Journal of Hydrology (2007) **333**, 21–34

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Isotopic variation of precipitation over eastern Mongolia and its implication for the atmospheric water cycle

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Received 29 August 2005; received in revised form 23 February 2006; accepted 24 July 2006

KEYWORDS
Atmospheric water cycle;
Stable isotope;
Rayleigh model;
Continental recycling;
Mongolia;
RAISE

Summary To investigate the atmospheric water cycle over eastern Mongolia and its surrounding regions, a monitoring network for stable hydrogen and oxygen isotopes in precipitation has been established. We obtained 66 monthly samples at six stations for a year from October 2002 to September 2003 and 204 daily samples at seven stations during the warm period from April to September of 2003. The observed isotopic composition showed considerable coherence in space and was characterized by a strong correlation with air temperatures (and a weak correlation with precipitation). A Rayleigh-type model involving the temperature and amount of precipitation successfully reproduced day-to-day variations in the observations with root mean square errors of 30‰ for δD and 2.7‰ for δ^{18}O. This good reproducibility demonstrates that isotopic variation of precipitation can be explained by rainout history during transportation from a single vapor-source reservoir. The conditions of the reservoirs generally corresponded with those for a subtropical marine atmosphere, indicating that continental recycling generally has a minor effect at least on the temporal variability of isotopes in the precipitation. In July, however, observed δ values were very much lower than predicted. Considering the atmospheric circulation pattern and its relationship to isotopic data, it is inferred that the additive water vapor with low δ might be supplied from regions in the south (e.g., rice paddy fields in southeast China). Transient eddies can play an important role in transporting such water vapor to eastern Mongolia.

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0022-1694/$ - see front matter
doi:10.1016/j.jhydrol.2006.07.022

Introduction

Objectives

The Mongolian landscape changes from desert in the south, through steppe in the middle, to forest in the north. Such an ecological transition zone (i.e., ecotone) is considered to be highly vulnerable to future climatic change including global warming (Roberts, 1994), and northeast Asia has indeed experienced one of the strongest warming signals on earth (Hansen et al., 1999; Chase et al., 2000). Global warming as an external force could potentially induce further changes in the local climate, hydrological cycle and ecosystem in Mongolia through interactions among them. According to numerical experiments, replacement of Mongolian grasslands with desert could reduce rainfall over and around the region through modification of water and energy exchanges between the land surfaces and the atmosphere (Xue, 1996). In fact, the summertime precipitation in Mongolia has shown a significant decreasing trend since the mid-1950s (Yatagai and Yasunari, 1995), although there are still uncertainties as to the mechanisms causing precipitation variability.

In order to understand precipitation variability and its relationship to land surface changes, it is essential to know the sources and transportation patterns of atmospheric moisture (e.g., Koster et al., 1986; Trenberth, 1999; Simmonds et al., 1999). Stable hydrogen and oxygen isotopes that constitute precipitating water molecules can be powerful tools in assessing these subjects (e.g., Yamanaka et al., 2002; Yoshimura et al., 2003). In the present paper, we address the atmospheric section of the hydrological cycle using isotopic tracers focusing on the Kherlen River basin, which occupies approximately one third of eastern Mongolia, under the framework of the The rangelands atmosphere–hydrosphere–biosphere interaction study experiment in northeastern Asia (RAISE) project (Sugita et al., this volume). Concrete objectives were twofold: (1) to clarify the characteristics of isotopic variation in precipitation over eastern Mongolia, and (2) to understand the mechanisms of the variation in terms of the continental-scale atmospheric water cycle. The following subsections summarize previous studies on the atmospheric water cycle and isotopes in precipitation over eastern Eurasia, and ''Materials and methods'' describes the methodology of the isotopic monitoring and meteorological data set utilized for the analysis. ''Fundamental characteristics of isotopes in precipitation over eastern Mongolia'' presents the fundamental features of the observed results, and in ''Application of a Rayleigh-type model involving temperature and amount effects'' a model to investigate isotopic variability and atmospheric hydrology in detail is proposed and tested. Finally, a general discussion and conclusions are given in ''Summary and conclusions''.

Previous studies on atmospheric moisture transport and recycling in northeastern Eurasia

Trenberth (1999) has presented seasonal mean fields of vertically integrated water vapor flux over the globe. According to these, zonal moisture transport is dominant throughout the year with strong westward components in the tropics and eastward components in the mid latitudes, whereas a southwesterly flux over the northern Indian Ocean and a northward flux over eastern China are strengthened in June, July and August (JJA) by the Asian summer monsoon. Simmonds et al. (1999) has decomposed the total summer moisture flux into mean and transient (less than a seasonal time scale) eddy components, and it was found that northward transport due to transient eddies is remarkable over northeastern Eurasia. In other words, atmospheric moisture transported by the mean flow from the northern Indian Ocean and western Pacific is further transported to higher latitudes by transient eddies. Eastern Mongolia (in contrast to western Mongolia) is clearly in the range of the transient moisture flux from the south, although the magnitude of the flux is less than that of the mean westerly flux across the Eurasian Continent.

Numaguti (1999) has assessed the origin of precipitating water over the Eurasian Continent using an atmospheric general circulation model (AGCM) with tagged waters. He showed that most waters precipitating over northeastern Eurasia ultimately originate from the northwestern Pacific, the northern Atlantic (both including the subtropics) and the northern Indian Ocean, while they experience a recycling process (i.e., having fallen onto the ground as precipitation they are then re-evaporated into the atmosphere) two or more times on average during JJA. It is noteworthy that the annual (JJA) mean ratio of precipitating water supplied most recently from the continent via evapotranspiration is calculated to exceed 0.5 (0.8) over northeastern Eurasia. Similar results for the continental recycling ratio have been obtained from another AGCM (Koster et al., 1986) and a simpler tagged-water transport model (Yoshimura et al., 2004b) driven by external meteorological forcing assuming a vertically well-mixed atmosphere. However, Bosilovich (2002) has shown that the vertical distributions of local (e.g., continental) and remote (e.g., oceanic) sources of water vapor can be different and that their relative contributions to precipitation and total precipitable water can also be different. These findings indicate not only the limitation of the ''well-mixed'' assumption but also the strong dependence of estimates against parameterization schemes in GCMs, such as cumulus convection.

Consequently, atmospheric moisture transport over northeastern Eurasia seems to be very complicated because the region is far from any ocean as the ultimate origin of the atmospheric moisture and has many potential sources for precipitation other than the ocean such as the semi-arid grasslands of central Asia, the boreal forest of Siberia, and the rice paddy fields of southeast China.

Previous studies on isotopes in precipitation over northeastern Eurasia

Stable hydrogen and oxygen isotopes in precipitation have been used for tracing the atmospheric water cycle. The major advantage of this approach is the capability of bringing out information about the real world, not a virtual world as in GCMs, even though there remain some limitations and uncertainties. To characterize the isotopic variability in precipitation, global network for isotopes in precipitation