

## **Manus Water Isotope Investigation Field Campaign Report**

JL Conroy  
D Noone  
KM Cobb

March 2016

## **DISCLAIMER**

This report was prepared as an account of work sponsored by the U.S. Government. Neither the United States nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

# **Manus Water Isotope Investigation Field Campaign Report**

JL Conroy, University of Illinois, Urbana-Champaign  
Principal Investigator

D Noone, University of Colorado  
KM Cobb, Georgia Institute of Technology  
Co-Investigators

March 2016

Work supported by the U.S. Department of Energy,  
Office of Science, Office of Biological and Environmental Research

## **Executive Summary**

The objective of this field campaign was to investigate climatic controls on the stable isotopic composition of water vapor, precipitation, and seawater in the western tropical Pacific. Simultaneous measurements of the stable isotopic composition of vapor and precipitation from April 28 to May 8, 2013, at the Manus Tropical Western Pacific Atmospheric Radiation Measurement site, provided several key insights into the nature of the climate signal archived in precipitation and vapor isotope ratios. We observed a large shift from lower to higher isotopic values in vapor and precipitation because of the passage of a mesoscale convective system west of the site and a transition from a regional stormy period into a more quiescent period. During the quiescent period, the stable isotopic composition of vapor and precipitation indicated the predominance of oceanic evaporation in determining the isotopic composition of boundary-layer vapor and local precipitation. There was not a consistent relationship between intra-event precipitation amount at the site and the stable isotopic composition of precipitation, thus challenging simplified assumptions about the isotopic “amount effect” in the tropics on the time scale of individual storms. However, some storms did show an amount effect, and deuterium excess values in precipitation had a significant relationship with several meteorological variables, including precipitation, temperature, relative humidity, and cloud base height across all measured storms. The direction of these relationships points to condensation controls on precipitation deuterium excess values on intra-event time scales. The relationship between simultaneous measurements of vapor and precipitation isotope ratios during precipitation events indicates the ratio of precipitation-to-vapor isotope ratios can diagnose precipitation originating from a vapor source unique from boundary-layer vapor and rain re-evaporation.

## **Acronyms and Abbreviations**

$\delta^{18}\text{O}$	stable isotopic composition of oxygen
$\delta\text{D}$	stable isotopic composition of hydrogen
ARM	Atmospheric Radiation Measurement Climate Research Facility
DOE	U.S. Department of Energy
VSMOW	Vienna Standard Mean Ocean Water

## Contents

Executive Summary .....	iii
Acronyms and Abbreviations .....	iv
1.0 Background.....	1
2.0 Notable Events or Highlights .....	1
3.0 Lessons Learned .....	2
4.0 Results .....	2
5.0 Manus Water Isotope Publications .....	6
5.1 Journal Articles/Manuscripts.....	6
5.2 Meeting Abstracts/Presentations/Posters .....	6
6.0 References .....	7

## Figures

1. Five-minute averaged Manus wind direction, wind speed, relative humidity, temperature, $\delta D_v$ and $\delta D_p$ , vapor deuterium excess, and precipitation rate .....	3
2. Hovmöller plot of daily 3B42 tropical rainfall measuring mission precipitation (mm/day) averaged from 3°S to 1°S.....	4
3. $\delta^{18}O$ and $\delta D$ values of measured Manus water vapor, precipitation, and open-ocean seawater.....	4
4. Theoretical q- $\delta D$ mixing lines following.....	5
5. Top panels: Precipitation rate (black) and $R_p/P_\infty$ (red) calculated using isotope ratios in vapor and precipitation (red circles) .....	6

## Table

1. Correlation coefficients of $\delta D_v$ , $\delta D_p$ , $dx_{sv}$ , $dx_{sp}$ , and atmospheric variables.....	5
---	---

## 1.0 Background

The purpose of this campaign was to collect water vapor, precipitation, and seawater for the stable isotopic composition of oxygen ( $\delta^{18}\text{O}$ ) and the stable isotopic composition of hydrogen ( $\delta\text{D}$ ) at the U.S. Department of Energy (DOE)'s Atmospheric Radiation Monitoring (ARM) Climate Research Facility Manus Tropical Western Pacific site, and analyze these data in association with atmospheric and oceanographic data to understand the climatic controls on  $\delta^{18}\text{O}$  and  $\delta\text{D}$ . The isotopic compositions are calculated using the following formulae:

- $\delta^{18}\text{O} = \{[(\delta^{18}\text{O}_{\text{sample}} \div \delta^{16}\text{O}_{\text{sample}}) \div (\delta^{18}\text{O}_{\text{standard}} \div \delta^{16}\text{O}_{\text{standard}})] - 1\} \times 1000$ , expressed as ‰ Vienna Standard Mean Ocean Water (VSMOW)
- $\delta\text{D} = \{[(\delta^2\text{H}_{\text{sample}} \div \delta^2\text{H}_{\text{sample}}) \div (\delta^2\text{H}_{\text{standard}} \div \delta^2\text{H}_{\text{standard}})] - 1\} \times 1000$ , also expressed as ‰ VSMOW.

Typically, in tropical regions the isotopic compositions  $\delta^{18}\text{O}$  and  $\delta\text{D}$  are interpreted in the context of local precipitation amount (referred to as the “amount effect”), but new modeling simulations and data are beginning to indicate that this concept is oversimplified and that  $\delta^{18}\text{O}$  and  $\delta\text{D}$  may serve as powerful indicators of more complex convective processes. The measurement campaign at Manus offered an ideal opportunity to understand controls on high-temporal-resolution water isotope variability in the tropics, given its location in the west Pacific warm pool on an island location that is minimally influenced by terrestrial processes (Riihimaki and Long 2014) and strongly influenced by sub-seasonal variability (i.e., the Madden Julian Oscillation) (Deng et al. 2013). The National Science Foundation was a collaborating agency, funding the lead investigator's (JL Conroy) postdoctoral fellowship (NSF-EAR 1049664) as well as providing grant funding to all three investigators (KM Cobb, JL Conroy, and D Noone, NSF-AGS 1203785). From April 28 to May 8, 2013, Conroy, Noone, and Jessica Moerman (Georgia Institute of Technology) visited the site to measure the stable isotopic composition of water vapor in situ, collect an initial spatial set of seawater samples for subsequent measurement, sample precipitation at high temporal resolution through individual rain events, and launch a long-term rain and seawater collection by training Manus Weather Observers working at the site. Daily precipitation and weekly seawater samples were taken by the Weather Observers from April 26, 2013, to July 12, 2014, when the site closed.

## 2.0 Notable Events or Highlights

During the course of our onsite visit, we were able to successfully install the Picarro L-1102 water-isotope instrument for measurement of vapor  $\delta^{18}\text{O}$  and  $\delta\text{D}$ . Over the period of measurement, we observed a remarkable transition from extremely low to high  $\delta^{18}\text{O}$  and  $\delta\text{D}$  values in both vapor and precipitation. Values  $\delta\text{D}$  in vapor went from  $-224.9\text{‰}$  to  $-71.0\text{‰}$ , a  $154.8\text{‰}$  shift that is rarely observed in  $\delta\text{D}$  data sets (see Coplen et al. 2008) for another example associated with an atmospheric river event). The large shift in isotopic values at Manus appears to reflect a transition from a stormy period at the beginning of the campaign, related to a mesoscale convective system to the west of the island, into a quiescent period of intermittent, local convective activity.

### 3.0 Lessons Learned

A key lesson learned was to budget adequate time for installation of the Picarro instrument. Because the instrument used was an older model, it took longer to equilibrate after shipment relative to newer instruments. Hence we also would not recommend using older versions of Picarro instruments in the field for short campaigns. We also recommend bringing an auto-sampler to facilitate calibration injections. The instrument also had difficulty operating at high humidity levels—again, an issue that is resolved in newer versions. In addition, the poor Internet connection at the site meant that it took longer to resolve instrument issues because technicians from Picarro could not log in remotely to the instrument.

### 4.0 Results

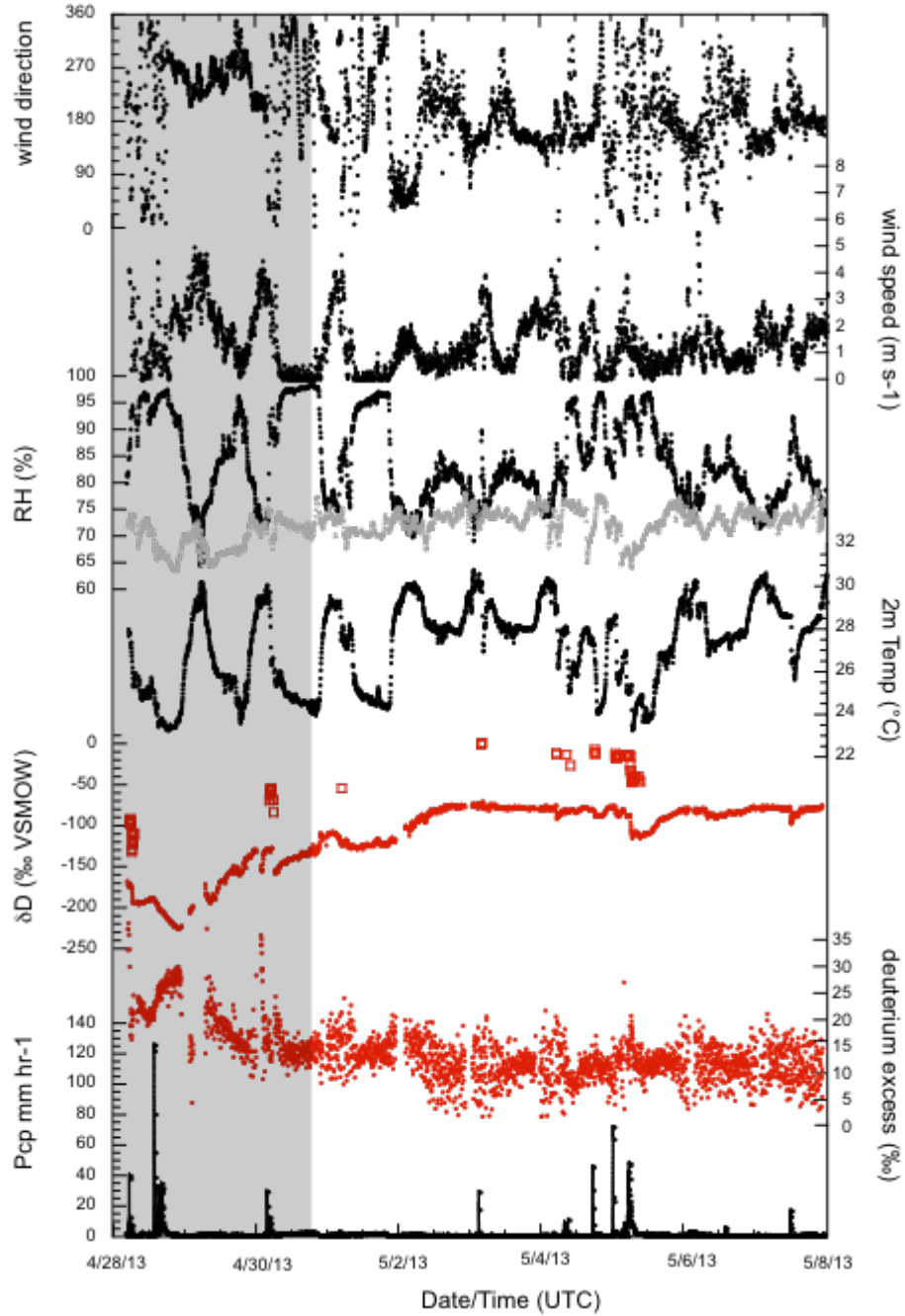
We observed a synoptic-scale transition from low to high  $\delta D$  in vapor and precipitation associated with passage of a mesoscale convective system and the subsequent transition into a more quiescent period (Figure 1 and Figure 2). This observation supports recent hypotheses advanced by Kurita et al. (2009) and Moerman et al. (2013) that the amount effect is related to regional convection rather than local precipitation amount.

The  $\delta^{18}O$  and  $\delta D$  values of vapor indicate that, during the quiescent period, vapor was derived mainly from ocean evaporation, whereas vapor from the earlier period of regional convection had undergone previous rainout, distillation, and rain evaporation (Figure 3 and Figure 4). A significant correlation between wind direction and  $\delta D$  values of vapor also suggests a remote, westerly source for vapor with lower  $\delta\Delta$  (Table 1).

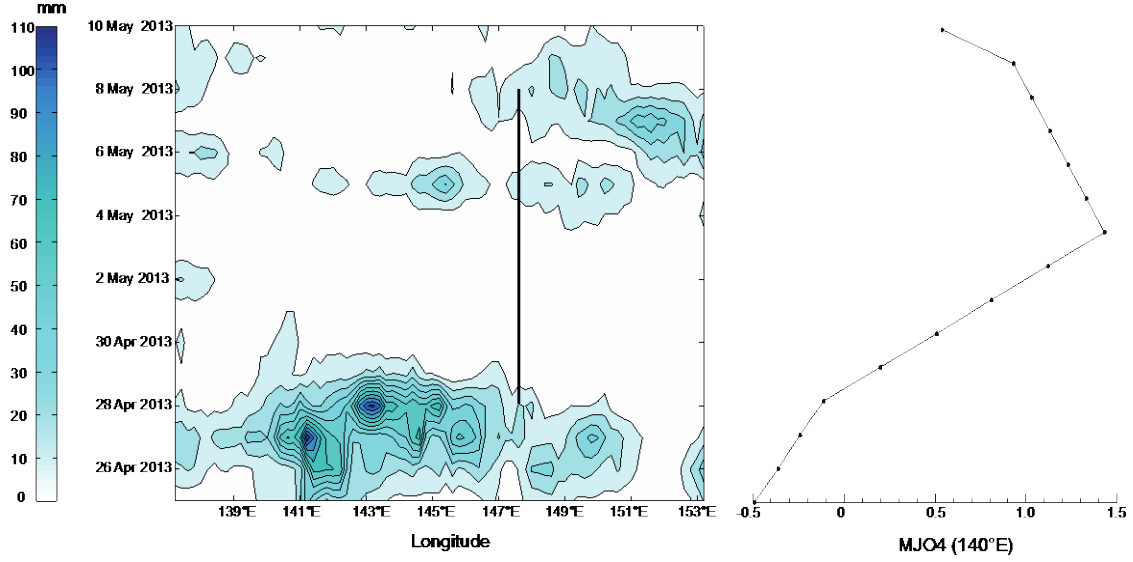
Values of  $\delta D$  from multiple precipitation samples collected during individual storms indicate that an ‘amount effect’ is not manifested in all events (Table 1, Figure 5). However, precipitation deuterium excess does show a consistent relationship with precipitation rate, temperature, mixing ratio, atmospheric pressure, and cloud base height, considering data from all events. The direction of the relationships between precipitation deuterium excess and these variables suggests that deuterium excess values are determined by conditions during condensation, rather than conditions at the site of initial vapor formation (i.e., ocean evaporation). Thus, deuterium excess on the intra-event time scale should be explored as a potential way to diagnose post-condensation processes, such as rain evaporation.

The results of this research should prompt further investigation into intra-event stable isotopic analysis at additional tropical Pacific locations. In particular, assessing intra-event variability during more organized events, such as tropical storms, phases of the Madden Julian Oscillation, and during storms in El Niño and La Niña periods would provide insight into how isotope-climate relationships scale temporally and spatially, and how background conditions can determine the relationship between stable isotopes in precipitation and atmospheric variables. This research also highlights the need for long-term measurement of vapor, as paired vapor and intra-event precipitation stable isotope data can be a powerful tool for diagnosing more complex controls on  $\delta^{18}O$  and  $\delta D$ .

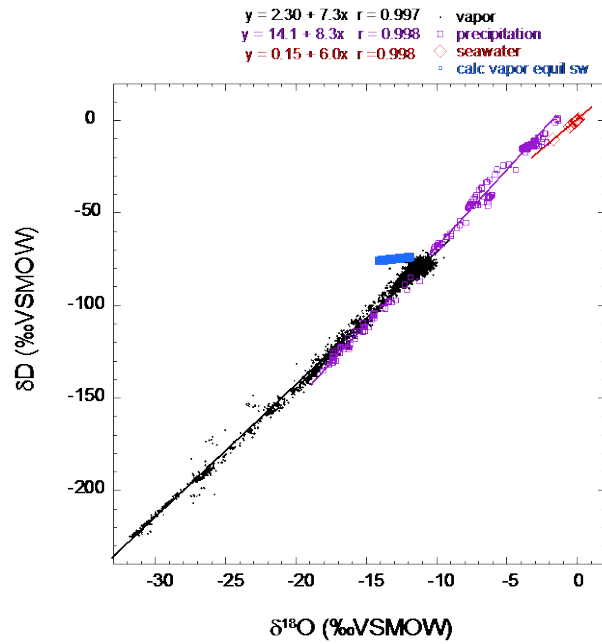




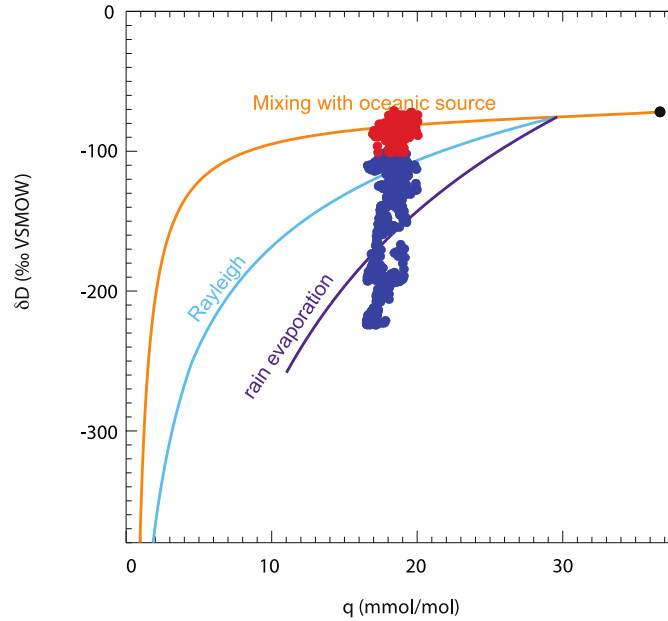
**Figure 1.** Five-minute averaged (from top to bottom) Manus wind direction, wind speed, relative humidity, temperature,  $\delta D_v$  (red circles) and  $\delta D_p$  (red squares), vapor deuterium excess, and precipitation rate. Gray relative humidity curve denotes relative humidity with respect to mean sea surface temperature (important for correct calculation of isotopes in vapor derived from evaporated ocean water). Gray shaded time period denotes period of overall lower  $\delta D_v$  and  $\delta D_p$ , and more persistent westerly winds.



**Figure 2.** Hovmöller plot of daily 3B42 tropical rainfall measuring mission precipitation (mm/day) averaged from 3°S to 1°S (Kummerow et al. 1998). The bold line indicates longitude of Manus (147.5°E) and period of measurement campaign. National Oceanic and Atmospheric Administration Climate Prediction Center Madden Julian Oscillation 4 Index (140°E). Negative values indicate enhanced convection, positive values indicate suppressed convection.



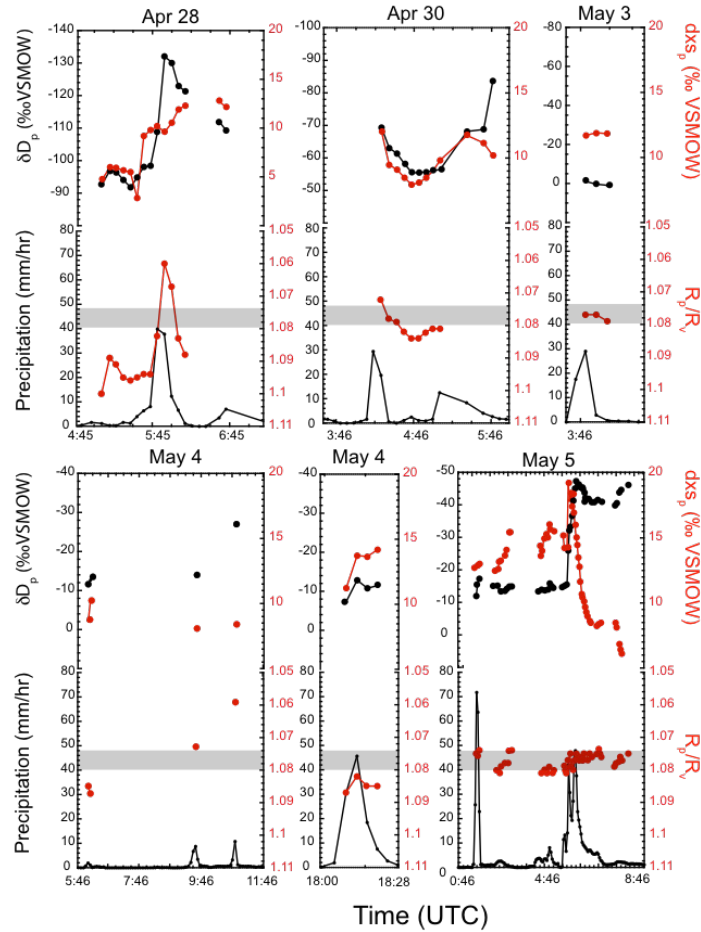
**Figure 3.**  $\delta^{18}\text{O}$  and  $\delta\text{D}$  values of measured Manus water vapor (black), precipitation (purple), and open-ocean seawater (red). Blue squares are calculated isotopic values of vapor in equilibrium with mean  $\delta^{18}\text{O}_{\text{sw}}$ ,  $\delta\text{D}_{\text{sw}}$ , mean sea surface temperature from the Tropical Atmosphere Ocean mooring at 0° 147°E, accounting for kinetic fractionation with RH relative to sea surface temperature. R-values indicate the correlation coefficient for  $\delta^{18}\text{O}$  and  $\delta\text{D}$ .



**Figure 4.** Theoretical  $q$ - $\delta D$  mixing lines following Noone (2012). Mixing ratio ( $q$ , in mmol/mol) versus  $\delta D_v$  values. Blue dots represent 5-minute averaged Manus data from period of strong regional convection, and red dots represent 5-minute averaged Manus data from subsequent quiescent period. The cyan line indicates a vapor pathway following Rayleigh distillation; the orange line indicates a mixing line between a dry end member and vapor in equilibrium with an oceanic source at 300K, and the purple line indicates a pathway representing re-evaporation of rain. The steeper  $q$ - $\delta D$  slope and points falling below the purple line suggest the process of rain re-evaporation during precipitation.

**Table 1.** Correlation coefficients (Spearman rank) of  $\delta D_v$ ,  $\delta D_p$ ,  $dx_{sv}$ ,  $dx_{sp}$ , and atmospheric variables. Bold values are significant at the 99% confidence level.

	$\delta D_p$ (‰ VSMOW)	$dx_{sp}$ (‰ VSMOW)	$T$ (°C)	Precip (mm/hr)	RH air (%)	$q$ (mmol/ mol)	Wind (m/s)	Wind direction	$P$ (kPa)	Cloud base (m)
$\delta D_v$ (‰ VSMOW)	<b>0.94</b>	<b>0.49</b>	<b>0.67</b>	<b>-0.53</b>	<b>-0.53</b>	<b>0.72</b>	<b>0.19</b>	<b>-0.37</b>	<b>-0.21</b>	<b>-0.21</b>
$dx_{sv}$ (‰ VSMOW)	<b>-0.40</b>	0.15	<b>-0.27</b>	<b>0.25</b>	<b>0.15</b>	<b>-0.46</b>	<b>0.08</b>	<b>0.15</b>	0.05	-0.03
$\delta D_p$ (‰ VSMOW)		<b>0.47</b>	-0.08	0.06	-0.05	-0.19	-0.02	0.08	<b>-0.30</b>	0.12
$dx_{sp}$ (‰ VSMOW)			<b>-0.34</b>	<b>0.40</b>	<b>0.50</b>	-0.21	0.04	0.09	<b>-0.57</b>	<b>-0.56</b>



**Figure 5.** Top panels: Precipitation rate (black) and  $R_{\pi}/P_{\pi}$  (red) calculated using isotope ratios in vapor and precipitation (red circles). Bottom panels:  $\delta D_p$  (black) and  $dx_{sp}$  (red) through Individual Events. Gray shading denotes equilibrium fractionation factor range for average surface temperatures during events. Note that the y-axis is inverted for  $R_{\pi}/P_{\pi}$ ,  $\delta D_p$ .

## 5.0 Manus Water Isotope Publications

### 5.1 Journal Articles/Manuscripts

Conroy, JL, D Noone, KM Cobb, JW Moerman, and BL Konecky. “Paired stable isotope measurements in precipitation and vapor: A case study of the amount effect within western tropical Pacific storms.” *Journal of Geophysical Research-Atmospheres*. In revision.

### 5.2 Meeting Abstracts/Presentations/Posters

Conroy, JL, DM Thompson, NJ Martin, KM Cobb, and D Noone. 2015. “Spatiotemporal variability in the salinity-oxygen isotope relationship of seawater across the tropical Pacific Ocean.” Presented at the American Geophysical Union Fall Meeting, San Francisco, California.

Conroy, JL, D Noone, and KM Cobb. 2015. “Water vapor and precipitation isotope variability associated with western tropical Pacific convective storms.” Presented at the International Symposium on Isotope Hydrology: Revisiting Foundations and Exploring Frontiers. International Atomic Energy Agency, Vienna, Austria.

Conroy, JL D Noone, KM Cobb, JW Moerman, and BL Konecky. 2014. “Paired vapor-precipitation isotope data from Manus, Papua New Guinea.” Presented at the American Geophysical Union Fall Meeting, San Francisco, California.

## 6.0 References

Coplen, TB, PJ Neiman, AB White, JM Landwehr, FM Ralph, and MD Dettinger. 2008. “Extreme changes in stable hydrogen isotopes and precipitation characteristics in a landfalling Pacific storm.” *Geophysical Research Letters* 35(21), doi:[10.1029/2008gl035481](https://doi.org/10.1029/2008gl035481).

Deng, L, SA McFarlane, and JE Flaherty. 2013. “Characteristics associated with the Madden–Julian oscillation at Manus Island.” *Journal of Climate* 26(10): 3342-3356, doi:[10.1175/JCLI-D-12-00312.1](https://doi.org/10.1175/JCLI-D-12-00312.1).

Kummerow, C, W Barnes, T Kozu, J Shiue, and J Simpson. 1998. “The Tropical Rainfall Measuring Mission (TRMM) sensor package.” *Journal of Atmospheric and Oceanic Technology* 15(3): 809-817, doi:[10.1175/1520-0426\(1998\)015<0809:TTRMMT>2.0.CO;2](https://doi.org/10.1175/1520-0426(1998)015<0809:TTRMMT>2.0.CO;2).

Kurita, N, K Ichiyonagi, J Matsumoto, MD Yamanaka, and T Ohata. 2009. “The relationship between the isotopic content of precipitation and the precipitation amount in tropical regions.” *Journal of Geochemical Explorations* 102(3): 113-122, doi:[10.1016/j.gexplo.2009.03.002](https://doi.org/10.1016/j.gexplo.2009.03.002).

Moerman, JW, KM Cobb, JF Adkins, H Sodemann, B Clark, and AA Tuen. 2013. “Diurnal to interannual rainfall  $\delta^{18}\text{O}$  variations in northern Borneo driven by regional hydrology.” *Earth and Planetary Science Letters* 369-370: 108-119, doi:[10.1016/j.epsl.2013.03.014](https://doi.org/10.1016/j.epsl.2013.03.014).

Noone, D. 2012. “Pairing measurements of the water vapor isotope ratio with humidity to deduce atmospheric moistening and dehydration in the tropical midtroposphere.” *Journal of Climate* 25(13): 4476-4494, doi:[10.1175/jcli-d-11-00582.1](https://doi.org/10.1175/jcli-d-11-00582.1).

Riihimaki, LD and CN Long. 2014. “Spatial variability of surface irradiance measurements at the Manus ARM site.” *Journal of Geophysical Research-Atmospheres* 119(9): 5475-5491, doi:[10.1002/2013jd021187](https://doi.org/10.1002/2013jd021187).



U.S. DEPARTMENT OF  
**ENERGY**

---

Office of Science