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HYDROGEN AND OXYGEN ISOTOPIC COMPOSITIONS OF TAIPEI PRECIPITATION: 1990 TO 1998

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ABSTRACT

The hydrogen and oxygen isotopes of precipitation collected at Taipei from January, 1990 to December, 1998 are reported as monthly and annual means similar to the standard IAEA format. A regression fit line of $\delta D=8.2\delta^{18}O+11.6$ is obtained for local meteoric waters. Correlations with precipitation amount and temperature of Taipei meteorological station show characteristics between subtropical continent and marine stations in the IAEA monitoring network. The long-term weighted mean values (δD=-33‰; $\delta^{18}O$=-5.4‰) are in accordance with those predicted in the IAEA isotope contour map for East Asia region. This study not only serves as a basis for future isotope hydrological work in Taiwan but also contributes valuable precipitation isotope data set for the regional atmospheric modeling work in Asia.

Key words: Hydrogen and Oxygen isotopes, precipitation, Taipei

INTRODUCTION

Precipitation is the primary source for the earth's surface runoff, groundwater recharge and evapotranspiration moisture. Hydrogen and oxygen isotopes in the water molecule are an excellent and useful tool for understanding both the past changes and the present behavior of global circulation (Gat, 1980, 1981, 1996, 1998; Jouzel *et al.*, 1997; Merlivat and Jouzel, 1979; Panarello *et al.*, 1998; Rozanksi *et al.*, 1997). The most significant changes in the isotopic compositions of meteoric water occur within the troposphere and exhibit a broad range of variations in time and space (Gat, 1981). The isotope discrepancy among precipitation, runoff and groundwater provides invaluable clues about the hydrological interactions among the precipitation, surface water, vegetation cover and subsurface recharge (Gat, 1996).

In 1961, the International Atomic Energy Agency (IAEA) in cooperation with the World Meteorological Organization (WMO) initiated a world-wide survey of the isotopic composition of monthly precipitation. The data collected in that network has provided a detailed and complete picture of isotopes in precipitation on a global scale and, consequently, contributed basic isotope data for the use of environmental isotopes on numerous hydrological investigations (Dansgaard, 1964; Gat, 1981; IAEA, 1992; Rozanski *et al.*, 1992, 1993).

Though several short-term cases represented various isotope meteoric water lines in Taiwan area with a limited time coverage of about one year (Shieh *et al.*, 1983; Liu, 1984; Liu *et al.*, 1990; Chen *et al.*, 1990; Peng, 1995; Wang *et al.*, 1994, 1996, 1997a, 1997b), a longer record is needed to better define the natural isotopic variations in precipitation for local hydrological study. Because there is no IAEA monitoring station in Taiwan, a similar monitoring study has been created since 1990 at the Institute of Earth Sciences, Academia Sinica. We report here the hydrogen and oxygen isotopic compositions of precipitation collected at Taipei from January 1990 through December 1998. The main goals are to investigate the isotopic characteristics of the Taipei precipitation with the climate parameters and to serve as a basis for a further isotope hydrological study for both local and regional scales. This study would also provide useful data for an atmospheric modeling work covering the western Pacific region.

DATA AND METHODS

Monthly precipitation samples were collected at the Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan (25°02'N, 121°30'E) according to IAEA guidelines (IAEA, 1983; Figure 1). Meteorological data for the Taipei station are retrieved from annual climatological data reports of Central Weather Bureau (1990-1998).

The hydrogen and oxygen compositions of rain samples were determined using well-established methods (IAEA, 1983; Coleman *et al.*, 1982; Brenninkmeijer and Morrison, 1987). Isotope data are reported as per mill (‰) relative to the V-SMOW (Vienna Standard Mean Ocean Water) standard (Gonfiatini, 1978; IAEA, 1983; ISO, 1992). Isotope compositions were analyzed by a MM602D mass spectrometer for δD and a SIRA 10 mass spectrometer for $\delta^{18}O$, respectively. Repeated analyses of samples and laboratory standards show that the 1σ uncertainties were 1.5‰ for δD and 0.11‰ for $\delta^{18}O$, respectively. In 1999, our laboratory participated "the Second Interlaboratory Comparison for Deuterium and Oxygen-18 Analysis of Water Samples" program sponsored by the Isotope Hydrology Laboratory, IAEA. Among four intercomparison samples (δD: -4‰ ~ -109‰; $\delta^{18}O$: -0.1‰ ~ -15.3‰), our analytical results show that the hydrogen isotope values are within the analytical precision (<1.5‰) and oxygen isotope values are identical to those of IAEA certified values, respectively (Lippmann *et al.*, 1999).

RESULTS AND DISCUSSION

Isotope, precipitation and temperature data are presented in Table 1 by month from January 1990 to December 1998 with a format similar to the IAEA report (IAEA, 1992). The time-series variations of hydrogen and oxygen isotopic compositions of Taipei precipitation from 1990 through 1998 are shown in Figure 2. In general, hydrogen isotope compositions range from 0‰ to -64‰ with a mean of -25‰, and oxygen isotope compositions from -1.3‰ to -8.9‰ with a mean of -4.5‰, respectively. The large amplitudes of isotope variations clearly indicate the complexity of its source and climatic characteristics in Taipei precipitation.

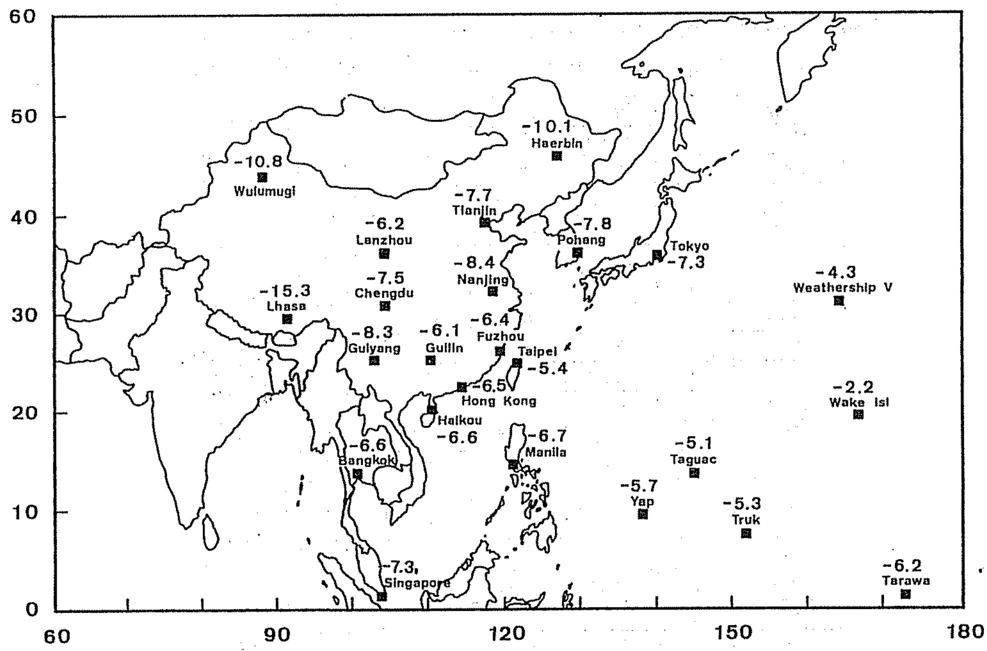

Figure 1. Weighted oxygen isotopic mean values of precipitation in Taipei. Also shown are selected IAEA stations in East Asia with oxygen isotopic values from Araguas-Araguas *et al.* (1998) .

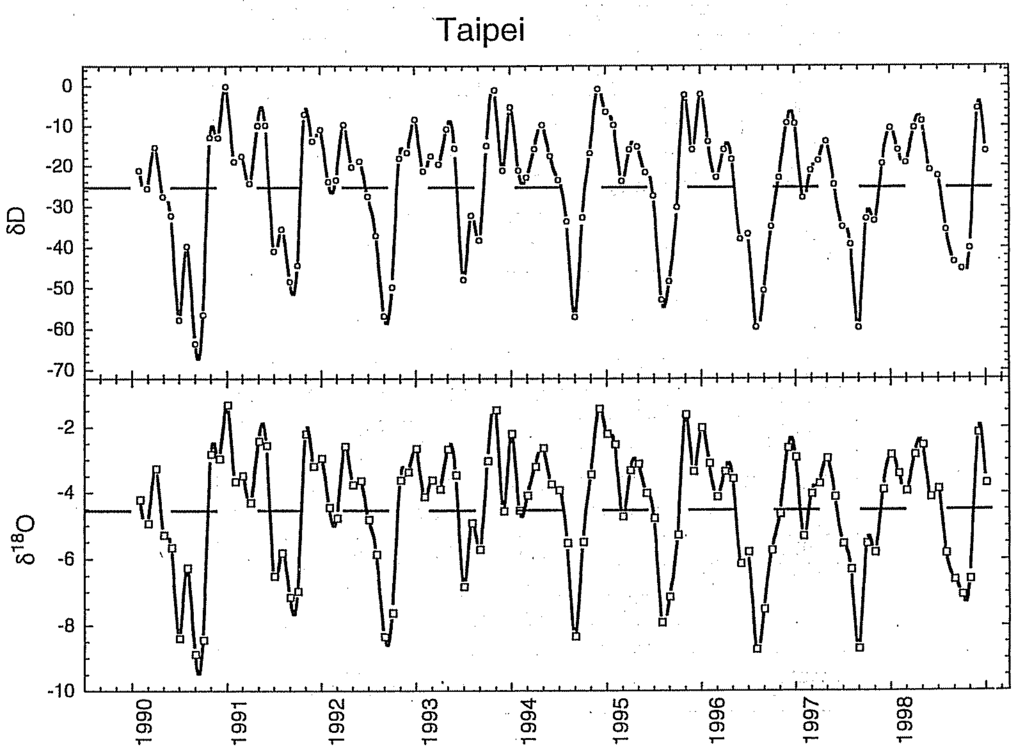

Figure 2. The time-series variations of hydrogen and oxygen isotopes for Taipei precipitation, 1990-1998.

Table 1. Isotope, precipitation and temperature data are presented by month for Taipie station from January 1999 to December 1998.

Year	Month	Prec.	$\delta^{18}O$	δD	dex	Temp
1990	1	186.9	-4.20	-21.1	12.5	17.1
1990	2	202.7	-4.91	-25.5	13.8	18.1
1990	3	85.5	-3.25	-15.3	10.7	18.7
1990	4	497.5	-5.27	-27.5	14.7	21.1
1990	5	131.5	-5.64	-32.1	13.0	25.7
1990	6	403.5	-8.37	-57.7	9.3	28.2
1990	7	352.6	-6.25	-39.7	10.3	30.1
1990	8	383.0	-8.86	-63.5	7.4	29.6
1990	9	554.2	-8.42	-56.5	10.9	27.6
1990	10	38.4	-2.80	-12.8	9.6	24.3
1990	11	69.6	-2.94	-12.9	10.6	22.8
1990	12	7.6	-1.29	-0.1	10.2	18.7
sum		2913.0				
mean			-5.18	-30.4	11.1	23.5
W.mean			-6.65	-42.1	11.1	
1991	1	108.4	-3.64	-18.9	10.2	16.4
1991	2	81.0	-3.46	-17.5	10.2	16.8
1991	3	127.4	-4.29	-24.3	10.0	20.3
1991	4	111.2	-2.39	-9.9	9.2	22.6
1991	5	89.1	-2.53	-9.8	10.4	26.5
1991	6	757.7	-6.49	-40.9	11.0	28.6
1991	7	133.9	-5.80	-35.5	10.9	30.6
1991	8	137.4	-7.13	-48.4	8.6	29.5
1991	9	455.8	-6.95	-44.3	11.3	27.7
1991	10	87.7	-2.17	-7.1	10.3	23.2
1991	11	51.3	-3.17	-13.8	11.6	21.0
1991	12	75.0	-2.93	-10.9	12.5	18.8
sum		2215.9				
mean			-4.25	-23.4	10.5	23.5
W.mean			-5.47	-33.1	10.7	
1992	1	91.3	-4.43	-23.9	11.5	15.9
1992	2	385.8	-4.75	-23.5	14.5	15.0
1992	3	179.7	-2.56	-9.7	10.8	18.3
1992	4	221.6	-3.74	-20.3	9.6	21.4
1992	5	222.2	-3.62	-18.8	10.2	23.9
1992	6	285.0	-4.80	-27.5	10.9	27.1
1992	7	122.6	-5.84	-37.1	9.6	29.0
1992	8	329.0	-8.32	-56.8	9.8	28.6
1992	9	329.2	-7.60	-49.8	11.0	27.0
1992	10	85.2	-3.60	-18.1	10.7	22.5
1992	11	65.9	-3.35	-16.6	10.2	20.1
1992	12	74.4	-2.63	-8.4	12.6	18.8
sum		2391.9				
mean			-4.60	-25.9	11.0	22.3
W.mean			-5.17	-30.3	11.1	

1993	1	116.0	-4.10	-21.3	11.5	14.8
1993	2	33.2	-3.60	-17.5	11.3	16.9
1993	3	188.0	-3.87	-19.6	11.4	17.9
1993	4	189.7	-2.65	-10.8	10.4	20.9
1993	5	160.6	-3.44	-15.6	11.9	24.9
1993	6	366.4	-6.81	-47.9	6.6	27.5
1993	7	219.1	-4.90	-32.1	7.1	29.6
1993	8	225.7	-5.70	-38.2	7.4	28.9
1993	9	74.7	-3.01	-14.9	9.2	27.5
1993	10	48.0	-1.46	-1.1	10.6	23.5
1993	11	73.6	-4.54	-21.1	15.2	22.3
1993	12	45.5	-2.17	-5.4	12.0	17.6
sum		1740.5				
mean			-3.85	-20.5	10.4	22.7
W.mean			-4.57	-27.3	9.3	
1994	1	72.0	-4.52	-21.1	15.0	16.3
1994	2	234.0	-4.06	-22.8	9.6	16.4
1994	3	135.7	-3.18	-15.7	9.7	17.0
1994	4	66.0	-2.61	-9.8	11.1	23.7
1994	5	210.0	-3.72	-17.5	12.3	25.8
1994	6	206.7	-3.90	-23.5	7.7	28.1
1994	7	198.9	-5.50	-33.6	10.4	29.6
1994	8	441.7	-8.31	-57.0	9.5	29.0
1994	9	180.0	-5.47	-32.6	11.2	26.2
1994	10	216.4	-3.42	-16.8	10.6	23.5
1994	11	8.2	-1.42	-0.8	10.6	22.2
1994	12	74.1	-2.17	-6.5	10.9	20.1
sum		2043.7				
mean			-4.02	-21.5	10.7	23.2
W.mean			-4.96	-29.4	10.3	
1995	1	98.8	-2.50	-9.8	10.2	15.6
1995	2	232.9	-4.70	-23.7	13.9	14.3
1995	3	161.3	-3.30	-15.9	10.5	17.2
1995	4	143.9	-3.10	-15.2	9.6	22.1
1995	5	173.1	-3.99	-21.6	10.3	24.4
1995	6	167.6	-4.75	-27.3	10.7	28.1
1995	7	288.1	-7.87	-52.9	10.0	29.0
1995	8	201.9	-7.12	-48.3	8.7	29.0
1995	9	146.0	-5.26	-30.1	11.9	27.2
1995	10	22.3	-1.60	-2.3	10.5	24.9
1995	11	55.9	-3.33	-15.9	10.7	19.8
1995	12	24.9	-1.99	-2.1	13.8	16.4
sum		1716.7				
mean			-4.13	-22.1	10.9	22.3
W.mean			-4.98	-29.1	10.8	
1996	1	19.3	-3.08	-13.9	10.7	15.7
1996	2	110.7	-4.10	-22.8	10.0	15.1
1996	3	159.2	-3.33	-15.9	10.7	18.6
1996	4	220.3	-3.55	-18.3	10.1	19.3
1996	5	334.5	-6.12	-37.9	11.1	23.4

1996	6	158.1	-5.77	-36.7	9.4	28.9
1996	7	524.9	-8.71	-59.5	10.2	29.3
1996	8	270.8	-7.49	-50.6	9.3	28.3
1996	9	307.6	-5.72	-34.9	10.9	27.5
1996	10	68.4	-4.62	-22.9	14.1	24.5
1996	11	61.6	-2.61	-9.3	11.5	21.8
1996	12	17.7	-2.90	-9.5	13.7	17.4
sum		2253.1				
mean			-4.83	-27.7	11.0	22.5
W.mean			-6.07	-38.1	10.5	
1997	1	62.1	-5.29	-27.7	14.6	15.3
1997	2	193.9	-4.01	-21.1	10.9	15.9
1997	3	104.7	-3.70	-18.7	10.9	19.1
1997	4	100.1	-2.93	-13.9	9.5	21.7
1997	5	211.3	-4.11	-24.6	8.3	25.2
1997	6	657.1	-5.52	-35.0	9.2	25.8
1997	7	289.7	-6.29	-39.3	11.1	27.9
1997	8	587.4	-8.69	-59.7	9.8	28.6
1997	9	221.5	-5.51	-32.9	11.2	25.8
1997	10	37.4	-5.78	-33.5	12.7	24.2
1997	11	37.4	-3.89	-19.5	11.6	22.2
1997	12	92.4	-2.83	-10.6	12.0	18.5
sum		2595.0				
mean			-4.88	-28.0	11.0	22.5
W.mean			-5.80	-36.2	10.2	
1998	1	138.7	-3.40	-16.1	11.1	16.1
1998	2	424.5	-3.92	-19.2	12.1	16.6
1998	3	208.3	-2.82	-10.5	12.0	19.0
1998	4	400.0	-2.53	-8.9	11.3	24.2
1998	5	553.3	-4.11	-21.0	11.9	25.9
1998	6	314.9	-3.86	-22.5	8.4	28.0
1998	7	273.0	-5.80	-35.7	10.7	30.2
1998	8	394.9	-6.60	-43.5	9.3	29.6
1998	9	485.2	-7.05	-45.2	11.2	26.7
1998	10	997.7	-6.58	-40.2	12.4	24.8
1998	11	87.1	-2.14	-5.7	11.4	22.3
1998	12	127.1	-3.69	-16.3	13.2	19.3
sum		4404.7				
mean			-4.37	-23.7	11.3	23.6
W.mean			-5.01	-28.7	11.4	

Note: dex denotes the deuterium excess value; W. mean represents the weighted values.

Local meteoric water line

The close and consistent proportionality between D and ^{18}O in meteoric water, defined by the best fit line δD=8δ18O+10 and commonly known as Global Meteoric Water Line (GMWL), is the basis of many hydrological and climatological applications (Craig, 1961; Gat, 1980; Rozanski *et al.*, 1993). Deviations from GMWL indicate specific atmospheric conditions at the source region of precipitation and/or at the site of its collection (Gat, 1981; IAEA, 1992; Ingraham, 1998).

The regression line derived from the 9-year δD and $\delta^{18}O$ precipitation data at Taipei is:

$$\delta D = (8.2 \pm 0.1)*\delta^{18}O + (11.6 \pm 0.4)\ (R^2 = 0.99)$$

The slight deviation of slope and intercept of Taipei MWL from GMWL is controlled by the local climatic factors (vapor sources, evaporation, precipitation and temperature), though both slope and intercept are close to those of the GMWL (Rozanski *et al.*, 1993). This Taipei MWL also reveals discrepancies with previous studies (Shieh *et al.*, 1983; EMRO. 1984; Liu, 1984; Liu, *et al.*, 1990; Chen *et al.*, 1990; Peng, 1995; Wang *et al.*, 1994, 1996, 1997a, 1997b) due to temporal and spatial effects (Tab. 2). For example, it is interesting to note that the Tatun Shan region has the highest slope (=9.3) and intercept (=27), whereas the Pingtung area exhibits the lowest slope (=7.6) and intercept (=7.7) among all MWLs. Evidently, the northeast and southwest monsoons play an important role for the moisture supply and cause the discrepancies for the slope and intercept of Taiwan MWLs in various regions. The long-term local MWL of this study, which covers a period of nine years, will naturally serve as the primary reference line for a further isotope hydrologic study in northern Taiwan.

Relationship with climatic parameters

Table 3 lists the annual mean values for hydrogen and oxygen isotopes together with precipitation, temperature and humidity data at Taipei. The weighted mean values of Taipei rains are -33‰ for hydrogen and -5.4‰ for oxygen, respectively. The weighted values are in good accordance with predicted values in the IAEA world contours map (Araguas-Araguas *et al.*, 1996, 1998; IAEA, 1992; Figure 1). The relative depleted nature of weighted values than those of un-weighted ones indicates that the amount effect plays an important factor in controlling the isotopic compositions of Taipei precipitation. Comparing to the nearby East Asia IAEA stations, Taipei site shows a typical subtropical marine environment characteristics and reflects its moisture sources and climate heterogeneity both seasonally and inter-annually. For example, during summer times, isotopic compositions exhibit relatively depleted values than those of winters.

Depending on the latitude, rainfall intensity or temperature may dominate the seasonal distribution of isotopes in precipitation (Dansgaard, 1964; Gat, 1981). In middle and high latitudes, the isotopes in monthly precipitation are well correlated with temperature. Seasonally changing temperature leads to variation in the total precipitable moisture in the atmosphere, due to the various rain-out processes from air mass as they are transported toward poles. In low latitudes, on the other hand, a different response shows. Isotopic composition is basically modulated by seasonal variations in the volume of precipitation instead (IAEA, 1992). During the rainy season, observations confirm that heavy precipitation is often isotopically depleted. The monthly values of hydrogen and oxygen isotopes with precipitation and temperature data at Taipei are summarized in Table 4 and illustrated in Figure 3. The seasonal signals are obvious for both hydrogen and oxygen isotopes. During summer months with torrential rains associated with

Meiyu and typhoon invasions, stable isotopes show most depleted values. During winter months when northeast monsoon prevails, the isotopic signals show relative heavier values. Regarding to seasonal variations, there are some discrepancies between Taipei and nearby IAEA stations, such as Hong Kong and Fuzhou (Araguas-Araguas *et al.*, 1998). Generally, the isotope values of Hong Kong and Fuzhou are relatively depleted during summer time (June to August) and relatively enriched during winter season (January to March) to Taipei. This feature demonstrates that the influence of maritime moisture is much heavier on Taiwan.

Table 2. The published MWL formula in Taiwan area.

Region	MWL formula	Reference
Taiwan	$\delta D = 8.0\ \delta^{18}O + 16.5$	Shieh et al., 1983
Taiwan	$\delta D = 7.9\ \delta^{18}O + 17.1$	Chen et al., 1990
Taipei	$\delta D = 8.2\ \delta^{18}O + 11.6$	Wang & Peng, this study
Tatun-Shan	$\delta D = 8.6\ \delta^{18}O + 17$ (summer) $\delta D = 7.6\ \delta^{18}O + 23$ (winter) $\delta D = 9.3\ \delta^{18}O + 27$ (yearly)	Liu, 1984
I-Lan	$\delta D = 7.8\ \delta^{18}O + 18$	Liu et al., 1990
I-Lan	$\delta D = 8.0\ \delta^{18}O + 9.0$ (summer) $\delta D = 8.6\ \delta^{18}O + 23.3$ (winter)	Peng, 1995
Hua-Tung	$\delta D = 8\ \delta^{18}O + 12.9$	EMRO, 1984
Yun-Lin	$\delta D = 8.3\ \delta^{18}O + 15.0$	Wang et al.,1997a
Chia-Nan	$\delta D = 8.0\ \delta^{18}O + 11.5$	Wang et al., 1997b
Ping-Tung	$\delta D = 7.6\ \delta^{18}O + 7.7$	Wang et al., 1996
Penghu	$\delta D = 7.9\ \delta^{18}O + 10.6$	Wang et al., 1994

Table 3. The yearly means of precipitation, temperature, humidity, oxygen and hydrogen isotopes at Taipie, Taiwan, 1990-1998.

Year	Precip. (mm)	$\delta^{18}O$ W. mean	$\delta^{18}O$ Aver.	δD W. mean	δD Aver.	Deu. Ex W. mean	Deu. Ex Aver.	Temp (C)	Humidity (%)
1990	2913	-6.65	-5.18	-42.1	-30.4	11.1	11.1	23.5	74.4
1991	2216	-5.47	-4.25	-33.1	-23.4	10.7	10.5	23.5	72.6
1992	2392	-5.17	-4.60	-30.3	-25.9	11.1	11.0	22.3	76.8
1993	1741	-4.57	-3.85	-27.3	-20.5	9.3	10.4	22.7	75.8
1994	2044	-4.96	-4.02	-29.4	-21.5	10.3	10.7	23.2	75.1
1995	1717	-4.98	-4.13	-29.1	-22.1	10.8	10.9	22.3	73.5
1996	2253	-6.07	-4.83	-38.1	-27.7	10.5	11.0	22.5	75.3
1997	2595	-5.80	-4.88	-36.2	-28.0	10.2	11.0	22.5	79.1
1998	4405	-5.01	-4.37	-28.7	-23.7	11.4	11.3	23.6	78.1
mean	**2475**	**-5.41**	**-4.46**	**-32.7**	**-24.8**	**10.6**	**10.9**	**22.9**	**75.6**
σ	**818**	**0.66**	**0.44**	**5.1**	**3.4**	**0.6**	**0.3**	**0.5**	**2.1**

Note: σ denotes the one sigma standard deviation.

Table 4. The monthly means of precipitation, oxygen and hydrogen isotopes, temperature, humidity at Taipei, Taiwan, 1990-1998.

Year	Precip. (mm)	$\delta^{18}O$ W. mean	$\delta^{18}O$ Aver.	δD W. mean	δD Aver.	Deu. Ex W. mean	Deu. Ex Aver.	Temp (C)	Humidity (%)
1990	2913	-6.65	-5.18	-42.1	-30.4	11.1	11.1	23.5	74.4
1991	2216	-5.47	-4.25	-33.1	-23.4	10.7	10.5	23.5	72.6
1992	2392	-5.17	-4.60	-30.3	-25.9	11.1	11.0	22.3	76.8
1993	1741	-4.57	-3.85	-27.3	-20.5	9.3	10.4	22.7	75.8
1994	2044	-4.96	-4.02	-29.4	-21.5	10.3	10.7	23.2	75.1
1995	1717	-4.98	-4.13	-29.1	-22.1	10.8	10.9	22.3	73.5
1996	2253	-6.07	-4.83	-38.1	-27.7	10.5	11.0	22.5	75.3
1997	2595	-5.80	-4.88	-36.2	-28.0	10.2	11.0	22.5	79.1
1998	4405	-5.01	-4.37	-28.7	-23.7	11.4	11.3	23.6	78.1
mean	**2475**	**-5.41**	**-4.46**	**-32.7**	**-24.8**	**10.6**	**10.9**	**22.9**	**75.6**
σ	**818**	**0.66**	**0.44**	**5.1**	**3.4**	**0.6**	**0.3**	**0.5**	**2.1**

Note: σ denotes the one sigma standard deviation.

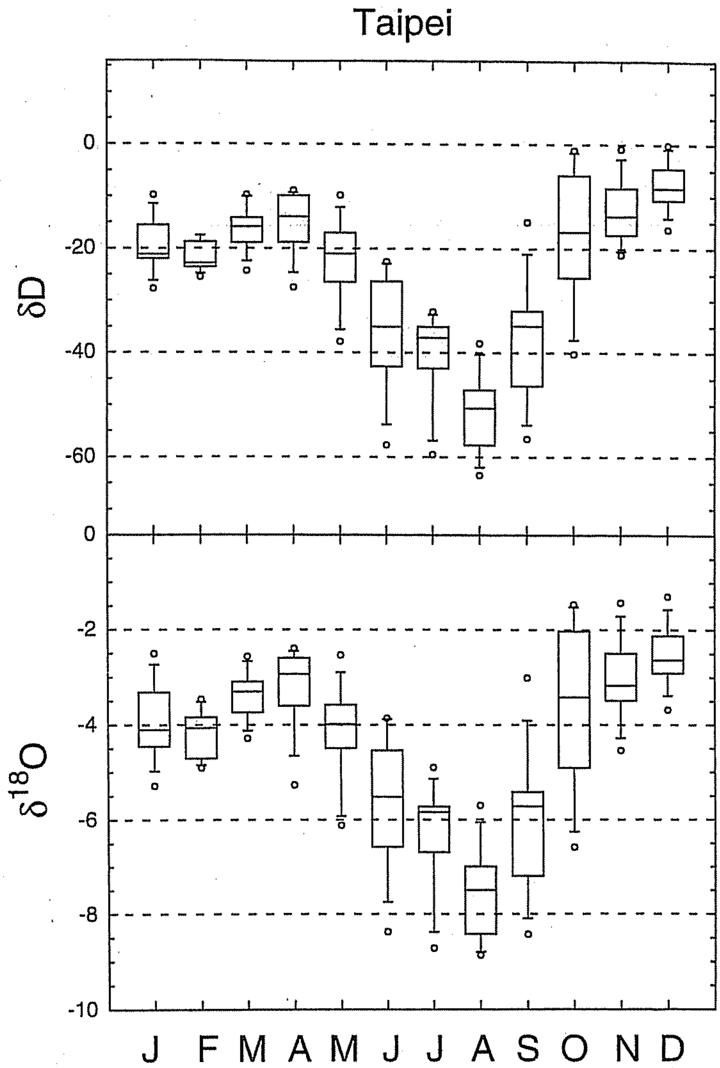

Figure 3. The monthly variations of hydrogen and oxygen isotopes for Taipei precipitation, 1990-1998.

The correlation relationships between hydrogen and oxygen isotopes with temperature and precipitation at Taipei from 1990 to 1998 are listed as Table 5. Normally, the long-term monthly and annual mean values for δD and $\delta^{18}O$ are well-correlated with the average monthly amount of precipitation, whereas the correlations with temperature are virtually nonexistent as commonly observed in other IAEA low latitude stations. However, the apparent correlations between monthly precipitation and temperature with δD and $\delta^{18}O$ in Taipei station are very similar. This observation further illustrates the complexity of the moisture sources on isotope signals for tropical marine stations.

Table 5. The correlation relationships between hydrogen and oxygen isotopes with temperature and precipitation at Taipei, Taiwan, 1990-1998.

	N	A	σ	B	σ	R^2	S.E.E.
Monthly δD vs. Monthly Precip.	108	-0.05	0.01	-13.13	1.76	0.412	11.69
Monthly $\delta^{18}O$ vs. Monthly Precip.	108	-0.01	0.00	-3.03	0.21	0.418	1.42
Monthly δD vs. Monthly Temp.	108	-2.02	0.24	21.56	5.50	0.412	11.70
Monthly $\delta^{18}O$ vs. Monthly Temp.	108	-0.23	0.03	0.87	0.69	0.367	1.48
Monthly δD vs. Monthly $\delta^{18}O$	108	8.17	0.08	11.62	0.41	0.989	1.63

Note: A and B are the slope and intercept of the least square fit line (Y=AX+B), respectively. σ denotes the one sigma standard deviation. S.E.E indicates the standard errors, as defined in IAEA(1992).

d-excess

The concept of the deuterium excess (d) was first proposed by Dansgaard (1964) and defined as $d=\delta D-8*\delta^{18}O$. Deuterium excess (d) is strongly affected by local humidity (Merlivat and Jouzel, 1979), as well as wind speed and sea surface temperature during primary evaporation. This relationship is now well understood and can be reproduced by models based on the Raleigh approach (Jouzel *et al.*, 1997). In addition to the phase changes under equilibrium conditions, a kinetic effect also results in a different diffusivity for the isotopically different water molecules in air. The higher diffusivity for $H^{16}O$ as related to $H^{18}O$ results in an additional separation, thus a higher deuterium excess. The result is a clear seasonal response as the hemispheric Global Network for Isotopes in Precipitation (GNIP) data demonstrate (Rozanski *et al.*, 1993). With an average humidity of about 85%, the global MWL has a d value of 10. Taipei has an average humidity of about 76% during the study period, its d value (=11.6) reflects nicely the negative correlation with humidity as expected.

The monthly d values can be used to identify vapor source regions (Jouzel *et al.*, 1997). Winter precipitation originated from the East China Sea is characterized by distinctly higher excess values (Tab. 4), reflecting the specific source conditions during water vapor formation. Increased deuterium excess in precipitation can also arise from significant addition of re-evaporated moisture from catchment basins to the water vapor traveling inland (Ingram, 1998). If moisture from precipitation with an average excess of 10‰ is re-evaporated, the lighter $H^{16}O$ molecule may again contribute preferentially to the isotopic composition of the water vapor and this, in turn, leads to an enhanced deuterium excess in subsequent precipitation. Some evident examples of deuterium-enriched precipitation derived by this way are known from the Amazon Basin, the Great Lakes Region in North America, or from Mongolian glacier data (IAEA, 1992; Rozanski *et al.*, 1997; Gat, 1998). In Taipei, when southwest monsoon prevails during the summer season, the d values are expected to be relatively lower as shown by those of June and August in Table 4. The relatively enriched d values observed in May and July of Taipei precipitation may imply an additional source induced by this re-evaporation effect to cause the d values higher. Since Taipei station has measured both δD and $\delta^{18}O$ for nearly a decade, the resulting time series in deuterium excess (Tab. 1) may offer a link to the variations between monsoon intensity and local evaporation, thus deserves a further study.

SUMMARY

The nine-year hydrogen and oxygen isotope composition records of precipitation in Taipei are presented and illustrated in this study. The weighted mean isotope compositions (δD=-33‰; $\delta^{18}O$=-5.4‰) agree well with IAEA predicted values and provide supplementary data in the existing archives. A local MWL is also obtained by a regression fit ($\delta D=8.2\delta^{18}O+11.6$) and would serve as an important reference for subsequent study in northern Taiwan. Many inspiring observations and appealing phenomena with climatic parameters shed valuable insights to the isotope hydrology both in local and regional scale. The isotope records in precipitation also contribute important data set to the regional atmospheric modeling work in the East Asia. This kind of isotope measurements will be carried on and accumulated continuously in the future for the benefits on isotope hydrology of Taiwan.

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