Why did a synoptic storm cause a dramatic damage in a limited area of Mongolia?

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In recent years, dust storms increasingly have caused enormous damages in Mongolia. An example of such storm is the one caused a historic damage in eastern Mongolia on 26-27 May 2008. This storm motivated us to study the relationship between the weather conditions, socioeconomic backgrounds, and damages of the dust storm and to answer the question why the damages were localized. We conducted two kinds of regression analyses on the county basis related to the cause-and-effect relationship in the dust storm event. That is, the predicted variables are the effects (damages) of the dust storm, while the predictor variables are the meteorological (forcing) and the socioeconomic (backgrounds) conditions.

The multiple regression model, significant at 5% level, selected the wind speed, precipitation, previous year's livestock loss rate, and the ratio of herders to the rural population as the predictors for the livestock loss rate. As well as these four predictors, the tree regression analysis suggested the air temperature as an important predictor.

Key words
Weather condition, dust storm, livestock loss rate, herder, ethnic group, malnutrition

Introduction

In Mongolia, 61% of dust storms occur in spring and they last from 3.1 to 6.0 hours (Natsagdorj et al., 2003). Accumulated facts evidenced that a number of people in the marginal areas of Mongolia have a high degree of vulnerability to severe dust and snow storms, because they are exposed to such storms and in those areas there provided limited water resources, poor communication, and transportation systems (Batjargal et al., 2006). In fact, recent dust storms damaged electricity, telephone, road networks, pasturage, agriculture, human and animal heaths etc, and the costs for recovery have become increasingly enormous. However, there have been limited investigations on the assessment of socioeconomic impacts of dust storms in Mongolia. Given this background, we made a statistical analysis to explore the relationship of the socioeconomic damages (predicted variables) with the dust storm conditions and with socioeconomic backgrounds (predictors). Our focus was placed on the dust storm that occurred on 26-27 May 2008.

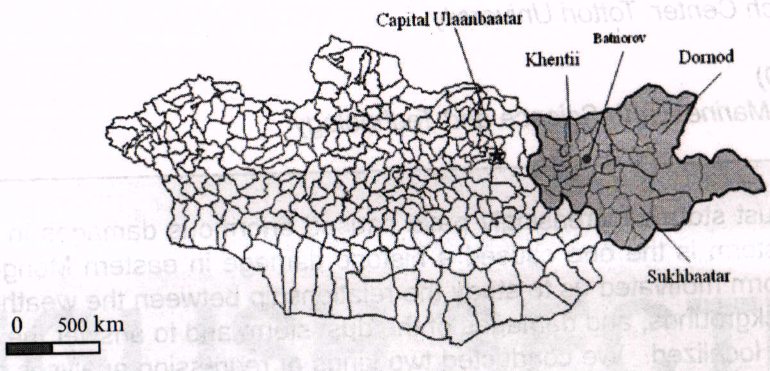
Study area and dust storm

An overview of the focused dust storm on 26-27 May, 2008 was given by Government of Mongolia and United Nations Development Programme (UNDP) (2008) as follows. The strong dust storm accompanied by snow attacked five aimags (states) of eastern Mongolia. During the storm, the air temperature dropped nearly to 0e C and the wind speed appeared to reach >40m/sec.

The dust storm killed 52 people, out of which 14 were children, and more than 278,000 livestock. It also caused many thousands of missing livestock. According to Government of Mongolia and UNDP (2008) this may be the greatest damage since 1980. As for infrastructure, it led to collapses of buildings, electric and communication poles, trees, gers (Mongolian houses), and fences, and consequently the electricity distribution had stopped. The direct, immediate cost for recovery was estimated to be 649.2 million tugrik (around $590,000).

The study area covers the eastern part of Mongolia including the Dornod, Sukhbaatar, Khentii aimags (states) (Figure 1), where the damage of the concerned dust storm was to a variety of degrees.

Figure 1. Study area (Dornod, Sukhbaatar, Khentii aimags)



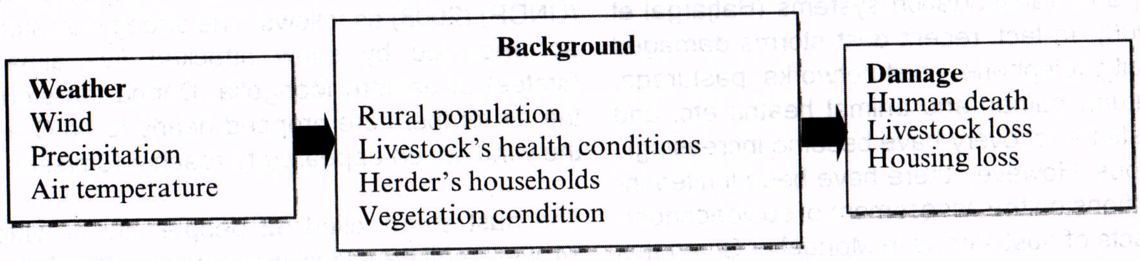
As the most critical weather condition, we used wind speed, precipitation, and air temperature data obtained from the Institute of Meteorology and Hydrology of Mongolia. In addition, we used data on socioeconomic damages in the affected areas from the Emergency Management Agency of Mongolia. Population and livestock data for 2006, 2007, and 2008 is derived from the National Statistical Office (2007, 2008, 2009). All these data was prepared for 35 soums (counties) of the three aimags in the following analysis. MODIS true-color images downloaded from the MODIS Rapid Response System (http://rapidfire.sci.gsfc.nasa.gov/) were also used to examine the weather pattern during the dust storm.

The population data consists of total population, rural population, and number of herders, total households, and herder's households. In rural places, herders live in gers which are very vulnerable to dust storms due to their unsheltered and unprotected conditions. In addition, we estimated a homeless rate as the ratio of damaged gers by the dust storm to the previous year's total herder's households. We also estimated (human) mortality rate, which is the ratio of (human) deaths by the dust storm to the previous year's total population. As for damages in livestock, we estimated livestock loss rate as a ratio of the livestock deaths resulted from the dust storm to the previous year's livestock numbers.

Methods

We present a conceptual model illustrating the cause-and-effect relationship for a meteorological disaster (Figure 2); with natural and socio-economic backgrounds, extreme weather conditions induce damages.

Figure 2. Schematic diagram of the cause-and-effect relationship for dust disasters considered in this study



First, we made a data pre-processing, in which data for small towns and villages were integrated to soum-scale data. Second, we calculated the predicted and predictor variables for each soum. Third, after mapping the predictor and the predicted variables, we selected the most efficient predicted variables that represent the immediate socioeconomic damages among the natural and socioeconomic indicators. For selection of the most important variables we used participatory system analysis (PSA) which is manageable compromise when other method such as system analysis and cost-effect analysis are more costly and complicated. It is designed to evaluate the relationships among relevant indicators within this study context. Herweg and Steiner (2002) reported that this method suggests a variety of stakeholders will define important elements of a project context and their relationships during a participatory exercise, based on their specific backgrounds, knowledge, expertise and experiences. Using this method we selected three environmental (wind speed, air temperature and precipitation), three social (human mortality rate, homeless rate and ratio of herders to the rural population), and three economic indicators (livestock loss rate, livestock loss of previous year, livestock number per herder). Fourth, we applied multiple and tree regression to the selected predicted and the predictor variables to examine what caused the localized damages.

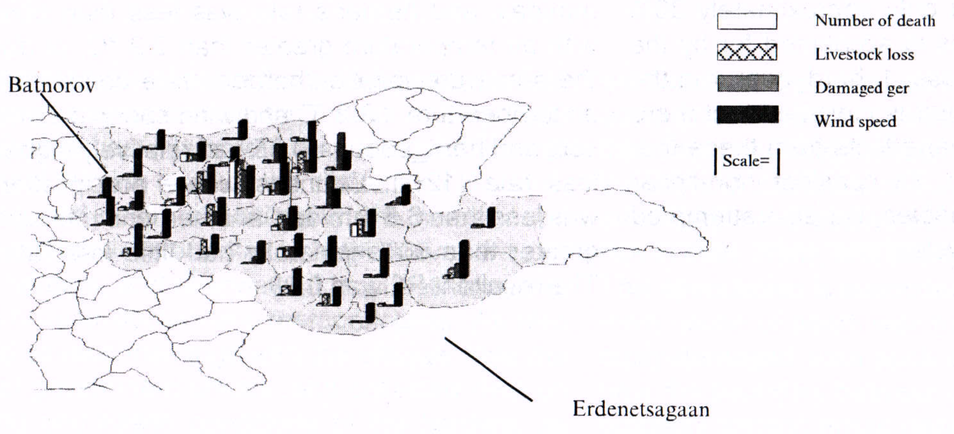
As the first regression, we applied multiple regression analysis using stepwise backward method starting with all predictor variables. Then these variables are tested one by one using F-test, and deleted if the F-value is less than the threshold.

In linear regression we have a single predictive formula over the entire data set. When our data set has lot of variables which interact in complicated, nonlinear ways and building a predictive formula can be difficult. The tree regression method provides an alternative approach which sub-divide or partition the data into smaller regions where the interactions are more manageable. Then we partition sub-divisions again - this process is called recursive partitioning. Each of the terminal nodes or leaves of the tree represents a cell of the partition, and has attached to it a simple model or a constant estimate of predicted variable only for this cell. We start at the root node which contains all observations. We calculate the root mean square error (RMSE) between the observations and the predicted values for all possible binary divisions. The next split is made so that the RMSE becomes a minimum. If the possible largest decrease in RMSE by this process would be less than the threshold, or one of the resulting nodes would contain less than the number of points, the model development process was stopped. Useful descriptions of tree based methods can also be found in Tachiiri et al. (2008).

Results and discussion

By mapping (Figure 3, all data are normalized using the maximum value presented) it was showed that three kinds of damage indicators were localized in the central region of the study area, whereas observation of the high wind speed was widespread over the study area.

Figure 3. Wind speed, damaged ger, livestock loss, and number of death that are arranged from right



The highest wind speed (40 m/sec) was recorded in the Erdenetsegeen soum, where approximately 7% of the total livestock, namely, 12,689 heads were lost. The highest number of livestock loss (52,162; 25% of the total livestock) and human death (19) were seen in the Batnorov soum, accompanied by the wind speed of >34 m/sec.

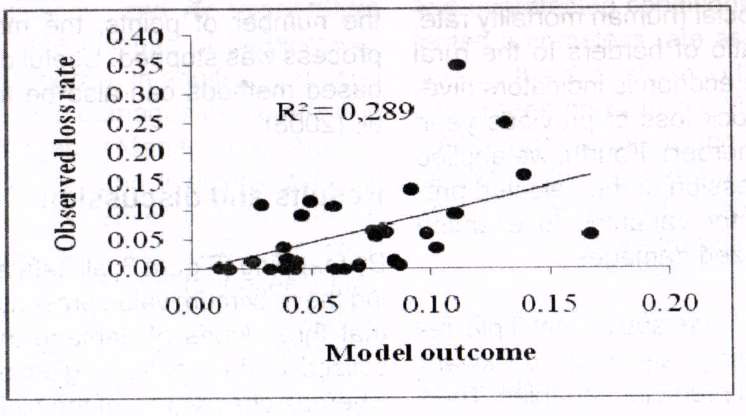
The multiple regression analysis identified a model with a statistical significance only for the livestock loss rate (eq. 1):

loss=0.082+0.003*wind+0.008*prec-0.795*loss-1-0.154*herd_poprur (1)

where loss is the livestock loss rate (predicted variable), while wind, prec, loss-1, and herd_poprur are the wind speed, precipitation, previous year's livestock loss, and herders rate as a ratio of herders to the rural population respectively (predictor variables).

This model exhibited a correlation of the 5% significance level (p=0.043, R2=0.289) (Figure 4). The negative coefficients for loss_1 and herd_poprur mean that the greater the livestock loss rate of previous year and the number of livestock per herder were, the lower the livestock loss was. This implies that large mortality in the previous year might make the herders more cautious and larger rate of herders in the rural areas were able to protect the livestock against the dust storm.

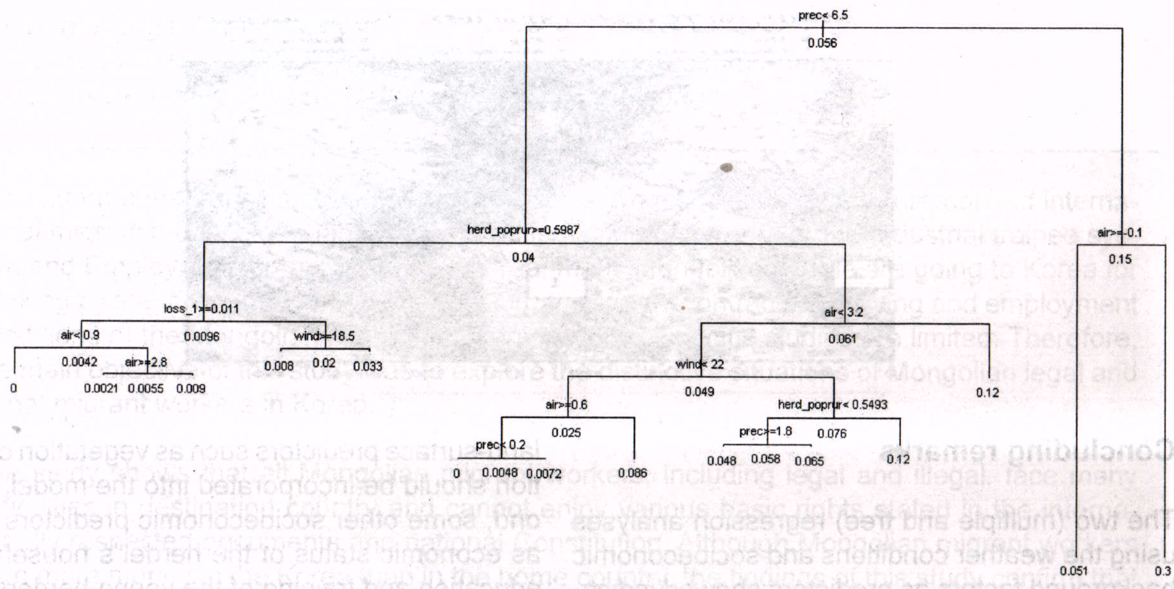
Figure 4. Scatter plot of the output of the multiple regression model and observed livestock loss rate



The multiple regression model indicates that high wind speeds associated with heavy precipitation resulted in high livestock loss. Although we conducted the similar analyses for the human mortality rate and the homeless rate, the models obtained were statistically non-significant. R-squared shows that only approximately 30% of the variability of loss is accounted for by the variables wind, prec, loss_1, herd_poprur in the model. From this result it is indicated that there may be some non-linear effects from these four and/or other variables. To consider non-linear contribution of the variables, we also attempted a tree regression analysis.

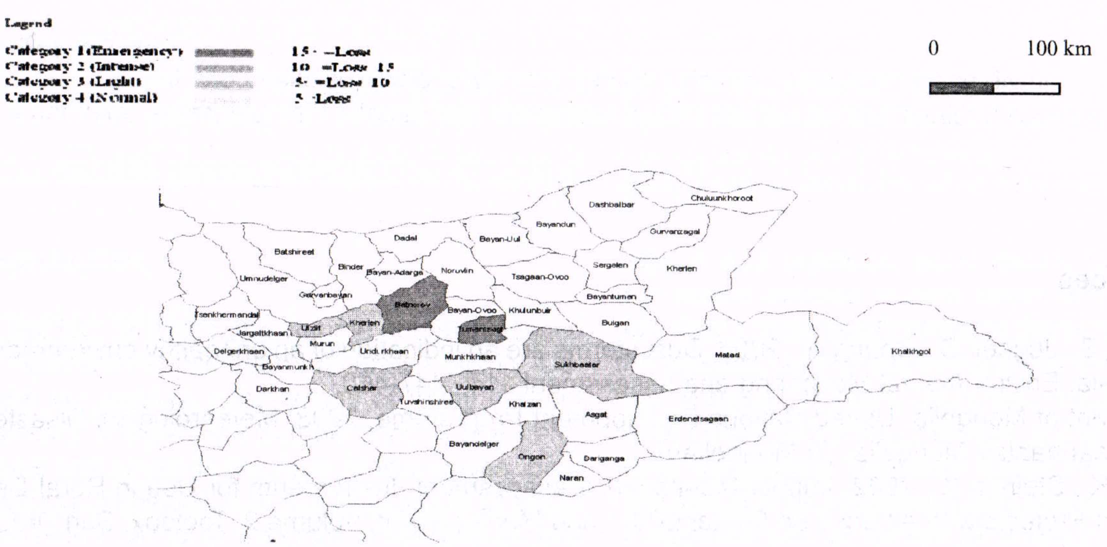
The regression tree (Figure 5) showed that the greatest loss rate (30%) was evident in the counties where the precipitation was greater than 6.5 mm/day and the air temperature was less than -0.1 °C. The regression tree also showed that counties where precipitation was less than 6.5 mm/day, and herder's rate was less than 60% with air temperature greater than 3.2 °C, or (for the same precipitation/herder's rate conditions) air temperature < 3.2 °C and wind speed ≥ 22 m/sec, and herd_popur > 0.55 had relatively higher loss rate (12%). Counties where precipitation was less than 6.5 mm/day, and herder's rate was greater than 60% generally had little loss rate. The resultant R2 was 0.93.

Figure 5. The tree regression model developed in this study (the "prune" process was skipped)



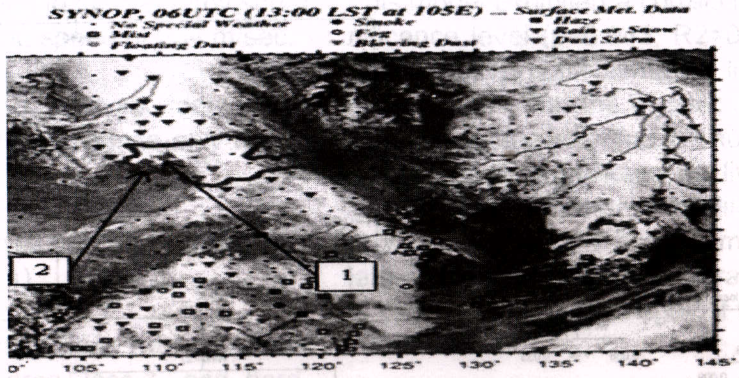
The localized livestock loss predicted by the tree regression model has shown in Figure 6.

Figure 6. Dust damage as indicated by predicted livestock loss (%) modeled by tree-regression



In order to corroborate the model results, a field survey was conducted for 5 days in May 2009 in 2 counties (Batnorov, and Berkh of Khentii aimag), aiming to study the climatological status, living and health conditions of the herders and the current livestock status. In the survey we met 60 herders, and interviewed local veterinarians, the hospital doctors and meteorologists. We also held several meetings with the officials from the local government offices, and collected data on living and health conditions of the herders, as well as on the livestock status. From these data we assessed the initial economic and social impacts of dust storms. The field survey suggested that the most likely reason which accounts for the highest numbers of human death and livestock loss in the localized area was the combination of dust, snow, and strong winds in the storm. This speculation is supported by the fact that the main cause of death was frostbite and the seriously-damaged area such as Batnorov located near the boundary between dusty and cloudy (ie, probably snowy) areas observed in the MODIS image. Such serious damage was not recorded in the Darkhan soum that experienced dust weather and strong winds, but was not cloudy as seen in the satellite image (Figure 7).

Figure 7. The satellite image of 26 May, 2008. 1: Batnorov, and 2: Darkhan



Concluding remarks

The two (multiple and tree) regression analyses using the weather conditions and socioeconomic background factors as predictors showed indicative results for the livestock loss rate.

To improve the model performance, future studies should consider the following points: First, land-surface predictors such as vegetation condition should be incorporated into the model; Second, some other socioeconomic predictors such as economic status of the herder's households, education and training of the young herders, behaviour of ethnic groups, diseases and malnutrition (productivity) of livestock (they were not included in the present models due to the limitation of available data) should also be considered.

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