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学位論文要旨

氏名: 小池崇子

題目: Synoptic climatological study on extreme weathers in Mongolia
（モンゴルにおける異常気象の総観気候学的研究）

Mongolia's territory is landlocked and sits at relatively high altitudes. This geographic location has a continental, dry and cold climate. In such a severe climate, people have continued nomadic life for long time. Stock-farming is still one of basic industries in Mongolia. However, stock-farming is affected directly by weather and pasture conditions. Especially, extreme conditions such as dzud and drought leads to marked loss of livestock. Dzud is a Mongolian word for disastrous livestock loss caused by harsh winters, but often influenced also by drought in the previous summer. There are several forms of dzud, depending on the characteristics, contributing factors and causes. For example, cold dzud is caused by extremely low temperature. White dzud is caused by of deep snow cover, which prevents livestock from feeding fodder. Melted snow cover and liquid precipitation freeze, and form icy ground surface which prevents livestock from feeding fodder. That is called iron dzud. Combination of these different dzuds is called combined dzud. So far, there has been very few systematic investigations to relate the dzud-causing extreme weathers to large-scale synoptic patterns. This background motivated us conduct a synoptic climatological study on extreme weather in Mongolia. The present study focused on two typical extreme weathers; One is deep snow cover which may cause white dzud, while the other was temperature drop. This may cause cold dzud and iron dzud, and often occurs in conjunction with snow storm and/or dust storm.

As for the white dzud, Eurasian snow cover in spring has followed a decreasing trend since the mid-1960s, but winter conditions remain unknown because of a lack of data. To address this issue with a regional focus on the eastern part of Eurasia, we conducted an observational study of winter temperature, precipitation, and snow depth in Mongolia and the associated atmospheric circulation. We used the meteorological data at 21 representative Mongolian weather stations for four winter months (November to February) from 1960 through 2007. Time series analysis was applied to three indices: standardized deviations from the mean for this 4-month period averaged over the 21 stations in Mongolia for snow depth (SI), precipitation (PI), and temperature (TI). This time series analysis revealed a significant multi-decadal trend in temperature, but not in snow depth. We focused on deep-snow winters with SI values higher than 0.5. During the 1960s and 1970s deep-snow winters coincided with extreme cold. However, beginning in the winter of 1992–1993, a new type of deep-snow winter with warmer conditions has occurred in some years. We defined deep-snow winters with a positive TI as warm-deep-snow winters and those with a negative TI as cold-deep-snow winters.

Moreover, a synoptic analysis was applied to the composites for the cold- and warm-deep-snow winters. The synoptic analysis at the 500-hPa level demonstrated that a trough that is usually climatologically located east of Mongolia extended westward to Mongolia during the cold-deep-snow winters. This indicates that enhanced cold surges from the north to Mongolia led to the historically typical deep snow conditions. On the other hand, the warm-deep-snow winters were characterized by a weakened trough, weakened cold surges, and concurrently intensified moisture transport from the west into Mongolia at the 775-hPa level. Two maximum axes of westerlies are climatologically located north and south of Mongolia. In the cold and warm winters, the southern and northern maximum axis, respectively, of the westerlies were enhanced in conjunction with the intrusion of cold air towards the areas delineated by the axis. The new circulation pattern observed here shows that warm winters, which may become more frequent in the future. In cold-winter regions such as Mongolia (with temperatures largely below 0 ºC), warm winters still have the potential to produce deep snow owing to increased water vapor flux, even though the spring snow cover is decreasing in Northern Hemisphere. Therefore, in future investigations, attention should be paid to the possibility that white dzud may occur more frequently in conjunction with increased warm-deep-snow winters.

Not only deep snow but also drastic temperature decreases after precipitation in the cold season, and sometimes even in the warm season, can harm livestock, often leading to high stock mortality. We investigated seasonal and regional temperature changes before and after precipitation in Mongolia. We conducted a time-series analysis of changes of temperature relative to daily mean temperature at 25 weather stations (including the 21 weather stations for snow data above mentioned) before, on, and after days of precipitation. We categorized the relative temperature time series into three types: peak shaped (P), valley shaped (V), and reverse S-shaped decreasing (D), which characterized spring–summer, winter, and autumn, respectively. We produced 11-day time series of relative temperature centered on precipitation days for each precipitation event at each station from 1961 to 2007 and applied principal component analysis to the relative temperature time series. Our results show that the first principle component (PC1) pattern is V-shaped, and the principal component analysis scores tended to be negative in winter and positive in spring. The PC2 pattern was closely related to the D-shaped trend of relative temperature, and the scores were positive from autumn to early winter and negative from spring to summer. Synoptic weather pattern analysis and time series analysis of temperature, wind, advection, and precipitation at the representative weather station and/or its nearest grid point of the reanalysis data before and after precipitation days elucidated the spatial patterns of temperature advection forming each temperature change pattern. In general, both the P- and V-shaped trends accompanied the passage of a cold front. The P- or V-shaped was determined by the thermal conditions of the background air mass into which the contrasting air mass invaded to produce a precipitation-bearing front. The D-shaped RT trend is accompanied by the southward migration of a cold air mass occurring mainly during the transition from autumn to winter.

To investigate temporal variations of temperature, radiation components, and precipitation, a detailed time series analysis before and after a precipitation event was made. The time series in summer showed that in addition to the effect of advective cold air, reduced solar radiation due to increased cloud cover and reduced sensible heat flux on the precipitation day suppressed diurnal temperature increases and contributed to the relatively low daily mean temperature of the V-shaped trend. In contrast, time series in winter showed that daily temperature was highest on the precipitation day, even though solar radiation was reduced. Increased solar radiation after the precipitation day did not immediately cause an increase of daily mean temperature; rather, the daily temperature continued to decrease. Low solar radiation due to low angle and short time day light, high albedo due to snow cover, and very low downward long-wave radiation from the cold air mass resulted in low net radiation, causing a low sensible heat flux.

The spatial distribution of the weather station averaged PC1 score for January showed large negative values (P shape) in the west and north of Mongolia. the weather station averaged PC1 score was negatively correlated with the weather station averaged precipitation intensity. The spatial distribution for May exhibited large positive values (V shape) in the east and south of Mongolia. The PC1 score for May was positively correlated with precipitation intensity. Correlations of individual PC1 scores with precipitation intensities (mm d^{-1}) at each event were significant for some stations. Significant negative and positive correlations were observed for January and May, respectively, which implies that when precipitation is more intense the amplitudes of the P- and V-shaped patterns increase. Larger amplitudes indicate a large contrast in temperature between two air masses forming a cold front. Intense precipitation events were associated with large temperature changes, that is, with large thermal contrasts in two air masses.

In brief, larger amplitude of temperature change before and after precipitation, caused by stronger contrast of two air masses which forms a cold font, produced larger amount of precipitation. Both in cold-deep-snow winters which had enhanced cold surges, and in warm-deep-snow winters which had enhanced warm wet air intrusions, the contrast between cold and warm air masses was strong producing more amount of precipitation leading to deep snow cover.