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Influences of large-scale convection and moisture source on monthly precipitation isotope ratios observed in Thailand, Southeast Asia

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ABSTRACT

Many paleoclimatic records in Southeast Asia rely on rainfall isotope ratios as proxies for past hydroclimatic variability. However, the physical processes controlling modern rainfall isotopic behaviors in the region is poorly constrained. Here, we combined isotopic measurements at six sites across Thailand with an isotope-incorporated atmospheric circulation model (IsoGSM) and the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model to investigate the factors that govern the variability of precipitation isotope ratios in this region. Results show that rainfall isotope ratios are both correlated with local rainfall amount and regional outgoing longwave radiation, suggesting that rainfall isotope ratios in this region are controlled not only by local rain amount (amount effect) but also by large-scale convection. As a transition zone between the Indian monsoon and the western North Pacific monsoon, the spatial difference of observed precipitation isotope among different sites are associated with moisture source. These results highlight the importance of regional processes in determining rainfall isotope ratios in the tropics and provide constraints on the interpretation of paleo-precipitation isotope records in the context of regional climate dynamics.

1. Introduction

Stable isotope ratios of precipitation have been widely used as hydrological and climatological tracers, due to their variations associated with conditions linked to condensation and evaporation of atmospheric moisture (Cai and Tian, 2016b; Dansgaard, 1964; Gat, 2000; Pfahl et al., 2012; Rozanski et al., 1993; Uemura et al., 2012). For the past 60 years, precipitation isotope ratios have been used for tracking atmospheric water vapor cycling processes at various scales, such as land-atmosphere exchange (Wang et al., 2016a), large-scale transport (Crawford et al., 2013; Dansgaard, 1964; He et al., 2015; Wang et al., 2017; Yoshimura et al., 2003), and cloud-related processes (Cai and Tian, 2016b; Crawford et al., 2017; Pfahl et al., 2012; Wang et al., 2016b, 2017). In addition, the stable isotope records of paleo-precipitation preserved nature archives, such as groundwater (Aggarwal et al., 2004), ice cores (Pang et al., 2014), speleothems (Liu et al., 2014), lake sediments (Leng and Marshall, 2004) and tree-ring cellulose (Royles et al., 2013), provide unique information relevant to paleoclimate and paleohydrology. All these studies require a good understanding of factors controlling isotope variability of modern precipitation. Furthermore, the isotope information has now been assimilated into a local transform ensemble Kalman filter (LETKF) and the Isotope-incorporated Global Spectral Model (IsoGSM) to constrain both the isotopic fields and the atmospheric dynamic fields (Yoshimura et al., 2014).

Traditional applications in hydrology and paleoclimate studies generally depend on empirical relationships between precipitation isotope compositions and meteorological parameters. One difficulty is that these relationships may vary over time and space, especially in tropical and mid-latitude regions (Breitenbach et al., 2010; Rozanski et al., 1993; Xie et al., 2011; Yang et al., 2012). At middle and high latitudes, the most well-known isotope/climate relationship is the linear dependence of precipitation $\delta^{18}O$ on temperature (the temperature effect), while in many tropical and monsoon regions, an inverse relationship between precipitation $\delta^{18}O$ and pre-

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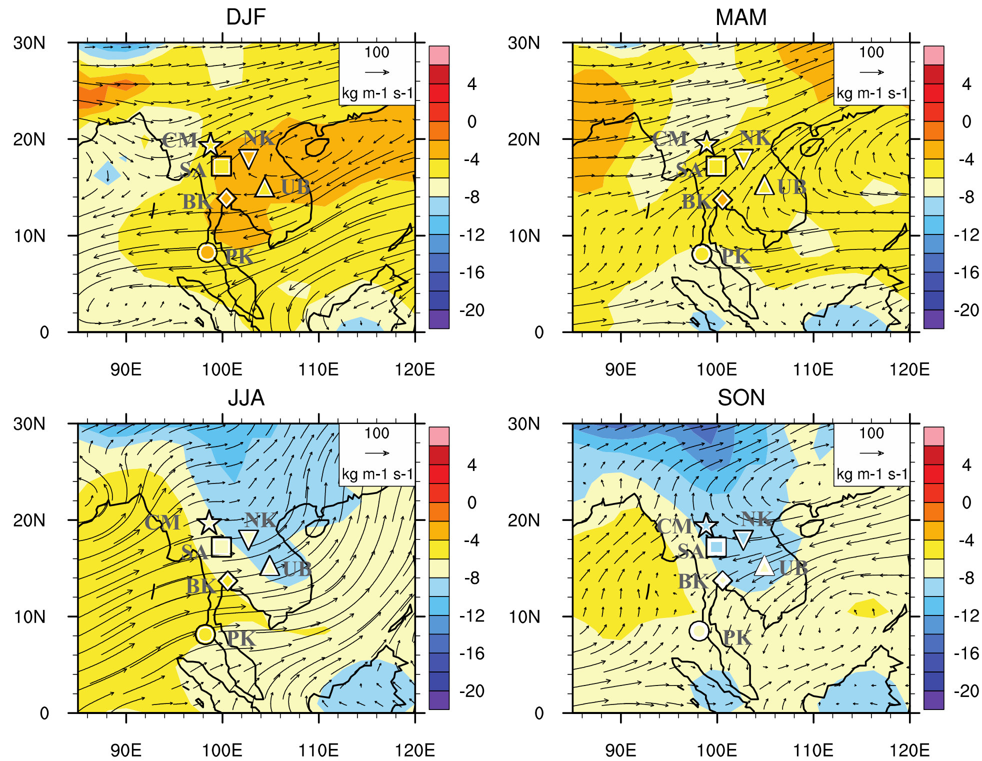

Fig. 1. IsoGSM-simulated spatial distribution of seasonal means of vertical integral water vapor (water vapor transport integrated between the surface layer to 300 hPa level) transport (plotted as vectors) and precipitation isotope ratios (plotted as shading) from 2003 to 2013. (For interpretation of the colors in the figure(s), the reader is referred to the web version of this article.)

cipitation amount (the amount effect) has been observed on the monthly time scale. Additionally, precipitation δ^{18}O is also sensitive to changes in the moisture origin (the source effect) and to the integrated histories of both condensation and mixing with surface flux (continental recycling) during the transport of the air mass from the source to the precipitation site (Risi et al., 2013; Zwart et al., 2016). Furthermore, isotopic enrichment of rain droplets occurs below the cloud base when droplets evaporate (Risi et al., 2010; Tremoy et al., 2014).

In the Southeast Asia monsoon region, the amount effect has often been invoked to explain isotopic variability of precipitation at the monthly time scale (Araguás-Araguás et al., 1998; Breitenbach et al., 2010; Cai and Tian, 2016b; Dansgaard, 1964; Lekshmy et al., 2014; Yoshimura et al., 2003). However, there are exceptions to this inverse relationship (Kurita et al., 2009; Rozanski et al., 1993; Tang et al., 2015; Yang et al., 2012). Recent studies suggest that precipitation isotopes in this region are clearly related to regional processes rather than to local precipitation amount (Kurita et al., 2009; Rozanski et al., 1993; Tang et al., 2015; Yang et al., 2012). Large-scale convection and moisture sources probably play an important role in the variability of the isotopic composition of precipitation (Cai and Tian, 2016b; Tang et al., 2015). Other processes associated with cloud microphysics such as cloud-top pressure (CTP) and cloud-top temperature (CTT) also alter the precipitation isotope ratios observed on the ground (Cai and Tian, 2016b). Globally, stratiform rainfall fraction (SRF) has been found to be more negatively correlated with precipitation δ^{18}O than local precipitation amount (Aggarwal et al., 2016).

These studies have improved our understanding of precipitation isotope systematics of modern precipitation in Southeast Asia. However, as mentioned above, the associated mechanisms still remain a subject of debate. In particular, uncertainties still exist about climate-isotope relationships over time and space, as well as the degree to which climate variables manifest themselves in precipitation isotopes both at the local and at the regional scale. This is partly because isotope records available are too sparse in space and their lengths too short to resolve the spatial and temporal variability of precipitation isotopic composition in this region. In the Global Network of Isotopes in Precipitation (GNIP), multi-year records of precipitation δ^{18}O in this region only exist for Bangkok.

In this study, monthly precipitation isotope records from a network of 6 sites across Thailand are analyzed. This analysis is supported by IsoGSM simulations and back trajectory calculations. We aim to identify atmospheric processes that control the precipitation isotope ratios in this region, improving the interpretation of paleo-isotope records.

2. Data and methods

2.1. Site and measurement

Precipitation isotope data was obtained from a network of six sites evenly distributed in Thailand, including Bangkok (BK), ChiangMai (CM), NongKhai (NK), Phuket (PK), SiSamrong Agromet (SA) and UBonrRatchathani (UB) (Fig. 1 and Table 1). This monitoring network was launched by the University of Tokyo in 2002 and was designed to provide sampling of water isotopes (δD and δ^{18}O) on a daily basis. Between 2002 and 2014, a total of 5239 samples were analyzed in the University of Tokyo Hydrological Laboratory, using a Picarro cavity ring-down spectrometer (model L2120-i). The measurement was normalized to the Vienna Standard Mean Ocean Water and the Standard Light Antarctic Precipitation (VSMOW-SLAP) scale using a two-point linear calibration generated from reference waters supplied by IAEA, with an analytical precision and accuracy of $\pm 0.1‰$ for δ^{18}O and $\pm 1.3‰$ for δD. Detailed information about field sampling and the laboratory procedure is described in Wei et al. (2016). The monthly precipitation δD and δ^{18}O are amount-weighted (Online Supplementary Information). The daily samples that were likely influenced by