# Improved Short-Term Predictions of Hospital Demand by Including Meteorological Information

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Abstract

The effect of weather on health has been widely researched, and the ability to forecast meteorological events can offer a valuable insight into the impact on public health services. In addition, better predictions of hospital demand that are more sensitive to fluctuations in weather can allow hospital administrators to optimise resource allocation services. Using historical hospital admission data and several meteorological variables for a site near the hospital, this paper develops a novel Bayesian model for short-term forecasting of the numbers of admissions categorized by the current system of international classification of diseases. The resulting method validates much more accurately than the methods currently in place in two participating hospitals in the UK. Moreover, methods for assessing the overall uncertainty in these forecasts that may arise from disparate sources are also developed and illustrative results from several 'what if?' scenarios are used to reveal the true extent of inherent uncertainty present in these forecasts.

## 1 Introduction

The ability to use weather data can offer an indispensable source of information on the demand for public health services. Many diseases are related to the weather, and there is a growing wealth of research that suggests that changes in the weather have either direct or indirect influence on human health and/or behaviour. However, it has been difficult to

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quantify such effects. In this paper we aim to develop an accurate model for short-term forecasting of hospital demand based on meteorological and other relevant variables such as seasonal variables, e.g. school holidays. The ultimate goal of this research project is to use the forecasts to better plan many health services provided by the hospitals.

There has been a long standing recognition of the relationship between weather and health dating back to the time of Hippocrates, who first discovered that disease was linked to changes in weather. In fact, there is a whole scientific discipline referred to as human biometeorology which studies the interrelationship between atmospheric conditions and people's health. However, this is a relatively new field of research, being established in the late 1950s (see, e.g. Sargeant, 1964).

One area of research that has been increasingly investigated is that of excess seasonal mortality and morbidity, in particular during the winter (see Healy, 2003; Donaldson and Keatinge, 2002; Aylin et al., 2001). The number of extra deaths that occur in the winter months compared to the other months is referred to as the excess winter mortality. Although it is very rare for cold weather to directly kill people, the cold is indirectly responsible for increased mortality and morbidity through cardiovascular (such as heart attacks and strokes) and respiratory (such as bronchitis and pneumonia) ailments.

Forecasting of weather is in itself an inexact science, and weather forecasts re made by collecting data about the current state of the atmosphere. However, the scientific endeavour involves being able to project how the day-to-day atmospheric processes will evolve over time. Typically, meteorologists will measure and record various aspects of weather such as temperature and rainfall. Additional to these, data from around the world from weather stations, balloons and satellites is collected routinely. These are then assimilated together and fed into computers. Computational power is very important in modelling the dynamics of the atmosphere through a series of thousands of equations so as to be able to predict weather. The United Kingdom (UK) Meteorological Office produces forecasts using high performance machines capable of doing more than hundred trillion calculations per second, using the assimilated data as a starting point to run complex equations (Golding, Mylne and Clark, 2006). However, despite all this, weather is still incredibly difficult to predict. Principally, the UK due to its location, being situated between Europe and the Atlantic Ocean and being at the meeting point of hot air from the tropics and cold air from the arctic, is predisposed to sudden changes in weather making forecasting conditions complicated. Furthermore, even with the great advances in reliability of weather forecasts, reliability of predictions at lower levels of geographical detail cannot be assured.

There are two hospitals involved in the project - Southampton University Hospital Trust (SUHT) and Cardiff and Vale University Health Board (CVUHB). SUHT serves a population of around 1.3 million people living in the Southampton and Hampshire area in the south east of England. Owing to its size, it also provides specialist services (such as cardiology and neurosciences) to more than 3 million people resident in the south of England and the Channel Islands. CVUHB provides health services to a population of around 500,000 in Cardiff and the Vale of Glamorgan in South Wales. In addition, it provides specialist services (for instance paediatric care and medical genetics) to the wider population encompassing mid and South Wales, with a population of roughly 1 million.

Meteorological information on the localised weather at the two hospitals are provided by the UK Met Office, the national weather service. Hourly readings of temperature, humidity, atmospheric pressure and other weather measurements are available. We have computed the daily mean, minimum and maximum values from the hourly measurements. Additionally, in order to obtain comparable daily statistics of various pollutants in the atmosphere, we have downloaded data from the UK Air Quality Data Archive on the levels of ozone, carbon monoxide, sulphur dioxide, nitrogen dioxide and particulate matter. Further, since it is often at extreme weather that health conditions are most affected, we have obtained data from the National Severe Weather Warning System, run by the Met Office, which issues alerts of extreme weather events such as floods, snow or gales with the view of allowing authorities and public to plan for the impact of weather.

## 2 Preliminary Results

Although the analysis was undertaken for both Southampton and Cardiff hospitals, the results presented will be focusing on Southampton admissions. Between the period of 1 Jan - 31 Dec 2009, there were approximately 47,000 admissions to the hospital. This works out to be roughly 130 admissions on average a day. These daily admissions differed significantly by age, sex and disease group. For instance, there were more males than females admitted, with there being 65 males and 62 females on average. The effect of age is slightly more complex to interpret, but as a whole, more older people are admitted than younger, with there being more female admissions at the older ages. This could be taken to be evidence in support of the ageing population of the UK. In addition there were variations due to day of the week, with more admissions occurring on Mondays, and the least occurring at the weekend (Saturday and Sunday). Furthermore, there were noticeable differences due to month, with more people being admitted in the months of January, November and December. Interestingly, the effect of month is similar to that of temperature. We have also observed high correlations between some meteorological variables, e.g. average monthly temperature and the number of monthly admissions.

We have also explored the effect of various demographic, temporal and meteorological variables on the daily number of admissions. We have found some evidence of positive skewness, so adopt the square root transformation for modelling. We have also considered the logarithmic transformation, but the square-root transformation was preferred because of the presence of many zero counts in the number of admissions categorised by age, sex, and disease type. We have considered a large number of explanatory variables to find the best combination of these variables that explains the greatest amount of variability in the observed data. As such, we have used the Bayesian Information Criterion (BIC) for initial model screening. We have also calculated the other popular model choice criteria such as the Akaike Information Criteria (AIC). The selected models often turned out to be the same using these criteria.

Using the above model choice criteria, we have found that the best model is the one with six variables: age, sex, day of the week, school holiday indicator, the minimum temperature last week and the day specific six-week moving average. Currently, the hospitals rely only on this last variable for their short-term forecasting needs. Here we find that the first five variables are also significant even after including the day specific moving average in the model.

The model with the above six explanatory variable has a high $R^2$ value of 0.80. The model based analysis also shows that, in general, on days that the temperature goes below freezing (0°C), there is about a 5% increase in the number of admissions. This translates to roughly 10 additional admissions on such cold days, and these vary by age and sex.

## 3 Concluding Remarks

This study provides evidence that weather, and specifically temperature, has an effect on the number of hospital admissions, with more people being admitted in periods of cold weather. The current methodology employed by hospitals in modelling their forecasted admissions, do not explicitly take into account the weather. Albeit, these models have been shown to perform well in their predictions, our study has shown that incorporating meteorological information has significant benefit by improving the accuracy of the predictions, and this is especially so during periods of cold weather.

We have developed new models by linking the meteorological and hospital information. These models are used to quantify the relationship between daily weather patterns and events and the corresponding daily admissions. The results of this statistical analysis will be used to forecast the number of beds required.

The next stage of the work will be looking at providing disease specific predictions of admissions after consensus has been reached on suitably homogeneous disease groups. The preliminary modelling suggest that the only significant meteorological variable is the minimum temperature last week which is technically observed. The implication is that in the prediction of the future admissions, there is no forecasting error associated with the model predictions. This has to be further investigated, especially in regards to the provision of daily estimates subcategorised by disease groups.

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