IUTAM Symposium on the Dynamics of Extreme Events Influenced by Climate Change (2013)

High-impact weathers in a changing climate over arid Eurasia and proactive disaster management

Masao Shinoda

Graduate School of Environmental Studies, Nagoya University, Nagoya 464-8601, Japan

Abstract

Drylands in the middle-high latitudes (such as seen in Eurasia) have a severe environment coupled with an arid and cold climate; the livelihood of people inhabiting drylands has long been repeatedly jeopardized by meteorological disasters that occur in such a climate. The present review paper aims (1) to provide an overview of synoptic conditions and dynamics of extreme high-impact weathers (HIWs) such as dust storm, dzud (harsh winter conditions), and drought over arid Eurasia and (2) to propose a methodology towards estimating the risk of extreme HIWs and developing an early warning system of the meteorological disasters as their proactive management. This paper also outlines a new project “Integrating Dryland Disaster Science” that has been implemented to propose a countermeasure against the combined impacts of multiple dryland disasters for FY2013–2017 under the Grants-in-Aid for Scientific Research program supported by the Japan Society for the Promotion of Science.

© 2015 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Selection and peer-review under responsibility of School of Civil Engineering and Mechanics, Lanzhou University

Keywords: Dust storm; Drought; Dzud; Climate memory; Early warning

1. Introduction

High-impact weather (HIW) is defined as a spectrum of weather that can result in significant impacts on safety, property and/or socioeconomic activity. In particular, extreme weathers have lower probability that can result in higher impacts and sometimes catastrophe. IPCC WG I stated that in many regions, extreme climate events are becoming increasingly frequent and that this trend will continue. The increase in extreme weather events poses a particular threat to people who depend on agriculture and livestock industry. However, few quantitative studies have examined the damage to society or industry that may be caused by future meteorological disasters. Given this background, first, the present review paper aims to provide an overview of synoptic conditions and dynamics of extreme HIWs such as dust storm, dzud (harsh winter conditions), and drought, that occurred in recent years and will likely occur in the future over arid Eurasia. Second, this paper aims to propose a methodology towards estimating
the risk of extreme HIWs and developing an early warning system of the meteorological disasters as their proactive management.

Fig. 1. Impacts of dust and snow storm on 26-27 May 2008 on (a) livestock and (b) infrastructures, and (c) surface weathers and MODIS true color image on 27 May 2008.

2. Dust storm

Severe dust storms pose a serious threat to grassland livestock and sometimes human lives. For example, 120,000 and 110,000 animals were killed in China during the 5 May 1993 and 14-16 April 1998 dust storms, respectively. A severestorm with dust and snow in eastern Mongolia on 26-27 May 2008 resulted in record-level damages, killing 52 people and 280,000 animals (Fig. 1a, b). The need for developing an early warning system to ameliorate damages is apparent.

An overview of the dust storm on 26-27 May 2008 in Mongolia was given by Government of Mongolia and United Nations Development Programme 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 0º C and the wind speed appeared to reach >40 m/sec. This storm revealed a distinct structure with combined snowy and dusty weather; this includes cloudy areas (with rain or snow) related to the southeastward-moving low pressure system and dusty areas accompanying a cold air outbreak after the passage of the cold front (Fig. 1c). This event 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.
On the decadal scale, dust outbreak frequency increased, while frequency of strong wind decreased or changed little from the 1990s to 2000s in Mongolia, eastern Inner Mongolia, and northeastern China. In conjunction with this trend, threshold wind speed decreased in these sub-regions. This suggests that land-surface conditions changed more vulnerable for dust outbreak, resulting in the increase of dust outbreak frequency. In some areas of Mongolian grasslands, decreased precipitation caused a reduction in vegetation amount in a summer, leading finally to a reduction in the amount of dead-brown leaves in spring in the following year. The reduced dead leaves enhanced dust emission due to loss of protective cover. Recently, more attention has been paid to temperate grasslands (widespread over arid Eurasia) that are sensitive to climate change and are significant, or potentially significant, dust sources. In a cold, arid climate such as seen in arid Eurasia, interannual anomalies of soil moisture and vegetation due to rainfall during a given summer are maintained through the freezing winter months to the spring. The concept of the memories will enable us to predict dust emission conditions half year in advance, by monitoring and assessing the detailed time course of the soil–vegetation system on the ground and by satellite.

Fig. 2 Real GDP growth rate (%) and number of livestock in Mongolia. Source: National Statistical Office of Mongolia.

Fig. 3 AtmospHERic circulation patterns on (a) normal (26 November 2009) and (b) cold (5 January 2010) days and time-series of (c) zonal wind at the 500 hPa level (U) in the domain of 99-108°E, 52.5-63°N (dotted area) and (d) temperature (T) that of a normal year (Tave) at Bulgan, northern Mongolia during the 2009/2010 dzud. The double line denotes a trough in westerlies.
3. Dzud

Dzud is a Mongolian word that indicates harsh winter conditions. This is biogeophysicallydefined as anomalous climatic and/or land-surface conditions leading to significant livestock mortality in winter-spring. In Mongolia, pastoral livestock husbandry has repeatedly suffered from drought and dzud. The dzuds during the three cold seasons of 1999–2002, that were accompanied by droughts, killed 11.2 million livestock, which accounts for about 33% of the total number of livestock for 1999. During 2009–2010, 10.3 million were killed due to dzud. These disasters impacted dramatically national-level economic conditions as clearly seen in the annual economic growth rate (Fig. 2).

During the most recent dzud event, colder-than-normal conditions were manifested in conjunction with the appearance of easterlies over Mongolia (Fig. 3c, d). This is because the intensity of dzud-producing cold surge was larger when westerlies’ meandering was enhanced and maintained (with the appearance of easterlies over Mongolia) (Fig. 3b). This synoptic pattern brought northern cold air mass into this region. In contrast, during the end of November 2009, themeandering was not strong, leading to near-normal temperatures (Fig. 3a). Another mechanism of cold surge is the wave-train pattern in the Northern Hemisphere that facilitates the eastward migration of cold air mass along with the movement of trough.

Fig. 4. Processes through which drought influences livestock.
4. Drought

Drought is a creeping phenomenon having a time-lagged carryover of anomalies in rainfall-soil moisture-pasture-livestock and eventually leading to a dzud\(^9\) (Fig. 4). That is, lower-than-normal precipitation leads finally to time-lagged lower-than-normal weight of livestock (health conditions) through the processes as illustrated in Fig. 4. These processes are referred to as a drought memory\(^{10}\) and are the same as mentioned in Section 2. It should be noted that the chain of the mechanism starts from the anomalies of atmospheric circulation (i.e., climate changes) and resultant suppressed cyclone activities.

Preparedness for dzud is ensured with the time lag that a drought in summer leads to a dzud in winter–spring. Monitoring and forecast of soil moisture and pasture is an essential need for the drought-dzud early warning system. Given this background, dzud risk assessment combining the information on the summer and winter climatic anomalies was carried out using remotely sensed vegetation and snow condition data\(^{13}\).

5. Integrating dryland disaster science

Drylands occupy 41% of the earth’s land area and are home to more than two billion people—a third of the human population in the year 2000. The largest proportion of these people are poor, forming the bottom of the economic pyramid. The nature-society system is among the most vulnerable to the projected increasing frequency of various kinds of extreme weather events. In particular, drylands in the middle-high latitudes (such as seen in Eurasia) have a severe environment coupled with an arid and cold climate; the livelihood of people inhabiting drylands has long been repeatedly jeopardized by natural disasters that occur in such a climate. The disasters are characterized as the so-called 4Ds, drought, dzud, dust storm, and desertification, which occur interactively. However, previous attempts to elucidate disaster mechanisms and implement appropriate land management techniques have not been fully integrated, since these efforts typically only deal with individual disasters. Given this background, a new project “Integrating Dryland Disaster Science” has been implemented for FY2013–2017 under the Grants-in-Aid for Scientific Research program supported by the Japan Society for the Promotion of Science.

The present project's dual aims include (1) relating the 4D disasters in the Eurasian dry inland area to each other in terms of causal mechanisms (especially drought memory) and the time scales of their occurrence, and (2) developing comprehensive proactive countermeasures and making policy recommendations designed to mitigate multi-disaster impacts. Objective 1 can be achieved by correlating impacts of 4D-producing extreme weather events in terms of the concept of drought memory, by evaluating risks for each disaster as the product of impact (hazard or forcing) and evaluating the vulnerability (expressed by the three elements of exposure, sensitivity, and resilience) of the nature-society system (Fig. 5). Objective 2 can be achieved by implementing approaches that integrate opinions of various stakeholders related to the countermeasures needed to reduce the vulnerability of both people and the environment to 4D disasters.
In Fig. 5, drought as a hazard (forcing) is linked to the other 3D hazards with different time-scales by the drought memory mechanism; drought is a background factor that influences dust storms and dzuds; the accumulated effect of multi-year droughts leads to desertification. The risk (influence) is calculated as the product of hazard and vulnerability of the natural environment-society system. In the conceptual model, each type of hazard is related to specific types of risk; sporadic and intense hazards such as dust storms and dzuds are related to economic and/or infrastructural losses and mortality, while drought and desertification are longer time-scale events leading to famine and poverty, respectively. The vulnerability of both the natural world and society is expressed by the three elements of exposure, sensitivity, and resilience in a clockwise sequence of a disaster cycle involving the social and natural domains. Damages caused by disasters provide feedback to vulnerability. In this context, an attempt has been made to identify hotspots on the Asian steppe that were vulnerable to widespread drought events in the Northern Hemisphere during 1999–2002, using newly proposed indices of vegetation response (sensitivity and resilience) to drought.

References