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UK regional scale modelling of natural geohazards and climate change

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ABSTRACT:

For over 10 years, the British Geological Survey (BGS) has been investigating geotechnical and mineralogical factors controlling volume change behaviour of UK clay soils and mudrocks. A strong understanding of the relationship between these parameters and the clays' shrink-swell properties has been developed. More recently, partly resulting from concerns of users of this knowledge, a study of the relationships between climate change and shrink-swell behaviour over the last 30 years has been carried out. Information on subsidence insurance claims has been provided by the Association of British Insurers (ABI) and the UK Meteorological Office (UK-MO) historical climate station data has also been utilised. This is being combined with the BGS's GeoSure national geohazard data, to build a preliminary GIS model to provide an understanding of the susceptibility of the Tertiary London Clay to climate change. This paper summarises the data analysis and identifies future work for model construction and refinement.

1 INTRODUCTION

It has been recognised that climate change is now one of the biggest environmental problems that the UK faces and, if current predictions are correct, we can expect hotter, drier summers in the south-east of England together with milder, wetter winters (UKCIP, 2009).
In the UK, some Mesozoic and Tertiary clay soils and weak mudrocks are susceptible to shrinkage and swelling as environmental conditions change. It has long been recognised that areas underlain by London Clay are particularly vulnerable to shrink-swell, which causes enough ground movement to damage the foundations of some light structures such as houses. This damaging movement results in subsidence insurance claims (Crilly, 2001). Swell-shrink susceptible clays change volume due to variation in moisture content, particularly in the upper two metres of the ground. Ground moisture content variations are related to a number of factors, including weather, vegetation (e.g. growth or removal of trees) as well as anthropogenic factors (road construction, paving) (Jones, 2002, 2004). Indications are that climate change will increasingly change the moisture conditions that UK soils experience. Therefore, the occurrence of damage to homes, buildings and roads due to shrink swell will also be affected.

2 METHOD

2.1 *THE DATASETS*

2.1.1 *GeoSure Natural Ground Stability Data*

Since 2002 the British Geological Survey has been creating 25m resolution national-scale models of natural geohazard susceptibility in Great Britain, known as GeoSure (Harrison et al., 2009; Walsby, 2007 & 2008). These models have been created using a multi-criterion approach in a GIS (ESRI ArcGIS 9.3). The GeoSure models consist of six data layers that identify areas of potential hazard in Great Britain (arising from shrink swell, landslides, soluble rock (dissolution), compressible ground, collapsible deposits and running sand). Each layer has national coverage.

2.1.2 *Subsidence claims*

Quarterly domestic subsidence claims data are available from the Association of British Insurers (ABI), for the period 1987 to 2008 (ABI, 2009). The data are provided in terms of the number of claims for losses caused by ground movement ('subsidence') between 1991 and 2008, and the gross incurred value of claims (£m) from 1987 to 2007. This monetary value has been adjusted to take account of inflation using the Retail Price Index (RPI), to allow comparisons between years. These adjusted monetary values have been used to identify trends in the data as they provide an indication of the severity of the subsidence (more severe shrink-swell causes more building damage).

2.1.3 *Met Office observed climate data*

Historical (observed) station data from the UKMO has been used (Met Office, 2009). Three stations lie within, or close to, the London Basin (Greenwich, Heathrow and Manston). The stations were selected as they are the closest to the model area and thus are the most representative of the area's climate. The locations of these stations are shown in Figure 1.

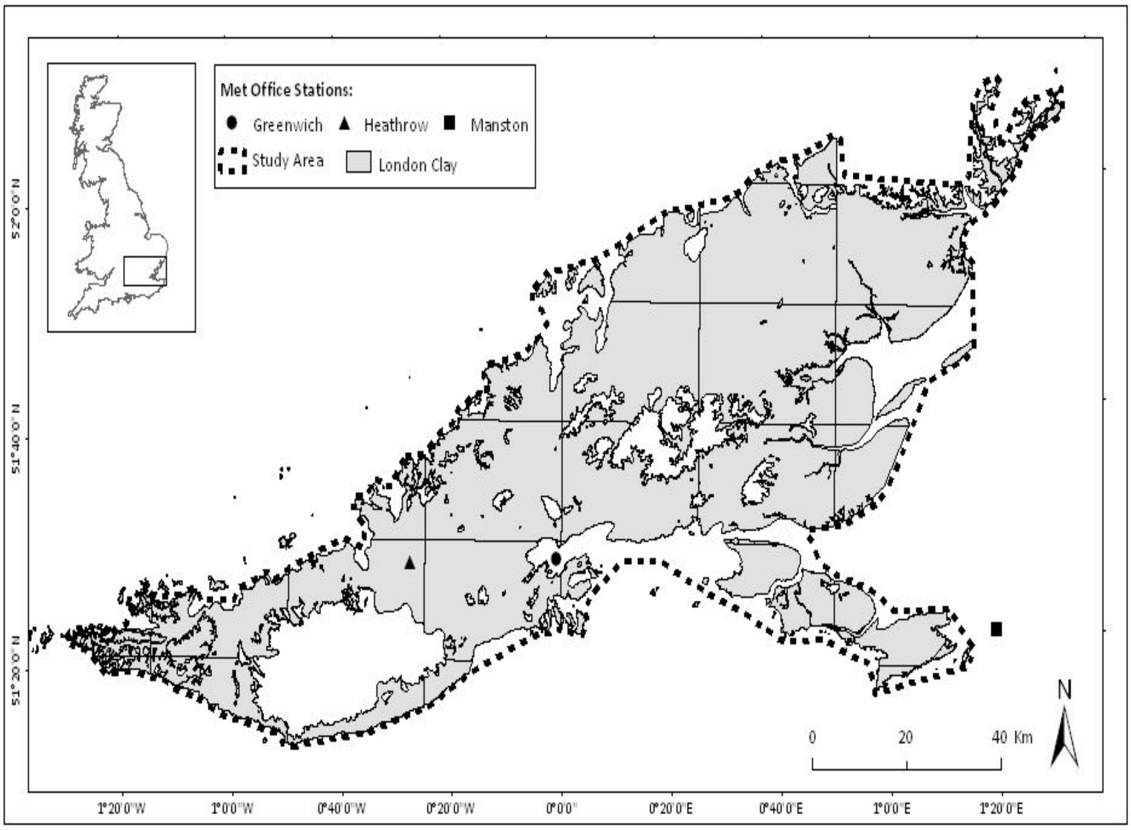

Figure 1. Study area and UKMO station locations

Because the insurance claims data are only available quarterly, quarterly climate data has been used to enable direct comparison of trends. The quarters of the year in which the insurance data has been provided by ABI are not ideal for comparison with climate data. This is because the claims data is provided for each quarter beginning in January whereas climate data is better utilised in relation to the seasons. This results in a one month shift between the two datasets, as demonstrated in Table 1.

Table 1. Climate and claims quarters

Quarter name	Quarter label	Months in climate quarter	Months in claims quarter
Winter	Q1	December, January, February	January, February, March
Spring	Q2	March, April, May	April, May, June
Summer	Q3	June, July, August	July, August, September
Autumn	Q4	September, October, November	October, November, December

2.2 *Research area*

The research area (Figure 1) has been defined based on geology. As London Clay is highly vulnerable to shrink-swell (Crilly, 2001) a large number of the subsidence claims come from the London Clay area, thus the area within the London Basin underlain by London Clay will be the research area. The area also has a high population and population density, as it includes almost the whole of the Greater London area (Figure 1).

2.3 *UKCIP02 predicted climate scenarios*

The United Kingdom Climate Impacts Programme (UKCIP), aims to assess the affects of the changing climate on various sectors of the UK. Their website provides datasets and information to help improve understanding of climate change and how these changes might affect the UK. All their tools and services are freely available (UKCIP, 2009).

Their second emissions scenarios dataset, released in 2002 and called UKCIP02 (UKCIP, 2002), provided climate change scenarios at a much improved spatial resolution, compared than their first set of scenarios, UKCIP98. UKCIP09 projections (UKCIP, 2009) are probabilistic rather than deterministic, as was the case with UKCIP02. UKCIP02 had four emissions scenarios whereas UKCP09 has three. There are also many differences in the techniques employed, relating to spatial resolution, modelling processes, outputs and delivery. Based on increased knowledge and understanding, as well as climate change data, it would be preferable to use the UKCP09 emissions scenarios for the subsidence susceptibility projections. However, due to spatial requirements and formatting issues, the UKCIP02 dataset is currently being utilised for this research.

2.4 *Assumptions*

A number of assumptions have been made in this research. These are listed below.

- Claims originate from within the area underlain by London Clay (the test area)
- Value of claims (£) adjusted by RPI, represent subsidence occurrence within the test area (the area underlain by London Clay)
- Houses are evenly distributed within the London Clay test area (preliminary assumption- can be refined later)
- Claims are evenly distributed within the London Clay test area (preliminary assumption- can be refined later)
- The average temperature and precipitation from the three historical stations is representative of the test area.
- It is assumed that there is short lag in the main effects of shrink/swell occurring and an insurance claim being made but that the claim is made within the quartile that the damage occurs.

3 DATA ANALYSIS AND INTERPRETATION

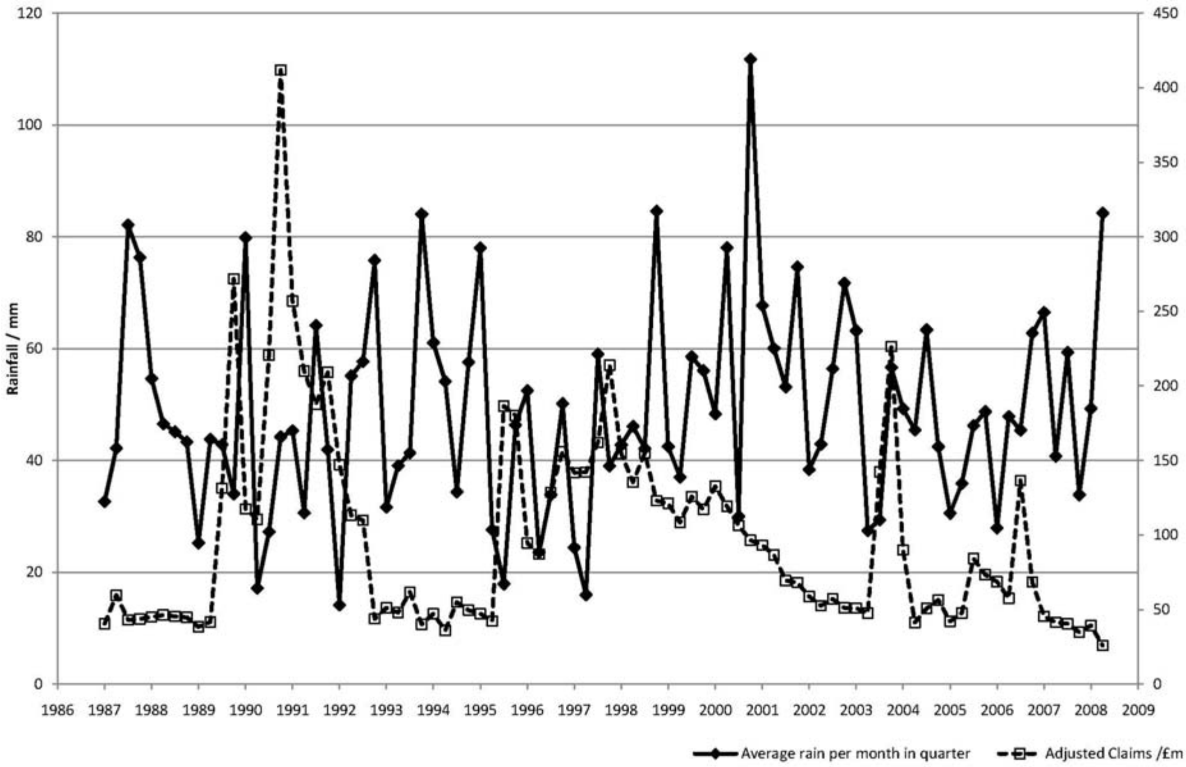

Figure 2. Quarterly rainfall and insurance claims 1987 to 2008

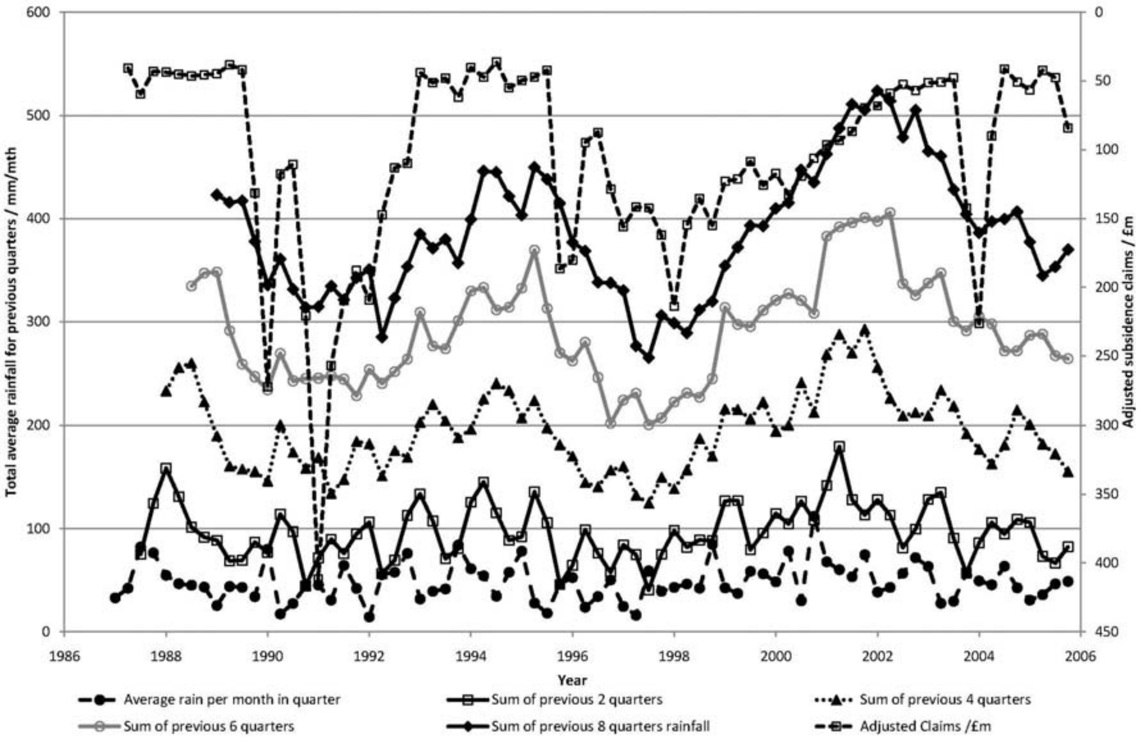

Figure 3. Previous rainfall (up to eight quarters) and subsidence claims

Figure 2 shows that, alone, the average rainfall per quarter does not show a close relationship with subsidence claims. However, it does demonstrate that periods of low rainfall lead to peaks in claims, and vice versa. Because rainfall is being used as a proxy for ground moisture conditions, a better picture might be provided by the summed rainfall of previous quarters (Figure 3).

Figure 3 demonstrates that the sum of previous rainfall appears to be noisy when the previous quarters do not add up to complete years. Further statistical work is required to improve this analysis, but for this preliminary assessment, the sum of the previous eight quarters (2 years) provides the best comparison with the adjusted claims data. As increasing the number of quarters included in the summation appears to improve correlation with insurance losses, three and four years of previous rainfall were also plotted (Figure 4).

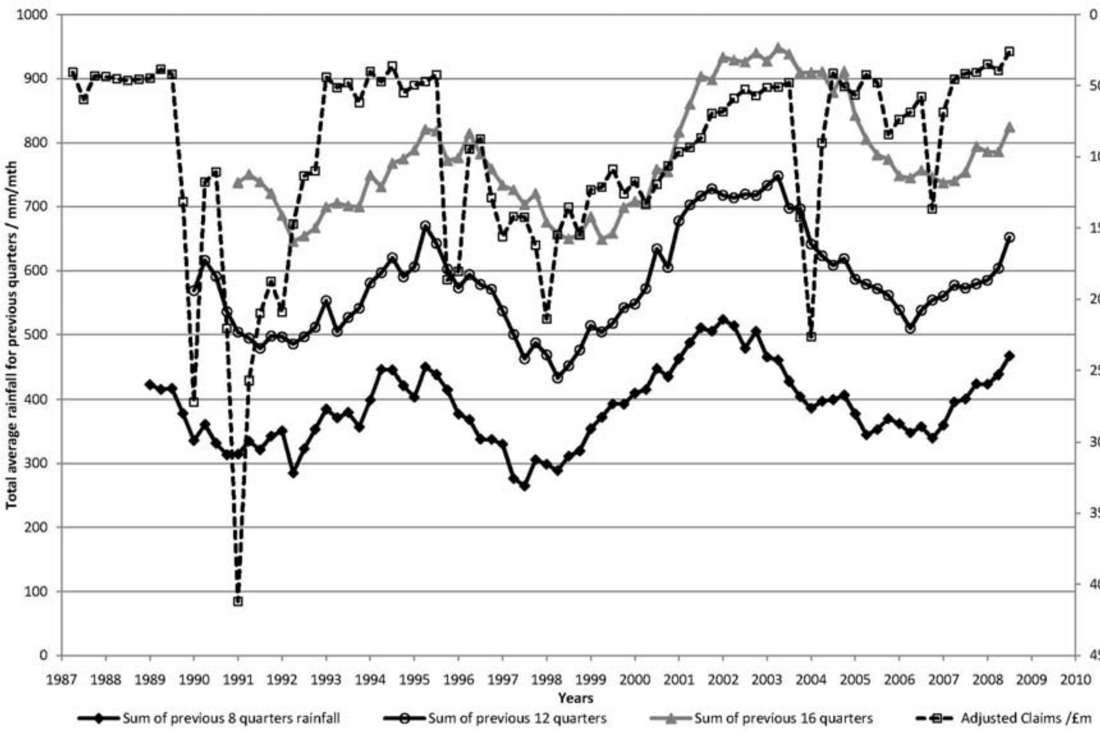

Figure 4. Previous rainfall (for 8 to 16 quarters) and subsidence claims

However, perhaps not surprisingly, looking at more than two years previous data seems to cause too much 'smoothing' of the resulting plots (Figure 4).

Figure 5 is a plot of the sum of the rainfall for the preceding eight month period and the value of insurance claims against time. It demonstrates a correlation between low levels of previous rainfall and increased value of subsidence claims. The rainfall amount has been divided into three classes that correspond with high, medium, and low potential of subsidence resulting from shrink-swell. Summed rainfall values above 450 mm are classed as high potential and those below 400 mm are classed as low potential.

As highlighted (circled) on Figure 5, there are six peaks in claims that may not be solely controlled by the rainfall. Figure 6 shows the value of subsidence claims is also related to temperature variation. This would be expected due to the effects of evapo-transpiration during warmer weather. As highlighted on Figure 6, when the average maximum temperature (TMAX) for the quarter is above 22.6^{o}C, this corresponds to a peak in claims (circled). The same applies when the maximum TMAX rises to above 25.5^{o}C. This is a relationship that would be expected as a high TMAX average for a quarter, indicates that all three months have a high TMAX value, thus representing a period of sustained high temperatures. This, in turn, will lead to higher evapo-transpiration leading to a decrease in soil moisture content, particularly if rainfall is low. It is interesting that there is a strong correlation between maximum TMAX and claim values, as this is a one-off daily temperature. More research is required to investigate whether these values represent a threshold temperature at which the clay changes its properties and how it reacts to temperature change.

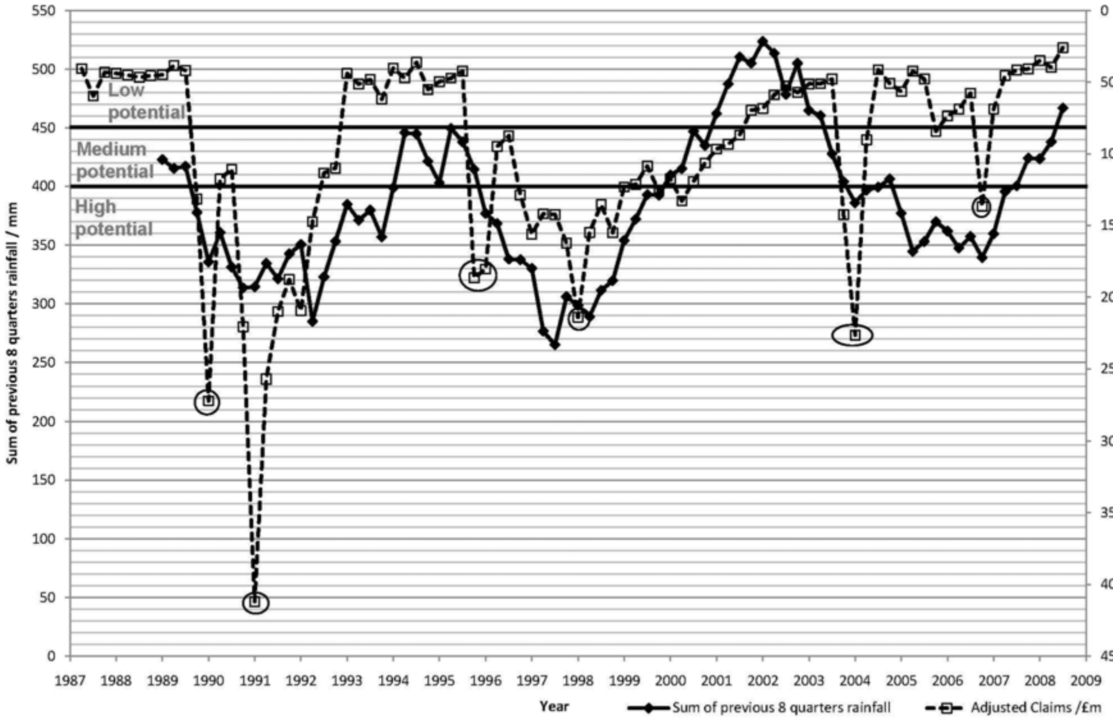

Figure 5. 2 years previous rainfall and subsidence claims

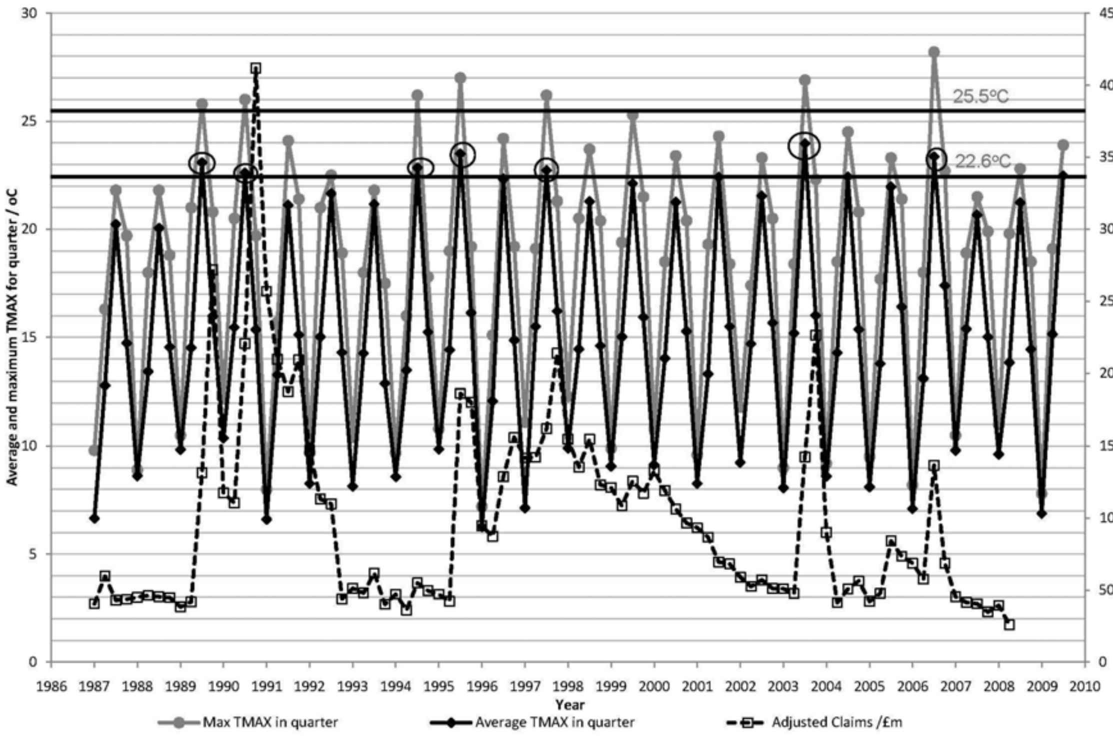

Figure 6. Average and maximum TMAX per quarter and subsidence claims

4 PREDICTED CLIMATE MODEL

Based on this research, rules are being identified for this preliminary GIS model. UKCIP02 (UKCIP, 2002) and UKCP09 (UKCIP, 2009) temperature and rainfall data is being used for the predicted climate values. Ratings are being allocated to high, medium and low rainfall values (Figure 5), and temperatures above and below 22.6°C (Figure 6). These values will then be combined with the GeoSure Shrink/Swell dataset (5km grid squares). GeoSure is categorised on a scale of 1 to 5 (1 being a very low risk and 5 being a very high risk). This will combine to provide a final subsidence susceptibility rating.

This classification work is in early stages and further research is required to understand the best ratings and thresholds to select to provide the most accurate susceptibility predictions. Detailed statistical work may be utilised to gain a stronger understanding of the mathematical relationship between rainfall, temperature and claims.

5 FUTURE WORK

This initial GIS model is simple, with the only climatic parameters involved being temperature and rainfall. One of the aims of this research was to improve the understanding of the processes and highlight areas for refinement. These areas are outlined below.

- Detailed statistical investigation to identify the mathematical relationship between previous years' rainfall and subsidence claims.
- Look at detail into the yearly 1975 onwards claims data and how it can be utilised to refine the model.
- Overcome the formatting and resolution issues encountered using the UKCP09 precipitation and rainfall datasets
- Enlarge the model geographically to match GeoSure (Great Britain).
- Investigate monthly rainfall and temperature data, thus avoiding "smoothing" that may be occurring by analysing the data in quarterly periods.
- Identifying and utilising a soil moisture dataset, potentially replacing rainfall and temperature, currently be utilised as proxies.
- Look into changes in rainfall, rather than actual rainfall of previous years. Investigate whether there is a relationship between long periods of decreasing rainfall, thus soil moisture, and shrink swell occurrence.
- Investigate not just the sum of previous rainfall, but extreme droughts and wet periods which could lead to desiccation cracks and infilling with debris in clay rich soils (Forster, 2006).
- Shrink swell laboratory investigation – research into the changes in clay at the temperature 22.6°C (the mean TMAX temperature that is associated with peaks in subsidence claims), so we can better understand the controlling processes.
- Shrink swell laboratory investigation – research into the changes in clay at the temperature 25.5°C (the maximum TMAX temperature that is associated with peaks in subsidence claims), so we can better understand the controlling processes.
- Look at varying the climatic data (temperature and rainfall) across the test area for the observed model, based on distance from climate station (currently using a mean average).
- Start investigating other UK geohazards, such as landslides, and the affects of climate change.

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Keywords

Shrink-swell, subsidence, precipitation, temperature, GIS