Seasonal Variation of the Stable Isotope Fingerprints in Daily Rainfalls from Northeastern Thailand (2013-2016), the Implication on Climate Change and Hydrological Management

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Abstract

Stable isotopes are a very powerful means in hydrological study of water cycle. In contrast, lack of isotope reference database in Thailand and SE Asia region, which available only irregularly database of IAEA's Global Network of Isotopes in Precipitation (GNIP), make inapplicable interpretation on very dynamic, seasonal control of local hydrological systems. Recently, high frequency stable isotope database in precipitation are developing by the monitoring network, funded by the Nation Water Database Project, Hydro and Agro Informatics Institute (HAII) during 2013-2016. In this study, data interpretation is based on the selected database from 6 rain stations from Northeastern Thailand, which are located in Nakhon Ratchasima (NMA) Surin (SRN), Khon Kaen (KKN),Ubon Ratchathani (UBN), Nakorn Panom (NPM) and Nong Khai(NKI). The database are including meteorological data (Surface Temperature, RH and Precipitation intensity, daily reported at 7am) and stable isotope ratios (δ^2H, $\delta^{18}O$) in daily rainfalls (24h) samples, which were collected by standard rain gages and analyzed by the Cavity Ring-down (CRDS) Isotopic H_2O Analyzer based on laser absorption spectroscopy. The results of 33 consecutive months from April 2013 to January 2016 provide new perspective of temporal variation and seasonal offset of stable isotopes in the local precipitation in NE region of Thailand, compared to the local meteoric water line (LMWL) of Bangkok (GNIP 4845500) and Luang Phrabang (GNIP 489300). The unique fingerprints of the stations in northern part (NPM and NKI) and eastern part (UBN) of the region indicate the difference in precipitation sources and strong influence of moisture transportation from the South China Sea comparing the other inland stations (NMA, SRN and KKN). The fingerprints demonstrate as effective tracers to investigate seasonal interaction of the run-off in different watersheds as well as the identification of groundwater (GW) recharge sources and mechanisms in local GW basins. Furthermore, yearly weighted average data (Average Annual Rainfall, AAR) show highly inter-annular variations including abnormally enrichment characteristics between 2014-2015. The observation can be implied the relation on regional climate change including the effect of recent warm phase of the El Niño Southern Oscillation.

Keyword: Stable isotope, Hydrological study, Daily precipitation, Northeastern Thailand

1. Introduction

Stable isotopes are a very powerful means in hydrological study of water cycle (Kendall and McDonnell, 1998). The isotope ratios of stable hydrogen and oxygen ($^{18}O/^{16}O$ and $^{2}H/H$) in waters molecules express the fractionation processes of waters along different environments from seawater, evaporated vapors, precipitations, run-off, and infiltrated soil water to groundwater (Mook, 2000). The isotope ratio were expressed in delta (δ) values respect to the Vienna Standard Mean Ocean Water (VSMOW) as for example

$\delta^{18}O$

$$\delta^{18}O = \left(\frac{\left(\frac{^{18}O}{^{16}O}\right)_{sample}}{\left(\frac{^{18}O}{^{16}O}\right)_{standard}} - 1\right) * 1000\ ‰$$

, where $^{18}O/^{16}O$ is 2005.20 ±0.45 ppm and $^{2}H/H$ is 155.75±0.08 ppm in VSMOW.The ocean water is the largest reservoir in water cycle, globally constant, limited seasonal fluctuation and close to 0 ‰ (Permil) (Coplen, 1996).

The $\delta^{2}H$ and $\delta^{18}O$ values in rainwater (RW) were surveyed by the Global Network of Isotopes in Precipitation (GNIP) program conducted by International Atom Energy Agency (IAEA) and World Meteorological Organization (WMO) (IAEA, 1992). In mainland SE Asia region, only monthly samples in few stations were operated in Thailand (Bangkok GNIP 4845500) and Ko Srichang GNIP 4846000), Malaysia (GNIP 486000 Langkawi), Myanmar (Yangon GNIP 4809700), Vietnam (Hanoi GNIP488201) and Lao PDR. (Luang Phrabang GNIP 489300). The$\delta^{2}H$and$\delta^{18}O$ can be related by linear relationship that represent by Global Meteoric Water Line (GMWL) of globally mean average. The regression line of GMWL can be defined in equation: $\delta^{2}H = 8\ (\delta^{18}O + 10)$ under isotopic equilibrium condition (Rozanski, Araguas-Araguas and Gofiantini, 1993). But the local isotopicdeviationby complicate kinetic processes of precipitations, the relationship represent by local meteoric water line (LMWL).

2. Research Objectives

In Thailand, there is a large gap between the available databases in precipitation, which are the input of all terrestrial water in water cycles including the local effect to the stable isotope variation. By incomprehensive and temporary of the IAEA's GNIP database, the utilizations of stable isotope database are in difficult and inapplicable interpretation on very dynamic, seasonal control of the local water systems. Thus, this research consisted of three objectives:

2.1 To make well defined stable isotope database in precipitation of Northeastern Thailand region on LMWL and their seasonal variations.

2.2 To identify the difference in isotopic "fingerprints" of the local precipitations, which can be compared to the archive data in Bangkok and Luang Phrabang

2.3 To identify the relationship between the observation data and the implication on climate change and water management issues.

3. Materials and Method

The high frequency stable isotope database in water cycles is on-going developed by the network of 25 rain stations nationwide, funded by the Nation Water Database Project, Hydro and Agro Informatics Institute (HAII) during 2013-2016.

3.1 Rain stations and sampling

In this study, the water samples of daily rainfall events (24 h from 7.00 am to 7.00 am next consecutive date) were collected by manual rain gauge in6 rain stations from Northeastern Thailand, located in Nakhon Ratchasima (NMA) Surin (SRN), Khon Kaen (KKN),Ubon Ratchathani (UBN), Nakorn Panom (NPM) and Nong Khai(NKI) (the location information shown in Figure 1. They water samples were consecutively collected for 33months from April 2013 to January 2016.

3.2 Stable Isotope Ratio Measurements

Stable Isotope Ratios were generally analyzed by conventional Isotope Ratio Mass Spectrometer (IRMS), but in high investing and operating costs. In this research, the new analytical method based on near-IR laser absorption optical "Cavity Ring-Down" Spectroscopy (CRDS) technique were used, which high frequency stable isotope database can be established. The water samples were carefully sealed to prevent evaporation and sent to Thailand Institute of Nuclear Technology (TINT) for analyzed with CRDS isotopic H_2O Analyzer (Model Picarro L2130*i*)with high precision vaporizer **(Figure 2)**. The average precision (1σ) of 4 duplicate consecutive injections is about 0.15‰ and 0.5‰ for $\delta^{18}O$ and $\delta^{2}H$ respectively.

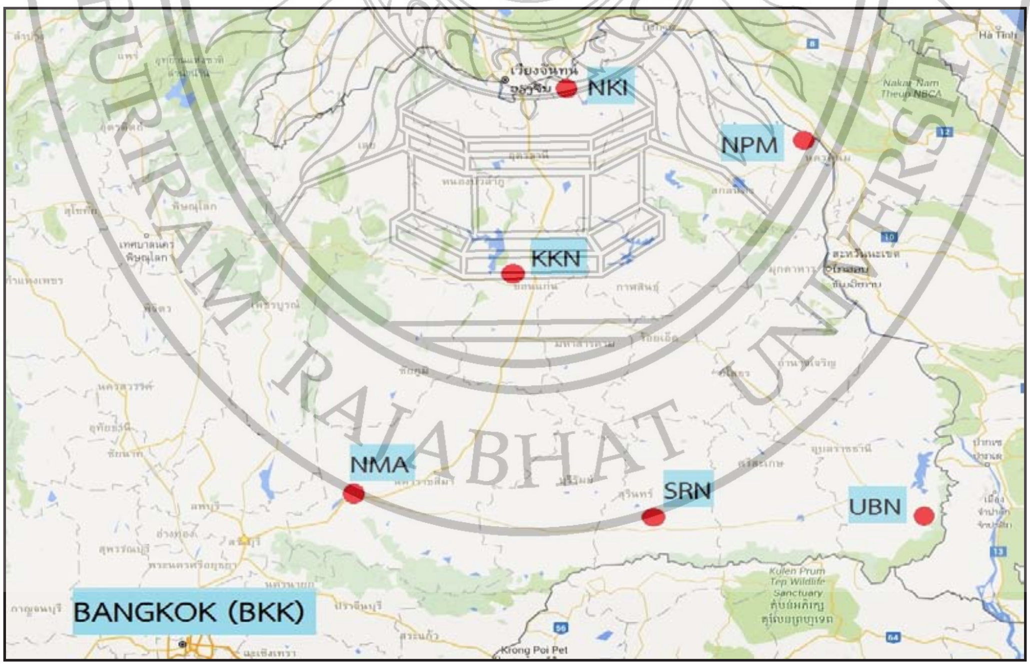


Figure. 1The location map of rain stations in Nakhon Ratchasima (NMA) Surin (SRN), Khon Kaen (KKN), Ubon Ratchathani (UBN), Nakorn Panom (NPM) and Nong Khai(NKI)

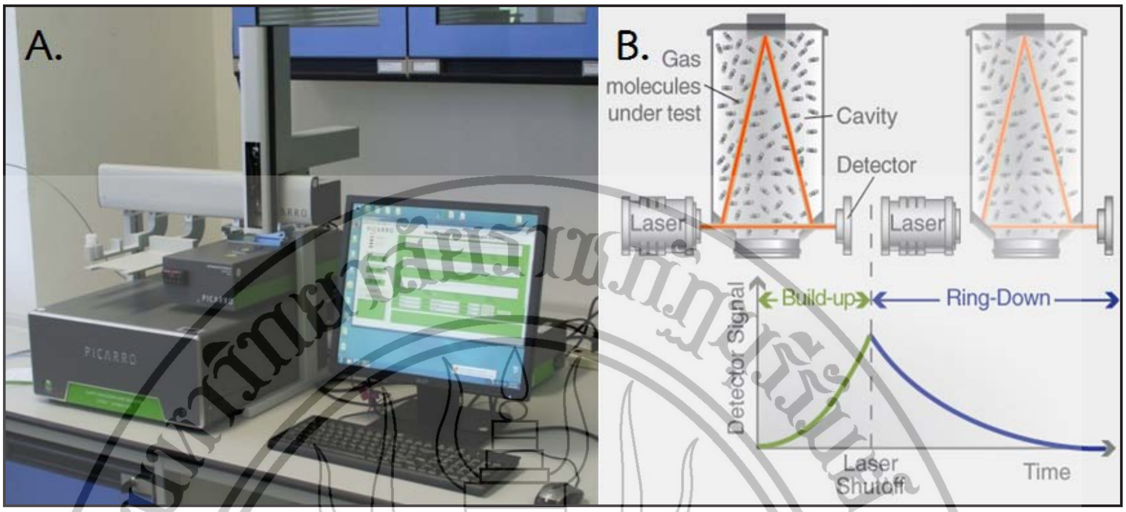


Figure 2. (A) CRDS Isotopic H_2O Analyzer (Model Picarro L2130i)with the high precision vaporizer and automatic sampler (B) Concept diagram of laser absorption characteristic in "Cavity Ring-Down" Spectroscopy (CRDS) method

3.3 Data Analysis

Total daily rainfalleventsare157 days in NMA, 140 days in SRN, 215 days in KKN, 208 days in UBN,290days in NPM, and 293 days in NKI, which are totally of 1,303 days available in the database. However, 40 events were cut-off by the condition of small amount less than 1 mm. that isotope data were affected by evaporation of very low volume/exposure area in the rain gauges.

4. Research Results

In this research, the reference of long-term precipitation can be represented by Bangkok LMWL was measured during 1968-2009, as well as Luang Phrabang LMWL was measured during 1961-1967, the regression line in following equations:

$$\delta^2\mathbf{H(y) = a}\ \delta^{18}\mathbf{O(x) + c}$$

y = 7.655x + 7.197, R^2 = 0.967 (Bangkok) and **y = 7.897x +7.965, R^2 = 0.971** (Luang Phrabang), including the monthly average fluctuations are showing in **Figure 3**.

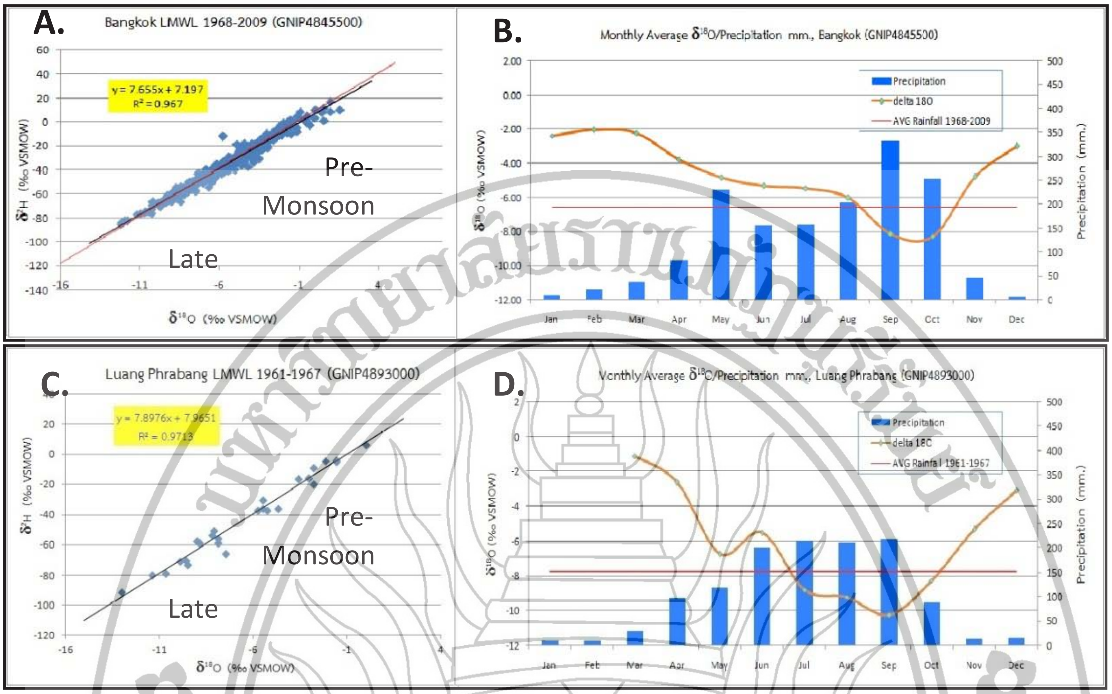


Figure 3. The δ^2Handδ^{18}O relationship of LMWL in Bangkok (A.) and Luang Phrabang (C) and the monthly averagefrom GNIP shows seasonal fluctuation of δ^{18}O value in different patterns between Bangkok (B) and Luang Phrabang (D)

In the analysis data sets, δ^2Handδ^{18}O relationship of initial LMWL (limited short period between 2013-2016, not theoretical long-term decade data) canbe represented bythe regression lines in equations:

$y = 7.5187x + 5.1287 R^2 = 0.9621$(Bangkok, BKK 2013-2016)

$y = 7.623x + 3.969, R^2 = 0.950$ (Nakhon Ratchasima, NMA)
$y = 7.264x + 2.882, R^2 = 0.974$ (Surin, SRN)
$y = 7.696x + 5.117, R^2 = 0.973$ (Khon Kaen, KKN)
$y = 7.729x + 6.343, R^2 = 0.966$(Ubon Ratchathani, UBN)
$y = 7.931x + 9.016, R^2 = 0.973$ (Nakorn Panom, NPM)
$y = 7.834x + 6.838, R^2 = 0.966$ (Nong Khai, NKI)

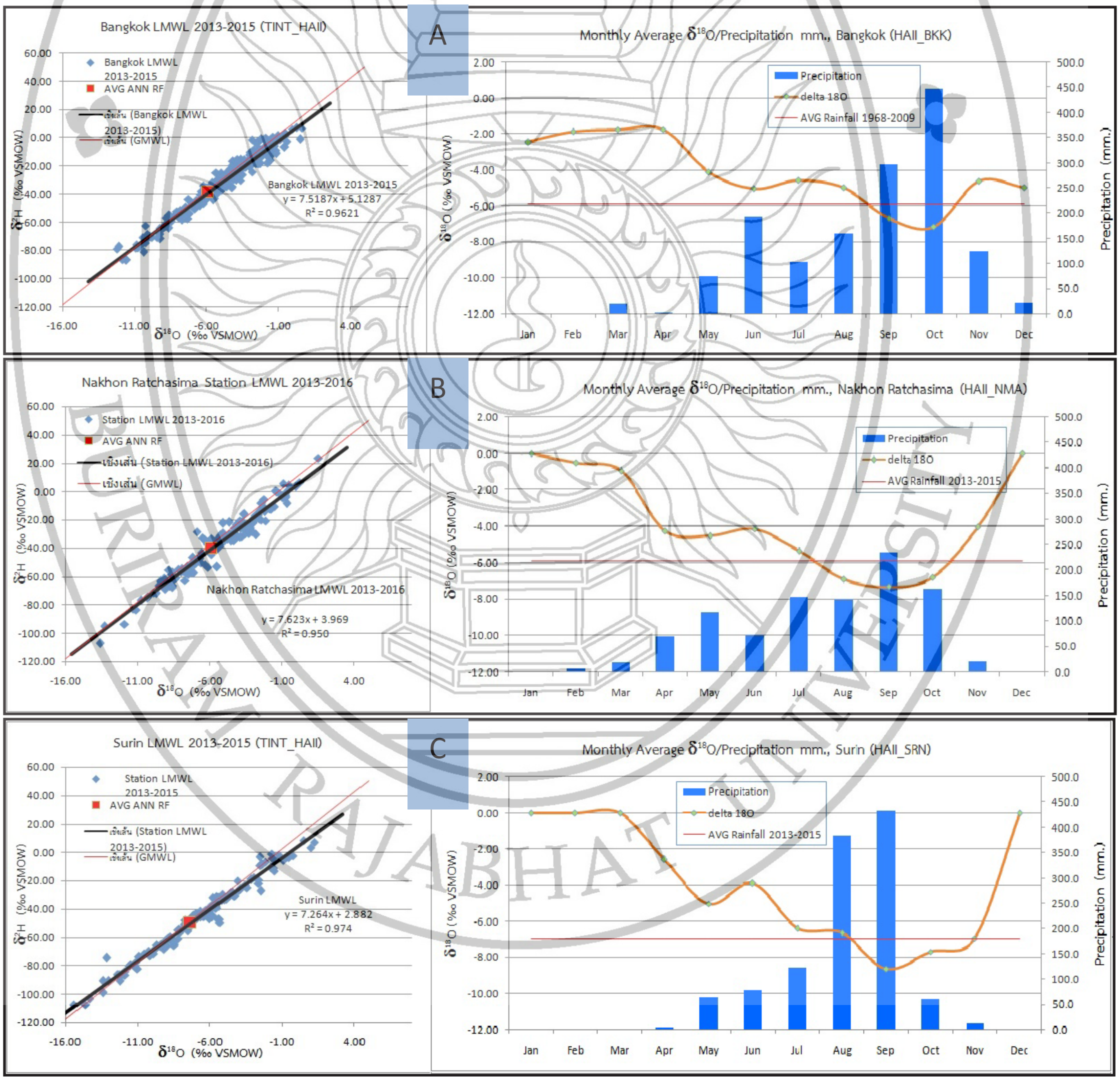
The isotopic data were evaluated monthly average (weighted by precipitation amounts)and plotted in time series (month) to analyze the seasonal fluctuations. Furthermore, the long-term variations in annual time scale can be analyzed by yearly weighted average data (Average Annual Rainfall, AAR), which indicate both of local isotopic characteristics in extended period and their inter-annular variations. The evaluated data are showing in Table 1and Figure 4.

Table 1

The δ^2Handδ^{18}O yearly weighted average data (Average Annual Rainfall, AAR) in 6 stations, compared with Bangkok (BKK) in 2013-2015

Stations	AAR 2013		AAR 2014		AAR 2015		Avg. 2013-2015	
	δ^{18}O	δ^2H	δ^{18}O	δ^2H	δ^{18}O	δ^2H	δ^{18}O	δ^2H
BKK	-5.76	-39.35	-5.76	-37.02	-6.15	-39.42	-5.89	-38.60
NMA	-6.06	-41.85	-5.05	-33.19	-6.62	-45.93	-5.91	-40.32
SRN	-6.91	-47.46	-6.30	-41.46	NA*	NA*	NA*	NA*
KKN	-7.00	-49.43	-6.29	-41.74	-5.91	-37.87	-6.40	-43.01
UBN	-6.82	-47.68	-5.62	-36.22	-5.61	-35.13	-6.02	-39.68
NPM	-7.55	-50.20	-6.32	-41.10	-5.88	-37.79	-6.58	-43.03
NKI	-6.84	-49.56	-7.94	-54.00	-6.77	-44.65	-7.18	-49.40

*Not available by incomplete collecting data



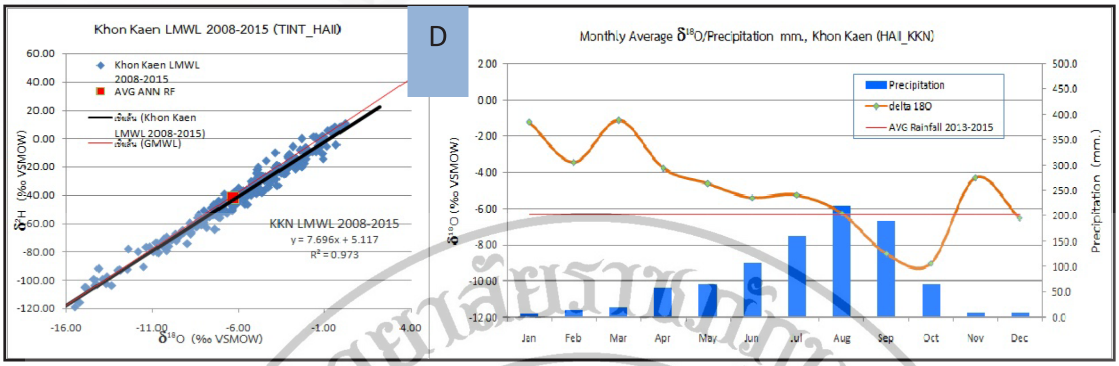


Figure 4. (cont.) δ^2Handδ^{18}O plotsshow the initial LMWL and monthly weighted average of δ^{18}Ointhe station in north-eastern and eastern parts of study area (E) UBN (F) NPM (G) NKI

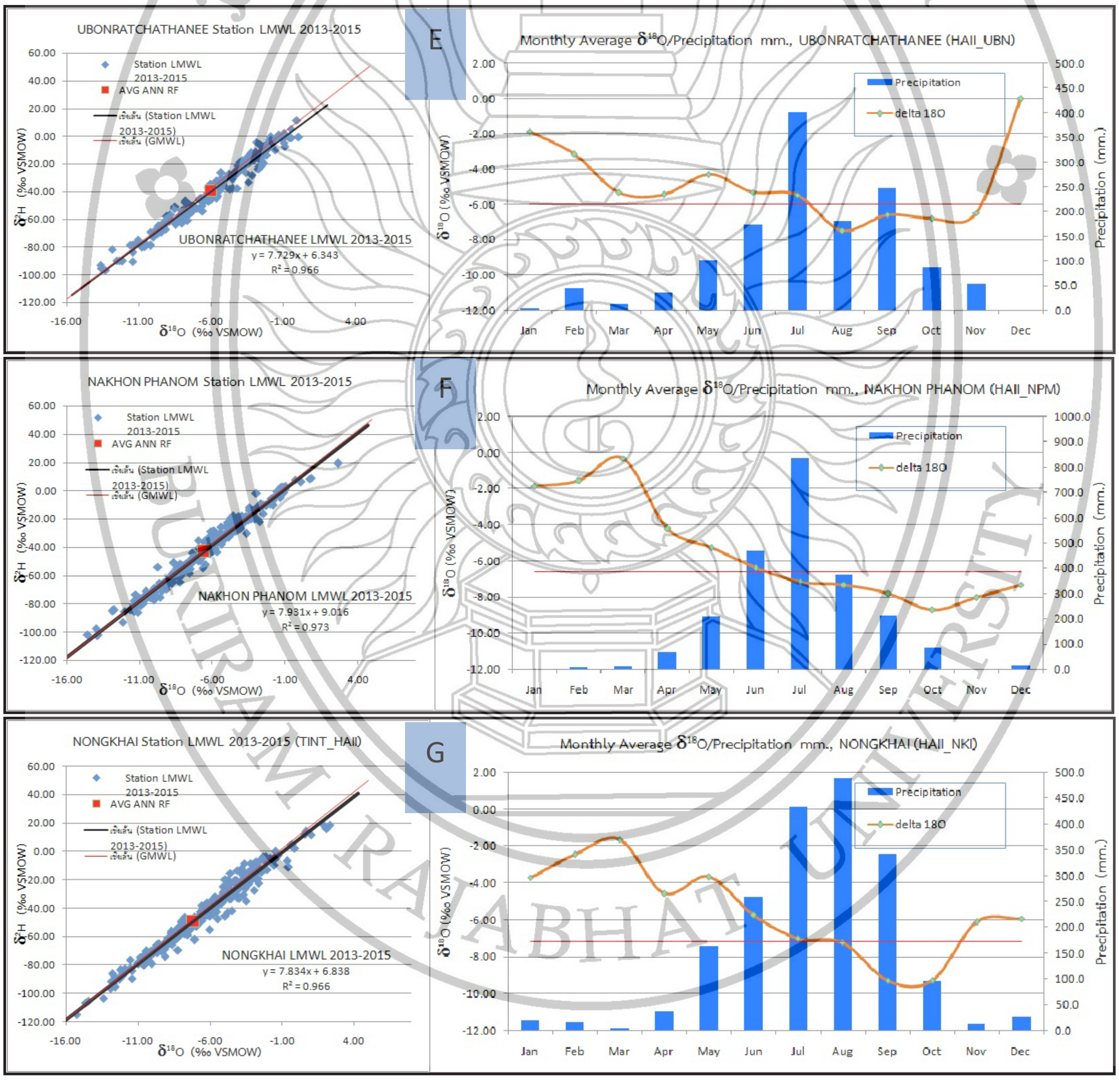


Figure 4. δ^2Handδ^{18}O plotsshow the initial LMWL and monthly weighted average of δ^{18}Oin(A) BKK comparing with the stations in south-western and central parts of study area(B) NMA (C) SRN (D) KKN

5. Discussions

From analyzed data, the monitoring station in the study area can be divided into 2 groups. Firstly, the stations in south-western and central parts of study area namely, Nakorn Ratchasima (NMA), Surin (SRN) and Khon Kean (KKN), have strong correlation to Bangkok (BKK). Their initial LMWLs are showing clearly deviation from GMWL by lower slop value of the regression lines (a) <0.770. This can be explained by the effect of evaporation in the vapor sources, which strongly re-evaporation effect occurred in summer rain of the continental vapor sources by longer distance from the sea (Mook, 2000). In this group, the monthly weighted average of isotopic data show the same patterns to BKK station as well as BKK GNIP (1968-2009). They display strong enrichment of heavy isotopes (less negative δ^2Handδ^{18}O values) in summer and first monsoon rainfalls (May-August, MJJA) and strong depletion of heavy isotopes (more negative δ^2Handδ^{18}O values) in late monsoon rainfalls (September-November, SON).

Secondly, the stations in north-eastern and eastern parts of study area namely, Ubon Ratchathani (UBN), Nakorn Panom (NPM) and Nong Khai (NKI) have strong correlation to Luang Phrabang (GNIP). Their initial LMWLs are showing less deviation from GMWL by higher slop value of the regression lines (a) >0.770 that indicate strong relation to oceanic vapor sources, which less effect of the continent by shorter distance from the sea (Mook, 2000). In this group, the monthly weighted average of isotopic data show different patterns to BKK station. They display weaker enrichment in first monsoon rainfalls (May-August, MJJA) and weaker depletion of heavy isotopes (more negative δ^2Handδ^{18}O values) in late monsoon rainfalls (September-November, SON). The first monsoon rainfalls mainly controlled by SW monsoon, which transport the moisture from Indian Ocean to Thailand. The stations in this group, which located in northern and eastern edge of the region, were most affected by continental effect on depletion of heavy isotopes in this period. But in late monsoon, the rainfalls were affected by NE moisture from the South China Sea, transport by the depression and tropical cyclone as well as NE monsoon in the end of period. This change result the less effect on depletion of heavy isotopes (by continental effects) in this group, compared with the first group by shorter path from NE moisture source.

The long-term variations of yearly weighted average data (Average Annual Rainfall, AAR) show close relationship between Bangkok and the most SW station Nakorn Ratchasima (NMA) by the average (2013-2015) AAR (δ^2H,δ^{18}O) < (-41‰, -6‰) in both stations. It can be distinguished to the other stations, which all average AAR (δ^2H,δ^{18}O)>(-41‰, -6‰), and the smallest AAR value found in Nongkhai (NKI), the most NE station (average AAR =-49.40‰, -7.18‰). This indicates the rainfalls in Northeastern Thailand are mainly influenced of SW monsoon moistures in annual average perspective.

Finally, the strongly agreement of isotopic enrichment abnormally (about +0.7-1.5‰) of the AARs in 2014-2015, compared with 2013 AARs in almost stations (except NMA and Bangkok), indicate clearly correlation to warm phase of the El

Niño Southern Oscillation (ENSO) between 2014-2015 in NOAA Multivariate ENSO Index (NOAA, 2016).

6. Conclusion

The unique fingerprints of the stations in northern part (NPM and NKI) and eastern part (UBN) of the region indicate the difference in precipitation sources and strong influence of moisture transportation from the South China Sea comparing the other inland stations (NMA, SRN and KKN). The fingerprints demonstrate as effective tracers to investigate seasonal interaction of the run-off in different watersheds as well as the identification of groundwater (GW) recharge sources and mechanisms in local GW basins. Furthermore, yearly weighted average data (Average Annual Rainfall, AAR) show highly inter-annular variations including abnormally enrichment characteristics between 2014-2015. The observation can be implied the relation on regional climate change including the effect of recent warm phase of the El Niño Southern Oscillation (ENSO).

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