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学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Statistical and numerical study of hot extremes in Mongolia: possible contribution of soil moisture to the recent increase in heat waves
(モンゴルにおける極端高温に関する統計解析と数値実験：　近年の熱波増加に対する土壌水分の寄与の可能性)

The Intergovernmental Panel on Climate Change 5th assessment report documents a warming trend of 0.85ºC during 1880–2012 in the global average combined land and ocean surface temperature. Due to climate change, the frequency and intensity of extreme weather events have increased since the 1950s, particularly over Europe, North Asia, and Australia. In this study, temporal and spatial change in hot extremes around Mongolia is investigated. Meteorological station and reanalysis data are used to investigate hot extremes around Mongolia in the past 30 years. The observation data at 70 meteorological stations during the summer of 1981–2010 is obtained by Mongolian National Agency of Meteorology and Environmental Monitoring (NAMEM). The hot day is assigned when daily maximum air temperature exceeds a threshold temperature determined as 95th percentile during 1981–2010 at each station. Heat wave (HW) is defined as a number of days when a daily maximum temperature is at least 5°C higher than its climatological mean (1981–2010) of a corresponding calendar day and this requirement satisfied at least 4 consecutive days. One-day discontinuity preceded and followed by 3 consecutive days, which satisfied the threshold, are added as HW. In addition, widespread HW is determined when more than a half of 70 stations observed HW simultaneously. During 1981–2010, observed June-July-August (JJA) mean daily maximum temperature and hot days are increased 1.21°C decade^{-1} and 3.7 days decade^{-1}, respectively with a sudden increase in the 2000s. A similar trend is identified for HW. Further analysis by using NCEP/NCAR reanalysis 1 data reveals that the change in HW is statistically significant for successive two decades around Mongolia that no other places in the northern Eurasia had a similar trend.

To discuss a possible mechanism for locally increasing HW trend around Mongolia, atmosphere and surface conditions are investigated. A 10-year mean JJA geopotential height pattern indicates high pressure anomaly was intensified at 500-hPa level over Mongolia in the 2000s, suggesting a zonal wave propagation with positive anomaly over Europe and Mongolia and negative anomaly over Central Asia. Moreover, a composite of 500 hPa geopotential height pattern during widespread HW in Mongolia exhibits a ridge covering over Mongolia together with similar ridge and trough structure over Europe and Central Asia, respectively. To capture this dominant atmospheric circulation pattern, a new index, called atmospheric circulation forcing (ACF), is introduced. The ACF is defined as the number of days per year when the geopotential height difference at 500 hPa between the Taklimakan Desert (40°N, 80°E) and the area around Lake Khovsgol (50°N, 100°E) is equal or less than 50 m over more than 3 consecutive days. The HW frequency during 1981–2010 increases with ACF ($r = 0.74$) that suggests atmospheric circulation is the key driver for HW. Data analysis demonstrates that modest HW appears along with wetter soil moisture. Despite the similar ACF condition, the maximum surface air temperature is responded differently according to soil moisture condition; larger (smaller) air temperature increase for the drier (wetter) soil condition, suggesting the importance of soil moisture on the HW intensity. However, under drying soil moisture and increasing HW during the analysis period, the role of soil moisture for controlling the HW intensity is yet controversial. An additional observational data analysis for each HW event during the 2000s indicates that the rate of temperature increase prior to HW is sensitive to the soil moisture condition. For the drier soil moisture condition, preceding warming before HW onset tends to begin earlier while under wetter soil moisture condition it tends to occur more slowly with a few days delay. Therefore, it is suggested that the recent drier soil conditions played a role in enhancing the frequency and intensity of HWs. Furthermore, the significant soil moisture decrease around the Mongolia causes a northward expansion of low soil moisture zone, which is also connected with the localization of HWs around Mongolia.

The reanalysis and observation data analysis suggests a possible contribution of soil moisture for the local intensification of HW in the 2000s. However, soil moisture deficit can be the result rather than the cause of recent HW increase because of soil moisture and atmosphere coupling. To evaluate the role of soil moisture quantitatively, numerical experiments were conducted by the Weather Research and Forecasting (WRF) model from May to August during 1981–2010. The initial and boundary conditions are obtained by 6-hourly ERA-interim data. The model domain has 340×260 grid points with a resolution of 20 km that centered in Mongolia. A simulation with realistic soil moisture successfully reproduces recent increase in HW in Mongolia although the model underestimated the observed daily maximum temperature and HW by 3.5°C and 1.2 days $year^{-1}$, respectively. Several sensitivity experiments were conducted for 2007 summer under the same atmospheric circulation at the lateral boundary; only the difference is initial soil moisture conditions in May that are ±20%, ±40%, and ±60% relative to its actual value. During the numerical experiment, soil moisture can evolve interactively with the atmospheric processes. The extreme dry (wet) simulation with −60% (+60%) initial soil moisture anomaly demonstrates drastic increase (decrease) of HW by 69.0% (67.3%) during the summer of 2007. Moreover, the model experiments confirm the delayed onset of HW under wet soil moisture condition. Therefore, this study concludes that slowly but steadily long-term soil moisture drying appears to be responsible for the recent increase in HW around Mongolia, together with the atmospheric circulation change by regulating surface energy partitioning that pushes near surface air temperature efficiently.