Isotopic Composition of Rainfall in Thailand Depends on the Convective System

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Abstract

The majority of past precipitation studies investigating stable isotopes and the amount effect have used monthly data. Only a few such studies have incorporated daily observation data in the Asia-Pacific Region. Daily rainfall was sampled at Bangkok and Phuket, Thailand, between August and November, 2001. The isotopic compositions and rainfall amounts at both stations revealed trends similar to each other with respect to monthly variability, but differed with respect to daily variability. Rainfall δ^{18}O decreased as amounts decreased, at both stations, when the rainfall rate was less than 30 mm/day; however, no clear trend was apparent when the rainfall rate exceeded 30 mm/day. Composites of 3-hourly rainfall and relative humidity data for light ($\leq$ 30 mm/day) and heavy ($>$ 30 mm/day) rain events were analyzed to determine diurnal variations. Two rainfall peaks, in the early morning and evening, occurred at Bangkok. Rainfall was more continuous throughout the day, except in the early morning, at Phuket. In addition, relative humidity showed large diurnal variations during both light and heavy rain events at Bangkok. At Phuket, relative humidity during the day for heavy rain events was much higher than during light rain events. Results show that a small number of rain events occurred only in the evening, and followed Rayleigh condensation processes at both stations. However, continuous westerly moisture flux, during heavy rain events at both stations, may violate the closed system assumption that is fundamental to Rayleigh condensation processes. Heavy rain events with different isotopic compositions occurred throughout the day at Phuket. These results suggest that the isotopic composition of rainfall is strongly influenced by cloud systems and formation processes at the collection site.

Keyword: stable isotopes, rainfall, diurnal variation, convective system, Thailand.

1. Introduction

Stable isotopes (δ^2H, δ^{18}O) in precipitation are widely used to infer temperature and precipitation within the global hydrological cycle. Dansgaard (1964) analyzed monthly observational datasets provided by the Global Network for Isotopes in Precipitation (GNIP) project (IAEA, 2001), of the International Atomic Energy Agency (IAEA) and the World Meteorological Organization (WMO). That study revealed a linear relationship between precipitation amount and isotopic composition, or the so-called precipitation amount effect, at low-latitude stations. The precipitation amount effect can be explained by Rayleigh condensation (i.e., enrichment of the atmosphere by evaporation from falling raindrops) and isotopic exchange between falling drops and surrounding vapor. Upwind exchange in organized storm systems is also important for determing isotopic composition (Lawrence et al., 2004).

Araguás-Araguás et al. (1998) revealed the spatial and temporal variability of long-term monthly means of the stable isotopic composition of precipitation over the Asia-Pacific region using GNIP datasets. They highlighted a region where the isotopic composition responded to precipitation amount because the air mass was modulated by monsoon activity and seasonal displacement of the Intertropical Convective Zone (ITCZ). They further reported that seasonal changes in precipitation isotopes in the tropical Pacific were controlled, mainly, by rain-out processes in deep convective clouds and by isotopic exchanges beneath the cloud. Datta et al. (1991) examined temporal variations in the stable isotopic composition of precipitation in New Delhi by statistically analyzing GNIP datasets. They suggested that long-term variability in δ^{18}O may be governed by the intensity and distribution of precipitation, and by the movement of the moist air mass. They also suggested that evaporation of raindrops could isotopically enrich monsoon precipitation.

The GNIP datasets contain monthly averaged values for precipitation amounts and isotopic compositions from 1968 to 1995 at Bangkok (IAEA, 2001). Ichiyanagi et al. (2003) noted a strong negative correlation between long-term monthly means of precipitation amounts and δ^{18}O. These monthly averaged values clearly show the amount effect. The correlation coefficient of 0.98 has a significance level exceeding 95 %. For individual months, negative correlations occurred in May, July, August, October, November, and December. No correlation was apparent in the other six months. To determine the true isotopic composition of precipitation, further analyses using daily or other short-term observations are warranted. A few studies have used event-based isotope data to study variability in the isotopic composition of precipitation. This study examines the amount effect using daily rainfall data observed in Thailand, and elaborates on important processes controlling the isotopic composition of rainfall.

2. Data and Methods

Daily rainfall isotopic data were collected at Bang Na Agromet (13.44°N, 100.34°E) in Bangkok and at Phuket

Airport (8.07°N, 98.19°E) from August to November, 2001, and were subsequently analyzed. Diurnal variability was calculated using three-hourly rainfall and relative humidity data provided by the Thailand Meteorological Department (TMD). There were no 3-hourly data at Bang Na Agromet in Bangkok, so data from Bangkok Metropolis station (13.73°N, 100.56°E) were used instead.

3. Results

3.1. Daily Rainfall Variability

Figure 1 shows daily rainfall and isotopic data at Bangkok and Phuket. Both stations show similar seasonal (monthly) variability trends in rainfall amount and δ^{18}O. Light rain and high δ^{18}O occurred in August and November; heavy rain and low δ^{18}O were common in September and October. Short-term (daily) variability, however, showed a different pattern. At Bangkok, two rainfall peaks occurred on 18 September and 7 October. At Phuket, a large peak at the end of September was followed by intermittent peaks of decreasing magnitude into early November. Phuket had more rainy days than Bangkok; however, both stations had approximately the same number of heavy rain days (> 30 mm/day). The δ^{18}O value was near -5 ‰ until early September at Phuket and until mid-September at Bangkok. Between mid-September and mid-October, sudden δ^{18}O drops to less than -10 ‰ appeared more frequently at Bangkok than at Phuket. Subsequently, δ^{18}O at Bangkok remained at a higher level than at Phuket.

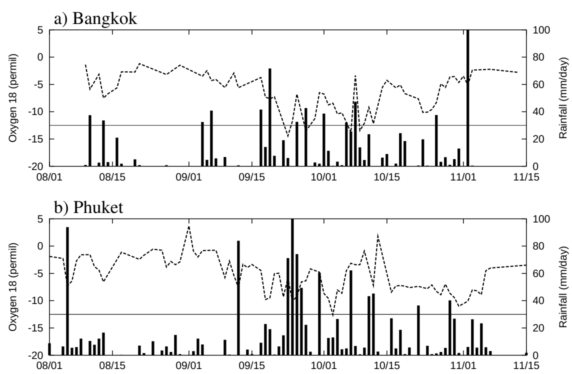

Fig. 1: Time series of daily rainfall (bar graph) and δ ^{18}O (line graph) at a) Bangkok and b) Phuket from August to November, 2001. The solid line indicates 30 mm/day.

Yoshimura et al. (2003) reported similar temporal variability at three stations in Thailand (Bangkok and two stations in northern Thailand) during the 1998 rainy season. In that study it was found that large-scale moisture transport influenced the short-term (daily) variability of rainfall isotopes at all stations. In this study, however, the daily rainfall isotope trends at Bangkok differed from those at Phuket. Phuket's location may explain why its isotopic variability differs from that of other stations in Indochina, in that it is located on the Malay Peninsula and is surrounded by ocean. Ohsawa et al. (2001) also showed the difference in diurnal variation of convective activity between coastal and inland area over Indochina.

Figure 2 shows the relationship between rainfall amount and δ^{18}O at the two stations. Light rain and low δ^{18}O were common at both stations. Njitchoua et al. (1999) reported that low δ^{18}O values accompanying daily rainfall of less than 20 mm were caused either by the condensation of residual vapor in a cloud system or by condensation at high altitudes (low temperatures). Precipitable water vapor, which constituted the rainwater source, was characterized by low δ^{18}O values. Datta et al. (1991) counted the number of days with rainfall exceeding 30 mm, and noted that the monthly δ^{18}O composition was affected by both rainfall amount and temperature.

Heavy rain (about 30 mm/day) and high δ^{18}O samples (more than -10 ‰) are common at Bangkok. Except for light rain/low δ^{18}O and heavy rain/high δ^{18}O samples, decreasing rain amounts are accompanied by decreasing δ^{18}O values. Additionally, there is an obvious negative correlation between rainfall amount and δ^{18}O when daily rainfall rates are less than 30 mm/day at Phuket. The δ^{18}O values ranged from -10 $\sim$ -5 ‰ when daily rainfall rates exceed 30 mm/day. In the next section, the amount effect is examined in relation to light ($\leq$ 30 mm/day) and heavy rain (> 30 mm/day) events.

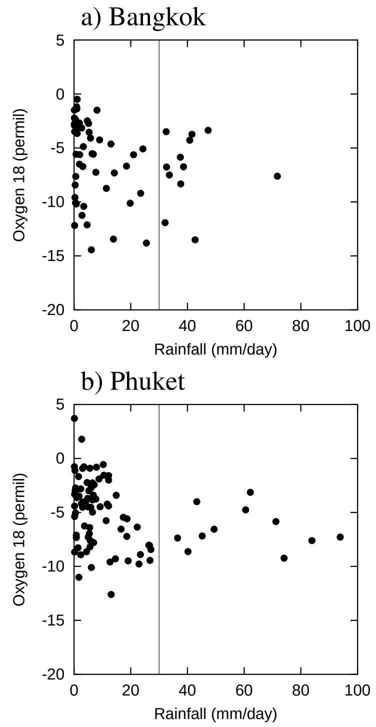

Fig. 2: Scatterplots between isotopic composition and rainfall amount effect at a) Bangkok and b) Phuket. The solid line indicates 30 mm/day.

3.2. Diurnal Variation

Diurnal variations in rainfall intensity, frequency of rainy days, and relative humidity were investigated using 3-hourly routine observations at Bangkok and Phuket. The frequency is defined as the ratio of rainy days to total days from 1 August to 15 November in 2001. Figure 3 shows the diurnal variations in rainfall intensity, frequency of rainy days, and relative humidity composites for light and heavy rain at the two stations. Rainfall intensity at Bangkok shows two peaks (about 4 mm in the early morning and more than 10 mm in the evening) for light rain events and one peak (about 3 mm in the evening) for heavy rain events. The frequency of rainy days also shows two peaks (more than 50 % in the early morning and evening) for light rain events and one peak (more than 30 % in the evening) for heavy rain events. Relative humidity for both events is less than 70 % and more than 90 % during night and day, respectively.

Rainfall intensity at Phuket is less than 1 mm throughout the day for light rain events and more than 3 mm throughout the day, except in the early morning, for heavy rain events. In addition, the frequency of rainy days is less than 40 % for light rain events throughout the day and more than 60 % for heavy rain events throughout the day, except in the early morning. Relative humidity is less than 70 % during the day for light rain events, and more than 80 % throughout the day for heavy rain events.

During heavy rain events at Bangkok, there are two peaks in rainfall, one in the early morning and one in the evening. Rainfall rates are relatively high throughout the day, except during the early morning, at Phuket. Relative humidity shows large diurnal variation for both heavy and light rain events at Bangkok. Relative humidity at Phuket, in contrast, shows large and small diurnal variation for light and heavy rain events, respectively. Relative humidity during the day for heavy rain events is much higher than for light rain events.

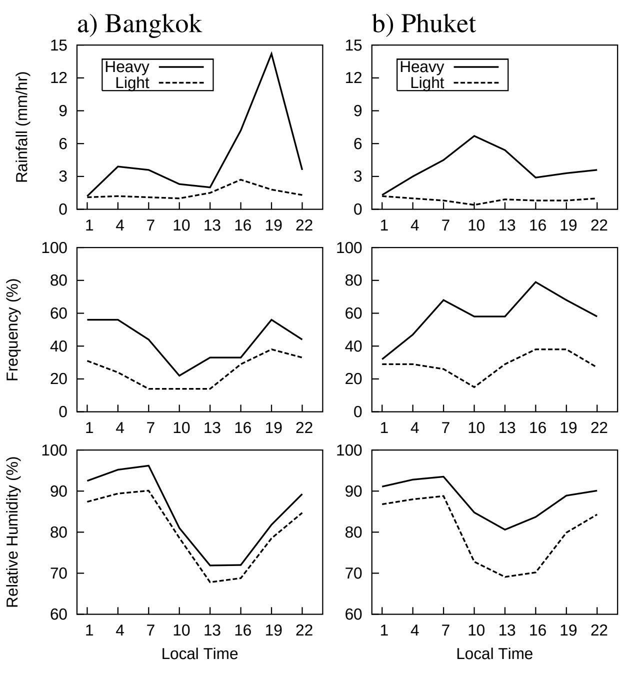

Fig. 3: Diurnal variations in rainfall intensity, frequency of rainy days, and relative humidity for light and heavy rain events at a) Bangkok and b) Phuket.

4. Discussions

These results show that the convective system and rainfall formation process are important for determining the isotopic compositions of rainfall. Light rain and low δ^{18}O, which were caused either by the condensation of residual vapor in a cloud system or by condensation at high altitudes, were common at both stations. Except for some light rain and low δ^{18}O samples, there is an obvious decreasing trend, at both stations, for light rain events: as rain amounts decrease, so too does δ^{18}O. Periods of light rain are characterized by a small number of rain events, occurring in the evening, and a discontinuous westerly moisture flux. The isotopic composition of rainfall at both stations is affected, therefore, by the Rayleigh condensation process, as the amount effect clearly shows.

At Bangkok, heavy rain (about 30 mm/day) and samples with δ^{18}O exceeding -10 ‰ are common. Periods of heavy rain occurred only during the evening, and each event resulted from a deep convective system. Isotopic ratios for convective rains are higher than ratios for stratiform rains (Gedzelman and Arnold, 1994, Fig. 1). Such a continuous moisture flux may violate the closed system assumption that is necessary for Rayleigh distillation processes. At Phuket, δ^{18}O values range from -10 $\sim$ -5 ‰ for heavy rain events. Periods of heavy rain are characterized by many rain events throughout the day, and by continuous westerly moisture flux. Temperature and humidity conditions in clouds can vary greatly during the day, so the isotopic composition of rainfall at Phuket may also differ among individual rain events. The isotopic composition of daily rainfall is the sum of many rain events, which may have different isotopic compositions. Thus, the daily isotopic composition may not show the amount effect during periods of heavy rain.

These results suggest that the type of convective system and rain formation process help to determine the isotopic composition of rainfall. However, Ichiyanagi et al. (2002) noted that flux and the transport path of moisture flux are the main influences on stable isotopes in precipitation. Lawrence et al. (2004) analyzed isotopic variations of rainfall and water vapor in detail using trajectory analysis. They showed that isotope ratios are related to the intensity and organization of storm systems upwind of the collection site; ratios decrease as storm activity and organization increases. Processes controlling rainfall isotopes include rainwater origin, transport processes in the air mass, and formation processes at the collection site. In this paper, the convective system and formation processes near the collection site only were considered. Further studies on transport and formation processes upwind of the collection site are needed to clarify the isotopic composition of rainfall.

5. Conclusions

Daily rainfall samples were collected at two stations in Thailand to examine whether the amount effect affected rainfall isotopes. Rainfall δ^{18}O decreased as amounts decreased, at both Stations, when the rainfall rate was less than 30 mm/day. There is no clear relationship when rainfall rates exceed 30 mm/day. Composites of rainfall and relative humidity were analyzed to compare periods of light ($\leq$ 30 m/day) and heavy (> 30 mm/day) rain.

There are two peaks of rainfall during heavy rain events at Bangkok. One is in the early morning and one is in the evening. Rainfall rates during heavy rain events at Phuket are relatively high throughout the day, except in the early morning. Large diurnal variations in relative humidity occur for both light and heavy events at Bangkok, but for only light rain events at Phuket. The relative humidity during the day in Phuket for heavy rain events is much higher than for light rain events.

For light rain periods, the relatively few rain events occurred only in the evening, and followed Rayleigh condensation processes at both stations. For heavy rain periods, the relatively frequent rain events occurred throughout the day, with different isotopic compositions at Phuket. Furthermore, relatively high humidity condition for the periods of heavy rain at both stations may violate the closed system assumption that is necessary for Rayleigh condensation processes. These results suggest that the cloud system and formation processes near the collection site are important for determining the isotopic composition of rainfall.

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