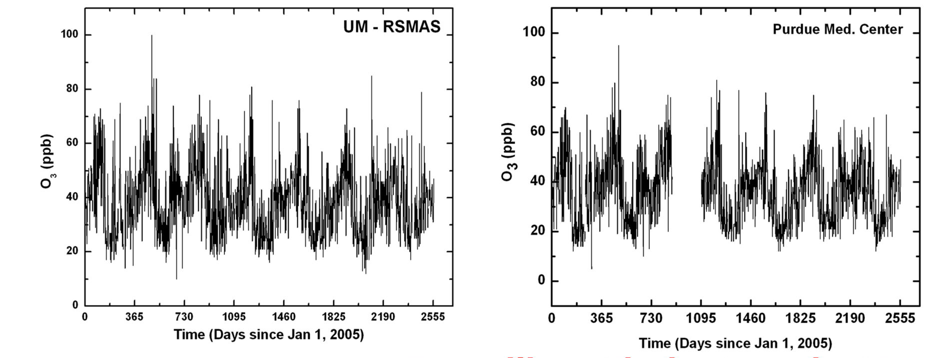
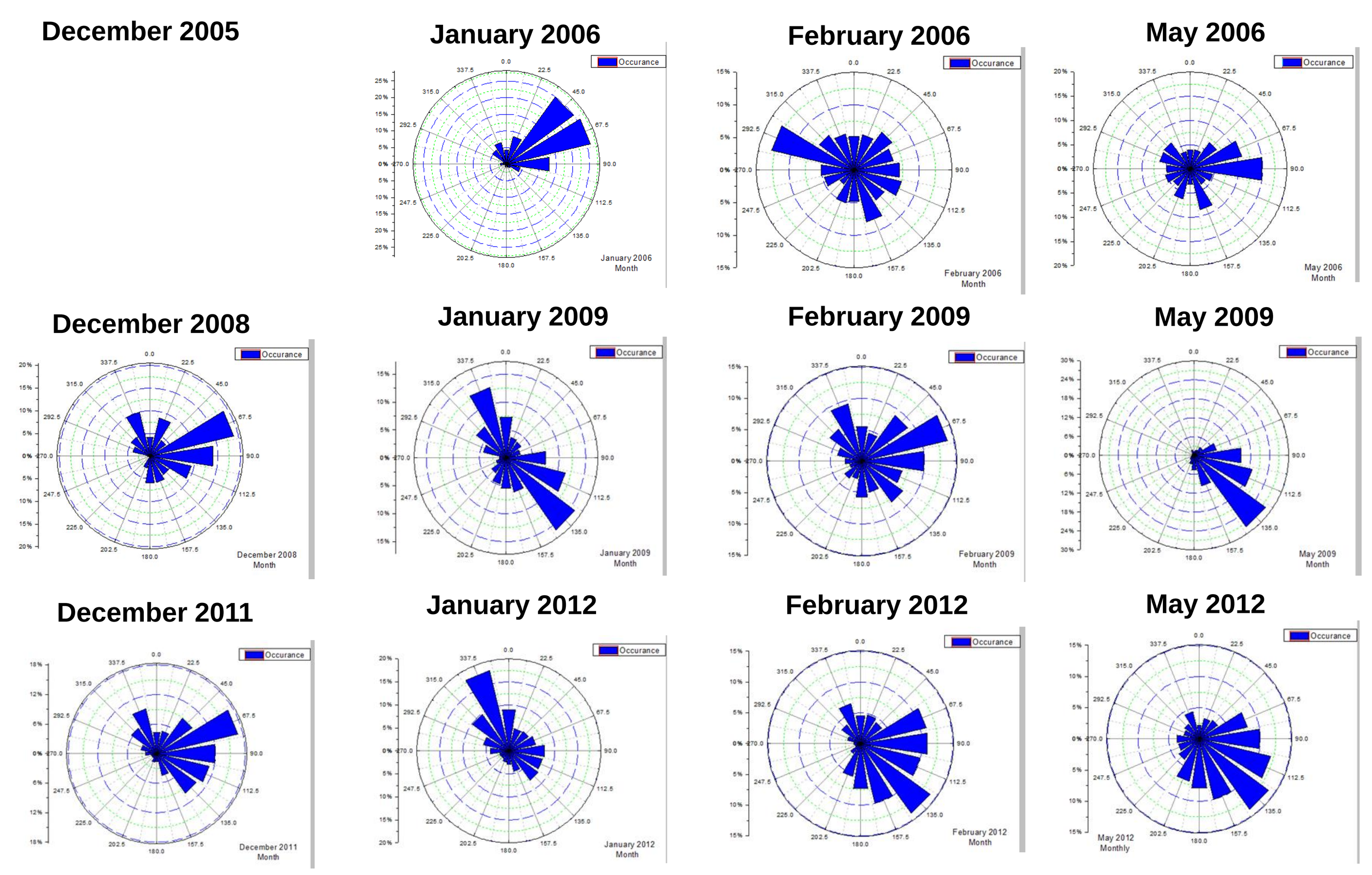


Fig. 7: Time series of ground Ozone (O_3) from both measuring stations in Miami Dade County.

Prevailing Winds Over the Years

December – February and May 2006, 2009, 2012 (Month data)



4. Linear Regression and Lagging Analysis

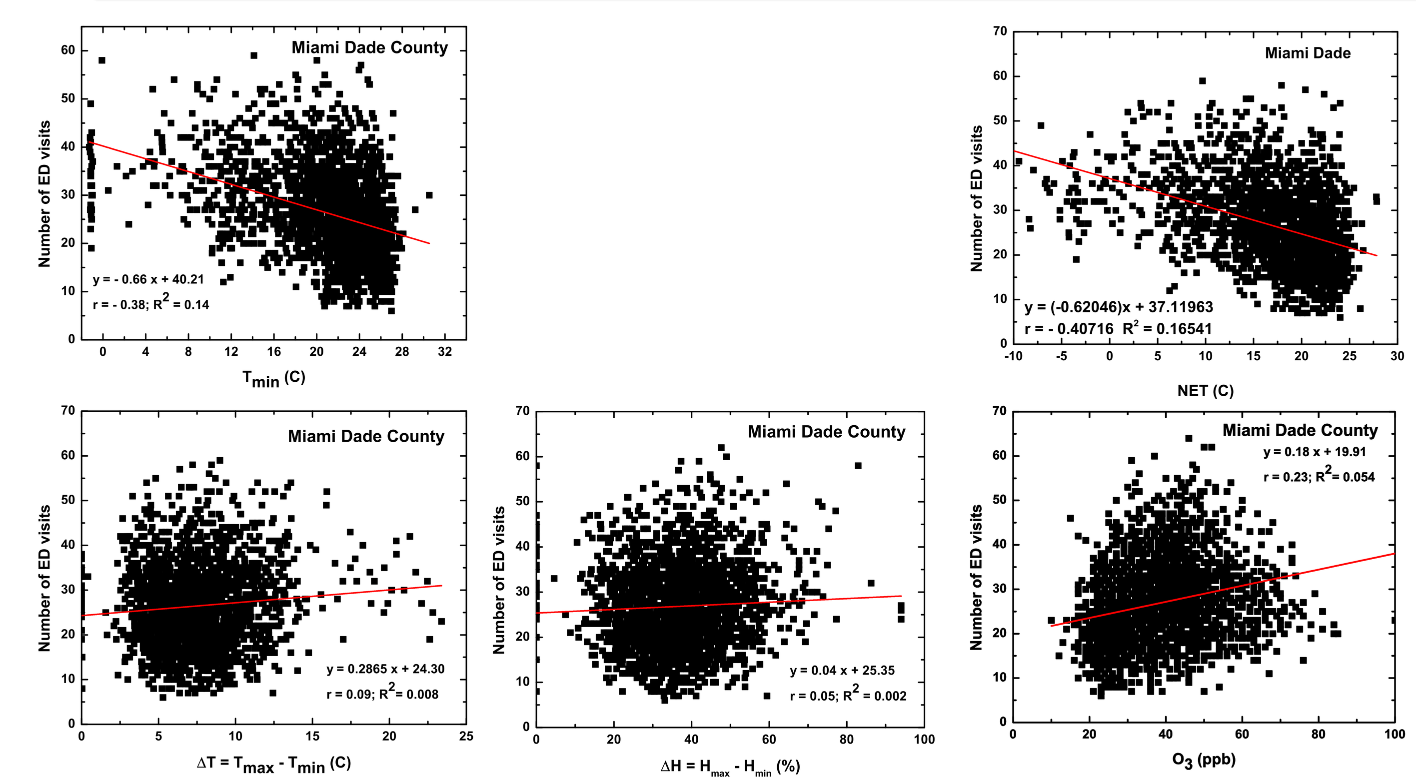


Fig. 8: Weather parameters with the largest Pearson's correlation coefficient. Notice the weak to moderate correlation.

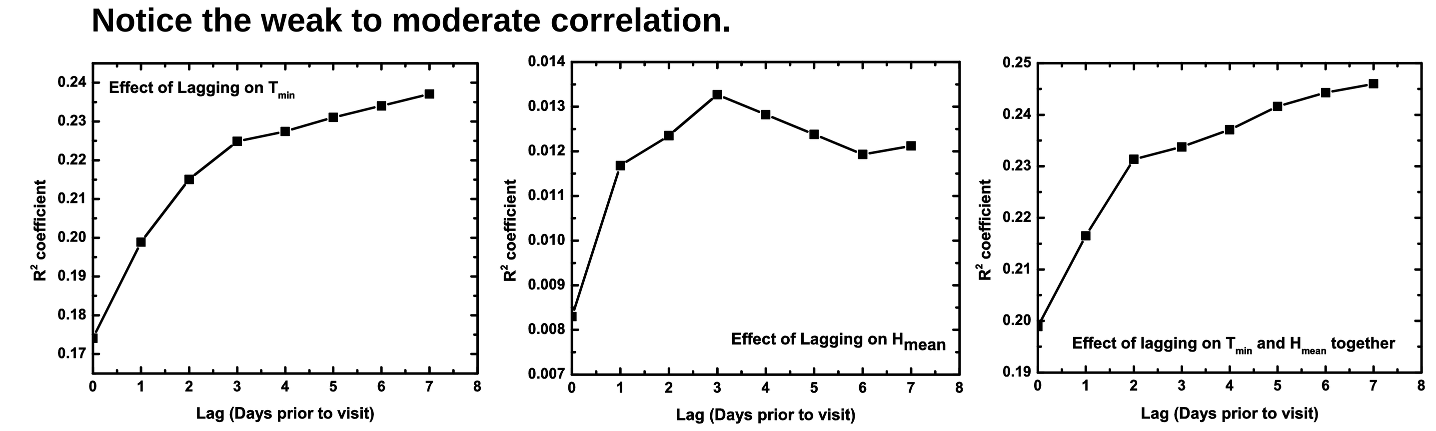


Fig. 9: Effect of lagging from two weather parameters (Tmin and H). Notice the weak to moderate correlation despite several days of analysis.

5. Seasonally Forced SEIR models

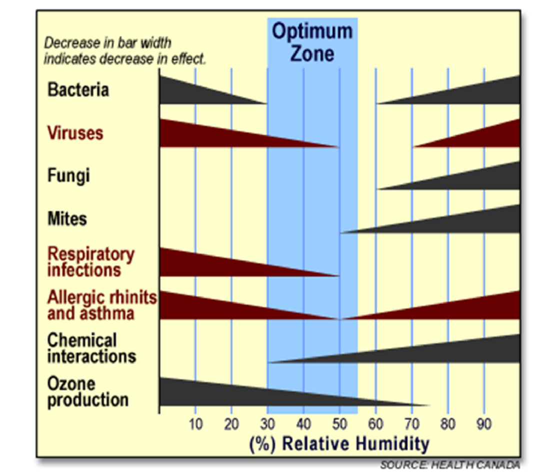


Fig. 11: Multiple agents might lead to asthma as soon as weather conditions promote their proliferation and incidence.

$\beta(t) = \beta(0)\,(1 + \sin[2\pi t/T])$
Seasonally forced infection rate

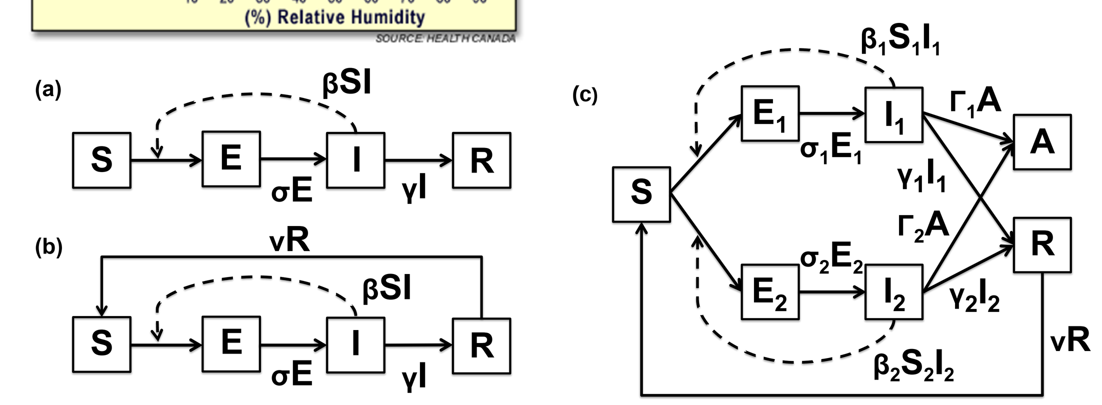
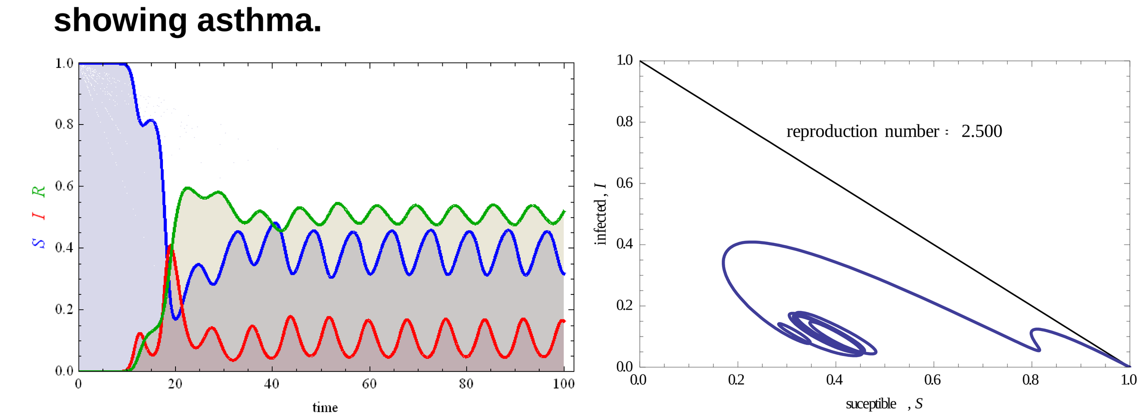
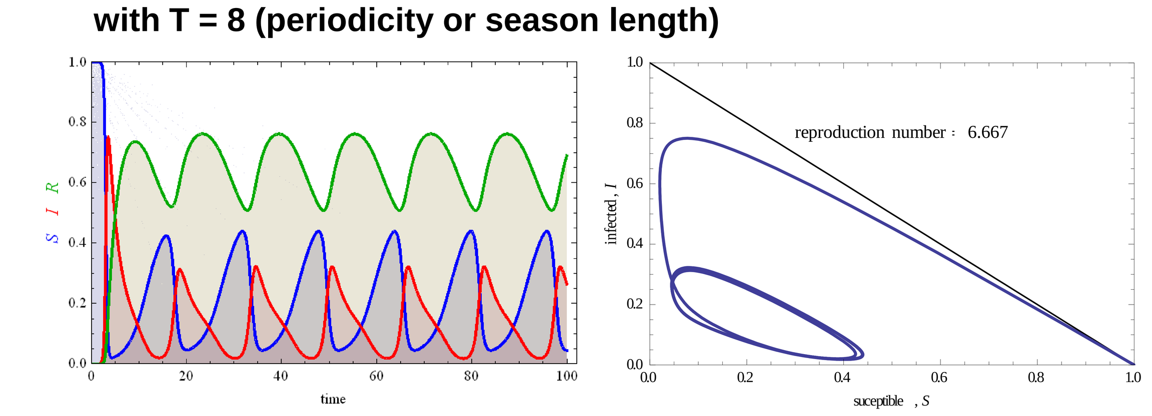


Fig. 12: Schematic representation of the SEIRS model (left panels), where S – susceptible, E – exposed, I – infected, R – recovered individuals, β(t) is the seasonally forced infection rate used to model the seasonal incidence of epidemics affecting asthmatic patients, σ is the rate exposed individuals are becoming infected, while γ is the recovery rate. In the right panel, the SEIRS model is represented in the event of two viral infections happening simultaneously during the season and both leading to asthma and recovery patients not showing asthma.



$\beta(0) = 1.2$, $\sigma = 0.45$, $\gamma = 0.4$, the model was run for 300 cycles with T = 8 (periodicity or season length)



$\beta(0) = 3.2$, $\sigma = 0.45$, $\gamma = 0.4$, the model was run for 300 cycles with T = 16 (periodicity or season length)

Conclusions

- Asthma is a complex disease demanding a system-based approach.
- Weather influence happens directly as well as indirectly.
- The lack of strong correlation between weather parameters and the number of visits to the ED may be associated with the robustness of the respiratory system to environmental changes.
- Weather seems to affect more the exposure to epidemics than the thermal regulation.

Acknowledgments

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