STABLE O, H ISOTOPES IN TUCSON RAIN ASSOCIATED WITH HURRICANES AND TROPICAL DEPRESSIONS, 2013-2016.

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Eastoe et al. (2014) published a set of stable O and H isotope data for rainwater associated with remnants of hurricanes and tropical depressions in Tucson between 1982 and 2012. There followed, in August, September and October 2014, the most active hurricane season in our record; four different storm remnants dropped rain in Tucson. The years 2015 and 2016 were also unusually active. In 2016, tropical storm Javier dropped the second-largest amount of rain from such a system in our records. This addendum to the 2014 paper presents new stable O and H isotope data for rain from tropical storm remnants entering southern Arizona from 2013 to 2016.

For the new measurements, an attempt has been made to relate each rain event to the evolution of the cyclonic system. Fig. 1 is a satellite view of Hurricane Odile (September, 2014), showing typical circulation patterns. In Tucson, rain may result from moisture advected to the northeast by the leading edge of the system, situated to the north of the cyclonic cell. Rain in Arizona may also result from landward moisture transport from south of the eye of the cyclone, once the cyclonic cell has moved into northwestern Mexico.

Data for 19 events that occurred in 2013 - 2016 are listed in Table 1, and plot close to the global meteoric water line (Fig. 2A). The amount-weighted averages of ($\delta^{18}O$, δD) for the new data are (-10.6, -75‰). Only 4 of these events have δD and $\delta^{18}O$ higher than the long-term summer (June-October, inclusive) precipitation means (-6.0, -42‰) for Tucson. Four of the new data are the isotopically lightest of all available data for tropical-depression rain in Tucson, and are among the most negative rain data for the entire Tucson dataset (cf. Eastoe and Dettman, 2016). There appears to be no relationship between low ($\delta^{18}O$, δD) and the stage of evolution of the cyclonic systems (Table 1). For instance, the leading edge of Hurricane Odile gave highly ^{18}O-depleted rain in Tucson, but the leading edge of Hurricane Javier did not.

There is no consistent amount effect (Fig. 2B). Note that Hurricane Javier (August 2016), responsible for the second largest precipitation amount of the entire dataset, yielded rainwater with unusually high ($\delta^{18}O$, δD).

Most of the rain from Hurricane Odile (September 2014) fell in areas south and east of Tucson. Totals of >100 mm were reported around the headwaters of the San Pedro River, generating the second- or third-largest flood in the river in the last century (United States Geological survey, 2016; see data for San Pedro River). A new set of data (Fig. 3) shows the effect on isotopes in the floodwater of the San Pedro River at Cascabel, with a comparison to early and late rain from the Odile system in Tucson. The flood peak reached Cascabel on Sept 19-20, with

isotope ratios like those of the earlier rain event in Tucson. The waning stage of the flood, 10-15 days later, had values comparable to the later rain event in Tucson.

Lastly, bulk winter rains succeeding the 2014 hurricane season were also unusually low in isotope composition. In the five-month period from late August 2014 to late January 2015, the amount-weighted average $\delta^{18}O$ value of all rain was -12‰, compared with a long-term average of -9‰ for winter. Five months of such anomalously negative precipitation provide an isotopically labeled pulse of recharge that should be recognizable in groundwater for some years to come.

Acknowledgements:

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References:

Eastoe, C.J., Hess, G. and Mahieux, S., 2014, Identifying recharge from tropical cyclonic storms, Baja California Sur, Mexico, Ground Water, doi 10.1111/gwat.12183

Eastoe, C.J. and Dettman, D.L., 2016, Isotope amount effects in hydrologic and climate reconstructions of monsoon climates: implications of some long-term data sets for precipitation. Chemical Geology 460, 76-89.

NASA, 2016, http://rapidfire.sci.gsfc.nasa.gov/cgi-bin/imagery/single.cgi?image=Odile.A2014257.1755.2km.jpg

United States Geological Survey, 2016, Current Water Data for Arizona, http://waterdata.usgs.gov/az/nwis/rt

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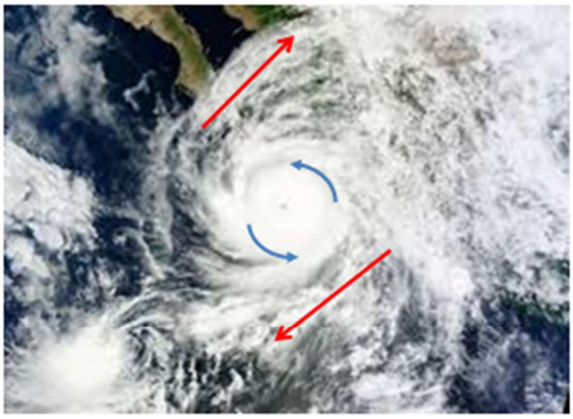

Fig. 1 Hurricane Odile, September 14, 2014 showing cyclonic circulation (blue arrows) and moisture advection directions for leading and trailing edges (red arrows). Modified from image available at NASA (2016).

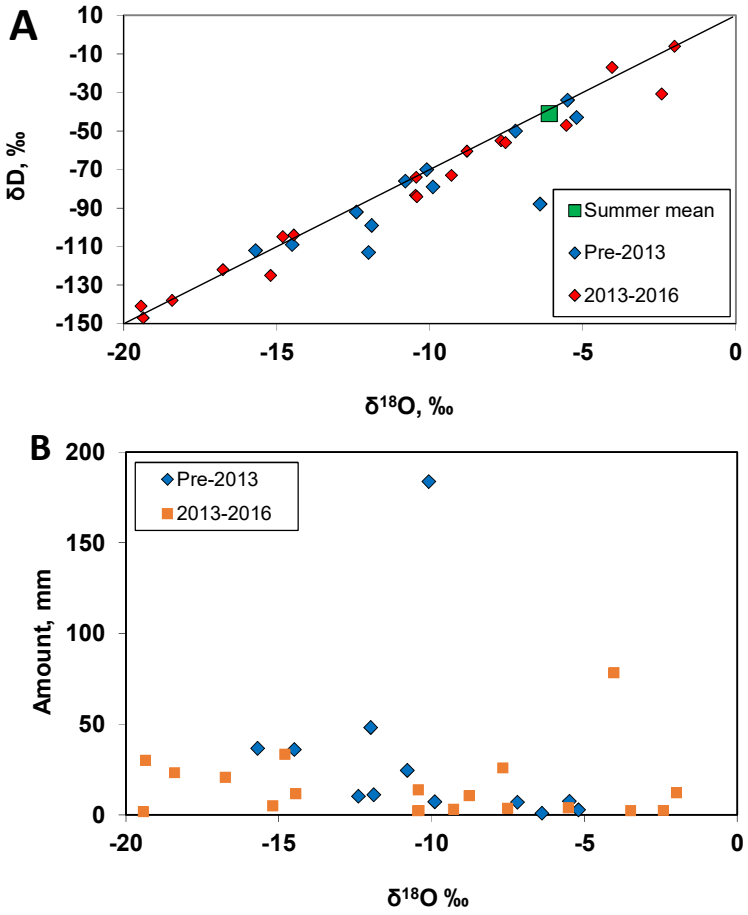

Fig. 2 A. δD vs. $\delta^{18}O$ for all rain events in Tucson associated with hurricanes and tropical depressions. Pre-2013 data from Eastoe et al. (2014). Summer mean from Eastoe and Dettman (2016). GMWL = global meteoric water line. B. Rainfall amount vs. $\delta^{18}O$ for the events shown in Fig. 2A.

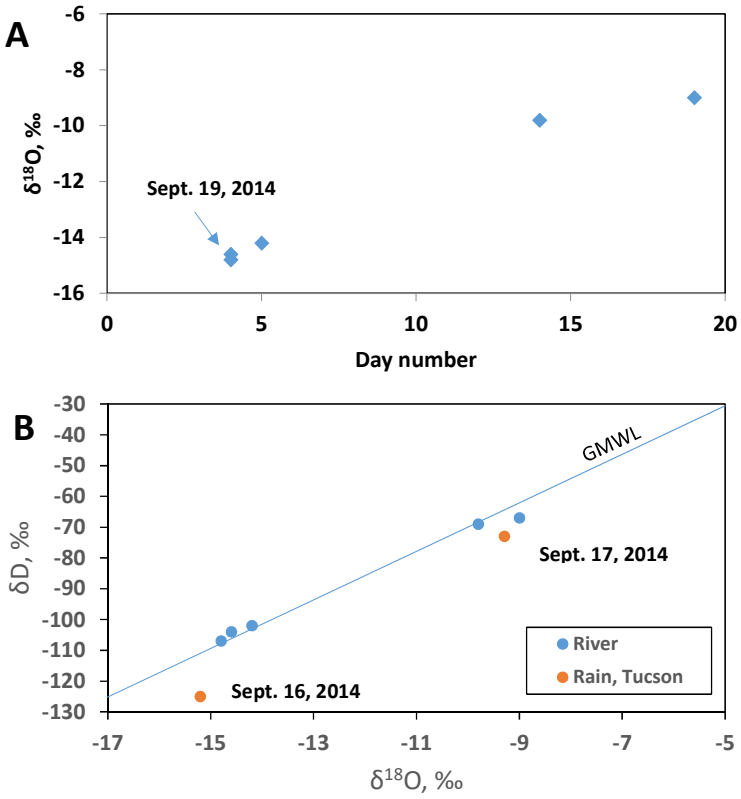

Fig. 3 Effect of Hurricane Odile on surface water in the San Pedro River, Cascabel, Arizona. A. Time series of $\delta^{18}O$. B. δD vs. $\delta^{18}O$, comparing river water with rain measured in Tucson. GMWL = global meteoric water line.

TABLE 1: STABLE OXYGEN AND HYDROGEN ISOTOPE DATA							
A. TUCSON RAIN EVENTS ASSOCIATED WITH HURRICANES AND TROPICAL DEPRESSIONS							
Date	**δ18O**	**δD**	**d**	**W**	**Amount**	**Name**	**Notes**
Mo/dy/yr	**‰**	**‰**	**‰**		**mm**		
8/25/13	-3.5	-27	1	11924	2.5	IVO	?
8/26/14	-7.7	-55	6	12290	25.9	MARIE	Leading edge
9/4/14	-2.0	-6	10	12299	12.2	NORBERT	Leading edge
9/6/14	-8.8	-60	10	12301	10.7	NORBERT	
9/7/14	-10.5	-83	0	12302	2.3	NORBERT	
9/8/14	-14.8	-105	14	12303	33.5	NORBERT	Gulf surge
9/16/14	-15.2	-125	-3	12311	5.1	ODILE	Leading edge
9/17/14	-9.3	-73	1	12312	3.3	ODILE	NE cyclonic circ.
9/19/14	-14.4	-104	12	12314	11.7		
10/7/14	-7.5	-56	4	12332	3.8	SIMON	NE cyclonic circ.
10/8/14	-10.4	-74	10	12333	14.0	SIMON	NE cyclonic circ.
10/9/14	-16.8	-122	12	12334	20.8	SIMON	NE cyclonic circ.
7/16/15	-5.5	-47	-3	12614	4.1	DOLORES	Leading edge
9/5/15	-10.4	-84	-1	12665	2.5	UNNAMED TD	Leading edge
9/10/15	-2.4	-31	-11	12670	2.5	UNNAMED TD	
9/21/15	-19.4	-147	8	12681	30.2	UNNAMED TD	
9/22/15	-19.4	-141	15	12682	1.8	UNNAMED TD	NE cyclonic circ.
8/9/16	-4.0	-17	15	13004	78.5	JAVIER	Leading edge
9/7/16	-18.4	-138	9	13033	23.4	NEWTON	
B. WINTER RAIN IN TUCSON, OCT. 2014 - JAN. 2015							
10/27/14	-1.8	-29	-15	12352	3.8		
12/4/14	-13.1	-95	10	12390	22.9		
12/6/14	-7.6	-98	-37	12392	0.8		
12/13/14	-5.3	-25	17	12399	13.2		
12/17/14	-8.1	-47	18	12403	12.4		
12/18/14	-6.5	-37	15	12404	0.8		
12/26/14	-2.3	-13	6	12412	0.8		
12/31/14	-6.1	-25	24	12417	14.5		
1/8/15	-6.1	-47	2	12425	7.9		
1/13/15	-3.1	-18	6	12430	2.5		
1/27/15	-7.3	-63	-5	12444	2.8		
1/30/15	-16.5	-121	11	12447	55.6		