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Riders under storms: Contributions of nomadic herders' observations to analysing climate change in Mongolia

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ABSTRACT

Predictions of climate change and its impacts are highly uncertain at regional and local levels. Downscaled models often operate with a too coarse scale and look at standard parameters that may be irrelevant to resource-dependent people. This article argues that a more robust analysis and prediction of climate change at local levels can be inferred from the integration of local people's observation of change with meteorological records and models.

The example proposed here is the analysis of climate change in the desert-steppe region of Mongolia. While regional models and local analyses agree that Mongolia has become warmer, predictions either ignore or are contradictory about the changes in precipitations and sand storms. The Mongolian pastoral nomads on the other hand identify longer and more intense droughts and sand storms as the most important recent climatic changes, relevant to their livelihoods. In addition, they record detailed changes in the precipitations regime. Thus, they are unequivocal that rains have become patchy – *'silk embroidery rains'* – (forcing pastoralists to move farther and more frequently), more intense (thus less effective due to runoff) and that summer rains are delayed (reducing the growing season).

The observations of the pastoralists can only partly be investigated in light of meteorological records due to different parameters observed by the two systems. Nevertheless, additional evidence derived from the analysis of meteorological records resonates with the perceptions of the herders and adds elements for further investigation. This combined evidence suggests that due to a southern shift of the East Asian Monsoon, rains in southern Mongolia rely on re-circulated local moisture, leading to large-scale droughts and in turn more frequent sand storms.

The analysis provided herein shows that combining the two knowledge systems (local people's observations and climatology) holds the potential to provide more reliant and relevant investigations of climate change and allow for better planned adaptations.

1. Introduction

There is unequivocal evidence that the Earth's climate is changing, very likely due to anthropogenic forces (IPCC, 2007a). There is, nevertheless, far larger uncertainty about *how* the climate is changing and what impacts these changes will have (Dessai et al., 2007). At regional and local levels this uncertainty results in an 'uncertainty explosion' (Jones, 2000; Nichols et al., 2004), hampering locally relevant analyses of the impacts of, and possible adaptations to climate change.

The present article argues that the integration of local observations recorded by resource-dependent people (in this case the Mongolian pastoral nomads), can significantly reduce the uncertainty of climate change predictions and models in two ways. Firstly, local people's observations and meteorological records can test the confidence in downscaled models, especially where competing predictions are proposed. For the arid part of Mongolia general circulation models (GCM) predict a doubling of precipitation by 2040 (Natsagdorj, 2000), while the analysis of meteorological records shows drastic reduction since 2000, yet no statistically significant long-term trend. The herders themselves present the period after 2000 as an increasingly dry period, with 2004–2007 as the worst drought spell in living memory. Secondly, an assessment of change starting with land users' perceptions may reveal parameters salient to understanding local climate change but which are either ignored by or inaccessible to standard climatological analyses. Herders identified changes in the spatial distribution of rains, their timing and intensity as the most important changes affecting their livelihoods and environments. Yet, these parameters were often beyond the scope of meteorological records or were not supported by statistical evidence. Nevertheless, the narratives of the herders and evidence from

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meteorological records do support a model of climate change that predicts droughts would generate further droughts and dust storms.

Local resource users' observations and practices (often termed traditional ecological knowledge—TEK) have increasingly been recognised as a valuable source of information regarding natural processes and their dynamics (Sillitoe, 1998; Berkes, 1999). Part of this knowledge pertains to observations and interpretations of weather phenomena and climatic trends. Some studies (see for example Sollod, 1990; Ovuka and Lindqvist, 2000; West and Vásquez-León, 2003; West et al., 2008) have shown a remarkable overlap between these observations and instrumental climatological records. Others went beyond the simple comparison of the two knowledge systems (TEK and formal science) and showed how the inclusion of local observations in analyses of climate change can improve the confidence of climate change analyses (Huntington et al., 2004; Nichols et al., 2004; Orlove et al., 2002; Riedlinger and Berkes, 2001).

These studies show that local resource users observe climatic changes and their biophysical impacts at smaller spatial scales and in greater detail, and can thus provide further evidence for or against general models and predictions, made at coarser scales. By having to account for two sets of observations, from different spatial and temporal scales, this integrative approach can also lead to more robust predictions of mechanisms of change (Huntington et al., 2004). By nature of its accumulation and transmission across generations, TEK can provide a longer time perspective on change and possibly a more accurate description of normal variability against which changes can be assessed: a better base-line for assessment (Riedlinger and Berkes, 2001). At the same time, by observing variables and processes that may not be investigated by formal science, TEK can reveal new significant parameters and phenomena, against which models should be 'falsified' and readjusted. In addition they can also expose subtle qualitative changes in variables otherwise ignored but with potentially great biophysical and socio-economic impacts.

Integrating the two kinds of observations is challenging on several accounts. Firstly, resource users often do not focus on individual variables but on how changes in one variable (e.g. temperature) results into changes in others (e.g. sea ice) (Nichols et al., 2004). Secondly, local observations may be aggregating variables (e.g. temperature and precipitations), in order to predict impacts (Berkes, personal communication). Moreover, if exposures and impacts are integrated or inferred one from the other, causal mechanisms may be blurred and the reliability of observations weakened. Equally important, base-lines may be constantly moving, as the perception of when the weather was normal changes under the influence of personal and inter-generational perceptions (Huntington et al., 2004). Since no explicit criteria and indicators are used for defining 'normality', the choice of base-line can be problematic (Usher, 2000).

Despite these challenges, the present paper shows that the integration of local knowledge into climate change analyses holds significant potential for diminishing uncertainty and improving assessments of relevant exposures, dangerous impacts and potential adaptations. This analysis of climatic change in Mongolia starts by describing which climatic changes represent dangerous exposures relevant to the herders. I then use these elements as hypotheses/research questions for analysing instrumental meteorological data. Finally, I discuss the results of the analysis with reference to local predictions and models.

I contend that this is not an exercise in validation of TEK against Western science, but rather an example of the kinds of contributions that TEK can make to a more detailed and relevant analysis of climate change and its impacts. I am comparing the results from the two knowledge systems in search of complementary stances rather than converging evidence. Since formal scientific and traditional knowledge systems often refer to different levels of analysis (average vs. individual occurrence) and types of variables, an agreement between the two views in regard to climatic changes may be coincidental or even misleading (Huntington et al., 2004). Alternatively, an apparent disagreement or lack of statistical support should also be treated with care. In the Mongolian case it may indicate that herders perceive change in relation to the favourable 1990s, rather than averages or long-term trends. It may also show that in highly variable climates such as in Mongolia, long-term change (although statistically sound) may be less adequate than short term variability in explaining the impacts of climate on people's livelihoods and local environments. Whatever the perspective, the results presented here underline the increasingly evident need that in order to understand climate changes we have "to start with contributions from (. . .) social sciences, married to a critical reading of the natural sciences" (Hulme, 2008, p. 5).

2. Mongolia's climate and pastoralism

2.1. Mongolia's climate

Mongolia is a land-locked country with an extreme continental climate defined by four seasons and high annual (−53 °C in January to +42 °C in July) and diurnal temperature fluctuations (Dagvadorj, 2000). Ecologically, the country is divided into six ecoregions from north to south: high mountains, taiga, forest steppe, steppe, desert-steppe, and desert (see Fig. 1). Precipitations range from 50 mm/year in the southernmost part, to 400 mm/year in small areas in the north, and fall mostly (85–90%) during the summer (June–August) (Natsagdorj, 2000). July is the hottest month of the year (average of 15–25 °C) and the peak of the vegetation growing season, leading to circa 90% of the yearly precipitation being lost to evapotranspiration (Dagvadorj, 2000).

Bad weather events have been documented for a long time in Mongolia. During the rule of the Manchu dynasty (1740–1911), weather reports show drought occurred in Mongolia on average once every 3 years, and *dzud* (winter disaster)[1] once every 2 years (Natsagdorj, 2000). In 1944–1945 a combination of drought and *dzud* killed more than 8 million adult livestock, a third of the total number (UNDP, 2000). More recently, snow and dust storms during 17–20 April 1980 and 5–6 May 1993 killed livestock (100,000 and 675,000, respectively), people, and damaged infrastructure (Dulam, 2005).

Despite this context of extreme weather, the long series of droughts and *dzuds* of 1999–2002 is unprecedented (AIACC, 2006). The impact of these shocks cannot be attributed to bad weather alone (poverty and removal of state assistance also play a major role). Yet, at the end of this period more than 12 million livestock had died, 12,000 herder households had lost all their animals and thousands more were brought under the poverty line (ibid), while the national GDP from agriculture decreased by 38% from 1999 to 2002 (NSOM, 2004).[2] Regional climate predictions anticipate an increase in areas affected by droughts and in frequency of extreme events (IPCC, 2007b). Predictions regarding precipitations diverge: either increase (Natsagdorj, 2000; Sato et al., 2007) or decrease (IPCC, 2007b), depending in both cases on changes associated with the East Asian summer monsoon.

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[1] The Mongolian term *dzud* denotes unusually difficult winter conditions which result in the death of a singnificant number of livestock over large areas of the country, a disaster. These conditions can be too much or too little snow, trampling of snow and plants by passing livestock, or too high grazing pressure. Thus, the term implies both exposure to difficult weather and a constraining context, but also the impacts thereof (see Legrand, 2002).

[2] The total GDP increased during the period, mainly due to revenues from mining.

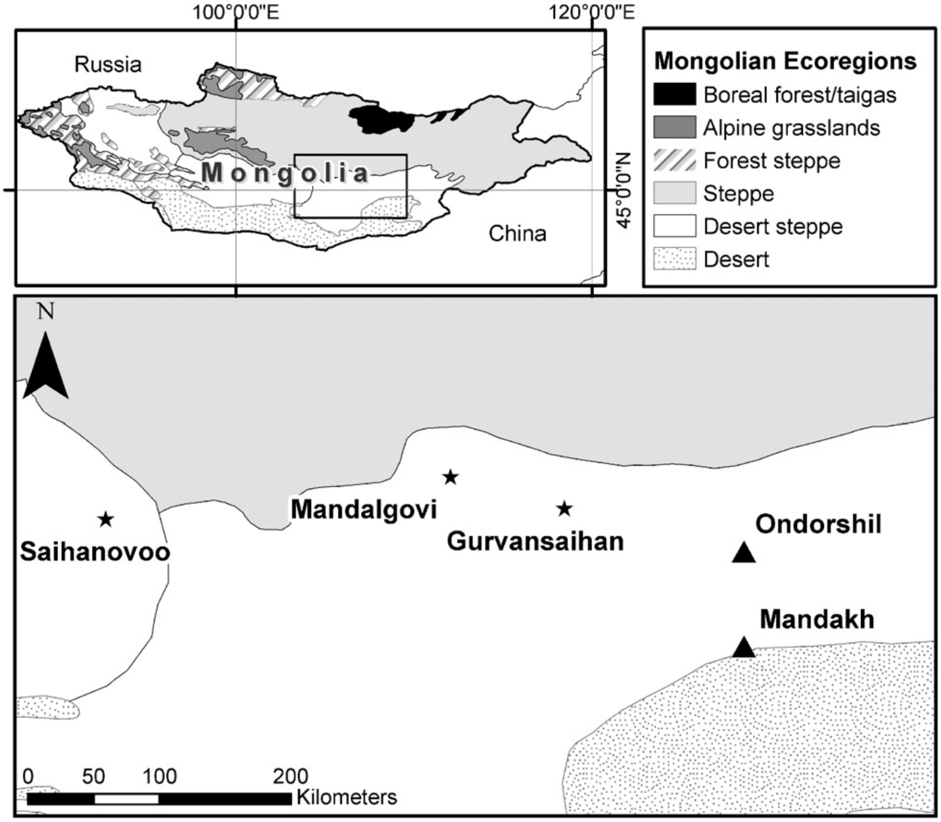

Fig. 1. Mongolia's ecoregions and the study area. Triangles (▲) mark the sites with monthly meteorological records; stars (★) show the sites with daily meteorological records. (Note. The length of the time series available differs between stations: Mandalgovi, 1967–2005; Saihanovoo, 1967–2005; Gurvansaihan, 1985–2005; Mandakh, 1974–2003; Ondorshil, 1973–2008.)

2.2. Mongolian pastoralism

Pastoralism is not only economically important in Mongolia—20% of the GDP came from agriculture in 2006. It is also the main livelihood for a third of the country's households and the main food supplier for the urban population, in addition to being an important element in Mongolian culture and identity.

The Mongolian pastoral system relies on the use of five animal species: camels, horses, cattle, sheep and goats. In the moister North there are larger numbers of cattle (including yak), while in the arid South more camels are kept. Herders move their livestock several times a year in search of seasonal pastures, usually within the borders of their districts (*sum*) and provinces (*aimag*). Migration patterns differ markedly between ecological regions. Households in the arid areas display the most frequent and farthest reaching movements while the ones in moist regions move least (Simukov, 1934; Mearns, 1993).

Springs are cold and stormy, with scarce pastures. This is also the calving and lambing season, when herds are kept over night in protective natural or man made enclosures, herded closely and watered 3–4 times a week. During the summer, the livestock are herded less closely, and horses and camels often roam freely, at a distance from the *ger* (felt tent, regular housing of herders). Animals are watered every day during summer, if no rivers or lakes are available. In the autumn, the herds are moved less and preferably towards the family's winter quarters, in order for animals to build up sufficient fat reserves that will see them through winter and spring. Winter is spent on pastures which have ideally not been grazed earlier during the year, allowing vegetation to grow tall so that it would not be covered by snow.

The migration strategies reflect complex calculations (Marin, 2008) but ultimately depend upon available resources: if the pastures are good, herders migrate to 3–4 fixed sites, preferably near their winter and spring shelters (*uvuljoo*, *khavarjaa*, respectively). Conversely, if the weather is bad or the pasture insufficient, they often employ a strategy of "following the grass"—moving out of their normal migration orbits, without many belongings, carrying a smaller tent. This later form of movement, named *otor*, is most often employed during summer but can last for several years and may include tens of movements per year.

Mongolian herders identify climate and weather as two distinct categories, defined by two expressions: *tsag agar* (weather), literally "hour air", and *uur amilsga* (climate), literally "steam breath". The most common weather related problems identified by herders are *gan* (drought), *dzud* (winter disaster) and *shuurga* (dust/sand storms). The herders perceive themselves as being constantly "under the weather"; the realisation that nature in general and weather in particular control their lives is ubiquitous and explicitly formulated. In addition, it is also implicit in their spirituality: the land is controlled by governing spirits (*gazarin ezed* lit. 'masters of the land') who have the power to bestow good weather or, if angered, drought and pestilence (Humphrey, 1995). The most powerful of these spirits are those who control mountains, but even these are inferior to the supreme power of the deified sky (*Tenger*). The spiritual dimension of weather as part of nature, controlled by the 'Eternal Blue Sky' is reconfirmed in worshipping rituals and offerings but also in daily language. Herders would occasionally enquire about the weather by asking how *Tenger* was, as opposed to the usual reference to *tsag agar* (hourly air).

2.3. Multiple stressors: political, economic and social change

The recent loss of livestock and the impoverishment of herders should not be attributed solely to their exposure to more difficult weather. During the last two decades Mongolia has undergone a complex of political, economic and social changes that have undoubtedly affected the adaptive capacity of its population. In 1990, Mongolia ended its communist regime and redirected towards multi-party democracy and market economy. During the communist period (1921–1990) the state provided cheap, reliable services to the herders: transportation of families and animals during migrations, wells maintenance, hay and shelters during difficult weather, wages and pensions, purchase of products. After 1990, these services were curtailed due to the severe cuts in government spending, leaving herders to fend for themselves. The state retreat also removed the formal institutions regulating the use of seasonal pastures, leading to reduced mobility and higher grazing pressure around settlements and the capital city (Fernandez-Gimenez, 1999; Fernandez-Gimenez and Batbuyan, 2004; Humphrey and Sneath, 1999). The concentration of grazing pressure is also exacerbated by a significant reduction of available pastures following recent allocation to other land uses (mining, conservation, agriculture), the reduction in the number of wells (NSOM, 2004), expensive transport, and inaccessible and unreliable livestock markets. Reduced mobility also has the potential to severely degrade pastures (Fernandez-Gimenez, 2002) although pasture degradation may not be wide-spread yet (Humphrey and Sneath, 1999; Sneath, 2003).

In addition, poverty has also increased among herders (Griffin, 1995; Mearns, 2004) as well as asset and income inequality (Fernandez-Gimenez, 2002), leading to a self-enforcing polarisation among herders. Rich herders can afford moving more and maintaining their wealth while poorer ones often depend on settlements as additional income sources (from mining, farming), further discouraging mobility (Fernadez-Gimenez, 2007).

The political and economic changes of the last two decades act therefore as additional stressors that have exacerbated the negative direct impacts of climatic changes. Caution is thus warranted in attributing the recent die-offs to climate alone. Nevertheless, the narratives of my informants showed clearly that they feel exposed to increasingly adverse weather, to an extent not experienced before.

3. Methodology and data

The article integrates an analysis of different types of data collected during July 2006–April 2007 in the desert-steppe ecoregion of Mongolia. I have conducted semi-structured and open-ended recurrent interviews with herder households, *sum* governors, and land officers. I have also acquired insight through informal discussions, landscape walks and participant observations derived from living with a herder family. I also conducted group discussions, and a questionnaire-based survey ($N = 51$). In addition to primary data, I use instrumental meteorological data provided by the Mongolian National Institute for Meteorology and Hydrology (NIMH) in Ulaanbaatar, and local statistics.

The narratives of the herders were analysed using a technique similar to that of Auerbach and Silverstein (2003) in order to identify recurrent ideas and encompassing themes in the herders' statements. The survey was undertaken in April 2007 and was structured on information collected during the preceding 10 months. The period of focus (1999–2006) had been previously identified by herders as a period of climatic changes, for which they demonstrated detailed recollection. They were asked to grade the previous 8 years into five categories derived from their own terms for qualifying the weather (between very bad and very good). In addition they were asked if in any given year they had been affected by droughts, winter disaster (*dzud*) or unusual sand storms.

The statistical analyses of quantitative data were performed by using *Excell* and *NSD Stat* softwares, including a special routine (Libiseller and Grimvall, 2002) for trend detection in time series. Since linear regression analysis requires a normal distribution of the data – a condition not met by longitudinal meteorological data series – trends in time series were inferred from the Mann–Kendall (MK) test. This is a non-parametric test (i.e. not based on the normality assumption), making it a better tool for the analysis of time series (Hirsch and Slack, 1984). In addition, the MK test is insensitive to abrupt breaks in inhomogeneous time series, with extreme outliers or missing observations. The results of the MK test are given in standard-scores (z-scores). A z-score larger than $(-)1.96$ is equivalent to a two-tailed p-value (significance probability) = 0.05, the highest value for the rejection of H_0 hypothesis ('no trend'). Any z-score larger than 1.96 (smaller than -1.96) is therefore interpreted as a statistically significant increasing (decreasing) trend.

4. Results

4.1. Significant climate changes and their impacts according to herders

In presenting the pastoralists' observations I acknowledge that their perceptions of climatic changes reflect a principle interest in weather elements that influence pasture and livestock production and quality, possibly ignoring others. At the same time, causes of change were sometimes framed within a value-laden socio-cultural context: drought was caused by 'masters of the land' angered by inappropriate behaviour (e.g. tree cutting, mining). This allowed people to re-construct their complex identities (as Mongolian, herder, spiritual person) and restate their loyalty to a 'right way' of using nature. Nevertheless, the evidence of climatic change and its impacts was for the most part argued from a pragmatic, positivist standpoint, relying on first-hand observations, rather than derived from ethical reflections.

The livelihoods of Mongolian pastoralists depend to a large extent on weather, forcing them to observe and record quantitative and qualitative characteristics of a large number of variables. Despite obvious limitations of human memory of past weather events, herders of the desert-steppe were able to recall the pasture conditions and weather of at least the previous 8 years, often related to detailed temporal accounts of migration orbits in particular years. Their precise temporal references were perhaps aided by symbolic, customary markers attached to specific dates in the traditional Mongolian calendar, which identifies auspicious dates for various activities (shearing, moving camp, etc.) (Bayarmaa, 2003). In addition, herders' conversations always revolved around information pertaining to weather and pasture conditions. Outsiders, local herders returning from *otor*, or city dwellers passing through were thoroughly questioned by my informants regarding the occurrence of rain, pasture quality, number of families encountered along the way during visits. In this way, herders acquire updated and detailed information regarding weather over a much larger area than their home ranges, in addition to the first-hand observations acquired along their migration orbits. This practice likely leads to building a mental model of normal environmental (including climatic) conditions which functions as a more reliable base-line for assessing abnormal environmental change (Berkes and Berkes, 2009). Such a model may partly explain why herders sometimes 500 km apart invariably identified the period after 1999 as the worst in living memory, exceeding the limits of normal variability.

In the summer of 2006, the impacts of bad weather were evident across the desert-steppe. In Ondorshil (the district most severely affected by drought) 80% of the families had moved out in search of better pastures. During the spring of that year, many of their livestock became weak and died following the bad summer of 2005 and unusually severe dust storms that reduced the grazing time and pasture availability. During January–May 2006, in Ondorshil, 18% of all adult animals (14,418 heads) died due to bad weather (SODu, 2006b). By comparison, during the whole of 2005, only 3% of adult animals (2576 heads) were similarly lost (SODu, 2006a). The loss of new-borns meant not only a reduction of the herd size in the longer run, it also resulted in immediate food insecurity. Without new-borns, animals lactate less or not at all, leading to people losing their main source of summer food: milk and dairy products. Invariably, during the summer and autumn of 2006, people apologised when during my visits they could only offer plain tea, without milk.

Despite the obvious negative consequences, herders conceptualised bad weather independently of its impacts. They were well aware that bad pastures can also result from trampling or insect infestation and animals can also die from disease or predators. Indeed, a common explanation for why certain families had lost many animals was that they had 'stopped listening to the needs of the animals'. As Fig. 2 shows, the grading of years according to weather is not consistent with the number of dead animals herders reported. This mismatch may also be explained by the fact that livestock would likely die during the spring subsequent to summer droughts, when their limited fat reserves would be completely depleted. Indeed, the number of dead animals reported by herders was better correlated to the drought in the *previous* year ($r = 0.1732$, $p < 0.01$) rather than the *current* year ($r = 0.1331$, $p < 0.05$).

Herders spoke of bad weather in connection to two main natural phenomena: drought, and dust storms. The changes identified by the herders were nevertheless much more detailed than the simple occurrence and intensity of drought or storms, referring to elaborate qualitative elements and scales. These phenomena were presented by my informants as constitutive elements of the evidence of change, conflated into one unifying discourse. The following section presents this discourse in a structured manner.

4.1.1. Diachronic perception: worse weather "now" than "before"

The desert-steppe herders presented their environment as challenging, normally beset by difficult weather. Often this acknowledgement contrasted the arid part of the country (the *govi*)[3] and the fertile forested-steppe and taiga zones (the *khangay*) by an illustrative proverb: "Better to be animal in the *khangay* than human in the *govi*!" and was invariably connected to rain and dust storms:

> Here, in the *govi*, there is too little water, no sea or ocean to get the water going up into the sky and make clouds. (Lovsangjamtz, January 16th 2007)

> In 1984–1985, I remember it was particularly good weather. We had wind at that time too but not dust storms (...) Last year we had dust storms more than 60 times. Many animals died, many families got poor. (Tsedevdorj, April 7th 2007)

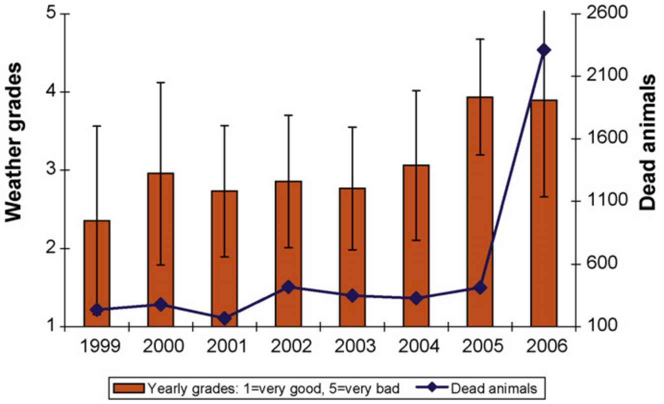

Fig. 2. Herders' ($N = 51$) grading of years according to weather vs. the total number of adult animals dead in each year (error bars are ±1 S.D.).

A clear distinction was thus being made between normal difficult weather and the recent unusually bad weather. If periods of good weather varied between informants, the start of the period with bad weather was consistently placed after 1999, and 2004–2006 was identified as a drought spell.

4.1.2. Less rain leads to drought

The Mongolian term for drought (*gan*) denoted an unusually long period without rain, leading to poor pastures. Since herders regarded their environments as normally arid, the term *gan* was not used to denote simply lack of rain: "During the last 9 years it's been lack of rain here, for the last 5 we've had *gan*" (Chuka, January 19, 2007).

The recent droughts were identified as the worst in living memory, when compared to previous episodes:

> I remember in 1952 it was a bad *gan*. We had to move the whole *sum* [district], the doctors, teachers, all families, to Hovsgol *sum* at the end of the autumn, 'cause there was no grass. But the *gan* is worst now, for the last 3 years. (Lovsangbaldan, January 21st 2007)

This coordinated movement of families and local administration was emphasised as a very seldom occurrence, employed only as the last resort in times of extremely difficult conditions. Therefore, if the present drought was even worse, as the quote states, it denotes an extreme phenomenon much exceeding the normal level of variability. The period after 1999 was identified as the worst in living memory due to both its intensity and length. The rain was getting scarcer every year and the droughts continued in an uninterrupted series:

> This year is worse than the last. And last one was bad as well. What's next? (Munkhbat, August 22nd 2006)

> It wasn't like this when I was a child. There were never so bad storms and *gan*. It **never lasted so long**. Between 1990 and 1999 it was very good [weather] for the herders, after the *dzud* in 2000 it was worse and worse. (Purev, 23rd August 2006-N.B. she is ca. 70 years old)

Just as not all lack of rain was a drought and not all droughts were equally bad, not all rains were enough to end the drought. Despite two rain events (one of them experienced by myself on August 17), herders in Ondorshil continued to express that 'we are having *gan*'. These rains were too short (15–30 min) and

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[3] In contrast to Western usage, the term *govi* is a common noun in Mongolian, not referring to the Gobi Desert; *govi* denotes the arid region of gravelly plains in southern Mongolia, roughly corresponding to the desert-steppe ecoregion.

Fig. 3. The silk embroidery: herders in traditional clothes (*deel*). Observe the embroidery patterns (*torgnii hee*—silk embroidery), referred to in the analogy of rain distribution (photo by the author).

insufficient to end the drought. Elsewhere, herders could point exactly to the day when the drought ended: "we've had *gan* until July 17th, then it was ok", or "we had *gan* until the Naadam,[4] then it rained", suggesting that even one rain could end drought and allow vegetation to (re)start growing:

> If it rains now, even for one day, the grass grows until October. The most rain we had here was in 1998, then it rained for one day and one night- and then we had lots of grass. (Bayanmunkh, August 17th 2006)

In addition to the quantitative aspect of rains, herders also demonstrated an elaborate perception of changes in qualitative attributes of rain that included geographical extent, intensity, and timing.

4.1.3. Rain becomes patchy: silk embroidery rain

The most important change in rain mentioned by the desert-steppe herders was its geographical extent: the perception that lately rain only occurred over small patches of land, what they called 'silk embroidery rain' (*torgnii hee boroo*—Fig. 3). Most herders perceived this as a puzzling new phenomenon:

> The rain is strange now. Here it doesn't rain and it rains just across the (*sum*) border. (Purev, August 23rd 2006)

> After 2000 it started to rain over smaller and smaller areas. Now some *sums* around here have much rain, others have nothing. (Chuka, January 19th 2007)

Although one key informant perceived that this was not a new phenomenon, he also identified it as unusual, and connected it to drought:

> When I was a child I heard people talk of *gan*, when the silk embroidery rain happened. Maybe it's the same now. I don't know, (. . .), but rain *is* different now. (Batamgarav, August 21st 2006- N.B. He is ca. 75 years-old)

Whether it was perceived as a new phenomenon or not, patchy rain was always regarded as negative. Islands of good pastures surrounded by large barren tracts are faster depleted and lead to increased migration. If these 'islands' are far apart, with no stepping stones of acceptable pasture and water in-between, animals may starve or even die during migrations:

> Last year we went on otor with our horses to Khenti aimag (. . .). For 200 km we found no grass but once we were there it was ok. Although, on the way all the mares miscarried because there was no grass. (Batsukh, August 25th 2006)

The scale of rain patchiness was not clear from the statements of herders, but by their use of topographical reference points, it appeared that distance between patches with rain could be as small as 15–20 km.

> We follow the rains, but it's difficult when it rains like this, in silk embroidery. Here it doesn't rain, but behind that mountain [ca. 15 km away] it does. So we follow it. (Tsetsegma, August 20th 2006)

4.1.4. Rains are more intense

The herders differentiated between at least two kinds of rain: hard rain (*shiruun boroo*) and soft rain (*shivree boroo*). Hard rains are usually shorter and occur during summer thunder storms, when large quantities can fall. Soft rains are slower, drizzling rains. Both types of rain are routinely mentioned by herders, often as a dichotomy, and both can be beneficial, but soft rain is always mentioned as a positive thing, the desirable kind of rain. Thus in order for grasses to start growing after a prolonged drought, they needed slow rain:

> Now the soil is very dry, so we probably need 2 days of soft rain [for the grasses to grow]; maybe even one day is enough. (Enebish, August 17th 2006)

A combination of soft and hard rain was also identified as beneficial, especially in the *govi* area:

> Here [in the *govi*] old people say: if it rains soft first and then hard it's very good. It's the blood of the *govi* they say, 'cause it cleans away the sand. (Munkhnasaan, January 22nd 2007)

Nevertheless, many herders perceived that hard rain was becoming more common. Since hard rain was regarded as being less effective in providing moisture to the plants, they attributed poor pastures also to hard rains:

> Each year the grass gets worse: thinner and thinner. Usually now the rains are short and hard- it's very hard for the grass (. . .) If the rain is hard and short, it runs away, it does not get into the soil. (Baatar Bazar, September 21st 2006)

4.1.5. Timing of rains

In addition to its extent and intensity, rain's timing is essential in several ways. In order for the rain to be beneficial, it has to come early enough to allow plants to grow and produce seeds before the cold season sets in. Failure to do so leads to a shortage of fodder and possibly to disappearance of certain valuable plants:

> [This summer] it rained only in the beginning of August. It was a good summer but late. Unusually late. During the last 4–5 years it's been raining later and later(. . .). *Mongol* [Stipa gobica Roshev.] is supposed to flower in June, now it only flowers in August. Less *mongol* means nothing to graze in the spring. Other

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[4] National celebrations, usually starting on July 11th.

> plants usually flower twice each year, now they only flower once. (Gangbayar, October 20th 2006)

> Grasses stopped growing well. Year by year they grow worse and worse. Some plants disappear, some get smaller. For example *hialgana* (Stipa spp.) used to grow with *shivee* (panicle), but now the seeds are not growing anymore (Enkhtaivan, March 4th 2007)

The general perception among the herders was that the start and length of the growing season were largely controlled by rain:

> Q: When does the grass start growing here?
> A: The grass can start growing in April or in August, it all depends on the rain. (Khorloo, February 13th 2007)

Even if drought intervened during the growing season, vegetation was ready to react to any moisture pulse as long as the temperatures were high enough to allow growth. Some plants would even be dormant for several drought years and then grow when the rains finally occurred:

> If it rained even once, the soil would get wet and plants would get better. It's not too late; at least until September 20th it would be good if it rained. (Nasaanbat, September 17th).

> I've noticed that some plants don't grow for 2–3 years and then they come back (. . .). Some plants disappeared, you can't see them anymore. Maybe it's 'cause of dryness, the plants cannot penetrate the surface anymore. (Serj, October 23rd 2006)

4.1.6. *The seasons have changed*

The observation that the summer "was late" (repeated across the desert-steppe) indicates that the herders conceive the seasons as fluid elements, defined by weather and plant phenology rather than as fixed yearly divisions:

> The spring starts right after new year, in February. In the middle of the spring the grass (. . .) starts getting roots (. . .). The summer starts when insects appear. The beginning of the autumn is when the *taana* [Allium polyrrhizum] flower starts to wither. Autumn ends when in the morning you can see water droplets on the grass. Winter begins with the first snow. Now it's much shorter summer, with much less rain. (Khorloo, August 20th 2006)

At the same time as the summer had become shorter, the spring and autumn had become longer. Thus, the most difficult season (spring),[5] prone to storms, cold and changing weather had increased at the expense of the growing season:

> We have big changes in the weather. Spring goes on and on and suddenly it's autumn. We have no summer anymore. (Tsetsegma, August 20th 2006)

Indeed, the connection with meteorological indicators was especially strong for spring as the season of dust storms:

> Q: Are there any changes in the seasons?
> A: Yes, the summer is very short, the spring is very long; the winter is okay, not so cold.

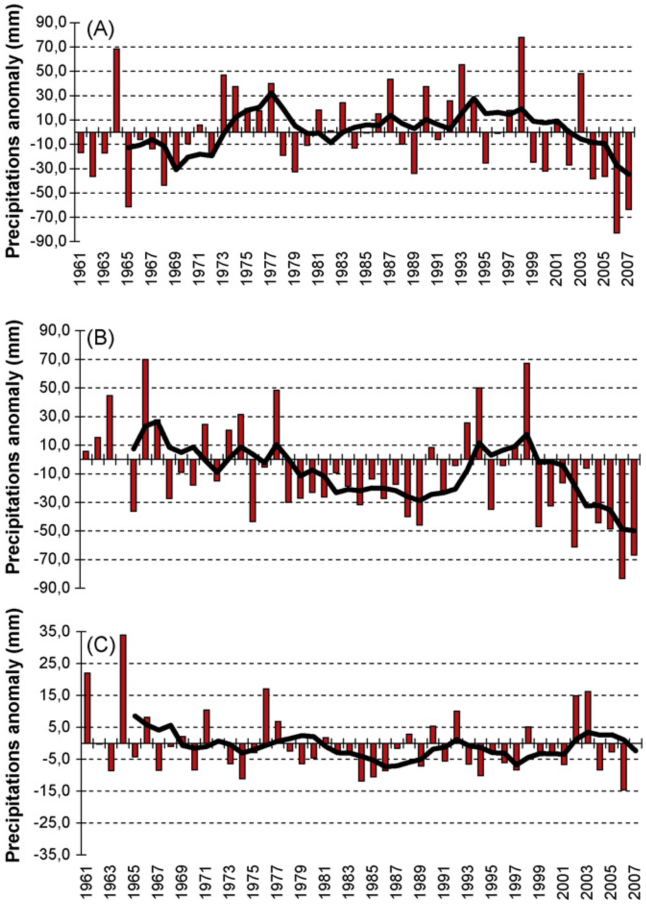

Fig. 4. Yearly (A), summer (B) and spring (C) precipitation anomalies (reference period is 1961–1990) (note the different scale in C).

> Q: How do you see when the seasons start?
> A. We don't know exactly (. . .) just if it's snowing, we say winter is coming, or if there's a sand storm we say spring has started. (Maruush, September 25th 2006)

Herders in the study area consistently reported that during the spring of 2006 they experienced dust storms everyday. The spectre of '100 days of storm' was often quoted and identified as something unusual and extremely damaging:

> From March we had sand storms every day for 3 months. It destroys the vegetation. Even the sheep cannot carry their weight anymore from all the dust in their wool. It's much more sand storm now than before. Some places the sand goes as high as the *ger*. The only plants that survive are the bushes close to the rocks. Those are the only ones which can be grazed. (Purev, August 24th 2006)

4.2. *Evidence of change from instrumental data*

The previous section outlines herders' discourse of climatic change in the desert-steppe, hinged on perceptions of more intense and frequent droughts and dust storms. More importantly, subtle changes in the geographical distribution of rain, its intensity and timing are also significant elements of change, potentially exacerbating the effects of meteorological drought.

These elements of change are now further investigated in light of instrumental meteorological records. Rather than validating the statements of the herders, this analysis is aimed at providing

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[5] In Mongolian lore, spring was referred to as 'the pass of desolation', as opposed to autumn—'the pass of celebration' (Taylor, 1954, p. 351).

additional clues to the understanding of herders' statements and trying to elucidate the context of change from a perspective based on both systematic instrumental records (quantitative) and herders' detailed perceptions (qualitative).

4.2.1. *Precipitation amounts have decreased*

Based on instrumental records from the five weather stations, it is apparent that both yearly and summer precipitation amounts have reduced considerably in the desert-steppe (Fig. 4). Only two of the last 10 years (1998 and 2003) presented above average precipitation amounts, while the period 2004–2007 appears as a drought spell, with 2006 being the driest year on record. More importantly, nine of the last 10 summers are drier than normal, and four of these (1999, 2002, 2006 and 2007) exceed the normal range of variation—the driest summers on record. None of the five stations analysed showed statistically significant trends for either yearly or monthly precipitations except for Ondorshil where precipitations in February had increased ($p = 0.02$) while those in August and September had decreased ($p = 0.001$ and 0.002, respectively).

Fig. 4 also indicates that precipitations have recently become much more variable. In Mandakh for example the coefficient of variation (CV) of yearly precipitation has increased from 30% during 1974–1990, to 59% during 1991–2003, while summer precipitation CV increased from 35% to 72% for the same periods.[6]

4.2.2. *Rains are patchy*

For the following analysis I defined rains that occurred on the same day in at least two locations (of Gurvansaihan, Mandalgovi and Saihanovoo) as large-scale rains, the others were regarded as patchy rains. Patchy rains appeared to provide a much lower amount of precipitation (on average 1.5 mm) than large-scale rains occurring simultaneously in two or three locations (3.1 mm and 4.7 mm, respectively), underlining the importance of the distinction between the two categories.

A monthly non-parametric (MK) trend analysis was performed for the number of days with large-scale rains for each pair of stations and for all three. Surprisingly, the results show some statistically significant *increasing* trends in the total number of days with large-scale rains (Table 1), implying that rains have become better synchronised between Mandalgovi and Gurvansaihan, apparently contradicting herders' evidence. Such a conclusion would be justified if the scale at which this analysis is performed (distance between stations varied from 60 to 200 km) is similar to the scale at which herders record patchiness. This may not be a valid assumption (see Section 5).

Yamanaka et al. (2007b) have showed that soil moisture in the desert-steppe was affected only by rains in excess of 5 mm/day, not by those of 2 mm/day or less. Following this model I divided the rains into three classes: less than 2 mm/day, 2–5 mm/day, and more than 5 mm/day. Trend analyses were performed for the monthly number of rains in the three classes. They revealed that only the rains of less than 2 mm in May ($p = 0.03$) and those of 2–5 mm in May ($p = 0.01$) and June ($p = 0.002$) had become more frequent between Mandalgovi and Gurvansaihan. No significant trends were recorded for the number of days with more than 5 mm/day, suggesting that if rains have indeed become more synchronised, it was only the ones with little influence on the soil moisture and therefore on the pasture.

The diverging trends between rains in excess of 5 mm/day and those providing less precipitation is also evident if we compare the

Table 1
Trends of the monthly number of large-scale rains of four classes (z-score for two-tailed testing, *p*-values indicated for statistically significant trends, empty spaces denote series with standard deviation = 0, and thus incomputable trends).

	Mandalgovi–Gurvansaihan (M–G)				Gurvansaihan–Saihanovoo (G–S)				Mandalgovi–Saihanovoo (M–S)				Mandaalgovi–Gurvansaihan–Saihanovoo (M–G–S)			
	Total	<2 mm	2–5 mm	>5 mm	Total	<2 mm	2–5 mm	>5 mm	Total	<2 mm	2–5 mm	>5 mm	Total	<2 mm	2–5 mm	>5 mm
January	0.7	1.1	−1.1		0.5	0.2			0.4	0.4			0.5			
February	−0.6	−0.2			−0.4	0.1			0.1	0.			−0.8	−2.3 ($p = 0.02$)		
March	0.4	0.4	0.8		−0.6	−0.6			1.1	1.1	0.80		−0.1	0.9		
April	0.4	0.4	0.9	−0.5	0.8	0.2	1.8		−0.4	−1	1.1		0.8	1.8	1.8	
May	2.2 ($p = 0.02$)	2.1 ($p = 0.03$)	2.5 ($p = 0.01$)	−0.7	1.7	1.7	0.7	−0.4	1.2	0.7	1.2	−0.2	2.07 ($p = 0.04$)	0.7	1.4	−0.5
June	2.3 ($p = 0.02$)	1.6	3.1 ($p = 0.002$)	−0.9	0.9	1.4	0.5	−0.9	−0.6	−0.7	−0.1	0.11	0.8	−0.2	0.6	−0.9
July	−0.5	−0.5	0.2	−0.7	0.1	−1	1.2	−0.6	1	0.2	0.2	0.3	0.1	0.9	0.9	−0.8
August	0.3	−0.8	0.8	1	1.1	1.3	0.1	−0.1	2.3 ($p = 0.02$)	0.9	1.5	0.8	1.3	0.2	0.5	0.4
September	−0.4	−0.2	−0.5	−0.41	−0.41	0.8	−1.2	−0.4	1.7	1.2	0.5	0.4	0.7	−0.3	−1.8	−0.4
October	−1.2	−0.6	−1.1	−1.7	−0.5	−0.4	0.4	−0.3	0.5	0.5	−0.1	0.6	−0.5	0.6	0.1	−0.3
November	−0.3	0.1	−1.2		−0.6	−0.2	−1.2		1.3	1.4	−0.5		−0.6	−1.2	−1.2	
December	−1.3	−1	−1.5		−0.6	−0.4	−1.1		−0.1	−0.6	1.3		−0.6	0.8	−1.1	

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[6] Precipitation CVs are usually considered reliable when they cover at least 25 years. Here, given the comparison between virtually equal periods (16 vs. 14 years) the much larger CV is interpreted as a strong indication of recent increased variability.

Table 2
Average number of large-scale rains of different intensities and differences between 1985–1999 and 2000–2005.

Stations combinations	<2 mm/day				2–5 mm/day				>5 mm/day			
	M–G–S	G–S	M–G	M–S	M–G–S	G–S	M–G	M–S	M–G–S	G–S	M–G	M–S
Average 1985–1999	10.1	18.5	10.9	13.4	12.3	22.3	13.9	17.3	1.9	4.4	2.0	3.1
Average 2000–2005	13.5	19.3	14.2	16.8	16.2	25.2	17.5	21.3	0.7	3.0	1.2	1.7
Change in %	34.1	4.3	30.4	23.1	31.1	12.7	26.2	34.6	−64.3	−31.8	−41.7	−46.8

Table 3
Trends of monthly precipitations during growing season at four locations (values are z-scores; *p*-values are indicated for significant trends only).

	Mandakh	Mandalgovi	Saihanovoo	Gurvansaihan
March	1.34	1.40	1.41	0.28
April	0.32	−0.02	0.79	−1.13
May	1.05	−0.20	−0.52	−0.51
June	0.02	−0.02	−1.36	−1.51
July	−1.16	−0.04	0.22	−0.18
August	0.61	0.63	−0.05	−0.18
September	−0.52	−0.65	0.46	2.68 ($p = 0.007$)
October	0.32	0	0.31	1.06

average frequency of large-scale rains for 2000–2005 and 1989–1999 (Table 2). Thus, for all combinations of stations, it appeared that the average number of large-scale rains was much higher in recent years (2000–2005) than during 1985–1999, but only for rains of less than 2 mm/day and 2–5 mm/day. The frequency of large-scale rains in excess of 5 mm/day, on the other hand, had markedly decreased for all pairs of stations (and the region) in the recent period.

4.2.3. Summer rains are delayed

The narratives of the herders would suggest that significant rains come increasingly late. An analysis of the day of the year (DOY) with the first rain in excess of 5 mm showed no significant trends in Mandalgovi, Gurvansaihan or Saihanovoo. Similarly, there was no statistically significant long-term trend for monthly precipitations (Table 3), except for an increase in September precipitations in Gurvansaihan ($p = 0.007$). Although not statistically significant, the signs of the trends indicate that rains during the beginning of the growing season (May–July) may be reducing, while the ones at its end (September–October) are increasing, suggesting a potential delay and shortening of 'summer conditions' (see Section 5.4).

The most important rains in the arid part of Mongolia occur in July. Not only is July the wettest month of the year, the development and growth of pastures seem to be highly dependent on the exact timing and extent of rains in mid-July. If rains occur in mid-July plant biomass may double (Zhang et al., 2005), if they do not, valuable plants may die (Shinoda et al., 2007).

An investigation of the dekadal (sum over 10 consecutive days) precipitations for July shows that at least in one location (Saihanovoo) there is a significant ($p = 0.01$) decreasing trend in mid-July precipitations. The other two stations also show decreasing trends although not statistically significant. Moreover, in years with mid-July precipitation breaks, rains have been documented to be patchy and heavy (Iwasaki and Nii, 2006). The recent increased frequency of such years (Table 4) suggests consistency with herders' observations of patchier and heavier rains.

Table 4
Trends for dekadal July precipitations (z-scores, *p*-value for significant trend) and frequencies of years with mid-July break.

	Mandalgovi (1967–2005)	Saihanovoo (1967–2005)	Gurvansaihan (1985–2005)
1st dekade (July 1–10)	1.14	0.51	0.67
2nd dekade (July 11–20)	−1.13	−2.56 ($p = 0.01$)	−0.36
3rd dekade (July 21–31)	−0.17	0.40	−1.69
Frequency of years with July breaks (%)			
Prior to 1990	23	16	20
1991–2005	46	46	33

4.2.4. The rains are (not) more intense

Two proxies were used for assessing rain intensity. Firstly, average amounts of precipitations during rainy days were calculated for Mandalgovi and Gurvansaihan. There were no significant trends of average amounts for the whole year, the summer (June–August) or July.

Nevertheless, herders are more likely to observe an increased frequency of intense rains, not an increase in the average rain. Therefore, the second proxy employed was the number of days when larger quantities of precipitations occurred, assuming that herders equate hard rains with abundant, heavy showers. I follow again Yamanaka et al. (2007a, p. 268) and consider abundant rains as those in excess of 5 mm/day and sorted rainy days into three classes: less than 2 mm/day, between 2–5 mm/day and more than 5 mm/day. An increase in rain intensity would in this case be reflected in a higher number of days with more than 5 mm/day. The trend in the three classes of rain was analysed over different intervals (year, summer, July)—see Table 5.

In Mandalgovi the total number of rainy days per year increased ($p = 0.0007$), but only rains of maximum 2 mm/day are more frequent ($p = 0.005$). An additional monthly MK test for trend in Mandalgovi shows that these weak rains occur significantly more often only outside the growing season, in October ($p = 0.05$) and November ($p = 0.02$). In Gurvansaihan, the only significant change is an increase in the number of days with 2–5 mm/day during the summer ($p = 0.03$).

The two proxies employed for assessing changes in rain intensity suggest therefore that there has not been any significant increase in rain intensity in the two locations, apparently contradicting the herders' observations. A discussion regarding the relevance of this conclusion and the explanatory power of the two proxies is warranted and included in Section 5.

Table 5
Trends of the number of days with precipitation, by timing and intensity (z-scores; *p*-values).

Rain events by season and intensity	Trends in Mandalgovi	Trends in Gurvansaihan
Annual (all)	3.37 ($p = 0.0007$)	−0.33
Annual, <2 mm/day	2.79 ($p = 0.005$)	−0.42
Annual, 2–5 mm/day	−0.31	1.17
Annual, >5 mm/day	0.25	−0.30
Summer (all)	1.50	0.52
Summer, <2 mm/day	0.18	0.06
Summer, 2–5 mm/day	−0.59	2.15 ($p = 0.03$)
Summer, >5 mm/day	0.51	−0.34
July (all)	−0.73	−0.12
July, <2 mm/day	−0.52	−0.15
July, 2–5 mm/day	−1.83	−0.09
July, >5 mm/day	0.08	−0.03

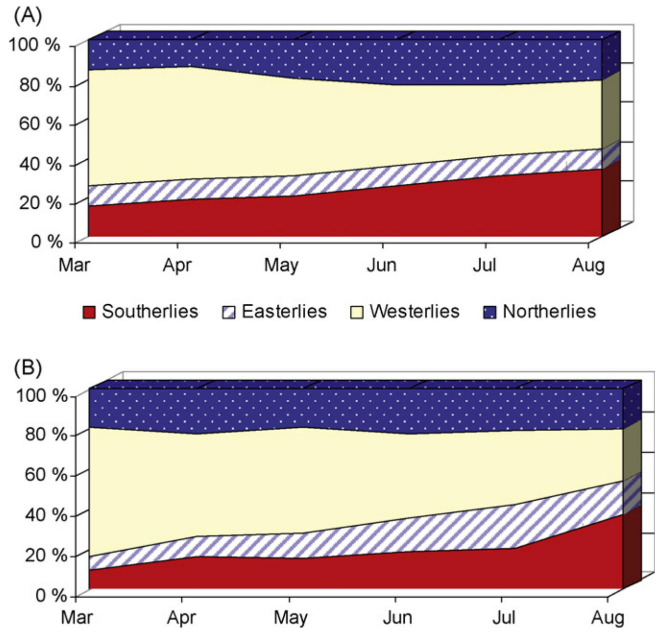

Fig. 5. Relative frequency of wind direction during spring and summer in Mandakh for 1974–2003 (A) and 2006 (B).

Table 6
Trends of the number of monthly cooling days in Mandalgovi, Saihanovoo and Gurvansaihan during spring (*z*-scores; *p*-values).

Spring cooling days trends	Mandalgovi (1961–2005)	Saihanovoo (1967–2005)	Gurvansaihan (1985–2005)
March	−0.92	−0.11	1.13
April	0.70	0.70	0.16
May	−2.38 ($p = 0.02$)	−1.53	−0.56

4.2.5. *Are there more dust storms?*

Two useful proxies for dust storms are the maximum wind speed and the passage of atmospheric cold fronts (Dulam, 2005; Hayasaki et al., 2006). Since most (65–91%) of the dust storms occur during the spring (Natsagdorj et al., 2003), the analysis of these two proxies focused on the period March–May.

An analysis of monthly-averaged maximum wind speed at Ondorshil for the period 1973–2008 revealed no significant trend for any month. Indeed May even showed a marginally significant *decreasing* trend ($p = 0.055$), suggesting that if indeed there are more dust storms, they cannot be explained by an increase in wind speed (see Section 5).

Winds can also contribute indirectly to dust storms by influencing precipitations and aridity. Yamanaka et al. (2007b) have shown that in southern Mongolia predominant wind direction influences precipitation by diminishing convection potential and/or as carriers of moisture from south-east China (see Section 5). In Mandakh, southerly winds were much less frequent than normal in May–July of the drought year 2006, while westerlies and easterlies occurred more often (Fig. 5).

The second proxy, cold front passage, has been approximated by Hayasaki et al. (2006) by cooling days (days in which mean air temperature is at least 5 °C lower than the temperature of the previous day). Table 6 shows that no statistically significant trends were apparent for the number of cooling days at three stations, except for a *decreasing* trend ($p = 0.02$) in May at Mandalgovi station. The results indicate therefore that the two proxies do not support the observations proposed by herders.

5. Discussion

5.1. *More frequent severe drought*

The statements of the herders that climate has changed, bringing the worst weather they had experienced, is largely supported by the meteorological records. In the period 1999–2007, the region has experienced the longest series of droughts and the driest summers of the last 47 years. This situation is broadly consistent with the predictions made for Asia (IPCC, 2007a,b) that the areas affected by droughts and the frequency of extreme events will likely increase. Other studies (AIACC, 2006) have also documented that in Mongolia drought has almost doubled in frequency during the last 60 years and that the worst droughts on record (over 50–70% of the country) have occurred during the last decade. Nevertheless, general circulation models (GCMs) applied to Mongolia have proven highly unreliable since their predictions for temperature and precipitation are very different from the observed values for the reference period 1961–1990 (Natsagdorj, 2000). According to GCMs the desert-steppe region should register an increase in precipitation of up to 220% by 2040 and 240% by 2070 (Natsagdorj, 2000, p. 32)—a highly unlikely prospect given the recent documented trends.

However, herders' distinction between simple lack of rain and drought (an unusually long arid period, potentially changing plant composition and survival) underlines the subjective, contextual nature in which climate changes are interpreted. This is a qualitatively different perspective than standard estimation of meteorological drought (rainfall deficiency when compared to a 'normal' reference period). Despite much of the herders' opinions having been expressed at the time of the severe 2006 drought, the recurrent interviews during the following 8 months confirmed the importance attributed to precipitations qualities: spatial scale, intensity and timing. Moreover, these changes were perceived and described in combination with the changes in dust storm occurrence and intensity. Such an emphasis on qualitative changes rather than on quantities may lead to a more meaningful analysis, relevant to social-ecological systems (Trenberth et al., 2003).

The recent virtual doubling of variability of precipitations in the Mongolian desert-steppe indicates that pasture quantity and quality are increasingly controlled by climate. Ellis (1995) has proposed that pastoral systems with precipitation CV exceeding 33% are non-equilibrial, systems where livestock numbers have limited influence on vegetation dynamics since plants recover faster than livestock after breakdown (Behnke and Scoones, 1993; Ellis and Swift, 1988; Westoby et al., 1989; Wiens, 1984). The arid part of Mongolia has previously been identified as a non-equilibrium region (Ellis and Chuluun, 1993; Fernandez-Gimenez and Allen-Diaz, 1999; Stumpp et al., 2005). The recent doubling in precipitation CV indicates that vegetation dynamics in the desert-steppe are increasingly dependent on climate, rather than the number of livestock. This evidence rejects the understanding that much of Mongolia's pastureland is degraded (Batjargal, 1998; Batkhshig and Lehmkuhl, 2003 in Humphrey and Sneath, 1999; Stumpp et al., 2005) by a too high grazing pressure. From this perspective, the recent high livestock mortality is more likely an effect of tougher climate (although the deaths may have complex, multiple causes) rather than the evidence of unsustainably high grazing pressure.

5.2. *Patchy rains*

The spatial distribution of rains (and consequently of good pastures) is paramount to the welfare of animals and herders' financial and labour investments. Good patches may be large enough to provide browse for a whole season (summer), but if other seasonal pastures are affected by large-scale droughts, herders have to migrate out of their customary orbits, even across administrative borders. On the other hand, if the patches are smaller than the required seasonal needs of each herd, the families have to move camp more often during summer or find alternative winter camps. Such migrations require significant effort on the part of livestock and people alike. Animals may lose weight, miscarry, even die on the way. Herders have to invest more in transportation and labour, and face potential conflicts with local herders and administration. Small patches of good pastures in an otherwise drought-stricken area, may also lead to high densities of livestock and people, precluding rapid livestock recovery and fattening.

There is therefore an important incentive for herders to observe and record the spatial distribution of rains. Their statements regarding the increased patchiness of rains were so consistent and detailed, that they left no doubt regarding their perception: rains *had* become patchier. This observation is further supported by one of the most encompassing studies of climate change in Mongolia showing changes in annual average precipitations during the last 30 years are very localized, decreasing at one site and increasing near by (AIACC, 2006—see their Fig. 2.11). Yet, the statistical analyses of meteorological records seem to contradict this perception. Despite the shortness of the time series for Mandalgovi and Gurvansaihan (possibly allowing a few years with large-scale rains to confound an otherwise patchy rain pattern) the results indicate that large-scale rains have become more frequent.

The apparent contradiction between the statements of the herders and the statistical trends could, in my opinion, be perceived in light of different types of rain identified. The herders seemed to only consider the more abundant rains as significant, worth mentioning, and disregarded the others. Rain abundance was inferred from the duration of rain and rains of 15–30 min were not perceived as important, often not even mentioned since they had no effect on the drought. On the other hand, herders in Ondorshil concurred that the most abundant rains in the area, in the summer of 1998, lasted ‘one day and one night’.

An important caveat here is that even short rains may be abundant if they are intense enough (see next section). Yet, if rains are too intense they are not effective in providing soil moisture. Herders might indeed be able to estimate the quantity of precipitations provided by rain events by observing their effect on soil and vegetation. A recent study from the steppe region showed that patchy rains provided less that 2 mm/day and did not affect soil moisture at 3 cm depth, while regional rains (at 4 stations simultaneously) measured on average more than 5 mm/day (Yamanaka et al., 2007a). Herders can obviously not register the difference between a 2 mm/day rain and a 5 mm/day one, yet by recording a combination of rain’s duration, ‘hardness’ and its impact on soil and vegetation might allow them to distinguish between significant and insignificant rains. This may explain the difference between their perceptions and statistical evidence, since only the rains with limited impact on soil moisture and vegetation have become more frequent, the contradiction is not so evident anymore. Yet, despite an obvious recent decrease in the number of large-scale rains in excess of 5 mm/day, there are no long-term trends to support this change. This may be partly explained by the recent period (2000–2005) coming at the end of a perhaps unusually favourable period, the 1990s with ‘very good weather for the herders’.

Evidence from the region also proposes a mechanism of change that seems to support the perceptions of the herders, that rains have become more localized. Summer moisture in the Mongolian desert-steppe originates most likely in the southern part of China (Yamanaka et al., 2007b) and is transported north by the East Asian Monsoon (Lee et al., 2002). Recently, this monsoon has been gradually weakening as a result of the southward shift of the Asian jet stream (Yu et al., 2004). As a result drought frequency has increased in Inner Mongolia (Yu et al., 2004) and probably in southern Mongolia as well. If this large-scale moisture source is removed, the only moisture source available is locally recycled moisture. This may also explain why the droughts take place in several-year spells (local moisture recycled), interrupted by very moist year, when the monsoon is strong enough to reach Mongolia. In the absence of large-scale moisture supply from the south, rains may become patchy, orographic rains confined to areas with sharp elevation differences. Mountains influence significantly precipitation distribution in Mongolia (Natsagdorj, 2000) and contribute to local convection via valley winds (Iwasaki and Nii, 2006). This mechanism would confirm the predictions (IPCC, 2007b, p. 886) that temperature and precipitation in mountain areas will change over very short distances.

The distribution of rains (and herder households) during the summer of 2006 supports this theory. In three locations across the desert-steppe, herders were confined to the southern slopes of the larger mountains in the area. Sometimes reference was made to pasture only growing in the vicinity of mountains, or that ‘behind the mountain’ (on its northern side) there was no rain. In all three places, herders from several neighbouring *sums* had migrated and spent a few months, leading to densities never-before experienced by the local people. This was an undesirable situation for all parties but legitimized by the scarcity of pastures.

Since the moisture transport over large areas provided by monsoonal flows and other large-scale circulation system is likely to decrease (IPCC, 2007b, p. 879), it is probable that the patchy distribution of rains in the Mongolian desert-steppe will continue.

5.3. More intense rain?

Trend analysis shows that average amounts of rain during rainy days have not changed and that only less abundant rains (of 2 mm/day and 2–5 mm/day) have become more frequent. Apparently, this evidence rejects the claim of the herders that rains have become more intense. There is nevertheless an important qualitative distinction between the observations made by the herders and the meteorological records. Rainfall intensity (a misnomer for rainfall rate) in most analyses is inferred from the average amount of precipitation fallen per unit of time (hour, day), regardless of rain only falling during part of that time. Alternatively, intensity expressed as the amount of rain fallen only during the interval when it rains is more informative of the potential for runoff and soil erosion of any rain event (Trenberth et al., 2003). However, the former definition (rain rate) is most often employed as a proxy for rain intensity, often for want of records of rain duration.

Nevertheless, the herders made it clear that what they perceived was rain’s ‘hardness’, in relation to its impacts on the soil and plants, and its runoff, a quality far removed from precipitation amounts. A study from the steppe region of Mongolia (Onda et al., 2007) showed that peak rain intensity (highest amount of rain recorded in 10 min) was not able to explain variations in runoff and the amount of sediments discharged. Instead, runoff and discharge were much better correlated with the impact energy of raindrops, which in turn was independent of the (peak) intensity of the rain event or its total amount.

Therefore, if herders do record a quality of rain similar to raindrop energy (its ‘hardness’), a comparison between their observations and the evidence suggesting no change in rain rate and in the number of rains with certain rain rates is not meaningful. This incompatibility is nevertheless illustrative of the potential contributions of traditional knowledge to uncovering important but ignored elements of change. The measurement of impact energy may provide a much more useful set of data, but its contribution to trends estimation is limited by the lack of base-line records.

5.4. Delayed summer rains

As other resource-dependent people (see Orlove, 2003), Mongolian herders associate change of seasons with a complex of weather and phenology indicators. Mongolians often refer to the 'summer conditions' (*zunshlaga*) in relation to pastures. Good *zunshlaga* usually suggest abundant fodder (Oyunchimeg, 2002), but herders always used the term to imply abundant rains. It is therefore difficult to relate the observations that the summer is getting shorter to changes in meteorological phenomena (rains) alone. More likely, the observation that summers are delayed and shorter integrates observation of rain occurrence and its effects on the vegetation.

If phenology is used as an indicator of summer start, the occurrence of the first potentially significant rains (>5 mm) could not alone explain the 'summer conditions'. Nevertheless, the negative precipitation trends for May–July (although not statistically significant) and the reduction of the mid-July rains indicate that summer conditions may indeed have worsened, with a negative impact on vegetation.

Iwasaki and Nii (2006) have explained the break in the mid-July rains as a result of the development of a barotropic ridge in Central Mongolia, effectively suppressing all rains except local, heavy rains due to thermally induced local circulation around mountains (Iwasaki and Nii, 2006). On the other hand, Park and Schubert (1997) have proposed that the extended East Asian drought of 1994 was caused by the unusually early development of an anticyclonic flow east of Tibet. This flow, usually taking place in August, started in 1994 in late June/July and resulted in the suppression of monsoonal moisture supply to large areas in East Asia. The anomaly was identified by the authors as a *shortening of the summer*, reminiscent of the herders' statements.

Changes in the temporal distribution of rains are even more important than those connected to their spatial patchiness. The growing season in the Mongolian steppe and desert-steppe ecoregions is controlled to a larger extent by precipitation rather than temperature (Gunin et al., 1999; Hilbig, 1995) and vegetation growth and composition are predicted to be most affected by precipitation changes (Christensen et al., 2004). Moreover, the green-up date depends on the precipitation accumulated during March–May (Lee et al., 2002). Fig. 4c shows lower than normal spring precipitations during 2004–2006, with the spring of 2006 being the driest on record, undoubtedly delaying the start of vegetation growth.

More importantly, vegetation in arid Mongolia grows discontinuously, reacting to moisture pulses (Keller and Hendrix, 1997; Li et al., 2006). The emergence of the important feather grasses (*Stipa* spp.) depends on precipitation that occurs in the previous 5-day period (Shinoda et al., 2007). These species have also developed a mechanism that allows them to grow and reach maturity faster if affected by drought in the early stages of the growing season, but in the case of later drought they may die before reaching maturity (Shinoda et al., 2007). This indeed confirms the observations of the herders that *hialgana* (*Stipa* spp.) does not 'grow with a *shivee* (panicle)' and testify to the severity of the droughts.

The break in the July rains may also result in another very important biophysical impact. It has been shown that additional precipitations of 2 mm/day had no impact on pasture biomass until July 7, but lead to an almost doubling of the biomass and plant cover when the precipitations continued until July 18 (Zhang et al., 2005). This difference was explained by daily evapotranspiration levels more than two times higher in the period from June 1 to July 7 as opposed to the subsequent period.

A turning point seems to exist where plant growth generates more growth by simply lowering evaporation, thus maximizing the marginal utility of rains. This point seems to be, at least for the semi-arid area of Mongolia, sometime in mid-July. If rains occur at that precise time, the effects on vegetation may be disproportionately large. If on the other hand rains fail in the beginning of July the positive feedback mechanism between lower growth and increased evaporation may lead to a decrease in productivity.

The meteorological records suggest less precipitation occurs during June–July, probably leading to reduced biomass, delayed development or even death among plants. If rain breaks in mid-July will indeed become more common this trend would likely be even more dramatic.

5.5. Wind and dust storms

The herders in the desert-steppe refer to the recent dust storms as unusually frequent and intense. Yet, their observations are not supported by trends in maximum wind speed or cold fronts. Given the unequivocal and consistent nature of herders' statements, and the acknowledgement among meteorologists (Dulam, personal communication) that indeed dust storms have become more frequent since 2000, a possible conclusion is that the two proxies may not be good predictors for dust storms. Indeed, Natsagdorj et al. (2003) have shown wind speed had moderate values during dust storms, raising doubts regarding the connection between maximum wind speed and storms. They have also demonstrated a significant increasing trend of the number of days with dust between 1960 and 1989, a development not reflected by trends of either proxy.

Local and regional evidence suggest the higher dust storm frequency and severity is real and the result of a combination of land use change (mining, more traffic on unpaved roads—see Bolortsetseg et al., 2000) and climate change. Zhang et al. (2008) have shown that an important source of dust storms in the area are dried river beds and lakes. During the recent droughts in Mongolia, more than 600 rivers and 700 lakes have dried up (AIACC, 2006). This suggests that the recent surge in dust storms frequency may be, at least partly, explained by the droughts themselves. Goudie and Middleton (1992, see their Fig. 12b) have shown a strong negative correlation between annual amounts of precipitation and dust storms occurrences in Mongolia. Thus, during the dry 1960s, more intense dust-storm activity was registered, compared to the moister period of 1970–1986. This is also supported by the observed decrease in the number of dusty days in the moist period 1990–1999 (Natsagdorj et al., 2003).

Elsewhere, wind erosion during severe droughts has been shown to degrade grasslands and change their vegetation composition (McTainsh and Strong, 2007). In Mongolia, spreading of dust and sand in the spring causes a delay in the green-up of the vegetation (Natsagdorj et al., 2003) and a potential shortening of the growing season by reducing the amount of incoming solar radiation, deposition of sand on top of emerging plants, and increased evaporation.

Moreover, whether winds result into damaging 'dust events' or not depends on very localized soil surface conditions: snow cover, vegetation cover, texture, precipitations (Yamamoto et al., 2007). It is not unlikely therefore that severe droughts, dust/sand storms and vegetation cover may be locked in a positive feedback mechanism which exacerbates the impacts of individual climate changes. This mechanism needs further attention regarding both its causes and impacts.

Iwasaki and Nii (2006) and Park and Schubert (1997) have demonstrated air circulation patterns may inhibit the production of the important large-scale summer rains. The lower relative frequencies of southerlies during the drought of 2006 (Fig. 5) suggests that the moisture supply from the south may indeed have been suppressed, especially since the largest differences of southerlies frequency occur during June–July. Thus, if the larger scale moisture supplied by the East Asian Monsoon is indeed decreasing due to the southern shift of the rain belt (Yu et al., 2004), precipitations in southern Mongolia increasingly depend on local recycled moisture. This recycling process is influenced by local surface heating and winds, in turn connected to vegetation cover. Since vegetation cover depends on the amounts and timing of precipitation, the feedback loop becomes evident. This positive feedback is not explicitly argued for by the herders but it is often suggested by their reflections:

> If we have good grass, there's no sand, and no winds. And that keeps the clouds above this place and so it rains. (Munkhnasan, January 21st 2007)

The mechanism has also been proposed by Xue (1996) based on simulations of the climate changes in the region. The nature of the feedback is nevertheless contentious. Dry soils reduce evaporation and increase heat flux, which may enhance convection and deepen cyclonic systems (Giorgi et al., 1996). If enough moisture is present, precipitation may result, leading to a negative feedback mechanism. If, on the other hand, not enough moisture is present, the heat flux will just reinforce the present dry conditions, in a positive feedback loop (Giorgi et al., 1996). The relative contribution of the these two mechanisms changes according to local conditions (Findell and Eltahir, 1997; Yamanaka et al., 2007b). In the desert steppe of Mongolia, the feedback mechanism seems to be positive at least for anomalous dry conditions, leading to drought spells of several years, but this may be highly dependent on local conditions as suggested by precipitation patchiness. Further investigations into these mechanisms are necessary in order to understand and predict the nature of climate changes and their impacts. The observations of the Mongolian herders may provide important valuable inputs to these investigations.

6. Conclusion

The nomadic herders of Mongolia demonstrate a detailed understanding of weather and climate and provide an account of climatic change that integrates multiple indicators. According to them the dust storms and droughts are more frequent and severe, rains are patchier, less effective ('harder') and delayed. Yet, their evidence of change is only partly supported (or even contradicted) by meteorological records, larger scale predictions and general circulation models.

Much of this divergence can be attributed to the different spatial scale of observation employed by the two systems. By nature of their nomadic lifestyle pastoralists are in the position to gather environmental information (including climatic) over larger areas and with much finer spatial resolution than weather stations which only register point occurrences. In addition, some of the changes documented by herders refer to qualities (e.g. rain 'hardness') and events (e.g. dust storms) not covered by instrumental measurements or downscaled predictions, and thus incomparable.

Mongolian pastoralists are part of a tradition and profession which has gathered, interpreted and transmitted this kind of observations for many generations, strengthening the credence of their claims. As other resource-dependent people (Berkes and Berkes, 2009), they also tend to integrate several variables and focus more on extreme events, unlike scientific models which rely on average changes of individual variables. Herders' evidence suggests the presence of a mental model of normality (Berkes and Berkes, 2009) against which the present situation is assessed. Such a model allows resource users to apply cues or rules of thumb in difficult, extraordinary situations and is founded on observations of extremes and variability, rather than average changes—the domain of trends analyses. The Mongolian nomads articulate a holistic mechanism of change that indicates a possible feedback mechanism between vegetation and local weather, according to which droughts generate more dust storms and more drought due to lack of vegetation cover. These observations support existing (although contentious) predictions and models of environmental change in the area, potentially diminishing their uncertainty.

Finally, the apparent divergence between the two sets of observations may in fact reflect different perspectives. The increase frequency in extreme weather events is not captured by trends analyses; long-term positive trends may conceal short-term (yet devastating) negative developments. For Mongolia, long-term assessments predict a significant increase in precipitation (Natsagdorj, 2000), in sharp contrast to the recent drought spell. The disastrous impacts of the recent bad period points therefore to the need to ingrate the two time scales in analyses of potential impacts of climate change. A combination of drought and dust storms, even if short-lived, leads to compounded negative impacts larger than the sum of individual events, potentially pushing herders into lasting vulnerability traps. Policy recommendations addressing these situations cannot therefore avoid integrating shorter perspectives into their analyses.

The present article uses the example of Mongolian pastoralists to argue that local environmental knowledge of resource-dependent people may significantly improve assessments of climatic change and impacts thereof. Climate change is a complex system phenomenon and should therefore be investigated at multiple geographical scales (Berkes and Berkes, 2009). Local environmental knowledge provides observations and interpretations at smaller geographical scales, where systematic meteorological records are often scarce and predictions of climate change and its impacts are most uncertain. These observations not only provide information regarding local perceptions of *what matters*, what locals identify as dangerous changes (Dessai et al., 2004), they also provide a more reliable answer to the question 'Vulnerable to what?' (Blaikie et al., 1994, p. 9). In addition, they may also offer a valuable source of local observations which can be used for a more rigorous choice of scenarios and models of change, an alternative to potentially flawed 'best guesses' and expert-judgements (Carter and Hulme, 2001; Keith, 1996). I submit therefore that combining the knowledge of local resource-dependent people with evidence provided by formal climatology analyses holds the potential to reduce uncertainty and increase the relevance of future assessments of vulnerability and adaptations to climate change.

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