Moisture sources and transport control year-round variations of stable isotopes in precipitation over Bangladesh

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Abstract

Indian summer monsoon (ISM) has profound impact on water resources over the Asian Water Towers (AWTs) and surroundings. Stable isotopes in precipitation ($\delta^{18}O$ and δD) are crucial tracers of ISM moisture transport processes. Here we presented spatiotemporal variations of stable isotopes in precipitation at three stations over Bangladesh in 2017-2018 to evaluate the influence of moisture sources and transport on intra-seasonal variations of stable isotopes in precipitation, combined with local meteorological data, ERA5 reanalysis data and HYSPLIT model. We found Bay of Bengal (BoB), tropical Indian Ocean (TIO) and Arabian Sea (AS) were the primary moisture suppliers throughout the year and moisture uptake process primarily occurred over BoB. The most enriched $\delta^{18}O$ and δD values exist in the pre-monsoon season, associated with >50% contributions from BoB, and gradually decline throughout the monsoon and post-monsoon seasons due to increased contribution of moisture from AS (~30%) and IO (~40%), and reach to their lowest values by the end of the post-monsoon season when >25% contributed from BoB and ~20% from TIO. The strongly positive $\delta^{18}O$-OLR and negative $\delta^{18}O$-humidity relationships were found at all three stations showing a decreasing pattern from south to north.$\delta^{18}O$-temperature ($\delta^{18}O$-precipitation) relationship was only found at southern stations at local scale. Convective activities over the AS, BoB and northern IO primarily regulate the $\delta^{18}O$ depletion, and a weak (strong) flux-$\delta^{18}O$ relationship for northward (eastward) transport was found. This study could improve understanding of moisture transport by the ISM for our societies to promote the water resource management over AWTs.

Keywords: Indian summer monsoon, deuterium excess, convective activity, meteorological influence, moisture transport

1. Introduction

The Indian summer monsoon (ISM) is directly associated with water resources and hydroclimate-related natural disasters in the Asian Water Towers (AWTs), influencing the lives and livelihoods of more than 2 billion people. Understanding the contribution of moisture transported by the ISM is crucial for the projection of the regional water cycle and evaluation of the water supply from AWTs to surrounding regions [*Breitenbach et al.*, 2010; *Cai et al.*, 2018; *Mukherjee et al.*, 2007]. Instrumental records of traditional meteorological parameters have already provided plenty of information to understand the dynamics of the ISM [*Ahmed and Karmakar*, 1993; *Ananthakrishnan and Soman*, 1988; *Day et al.*, 2015; *Rafiuddin et al.*, 2010]. However, this information is still not enough to illuminate regional moisture transport processes and quantify the moisture contribution from the Bay of Bengal (BoB) to the AWTs. Water stable isotopes, water molecules consisting of stable isotopes of hydrogen and oxygen, were frequently used to quantify atmospheric water budget, predict moisture source region, and track isotopic fractionation occurred at different reservoirs of the global hydrologic cycle. Due to their efficiency as a tracers of water transfer, water stable isotopes can improve our understanding on the variation of ISM throughout Earth's evolutionary history [*Cai and Tian*, 2016; *Chakraborty et al.*, 2016; *Rahul et al.*, 2016; *Yang et al.*, 2016]. ISM-driven moisture from the BoB is transported to the AWTs through Bangladesh (extending from 20°34'N to 26°38'N latitude and 88°01'E to 92°41'E longitude, Figure 1). Therefore, the event-based observations of stable isotopes in precipitation provide a unique tool to evaluate the contribution of different moisture sources and transport to Bangladesh before reaching to AWTs.

Isotopes are atoms of the same element that has the same number of protons in their atomic nucleus with a difference in the number of neutrons. Stable isotopes do not spontaneously decay into another isotope or atom and several naturally occurring stable isotopes of oxygen (^{16}O, ^{17}O, and ^{18}O) and hydrogen (^{1}H and ^{2}H or D) can be found in natural environment. Due to a very small abundance of the heavier isotopes compared to that of the lighter one, the concentration of the heavier isotopes is often expressed as isotopic ratios. Isotopic ratios of ^{18}O and D can be expressed using δ notation as $\delta^{18}O$ and δD. Based on isotopic measurements of meteoric water samples from different parts of the world, *Craig* [1961] established a linear relationship between δD and δ^{18}O:

$$\delta D = 8*\delta^{18}O + 10$$

This relationship is commonly referred to as the global meteoric water line (GMWL). The GMWL serves as a good indicator of post sampling evaporation because samples that did not undergo excessive evaporation will display a strong linear correlation between δD and δ^{18}O. In studying regional and local hydrological processes, the local meteoric water line (LMWL) is used to express the relationship between δD and δ^{18}O in a region. *Putman et al.* [2019] investigated the global distribution of LMWLs and suggested that the δD-δ^{18}O relationship in the LMWL stems from the interplay of water isotope systematics and hydroclimatic seasonality at a given site. Relative differences in geographical location also lead to subtle variations in the slope and intercept of the LMWL [*Putman et al.*, 2019]. Therefore, differences in the slope and intercept between the LMWL and GMWL can be used to trace moisture sources and estimate the degree of sub cloud evaporation [*Putman et al.*, 2019; *Wang et al.*, 2019].

Many previous studies documented the effects of local meteorological variations and atmosphere circulations as well as convective activities on precipitation stable isotopes worldwide. *Dansgaard* [1964] established the 'temperature effect' (decrease in δ-values with increasing temperature) and 'amount effect' (higher δ-values in sparse rain) as two of the important mechanisms controlling stable isotopic variation in precipitation. The amount effect is primarily noticeable in low-latitude regions that are influenced by monsoons, while the influence of the temperature effect is significant in temperate and polar regions [*Zhang et al.*, 2019]. However, the majority of recent studies over the Indian subcontinent suggested that the amount effect is weak and even nonexistent in this region [*Araguas-Araguas et al.*, 1998; *Bhattacharya et al.*, 2003; *Breitenbach et al.*, 2010; *Datta et al.*, 1991; *Midhun et al.*, 2013; *Tang et al.*, 2015].

Investigations of the influences of convective activities and moisture transport processes on precipitation stable isotopes have grown in the past 20 years. *Bhattacharya et al.* [2003] revealed that precipitation stable isotopes at Bombay and New Delhi bear a greater influence to the moisture source region and that lower (higher) δ^{18}O values were associated with oceanic (continentally recycled) moisture sources. *Breitenbach et al.* [2010] studied air parcel travel distance histories during parcel transport from vapor source regions and found that lower (higher) $\delta^{18}O$ values were associated with long (short) transport distances at Southern Meghalaya, NE India. *Lekshmy et al.* [2015] and *Chakraborty et al.* [2016] studied the convective influence on $\delta^{18}O$ and found that lower $\delta^{18}O$ values occur when air parcels come across a convective system over the Indian Ocean. *Midhun et al.* [2018] investigated moisture transport pathways and found that $\delta^{18}O$-depleted (enriched) precipitation events were associated with a higher number of air parcel trajectories originating from the Bay of Bengal (Arabian Sea) branch of moisture transport at six stations across northern and central India. By investigating isotopic relationship between the source moisture, ambient vapor and rainwater, *Sinha and Chakraborty* [2020] suggested that isotopic composition in precipitation over Port Blair, BoB is influenced by the interaction of precipitation with source and ambient vapor. Event scale $\delta^{18}O$ values in precipitation and ambient vapor displayed significant correlation over a wide range of rainfall amount, however, correlation considerably weakened for rainfall exceeding ~36 mm/day. Weaker correlation during heavy rainfall events might have resulted from the limitations of the Rayleigh fractionation and Craig-Gordon Model. Therefore, isotopic variability in source moisture should be considered for the comprehensive isotopic studies over the coastal regions. Their case study suggested that vapor-rainwater isotopic exchange contributes to $\delta^{18}O$ enrichment in subsequent precipitation events. *Tanoue et al.* [2018] reported seasonal variation of stable isotopes in precipitation and the influence of moisture source variation over Bangladesh during January to December 2010. Based on IsoGSM simulations they suggested that moisture from the BoB and Arabian Sea (AS) primarily contributed to pre-monsoon precipitation, while, the influence from the BoB and AS decreased significantly in ISM season when moisture predominantly originated from the Indian Ocean (IO). In post-monsoon season, moisture from Pacific Ocean (PO), BoB and continentally recycled moisture primarily contributed to precipitation over Bangladesh. *Tanoue et al.* [2018] provided an improved understanding on moisture source variation, however, understanding on local and regional meteorological influence is still limited. Moreover, their studies comprising of three stations primarily focused on eastern and central part. however, understanding of isotopic variation over southern part of Bangladesh where ISM moisture makes the first interaction with land is poorly understood.

To improve our understanding of the relationship between moisture sources and stable isotopic compositions of precipitation over Bangladesh, the current study presented the event-based precipitation stable isotopes during February 2017 and September 2018. In section 2, we provide details of study area and data used in this study. In section 3, we probe the local meteorological influence by correlation analysis between event-based precipitation $\delta^{18}O$ and meteorological observations (air temperature, precipitation amount and relative humidity) and regional moisture influence by combined analyses with back trajectory, outgoing longwave radiation (OLR) and regional meteorological elements. Conclusions and perspectives are provided in the last section. This study improved our understanding of the ISM influence on precipitation stable isotopes and could help us to understand behavior of ISM moisture, which is necessary for our societies to address hydroclimatic disasters and promote water resource management over AWTs.

2. Materials and Methods

2.1 Study Area

Located in the tropical monsoon region, Bangladesh is in the south of Himalayas and is southwardly open to the BoB (extending from 20°34'N to 26°38'N latitude and 88°01'E to 92°41'E longitude, Figure 1) where ISM-driven moisture first interact with land on its way to AWTs. The climate of Bangladesh is characterized by moderately warm temperatures and high relative humidity with marked seasonal variations in rainfall related to ISM [*Pour et al.*, 2018]. Four seasons distinguish the climate of Bangladesh, namely, pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-November) and winter (December-February) [*Dewan et al.*, 2018; *Fahad et al.*, 2018; *Pour et al.*, 2018; *Whitehead et al.*, 2018].

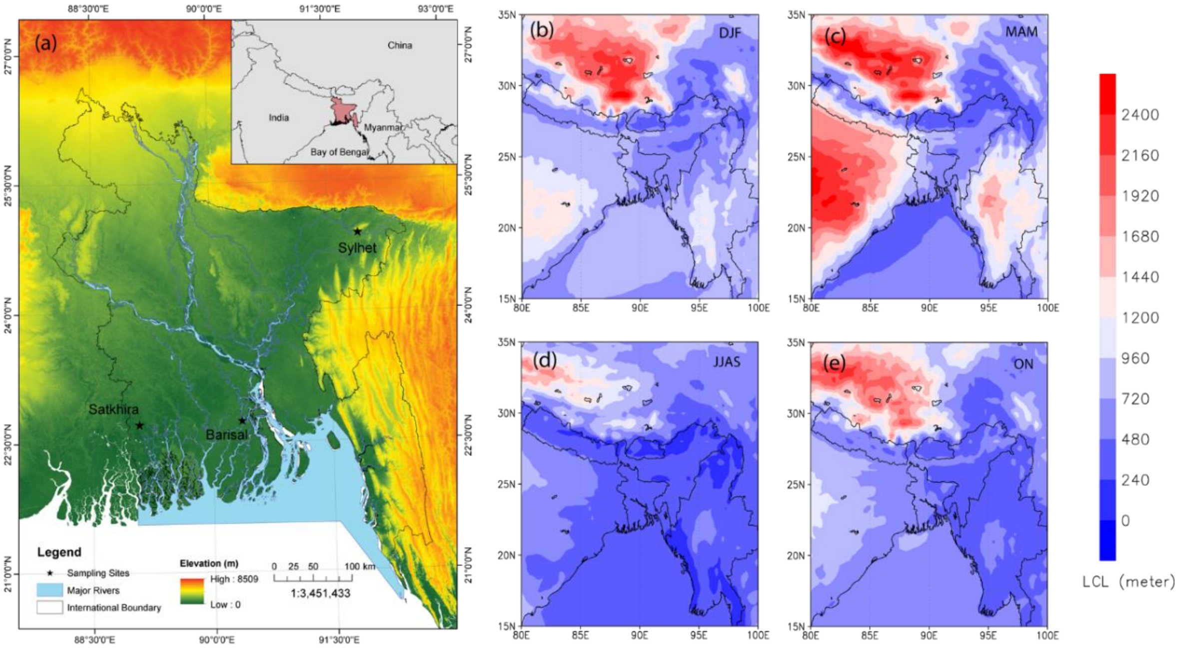

Figure 1: Location of precipitation sample collection sites (a) and 1979-2018 average seasonal lifting condensation level (LCL) climatology over the study area (b-e).

The pre-monsoon (MAM) period is characterized by the highest evapotranspiration rate and temperature with the occurrence of occasional line squalls and tropical cyclones in coastal areas. Nineteen percent of the total annual rainfall occurs in MAM, and the average air temperature ranges between 23.50°C and 30.30°C. Moisture mainly comes from the Mediterranean region, which occasionally contributes to heavy rainfall that causes flooding [*Rimi et al.*, 2019]. In JJAS, more than 70% of the total annual rainfall occurs with the highest cloudiness [*Das*, 2017; *Mullick et al.*, 2019], and the temperature ranges between 27.40°C and 29.80°C. a tremendous amount of moisture is transported through Bangladesh to the AWTs. In The post-monsoon (ON), 8% of the total annual rainfall occurs, and the temperature ranges between 22.20°C and 27.90°C. Only 2% of the total annual rainfall occurs in the winter DJF, and the temperature ranges are between 16.30°C and 23.30°C. In this study, we primarily focused on MAM, JJAS and ON, and exclude DJF because of the very small number of precipitation events in that season.

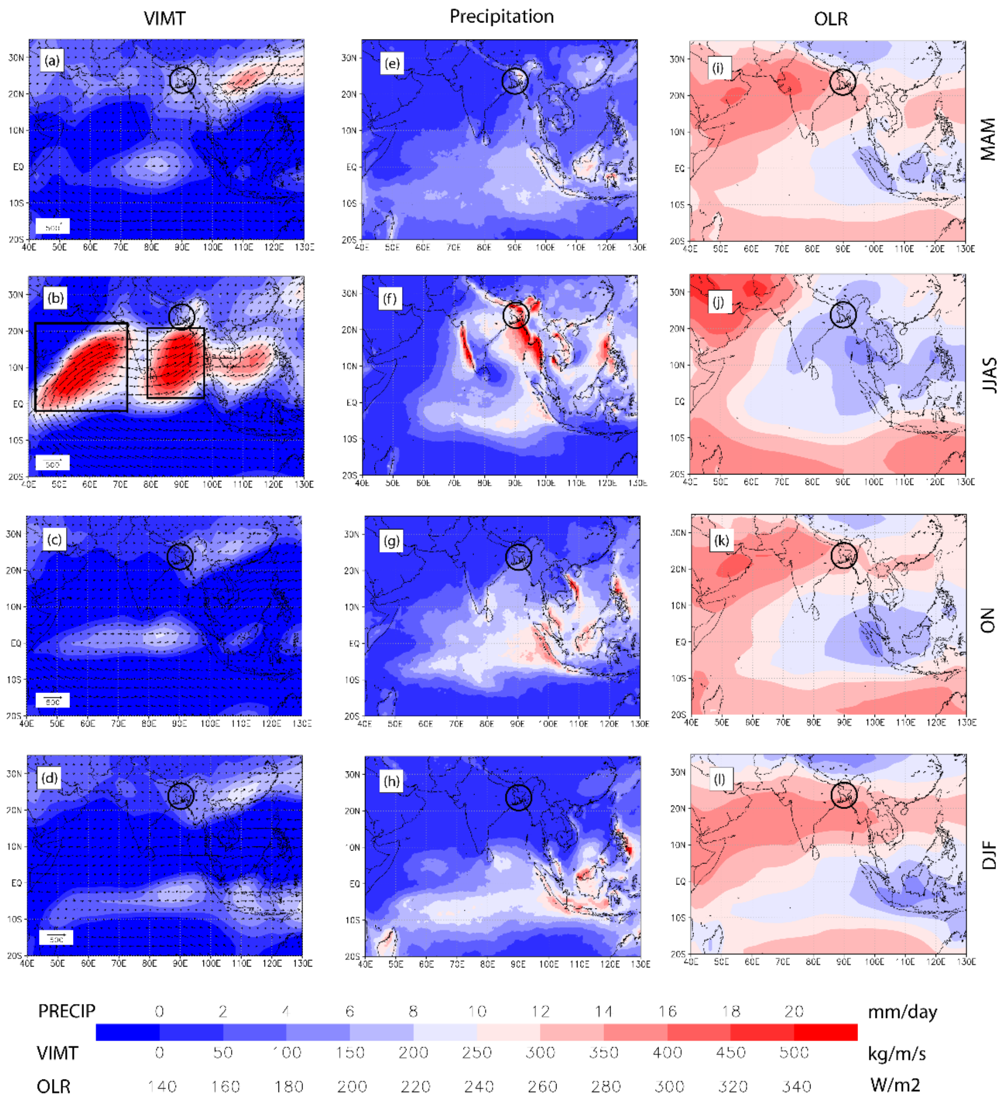

Figure 2: The 2015-2019 average vertically integrated moisture transport (a-d) illustrates the regional moisture transport (in vectors) and moisture flux (shaded color) in the region during different seasons. Additionally, the 1998-2018 average seasonal precipitation (e-h) and OLR (i-l) distribution in the region are included. Two rectangles indicate regions where maximum total flux centered in JJAS, while, the circle indicates location of Bangladesh.

Figure 2 illustrates the spatial distribution of seasonal average precipitation, OLR and moisture transport in the region. As discussed earlier, maximum precipitation (~3000 mm) occurs in JJAS over the northeastern part of Bangladesh, the western part of Myanmar and the southwestern part of India. The seasonal average precipitation in these regions was ~20 mm/day. Although the southwestern part of India received more rainfall in JJAS, it was relatively small over the southeastern part. In MAM, higher (~10 mm/day) rainfall occurred over the northeastern part of Bangladesh and the southern part of Myanmar, Thailand and Indonesia. Although Bangladesh received little rainfall in ON, it was significantly higher over Indonesia, Vietnam and Thailand. In DJF, precipitation occurred only over Indonesia but seasonal average precipitation amount was small (<10 mm/day). Seasonal average OLR for MAM displayed higher values at majority of places in the region indicating significant reduction in convective activities. Lower values were only observed in Indonesia (~200-220 W/m^2), while, it was ~320 W/m^2 over western part of India. OLR over Bangladesh typically ranged in between 260-300 W/m^2. In JJAS, OLR decreased significantly over ISM regions, particularly, BoB, eastern part of India, Bangladesh, Myanmar and Thailand. Seasonal average OLR remained within 200-240 W/m^2 range over the ISM region, while, higher values were observed over Pakistan, Afghanistan and Mediterranean regions (280-320 W/m^2). In ON, lowest OLR values were observed over Indonesia with significantly higher values over the north-western part of India, while, significantly higher (~300 W/m^2) values were observed for DJF within 10-20°N latitude band. We also found a distinct pattern for vertically integrated moisture transport (VIMT) in the region. The total moisture flux (sum of zonal and meridional flux) was ~100 kg/m/s during MAM and ON; however, it increased significantly to ~500 kg/m/s in JJAS due to the development of ISM. The maximum total flux was centered over AS adjacent to India and the BoB (Figure 2).

2.2 Sampling and Laboratory Analysis

Event-based precipitation samples were collected at the Barisal, Satkhira and Sylhet stations located in the southwestern, southcentral and northeastern parts of Bangladesh (Figure 1). Basic information about these sampling stations can be found in Table 1. From February 2017 to September 2018, a total of 502 event-based precipitation samples were collected at the Barisal, Satkhira and Sylhet stations with assistance from the Bangladesh Atomic Energy Commission (BAEC). During our sampling period, the air temperature remained within the 12.8-34°C range with an average of ~25°C. Approximately 70% of the total annual rainfall occurred in JJAS, and therefore, we consider our study period a representative sample for a typical monsoon year representing an identical stable isotopic composition in precipitation. All these stations are manned to ensure continuous operations, and each precipitation event yielded only one sample bottle, which was filled as much as possible. The humid environment, immediate collection and cold storage facilities ensured minimal post-sampling evaporation. Samples were later transported to the Key Laboratory of Tibetan Plateau

Climate Change and Land Surface Processes, Chinese Academy of Sciences for laboratory analysis.

Table 1: Geographic information and 1980-2010 average seasonal precipitation amounts

Station	Number of Samples	Geography			Precipitation (mm)			
		Lat (N)	Lon (E)	Elev (m)	DJF	MAM	JJAS	ON
Barisal	130	22.75	90.36667	10	48.5	422.3	1446.4	211.0
Satkhira	114	22.71667	89.08333	10	65.2	276.5	1249.4	151.8
Sylhet	258	24.9	91.883333	20	55.0	1100.5	2786.2	254.3

Measurements were performed with a Picarro Li-2130 analyzer using a cavity ring-down system at an analysis rate of 18-21 samples per batch, not including standard samples. Analytical uncertainties for $\delta^{18}O$ and δD were ±0.1‰ and ±0.4‰, respectively. One primary (USGS50) and one secondary standard of identical isotopic compositions with respect to sample values were used during measurements, with the secondary standard being the main standard. All the precipitation and standard samples were continuously injected six times. To avoid the memory effect of the analyzer during isotopic measurements, the first three injections were discarded, and the average of the last three injections was used in the analyses. All the standard samples were tested against Vienna Standard Mean Ocean Water (VSMOW) and were selected based on our empirical knowledge of the isotopic composition of measured samples in the region.

2.3 Meteorological Data

The daily air temperature, relative humidity and precipitation amount data collected from the Bangladesh Meteorological Department (BMD) are used in this study to detect the local meteorological influence. The daily air temperature and relative humidity data at the 1000 hPa level from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 reanalysis as well as precipitation data from the Tropical Rainfall Measurement Mission (TRMM) are used for regional analysis. Multisatellite estimates from the TRMM daily precipitation product (3B42 V7.0) come with gauge calibration and were selected because of their higher spatial resolution (0.25° x 0.25°) and extensive usage in previous studies

[*Chakraborty et al.*, 2016; *Rahul and Ghosh*, 2019; *Rohrmann et al.*, 2014; *Vimeux et al.*, 2005]. To evaluate the influence of convective activities on precipitation $\delta^{18}O$, we used OLR data from NOAA's National Centers for Environmental Information (NCEI) website available at https://www.ncei.noaa.gov/data/outgoing-longwave-radiation-daily/access/.

2.4 Lagrangian Back Trajectory Analysis and Moisture Fluxes

Using the Hybrid Single-Particle Lagrangian Integrated Trajectory model (HYSPLIT) developed at the Air Resources Laboratory of National Oceanic and Atmospheric Administration (NOAA), we performed back trajectory analysis to identify moisture sources and transport pathways [*Stein et al.*, 2015]. The September 2019 release (version 4.2.0) of HYSPLIT was used in this study. Meteorological data from the Global Data Assimilation System (GDAS) were used for the computation of daily trajectory endpoints because of their higher spatial resolution (1.0° x 1.0°) compared with those of the National Centers for Environmental Prediction (NCEP) data (2.5° x 2.5°). A higher spatial resolution enables us to minimize errors in calculating trajectories; therefore, the majority of recent studies used GDAS to perform the HYSPLIT simulations [*Kostrova et al.*, 2020; *Munksgaard et al.*, 2020; *Saranya et al.*, 2018; *Sinha et al.*, 2019; *Wu et al.*, 2019; *Zhang et al.*, 2019].

We used 500 m AGL as the starting height because our analysis for the 1979-2018 average LCL suggests that air parcels typically become saturated with moisture at this height over Bangladesh throughout the year (Figure 1). We computed trajectories in reverse mode (backward in time, inverting the wind components) for 120 hours, and at each point, particles were released every 6 hours (at 0000, 0600, 1200, and 1800 UTC). Later, trajectory endpoints for days with precipitation events were used for cluster analyses. Statistical clustering of similar trajectories was performed through HYSPLIT's internal clustering module. Changes in specific humidity along the clustered trajectories were also computed to obtain a clear visualization of the moisture uptake process in the region.

3. Results and Discussion

3.1 Temporal Variation in Precipitation $\delta^{18}O$

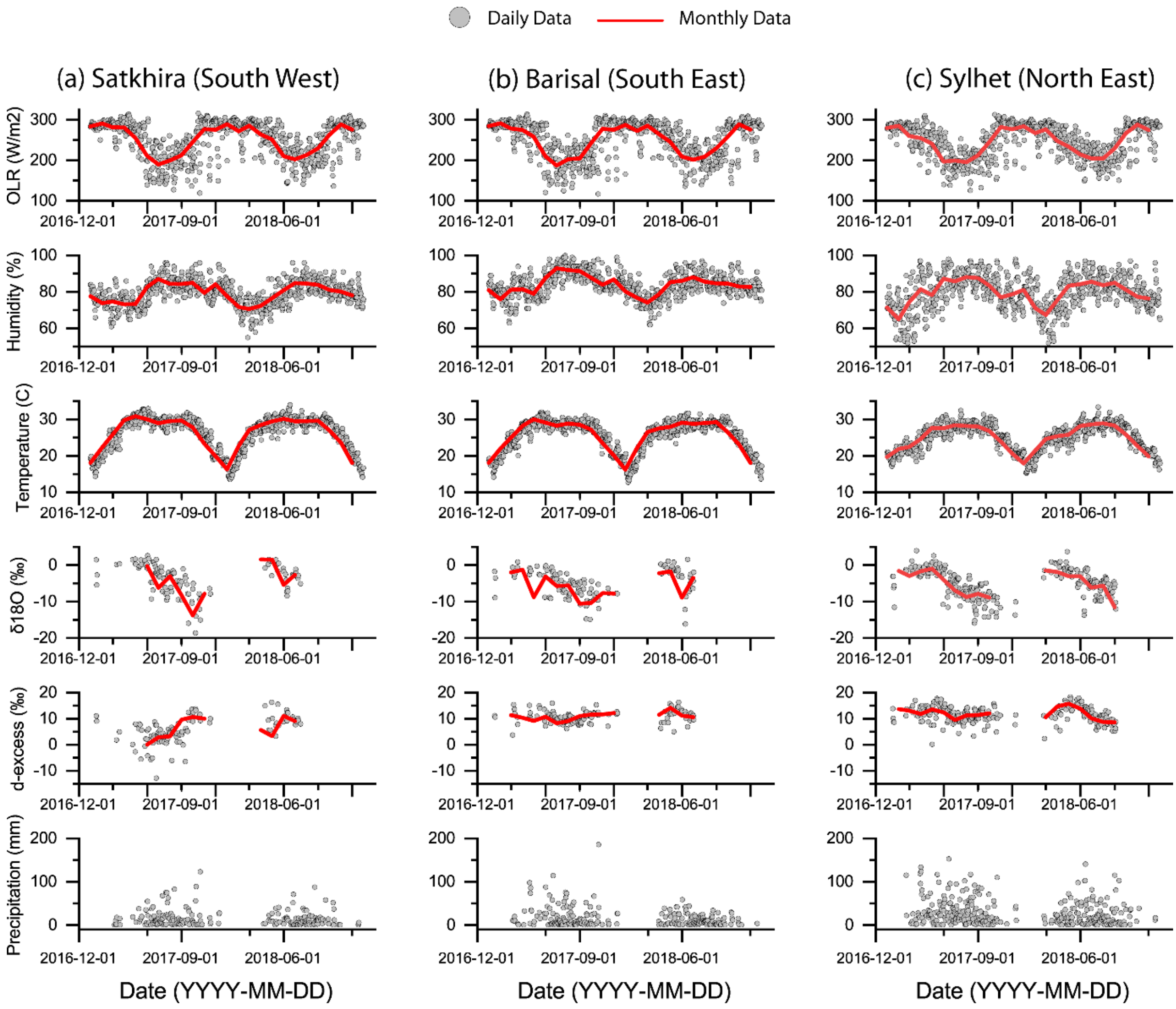

Figure 3: Temporal variation in precipitation δ^{18}O and local meteorological parameters (OLR, relative humidity, air temperature and precipitation)

Figure 3 illustrates event-scale variation of stable isotopes in precipitation (δ^{18}O and deuterium excess) and local meteorological parameters (air temperature, relative humidity, precipitation amount and OLR) over Bangladesh. δ^{18}O displayed the highest values in March, while it was the lowest for δ^{18}O in October. Throughout the study period, the average amount weighted δ^{18}O values at the Barisal, Satkhira and Sylhet stations were -4.01‰, -5.40‰ and -5.07‰, respectively, while they were -25.90‰, -34.15‰ and -28.62‰ for δD, respectively showing a decreasing trend from west to east. δ^{18}O and δD values were significantly lower at the stations located to the north (Sylhet) than those for the south (Barisal and Satkhira) showing a decreasing trend with increasing latitude which is consistent with current understanding on spatial variation in precipitation stable isotopic variation over India and Tibetan Plateau [*Kumar et al.*, 2010; *Yao et al.*, 2013]. δ^{18}O ranges between the northern

(Sylhet, -15.88‰ to 4.01‰) and southern (Barisal, -16.12‰ to 1.61‰ and Satkhira, -18.58‰ to 2.64‰) parts of Bangladesh were similar. Our observations were consistent with *Tanoue et al.* [2018], who reported stable isotopic variation in precipitation over Bangladesh within the -15.0‰ to 1.0‰ range. The average amount weighted deuterium excess values were 6.16‰, 10.94‰ and 11.93‰ for the Satkhira, Barisal and Sylhet stations, respectively showing similar decreasing pattern from west to east. At Satkhira station located to the south-western part of Bangladesh displayed the highest $\delta^{18}O$ and lowest deuterium excess values throughout MAM and JJAS suggesting a stronger influence of sub-cloud evaporation. Although we did not include δD in the figure, the variations in δD were identical to $\delta^{18}O$ because they are mathematically related to each other.

Table 2: Summary statistics for annual and seasonal amount weighted average $\delta^{18}O$, δD and deuterium excess at Barisal, Satkhira and Sylhet Station during 2017-2018 period. Also included seasonal maximum and minimum $\delta^{18}O$, δD and deuterium excess values for Barisal, Satkhira and Sylhet

Time	Statistic	Barisal			Satkhira			Sylhet		
		δ18O	δD	d-excess	δ18O	δD	d-excess	δ18O	δD	d-excess
Annual	Average	-5.40	-34.15	10.94	-4.01	-25.90	6.16	-5.07	-28.62	11.93
DJF	Minimum	-7.80	-50.26	11.81	N/A	N/A	N/A	-13.62	-101.30	2.41
	Maximum	-7.68	-48.83	12.70	N/A	N/A	N/A	-1.17	1.76	13.71
	Average	-7.79	-50.11	12.19	N/A	N/A	N/A	-5.81	-33.87	9.61
MAM	Minimum	-8.75	-60.88	3.78	-2.88	-6.67	-5.52	-10.77	-80.51	0.20
	Maximum	1.12	17.53	16.35	1.73	18.66	16.33	4.01	43.39	20.48
	Average	-1.78	-12.16	11.58	0.88	10.20	3.17	-1.97	-2.51	13.25
JJAS	Minimum	-16.12	-117.44	6.20	-15.91	-114.78	-12.79	-15.88	-113.11	3.36
	Maximum	1.61	19.82	15.96	2.64	20.48	13.63	-0.01	12.48	16.65
	Average	-6.20	-39.28	10.35	-4.22	-26.71	7.05	-6.73	-43.09	10.76
ON	Minimum	-11.90	-83.72	7.13	-18.58	-134.80	8.42	-14.21	-102.95	4.89
	Maximum	-4.36	-24.30	15.37	-4.97	-27.33	13.81	-7.28	-48.12	15.73
	Average	-8.99	-60.31	11.65	-10.82	-76.16	10.37	-8.89	-59.08	12.06

Table 2 lists average, minimum and maximum $\delta^{18}O$, δD and deuterium excess values of precipitation at different seasons along with annual average at Satkhira, Barisal and Sylhet stations. Satkhira station did not have any precipitation samples for DJF. Seasonal average $\delta^{18}O$ (δD) values for DJF at Barisal and Sylhet station were -7.79‰ (-50.11‰) and -5.81‰ (-33.87‰). At Barisal and Sylhet station, deuterium excess values for DJF were closely aligned with 10.0‰ that equal to global mean deuterium excess in precipitation. In DJF, $\delta^{18}O$ and δD displayed the most enriched values at the northern station (Sylhet), while, it was significantly depleted at Barisal. In MAM, average $\delta^{18}O$ values for Satkhira, Barisal and Sylhet stations were 0.88‰, -1.78‰ and -1.97‰, respectively showing significant isotopic enrichment at Satkhira and eastward increase in isotopic depletion. δD showed similar pattern with an average of 10.20‰, -12.16‰ and -2.51‰, respectively. Average deuterium excess for MAM had the smallest values at Satkhira (3.17‰), although they were considerably higher at Barisal (11.58‰) and Sylhet (13.25‰). In JJAS, average $\delta^{18}O$ (δD) values at Satkhira, Barisal and Sylhet were -4.22‰ (-26.71‰), -6.20‰ (-39.28‰) and -6.73‰ (-43.09‰), respectively showing eastward decreasing trend. Deuterium excess values were the smallest at Satkhira (7.05‰) although they were significantly higher at Barisal (10.35‰) and Sylhet (10.76‰). In ON, average $\delta^{18}O$ (δD) values for Satkhira, Barisal and Sylhet stations were -10.82‰ (-76.16‰), -8.99‰ (-60.31‰) and -8.89‰ (-59.08‰) making it the seasons with the most depleted values in the year. $\delta^{18}O$ and δD values displayed an eastward increasing trend having the most enriched values in the east, In ON, deuterium excess values for all three stations were above 10.0‰ with maximum and minimum vales at Sylhet (12.06‰) and Satkhira (10.37‰).

At the monthly scale, a decreasing trend in $\delta^{18}O$ starting in May was found (Figure 3), $\delta^{18}O$ became the lowest (~-10.0‰) in October, then the $\delta^{18}O$ values started to increase again till December (~0.0‰). The monthly average $\delta^{18}O$ ranged between -12.0‰ and 3.0‰ throughout the study period, with March-May $\delta^{18}O$ values within the -5.0‰ to 3.0‰ range, while the range for July-November was -12.0‰ to -6.0‰. Previously, *Tanoue et al.* [2018] reported March-May $\delta^{18}O$ values for the eastern part of Bangladesh within the -1.82‰ and -3.45‰ range, while they were between -7.28‰ and -15.94‰ during the July-November period, similar with our observation. Variations in OLR seem to have similar patterns with $\delta^{18}O$, especially during MAM and JJAS, which show gradual decreases after April from ~300 W/m^2 to ~200 W/m^2. Temperature correspondingly increase from winter (~20°C) to summer (~30°C) and have an inverse relationship with $\delta^{18}O$. An inverse relationship between $\delta^{18}O$ and humidity was also found; however, it was difficult to establish a significant relationship between precipitation amount and $\delta^{18}O$. The monthly average precipitation range at Sylhet (0.0 mm/day to 30.omm/day) was significantly higher than that of the Barisal and Satkhira stations (0.0 mm/day to 16 mm/day). Monthly amount weighted deuterium excess values in precipitation for Barisal and Sylhet stations were found in between 8.25‰ and 15.73‰ range, while, it was significantly depleted for Satkhira ranging from 0.09‰ to 11.11‰. Monthly deuterium excess values at Satkhira station remained below 3.30‰ during March-August 2017, while, it was >8.25‰ for Barisal and Sylhet throughout the study period.

Majority of heavy rainfall (>50 mm) events occurred in monsoon season when we observed significant isotopic depletion, however, non-monsoon heavy rainfall events deviated this rule significantly. At Sylhet station, we observed several heavy rainfall events in MAM that contributed to flash flood in 2017 [*Rimi et al.*, 2019]. At Sylhet station, >70 mm daily rainfall was recorded for six consecutive days during March 30 and April 4, 2017 however, we found little change in $\delta^{18}O$ values from pre and post heavy rainfall events. When we compared MAM heavy rainfall events with those that occurred during October 20-22, 2017, we found ON heavy rainfall events resulted in a significant $\delta^{18}O$ depletion at all three stations. Satkhira station displayed the strongest isotopic depletion where $\delta^{18}O$ values became as low as -20.0‰. However, we found no $\delta^{18}O$ depletion during MAM heavy rainfall events. Based on back trajectory analysis and evaluated changes in specific humidity (~15.0 g/kg) along the clustered trajectories, we found that, moisture from BoB accounted for >50% of total airmass trajectories for MAM, while, >20% trajectories for ON originated over AS or tropical Indian Ocean (TIO). *Midhun et al.* [2018] found that $\delta^{18}O$-depleted (enriched) precipitation events were associated with a higher number of air parcel trajectories originating from the BoB (AS) branch of moisture transport at six stations across northern and central India. Moreover, moisture from BoB had relatively short transport distance from the source region, while, it was significantly long for AS and TIO. Breitenbach et al. [2010] found that lower (higher) $\delta^{18}O$ values for precipitation at Southern Meghalaya, NE India were associated with long (short) transport distance. Therefore, we conclude that, such a discrepancy in $\delta^{18}O$ depletion between MAM and ON heavy rainfall events were resulted from source moisture effect and this conclusion is consistent with Breitenbach et al. [2010] and *Midhun et al.* [2018].

3.2 Local Meteoric Water Line

We used the ordinary least square regression method to calculate the LMWL from the unweighted event-scale δD and $\delta^{18}O$ values obtained through isotopic measurements to enable our results to be easily comparable with the published literature on meteoric water lines in this region [*Crawford et al.*, 2014; *Hughes and Crawford*, 2012; *Putman et al.*, 2019].

Figure 5 illustrates the δD-$\delta^{18}O$ relationship observed at different timescales (throughout the study period, only during the monsoon season and only during the non-monsoon season) at the Barisal, Satkhira and Sylhet stations. Among the stations, the highest LMWL slopes were found at Sylhet, while the lowest exist at Satkhira in both the monsoon and non-monsoon seasons, which indicate the significant evaporation occurred at Sylhet (8.23 and 8.11 for monsoon and non-monsoon) and weak condensation at Satkhira (7.56 and 7.49 for monsoon and non-monsoon, respectively). The LMWL slopes were smaller in the non-monsoon season than in the monsoon season, suggesting higher condensation effects in the non-monsoon season for the Satkhira and Sylhet stations. Slopes at Barisal are very close to GMWL (8 for annual, 7.91 and 7.92 for monsoon and non-monsoon, respectively). During the 2017-2018 period, the LMWL intercepts displayed an increasing trend from west to east with the smallest values at Satkhira (4.07), while they were the largest at Sylhet (12.93). Intercepts at the Barisal were close to the GMWL intercepts (10.83), indicating the wetter moisture sources in the west than that in the east. The smallest (highest) values in the monsoon (non-monsoon) season at all three stations due to >80% (~20% in DJF) moisture originating from oceans.

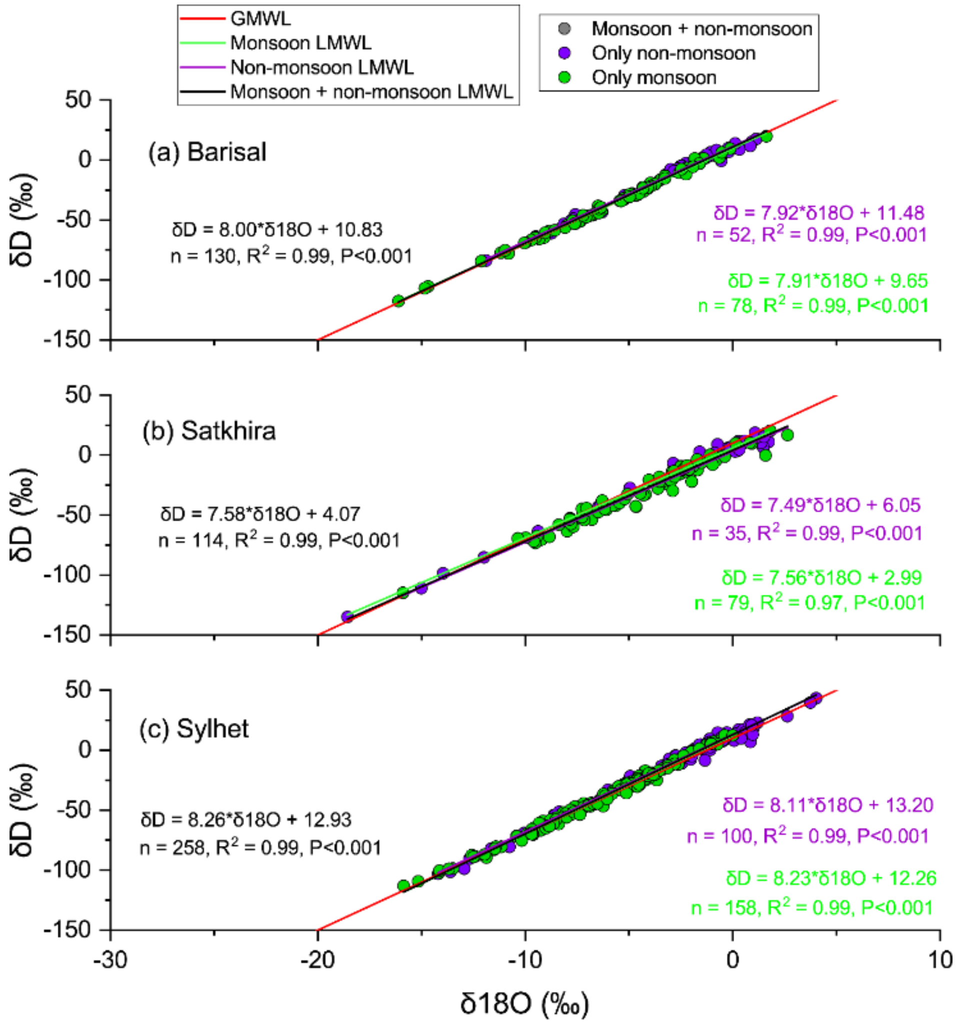

Figure 4: LMWL showing the δ^{18}O-δD relationship and their deviation from the GMWL proposed by *Craig* [1961]

Jeelani et al. [2018] studied stable isotopic variation at Jorhat station located near Sylhet, where we found very close LMWL slopes (8.23 at Sylhet and 8.38 at Jorhat) for the monsoon season; however, a large discrepancy was found for the non-monsoon season slope calculated at the Sylhet station (8.11) from that reported for the westerly disturbance period (7.70) at the Jorhat station. This may result from different years' sampling. Previously, *Kumar et al.* [2010] established the Indian meteoric water line (IMWL) as $\delta D = 7.93*\delta^{18}O + 9.94$ and reported 8.15, 7.82 and 7.95 as the slopes for the northern India, southern India and western Himalayan meteoric water lines, respectively. Although the LMWL slopes for the Sylhet station (northeastern part of Bangladesh) were consistent with the findings of *Kumar et al.* [2010], considerable differences were found between the Barisal and Satkhira stations (southern part of Bangladesh). The LMWL slopes at the Barisal station (8.00) were higher than those reported for southern India, while they were smaller than those at the Satkhira station (7.58).

3.3 Processes Controlling δ18O in Precipitation Over Bangladesh

3.3.1 Meteorological Elements Effects

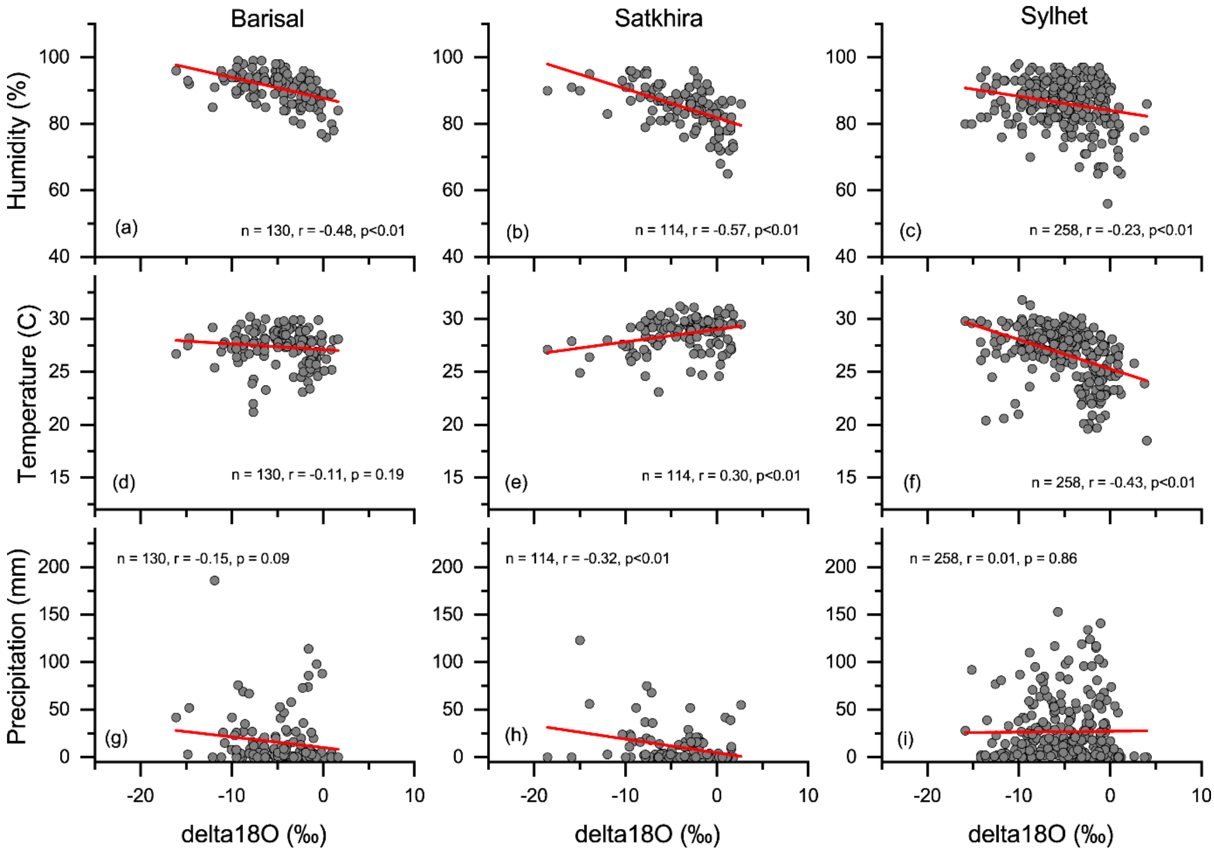

Figure 5: At the event scale, a strong and statistically significant negative correlation between $\delta^{18}O$ and relative humidity was observed at all three stations. The Sylhet and Satkhira stations revealed a significant association between $\delta^{18}O$ and air temperature; however, only the

Satkhira station reported a statistically significant association between precipitation amount and $\delta^{18}O$.

Dansgaard [1964] established the 'temperature effect' (decrease in δ-values with increasing temperature) and 'amount effect' (higher δ-values in sparse rain) as two of the important controls that influence variations in the isotopic compositions of precipitation. The temperature effect is significant in the temperate and polar regions while amount effect is primarily noticeable in low-latitude regions [*Zhang et al.*, 2019]. The majority of recent studies over the Indian subcontinent at different temporal resolutions ranging from event to interannual scales suggested that the amount effect is weak and even nonexistent in this region [*Araguas-Araguas et al.*, 1998; *Bhattacharya et al.*, 2003; *Breitenbach et al.*, 2010; *Datta et al.*, 1991; *Midhun et al.*, 2013; *Tang et al.*, 2015].

Table 3: Correlation coefficient between precipitation $\delta^{18}O$ and meteorological parameters

Station	$\delta^{18}O$-RH	$\delta^{18}O$-T	$\delta^{18}O$-P
Barisal	-0.48**	-0.11	-0.15
Satkhira	-0.57**	0.30*	-0.32**
Sylhet	-0.23**	-0.43**	0.01
T = Temperature (°C), P = Precipitation (mm), RH = Relative Humidity (%)			
Numerals with ** and * represents statistically significant correlations at the 0.01 and 0.05 levels, respectively. Numerals without * indicates a failure to pass the significance test.			

Here a weak (n = 114, r = 0.30) but statistically significant ($p<0.01$) positive association between air temperature and $\delta^{18}O$ at Satkhira is found (Figure 5, Table 3). Such correlation gradually weakens from the west to east with a statistically significant negative relationship (n = 258, r = -0.43 $p<0.01$) at Sylhet, however, it was weak and statistically insignificant at Barisal (n = 130, r = -0.11 $p>0.05$). A statistically significant ($p<0.01$) but moderately negative association between precipitation amount and event-based $\delta^{18}O$ at Satkhira (n = 114, r = -0.32) (Figure 6) was found; however, it was disappeared at Barisal (n = 130, r = -0.15) and Sylhet (n = 258, r = 0.01) . *Tanoue et al.* [2018] and *Rahul and Ghosh* [2019] also reported an extremely weak (r = -0.01) relationship between $\delta^{18}O$ and precipitation amount in the region. All three stations revealed a significantly ($p<0.01$) negative association between $\delta^{18}O$ and relative humidity and gradually decreases with increasing latitude or longitude from southwest to northeast, with the strongest association at Satkhira ($n = 114$, $r = -0.57$) and the weakest at Sylhet ($n = 258$, $r = -0.23$) as well as Barisal ($n = 130$, $r = -0.48$) in between.

Although we found statistically significant correlation between precipitation $\delta^{18}O$ and local meteorological parameters (relative humidity, air temperature and precipitation amount), the correlation between $\delta^{18}O$ and regional meteorological variation were statistically insignificant. Correlation coefficients between the precipitation $\delta^{18}O$ measured at these three stations and the precipitation amount/ temperature/humidity for the surrounding region are in significant in all seasons. Thus, we suggest temperature, precipitation amount and humidity are not dominant controls for event-based and seasonal variations of precipitation $\delta^{18}O$ at Bangladesh.

3.3.2 Influence of Convective Activities

Convective activities impact precipitation events, which leave signals on stable isotopes in precipitation, especially in tropical region [*Chakraborty et al.*, 2016; *Rahul et al.*, 2016; *Saranya et al.*, 2018; *Wei et al.*, 2018]. OLR is widely considered to be a proxy for convective activities. Low values indicate increase and intensive convective activities, vice versa. To quantitatively account for the convective influence, we followed a simplified two-step procedure. First, we quantified the deviation of OLR from the long-term average, which allows us to formulate a simplified index of convective strength. Later, pixel-based correlation coefficients were calculated to determine the regional OLR-$\delta^{18}O$ relationship at the grid-point level, providing the estimation of the convective effects on $\delta^{18}O$. A significant OLR increase (decrease) in a region with a negative (positive) OLR-$\delta^{18}O$ relationship can justify the convective influence of $\delta^{18}O$ depletion (enrichment) in the region.

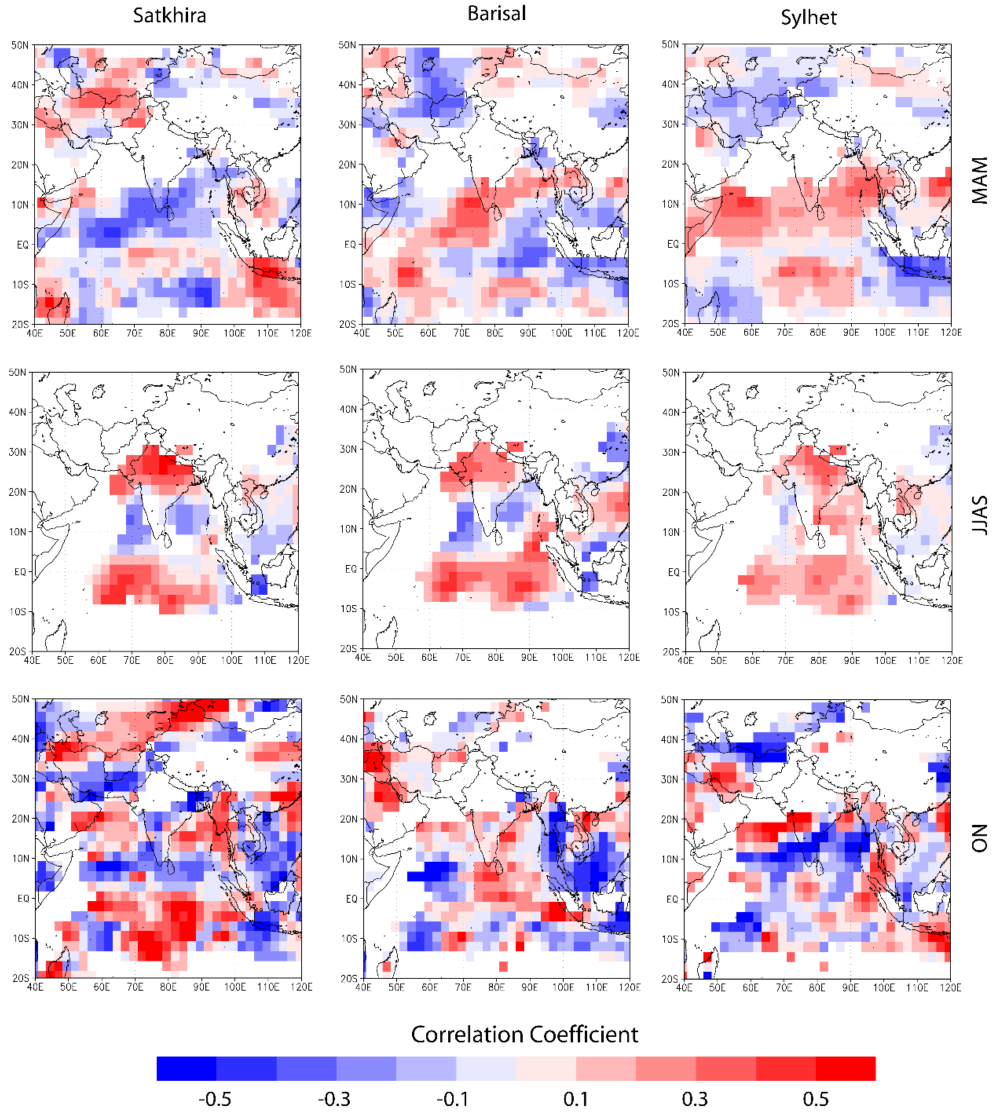

Figure 6: Spatial distribution of correlation coefficients between precipitation $\delta^{18}O$ and OLR indicating the relationship between convective activities in the region and $\delta^{18}O$ in different seasons during the 2017-2018 period. Correlation coefficients significant at $p<0.05$ are displayed in the figure.

During MAM, the same convections result in the opposite variations of precipitation $\delta^{18}O$ in west and east Bangladesh, i.e. the strong convections above BOB associated with depleted $\delta^{18}O$ at Barisal and Sylhet, while enriched $\delta^{18}O$ at Satkhira (Figure 6). Similar influence was observed for Indonesia and stronger convective activities result in $\delta^{18}O$ enrichment at Barisal and Sylhet, while, Satkhira station experiences $\delta^{18}O$ depletion. Strong convective activities over Pakistan and Afghanistan also leads to $\delta^{18}O$ depletion (enrichment) at Satkhira (Barisal and Sylhet) stations. During JJAS, strong convective activities over IO, AS and north-western part of India leads to $\delta^{18}O$ depletion at all three stations. At Satkhira and Barisal stations located to the south, strong convective activities over BoB resulted in $\delta^{18}O$ enrichment, while, Sylhet station located to the north experienced $\delta^{18}O$ depletion. During ON, strong convective activities over IO and BoB leads to $\delta^{18}O$ depletion (enrichment) at Barisal and Satkhira (Sylhet) station. Convective activities over AS, however, leads to $\delta^{18}O$ enrichment at all three stations. We did not have enough observations to perform statistical correlation between $\delta^{18}O$ and OLR for DJF.

3.4 Deuterium Excess and Moisture Source

Many studies over the Tibetan Plateau have suggested that changes in the moisture source region and moisture transport process significantly change the stable isotopes in precipitation [*Chen et al.*, 2015; *Li et al.*, 2017; *Li et al.*, 2015; *Meiliang et al.*, 2014; *Tang et al.*, 2015; *Tian et al.*, 2007; *Wu et al.*, 2015; *Yu et al.*, 2015; *Yu et al.*, 2014; *Yu et al.*, 2008]. Here, back trajectory analysis with HYSPLIT for days with precipitation events revealed four main moisture transport pathways for the stations, namely, southwest winds from the BoB, southwest winds from the AS, southwest winds from the tropical IO, and continentally recycled moisture (CR). Definitions for BoB, AS, IO and CR used in this study were consistent with the classification system used by *Tanoue et al.* [2018]. Changes in specific humidity along the clustered trajectories were also computed to obtain a clear visualization of the moisture uptake process in the region.

During MAM, moisture predominantly originated from the BoB and changes in specific humidity along clustered trajectories were approximately 15.0 g/kg (Figure 7). Approximately 64%, 51% and 56% of total airmass trajectories for Barisal, Satkhira and Sylhet originated from the BoB. Neither Satkhira, nor Sylhet stations received any contribution from AS where 1% of total trajectories for Barisal originated. Changes in specific humidity along the clustered trajectories also indicated that the moisture uptake process primarily occurred over the BoB suggesting greater influence of moisture from BoB on stable isotopic variation in precipitation over Bangladesh. *Tanoue et al.* [2018] suggested that, BoB and AS primarily contributed to MAM precipitation, however, we found very little influence from AS with little moisture uptake, High amount-weighted $\delta^{18}O$ depletion (-1.78‰) observed at the Barisal station could be associated with moisture from BoB that accounted for 64% of total trajectories for the station. Primary moisture uptake over the BoB through southerly winds contain highly depleted moisture [*Bhattacharya et al.*, 2003].

Midhun et al. [2018] confirmed that $\delta^{18}O$-depleted precipitation events were associated with a higher number of trajectories originating from the BoB. In our study, we found significant influence of IO that accounted for 29%, 42% and 5% of total airmass trajectories for Barisal, Satkhira and Sylhet stations, respectively. This indicated an eastward weakening of IO influence with maximum (minimum) influence in western (eastern) part of Bangladesh. Contributions from CR accounted for 5%, 7% and 39% of total airmass trajectories for Barisal, Satkhira and Sylhet stations, respectively that brought moisture from India and Mediterranean region. Higher amount-weighted $\delta^{18}O$ at the Satkhira station (0.88‰) with very low deuterium excess (3.17‰) could be associated with BoB moisture that accounted for >50% of total trajectories.

The $\delta^{18}O$ values started to decrease in the beginning of the monsoon season when a large volume of moisture driven by the ISM started to move inland. During JJAS, moisture transport from AS increased significantly (Figure 7). Contributions from AS accounted for 38%, 32% and 29% of total airmass trajectories for Barisal, Satkhira and Sylhet stations, while, influence of BoB accounted for 9%, 8% and 9% of total trajectories for Barisal, Satkhira and Sylhet stations. However, changes in specific humidity suggested that moisture uptake primarily occurred over the BoB, with increase of specific humidity ~12.0 g/kg. Continental moisture recycling supplied a large amount of the moisture originating over India with increase of specific humidity ~10 g/kg, especially at Satkhira and Sylhet where 12% and 21% of total trajectories originated over land. The seasonal average $\delta^{18}O$ values were -6.20‰, and -6.73‰ for Barisal and Sylhet, respectively, while they were significantly enriched at Satkhira -4.22‰, due to the different moisture contribution between BOB and CR. Both Sylhet and Satkhira stations received contributions from CR, however, only Satkhira displayed isotopic enrichment because of the moisture origin. Moisture for Satkhira originated from west-central part of India and arrived at Satkhira station located in the south-western part of Bangladesh with relatively short air parcel travel distance. On the other hand, moisture for Sylhet station originated at southern part of India and traveled long distance before arriving at Sylhet station located at the north-eastern part of Bangladesh. *Breitenbach et al.* [2010] demonstrated that longer travel distance resulted in $\delta^{18}O$ depletion, while, shorter travel distance led to $\delta^{18}O$ enrichment over north-eastern part of India. Such variations of moisture contributions through transport paths might have also resulted in gradual increase of deuterium excess values from southwest to northeast (7.05‰ at Satkhira, 11.58‰ at the Barisal and 13.25‰ at Sylhet).

During ON, the BoB and AS supplied majority of the moisture that contributed to precipitation in this season, and changes in specific humidity also suggested higher moisture uptake along the BoB and AS branches of moisture transport. Contributions from the BoB accounted for 38%, 34% and 25% of total trajectories for Barisal, Satkhira and Sylhet stations. Sylhet station did not receive any contributions from AS, while, it accounted for 19% and 26% of total trajectories showing an eastward weakening of AS influence in the season. CR accounted for 4%, 14% and 55% or total trajectories at Barisal, Satkhira and Sylhet stations. Deuterium excess values at Barisal and Satkhira were 11.65‰ and 10.37‰, while it was 12.06‰ at Sylhet station. Besides strong influence of CR that brought moisture through westerly wind, 50% of total trajectories supplied locally recycled moisture that had very short transport distance from the station that can explain increase in deuterium excess values at Sylhet. Significant $\delta^{18}O$ depletion was recorded at Satkhira (-10.82‰) compared to that of Barisal (-8.99‰) and Sylhet (-8.89‰). Such a $\delta^{18}O$ depletion at Satkhira might have occurred due to heavy rainfall events of October 20-22, 2017 when $\delta^{18}O$ values at Satkhira became as low as -20.0‰.

During DJF, BoB accounted for 32%, 4% and 23% of total trajectories for Barisal, Satkhira and Sylhet stations. AS accounted for 4% of total trajectories for Satkhira, however, Barisal and Sylhet did not receive any contributions from AS. CR accounted for 69%, 75% and 72% of total trajectories for Barisal, Satkhira and Sylhet. IO accounted for 5% of total trajectories for Satkhira. Satkhira station did not have any precipitation samples for DJF and the number of samples for Sylhet and Barisal were small making our confidence limited for isotopic variation in the season. Average amount weighted $\delta^{18}O$ for Barisal and Sylhet were -7.79‰ and -5.81‰, while, it was 12.70‰ and 13.71‰ for deuterium excess, respectively. Higher deuterium excess value for Sylhet might have resulted from stronger (59% of total trajectories) influence of westerly wind that brought moisture from the Mediterranean region and north-western part of India.

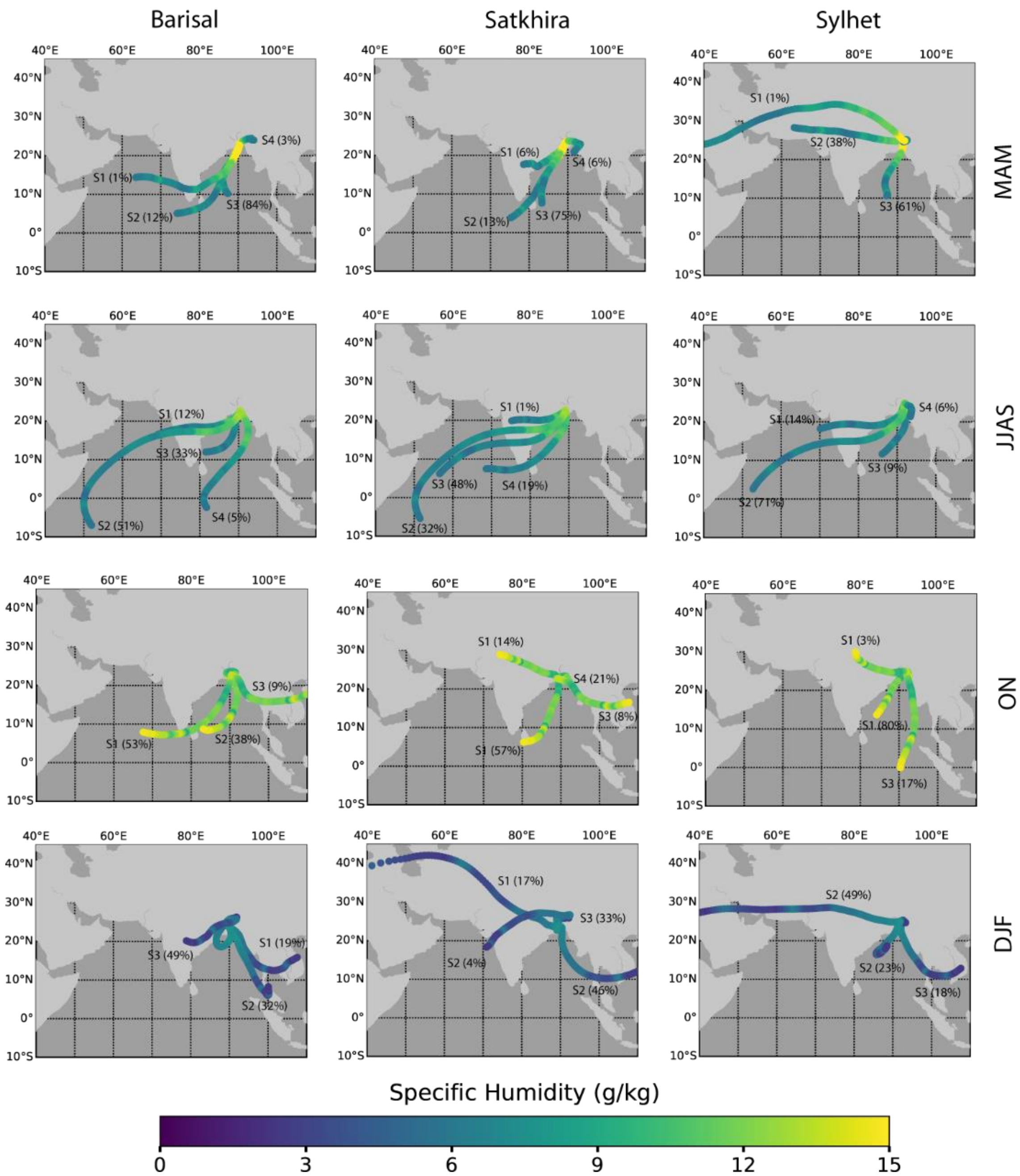

Figure 7: Specific humidity plotted along the clustered trajectory showing the moisture uptake process in the region

Tanoue et al. [2018] suggested that moisture from BoB and AS primarily contributed to MAM precipitation, however, we found little influence of AS in MAM at all three stations. Satkhira and Sylhet station did not receive any contribution, while, only 1% of total trajectories originated over AS. According to *Tanoue et al.* [2018], the influence from BoB and AS decreased significantly in JJAS and moisture predominantly originated from IO. However, our study found ~30% of total airmass trajectories at all three stations originating over AS, while, maximum moisture uptake process occurred over BoB that accounted for ~8% of total trajectories. Indeed, ~50% of total trajectories originated over IO, however, moisture uptake over IO were very small. *Tanoue et al.* [2018] reported origin for ~30% of total trajectories as PO, however, we found ~8% of total trajectories that originated over PO. Although we found similar percentage of trajectories originating from the BoB at Sylhet station, it was significantly different for CR that revealed significantly higher percentages (55%) than that being reported (37%) previously [*Tanoue et al.*, 2018].

Except a significant depletion at Satkhira, monthly amount weighted deuterium excess values lacked any regular pattern. Only Sylhet station revealed a regular maximum value in May (~13.5‰), while, minimum values occurred in July (2017) and September (2018). At Sylhet, minimum value was ~8.5‰, while, it was extremely depleted at Satkhira (0.09‰) that occurred in June 2017. As Satkhira, we found maximum values in June 2018 (11.11‰), however, June 2017 had very depleted (2.91‰) values. Throughout the study period, deuterium excess values remained within the 0.09‰ to 15.0‰ range at these three stations. Deuterium excess values showed a consistent eastward increasing trend with lowest values at Satkhira and highest values at Sylhet in MAM, JJAS and ON. Satkhira station did not have any observation for DJF and we found highest deuterium excess values at Barisal.

To quantitatively account for the moisture source influence, we investigated vapor flux anomalies and examined their influence on $\delta^{18}O$. In the 2017 MAM, northward flux anomalies were positive within the 20°S and 20°N latitudes. Within the 20°N and 40°N latitudes, the northward flux had slightly lower values (~5 kg/m/s) than the long-term average (Figure S1). In the 2018 MAM, a significant decrease in the northward flux was experienced within the equator and 30°N latitude, with the lowest values at 15°N, where the northward flux was ~18 kg/m/s. On the other hand, little variation in the eastward flux anomalies was observed in 2017 and remained closely aligned with the long-term average; however, a significant decrease in the eastward flux anomalies was found for 2018 within the 60°E and 130°E longitudes. Although the difference between the 2017 and 2018 northward flux anomalies over the BGD_Domain (rectangular region in between latitude 20°N-26°N and longitude 88°E-92°E) was minute, it was significantly higher (as high as ~60 kg/m/s at 90°E) for the eastward vapor flux. In JJAS of both 2017 and 2018, the northward flux anomalies were significantly higher (~20 kg/m/s) than the long-term averages within the 20°S and 15°N latitudes; however, differences between 2017 and 2018 were significantly higher within the 15°N and 30°N latitudes. The 2018 anomalies were closely aligned with the long-term average, while it was 25 kg/m/s higher in 2017. Although the eastward flux revealed similar variations, we found large differences in anomalies for 2018 within the 70°E and 130°E longitudes. Both eastward and northward fluxes showed large differences between 2017 and 2018 over the BGD_Domain. In ON, northward flux anomalies remained similar in 2017 and 2018, with values closely aligned with the long-term average. However, large differences in the eastward flux anomalies were found over the 60°E and 110°E longitudes, where the difference between the 2017 and 2018 anomalies was ~40 kg/m/s.

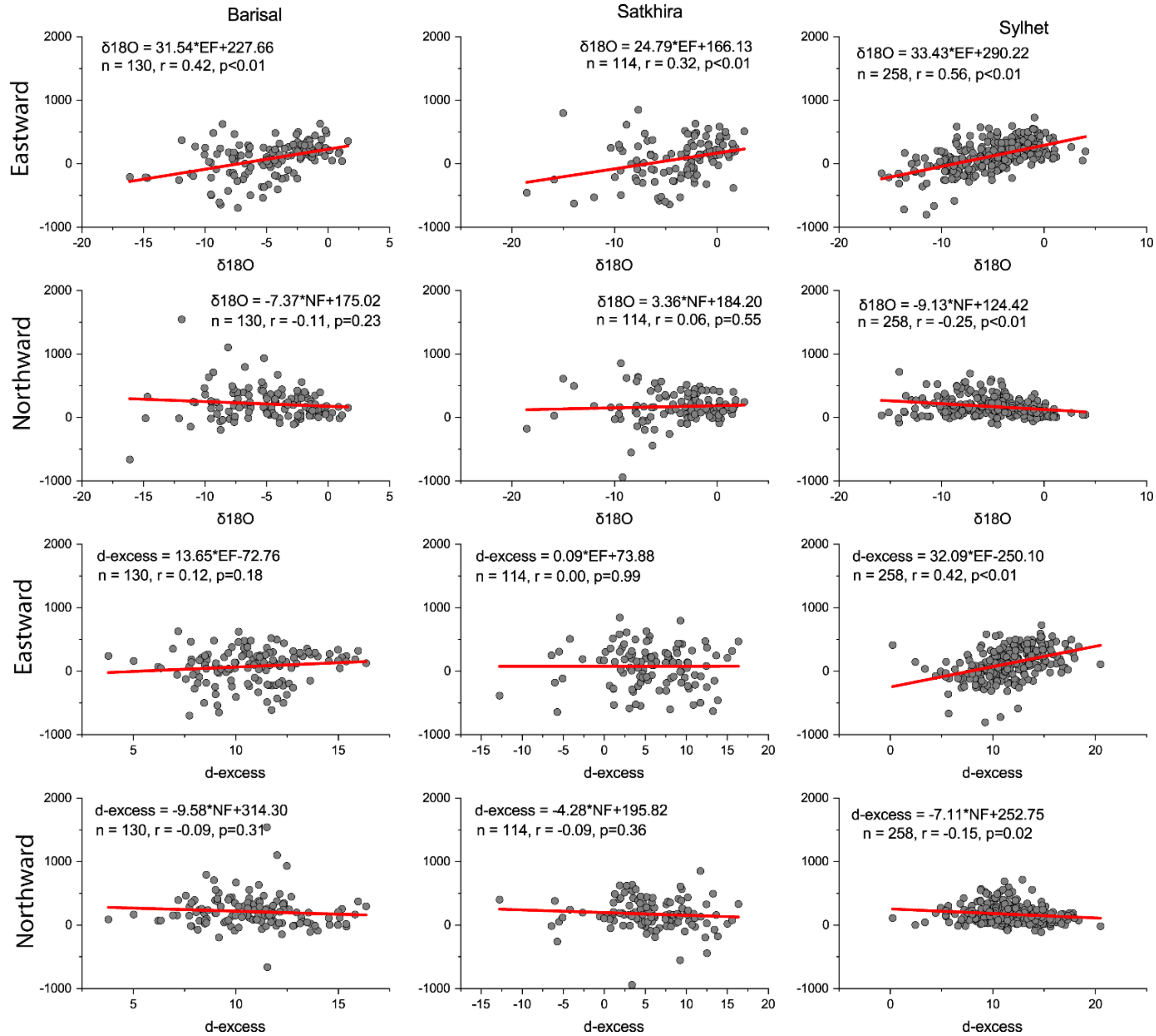

Figure 8: Influence of eastward and northward vapor fluxes on precipitation $\delta^{18}O$ and deuterium excess.

To investigate the influence of moisture flux on precipitation stable isotopic variation over Bangladesh, correlations between precipitation $\delta^{18}O$ and moisture flux are calculated at three stations. Based on vapor flux data from the ERA5 reanalysis, The zonal average of the northward (between 40°E and 130°E longitude) and eastward (between 20°S and 40°N latitude) vapor flux anomalies displayed significant variation within the BGD_Domain. relationships between the $\delta^{18}O$ and eastward fluxes were intensifying from southwest to northeast ($p<0.01$) , showing the strongest at Sylhet (n = 258, r = 0.56) and the weakest at Satkhira (n = 114, r = 0.32) , which is not consistent with the finding on the Eastern Tibetan Plateau [*Tian et al.* [2008]]. weak and insignificant relationships between the $\delta^{18}O$ and northward fluxes at Satkhira (n = 114, r = 0.06) and Barisal (n = 130, r = -0.11) were found, while the relationship was significantly moderate ($p<0.01$) at the Sylhet (n = 258, r = -0.25) (Figure 8). Deuterium excess at Barisal and Satkhira displayed a weak relationship with both the eastward and northward vapor fluxes; however, this relationship was statistically significant at the Sylhet station. At Sylhet, the relationship between the eastward flux and deuterium excess (r = 0.42, $p<0.01$) was stronger than the relationship between the northward vapor flux and deuterium excess (r = -0.15, $p<0.05$), which is consistent with back trajectories and OLR analysis in above sections.

4. Conclusions

We investigated the local and regional controls of the seasonal variations in precipitation $\delta^{18}O$ over Bangladesh, based on an event-based precipitation sample analysis during the 2017-2018 period. Precipitation $\delta^{18}O$ displayed a distinct temporal and spatial pattern having the highest values in March following gradual decrease until it became the lowest in October. Amount weighted $\delta^{18}O$ values displayed a decreasing trend with increasing latitude which is consistent with current understanding on spatial variation in precipitation stable isotopes over India and Tibetan Plateau where monsoon dominants the moisture transport. In DJF, $\delta^{18}O$ and δD displayed the most enriched values at the northern station (Sylhet), while, it was significantly depleted at Barisal station located in the south. $\delta^{18}O$ and δD displayed eastward depletion in MAM and JJAS with most enriched (depleted) values over the western (eastern) part of Bangladesh. We found the most depleted deuterium excess values over the western part of Bangladesh, while, it was the most enriched at the station to the east. $\delta^{18}O$ and δD values for ON displayed the opposite pattern of MAM and JJAS and we found the most enriched $\delta^{18}O$ and δD values over the eastern part of Bangladesh.

We performed a comparison between the response of MAM and ON heavy rainfall events on stable isotopic composition of precipitation and it was found that, MAM heavy rainfall events do not cause significant isotopic depletion that is typical of JJAS and ON heavy rainfall events. By performing back trajectory analysis, we found that moisture source was different for these two types of heavy rainfall events. MAM heavy rainfall events received moisture through continental recycling, while, ON events received moisture from IO, BoB and AS.

We report the existence of a strong convective effect that influence stable isotopic variation in precipitation over Bangladesh. Strong convective activities over BoB, AS and IO significantly influence stable isotopic composition throughout the year. We also demonstrated a significant influence of moisture source region and flux on δ^{18}O variation. Our study suggests that, Eastward vapor flux displayed statistically significant correlation with both δ^{18}O and deuterium excess which is inconsistent with the results obtained over the Tibetan Plateau. The shifts of moisture contribution from BoB, AS and IO primarily influence stable isotopic composition in precipitation, especially in JJAS and ON. Changes in specific humidity along the trajectory revealed that, despite having larger percentages of airmass trajectories originates over IO or AS, BoB still controls variations of precipitation stable isotopes over the Bangladesh because of a larger share of moisture uptake.

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