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Atmospheric circulation controls on the inter-annual variability in precipitation isotope ratio in Japan

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This study explored the primary driver of variations of precipitation isotopes at multiple temporal scales (event, seasonal and inter-annual scales) to provide a greater depth of interpretation for isotope data in Japan. Using a new one-year record of the isotopic composition of event-based precipitation and continuous near-surface water vapor at Nagoya in central Japan, we identify the key atmospheric processes controlling the storm-to-storm isotopic variations through an analysis of air mass sources and rain-out history during transport of moisture to the site, and then apply the identified processes to explain the inter-annual isotopic variability in the historical 17-year long Tokyo station record in the Global Network of Isotopes in Precipitation (GNIP).

An event-based one-year record of HDO in precipitation at Nagoya in Japan showed less seasonal variations, but there is large variability in HDO on a storm-to-storm basis. In summer, southerly flows transported moisture with relatively higher HDO from subtropical marine regions, and the warm rainfall type was relatively enriched in heavy isotopes compared with the other rainfall events. In contrast, low HDO were observed when northerly winds brought relatively cold air to the observation site. Some of the observed isotopic variability can be explained by changes in air mass sources, however this is not enough to have a large storm-to-storm isotopic range. The additional source of variability is attributed to rainfall amounts occurring both at the site and prior to the site. A clear decreasing trend in HDO with cumulative rainfall over nine-hour back trajectories demonstrates that rainout history plays a dominant role on the storm-to-storm isotopic variability in the summer. The more isotopically depleted precipitation is from large-scale weather systems accompanied by prolonged rainfall over wide areas. In winter, low HDO occurred when a cold frontal rainband associated with extra-tropical cyclones (Nangan cyclones) passed south of the Japan coast. Easterly or northeasterly winds north of the cyclone transport relatively cold air from the mid- or high-latitude regions to the site, and feed the cold frontal rainband. Therefore, the precipitation related to the Nangan cyclone is characterized by relatively lower isotopic values than those from another type of cyclone. It follows that the occurrence of Nangan cyclones is the most likely contributor to changes in winter mean precipitation HDO.

Using the historical record of monthly isotopes in precipitation at GNIP Tokyo station, we explored if factors controlling storm-to-storm isotopic variability can account for inter-annual isotopic variability. The 17-year variation of summer precipitation $H_2{}^{18}O$ was independent of the variation in regional-scale summer precipitation, which is a substitute for cumulative rainfall along the trajectories. On the other hand, year-to-year variation of $H_2{}^{18}O$ related closely to changes in air mass sources. The relatively higher $H_2{}^{18}O$ in summer precipitation corresponded to the higher contribution of warm rainfall to the total summer precipitation, whereas the inter-annual variation of winter precipitation $H_2{}^{18}O$ correlated to the relative ratio of the rainfall from Nangan cyclones to the total winter precipitation. The activity and storm track of intensified Nangan cyclones were responsible for increasing the contribution of cold frontal rainfall fed by northerly winds, and for further decreasing $H_2{}^{18}O$ in winter precipitation. These indicate that inter-annual isotopic variability in winter and summer precipitation in the central Japan is primarily related to changes in meridional moisture transport due to the distinctive difference in isotopic composition between low- and high-latitude moisture.

Keywords: Stable water isotopes, East Asian monsoon, Baiu, Southern coastal cyclone