Quantifying drought induced water cycle changes in the isotope-enabled Community Atmosphere Model

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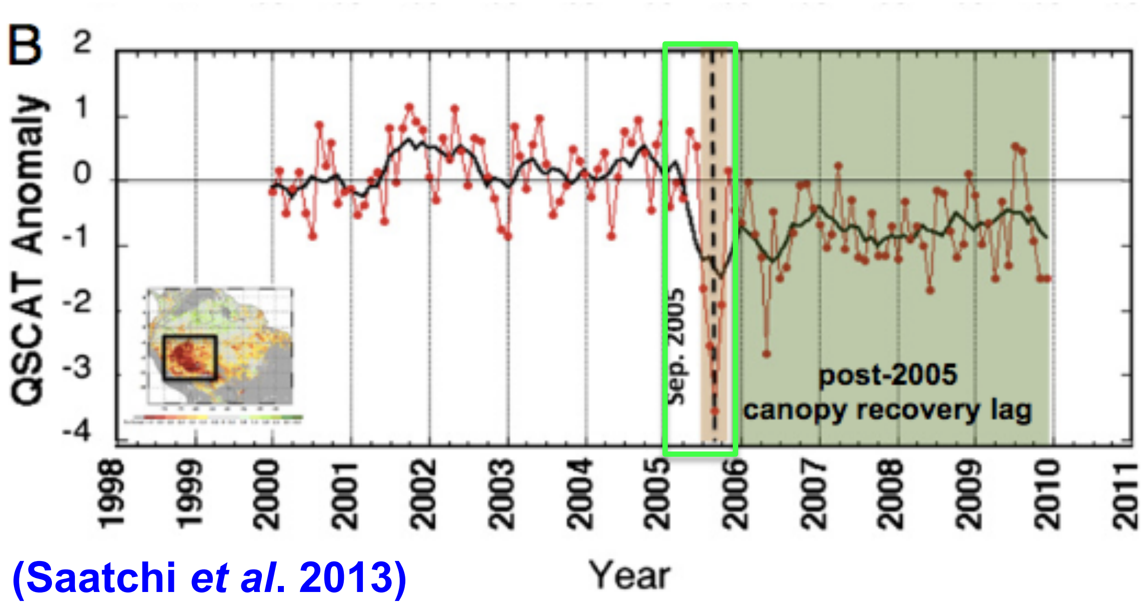
Motivation

Amazonia has been experiencing severe droughts in the recent decades.

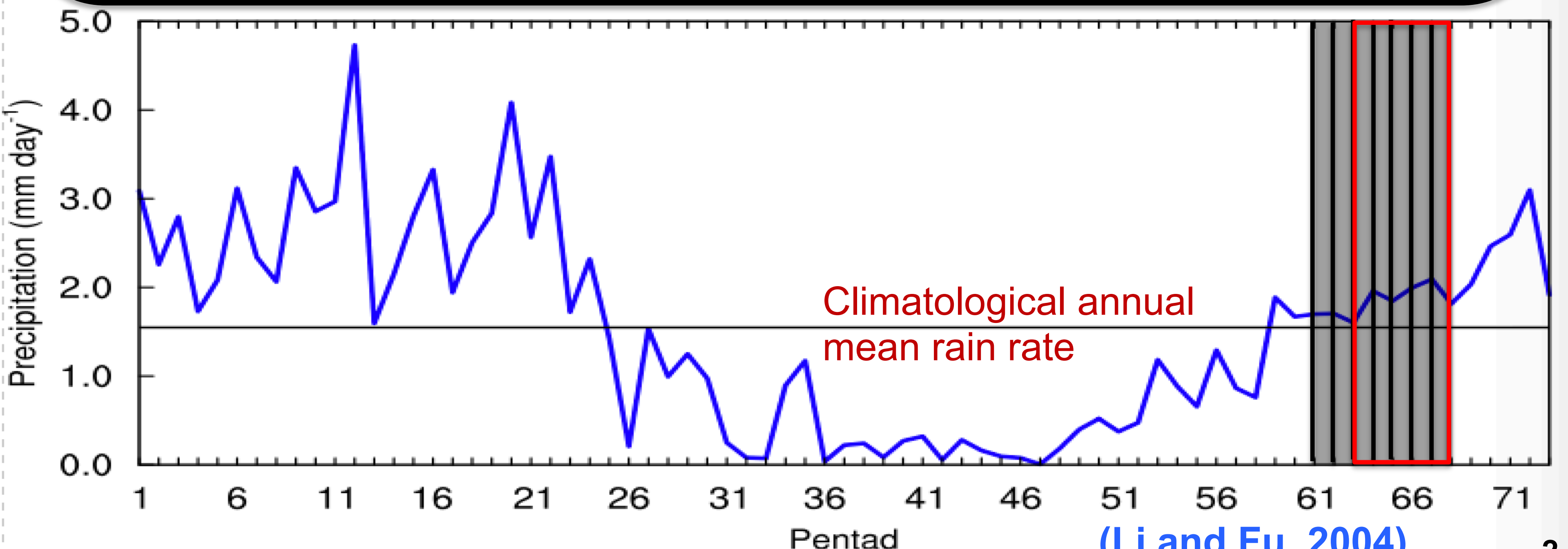


(Saatchi *et al*. 2013)

The SeaWinds Scatterometer onboard QuikSCAT (QSCAT) captured the long-term impact (i.e., legacy effect) of the 2005 drought in southern Amazonia (4°–12°S, 76–66°W).

Scientific questions

- Does the drought legacy effect on trees influence southern Amazonian wet-season precipitation onset?
- If so, what land–atmosphere feedback processes cause the changes of wet-season onset (WSO) over southern Amazonia?



(Li and Fu, 2004)

TRMM shows that the WSO is delayed after the 2005 drought

Year	Pentad	Day of Year	Year	Pentad	Day of Year
2001	59	Oct 18th	**2009**	60	Oct 23nd
2002	63	Nov 7th	**2010**	61	Oct 28th
2003	66	Nov 22nd	**2011**	59	Oct 18th
2004	64	Nov 12th	**2012**	61	Oct 28th
2005	**64**	Nov 12th	**2013**	55	Sep 28th
2006	**64**	Nov 12th	**2014**	61	Oct 28th
2007	58	Oct 13th	**2015**	66	Nov 22nd
2008	66	Nov 22nd	**Mean**	**62 ± 3**	Nov 2nd

Hypothesis: Drought induced biomass reduction reduces local evapotranspiration (ET), which contributes to the delay of wet season onset with relatively same amount of large-scale water vapor convergence.

Datasets used in this study

- The atmosphere over the southern Amazon has two main moisture sources: **rainforest ET and ocean evaporation** (Salati *et al*. 1979).
- We study the two water vapor sources from multiple observations over the southern Amazon.

$$P - E \approx -\nabla \cdot (\mathbf{QV})$$

P is precipitation, E is ET, $-\nabla.(QV)$ is the large-scale water convergence flux (Wong *et al*. 2016).

Datasets	Purpose
Specific humidity and wind speed from ECMWF re-analysis (ERA)	To identity the baseline years with similar atmospheric large-scale water vapor convergence compared to 2006
Deuterium retrievals from the Tropospheric Emission Spectrometer (TES)	To separate the ET sources (i.e., local ET or oceanic evaporation) of the baseline years

Observed wet season onset and water vapor dynamics

Year	ERA Q_{ATMO} (mm month^{-1})	Pentad of wet season onset	Day of Year
2006	**32**	**64**	Nov 12th
2003	21	66	Nov 22nd
2004	22	64	Nov 12th
2007	48	58	Oct 13th
2009	30	60	Oct 23nd
2014	55	61	Oct 28th
Mean	35±15	62±3	Nov 2nd

- Q_{ATMO} is calculated by following Wong *et al.* (2016).
- We select baseline years during 2001– 2015 with -6 – 0 pentad (i.e., -30–0 day) $Q_{ATMO} - Q_{ATMO,\ 2006} < 1\sigma$.
- Five years are selected and they are 2003, 2004, 2007, 2009, and 2014.

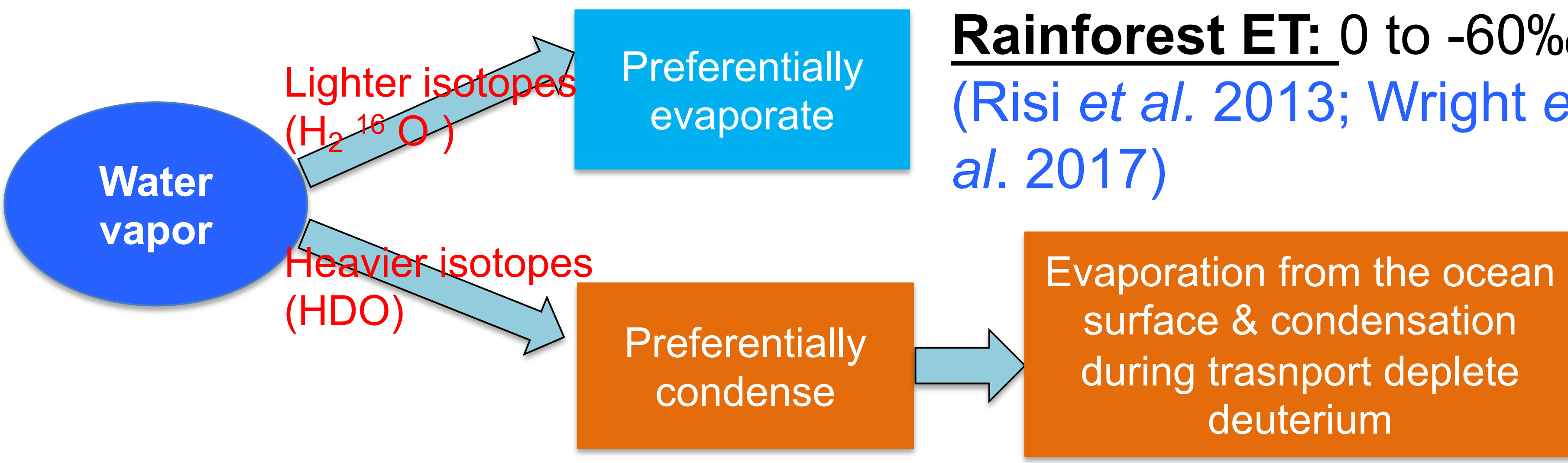
Water isotopes

- Stable water isotopes are valuable tracers of the origin and history of air masses.
- Molecular differences among common isotopes, such as $H_2{}^{16}O$ and HDO, cause fractionation during most phase transitions:

$$\delta D = 1000 \times \left(\frac{R - R_{std}}{R_{std}} \right).$$

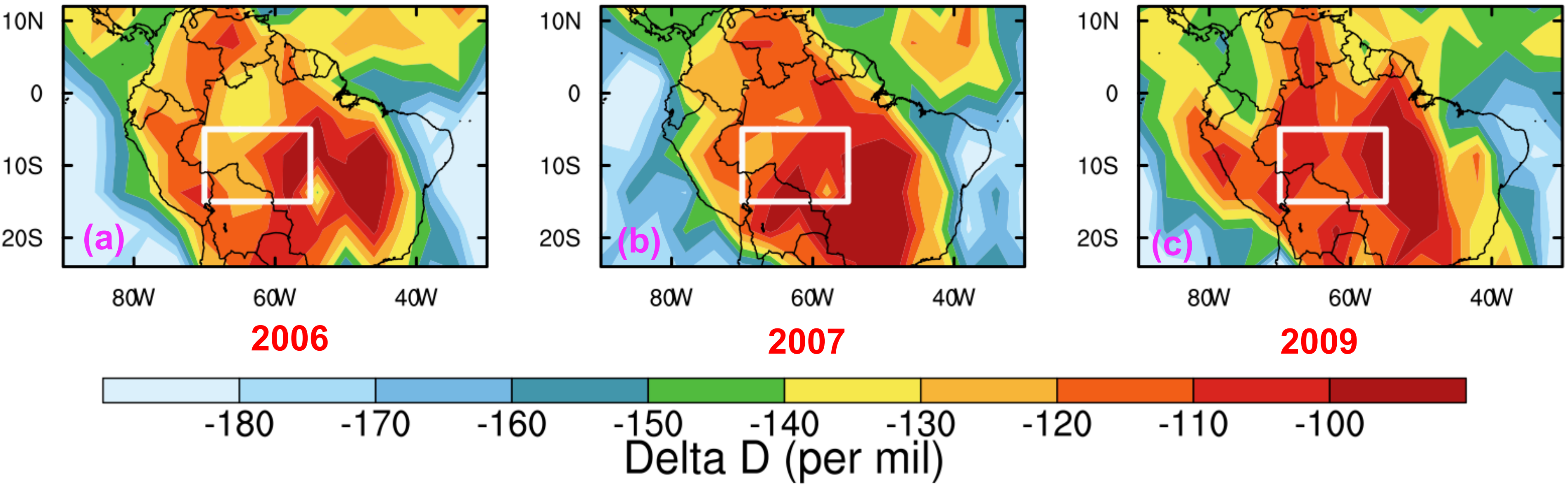
R is the ratio of the number of HDO molecules to the number of H_2O molecules and $R_{std}=3.11\times10^{-4}$

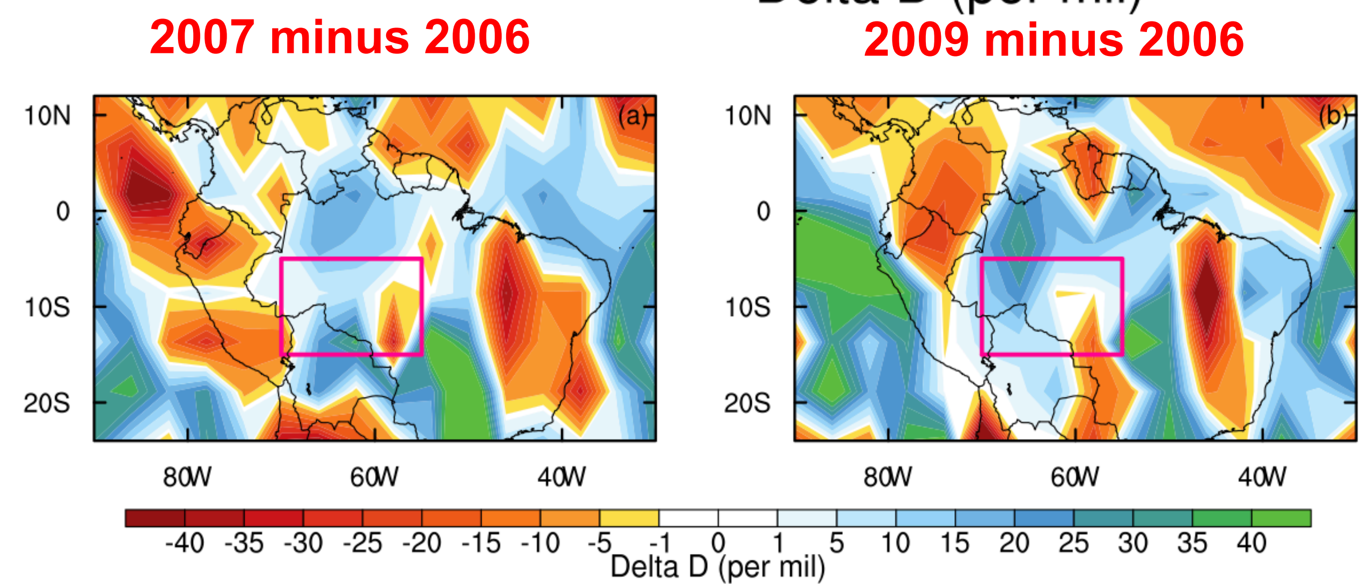
<u>Tropical ocean:</u> isotopic composition of -70 to -90‰, **<u>Rainforest ET:</u>** 0 to -60‰ (Risi *et al.* 2013; Wright *et al.* 2017)



TES observed HDO variations

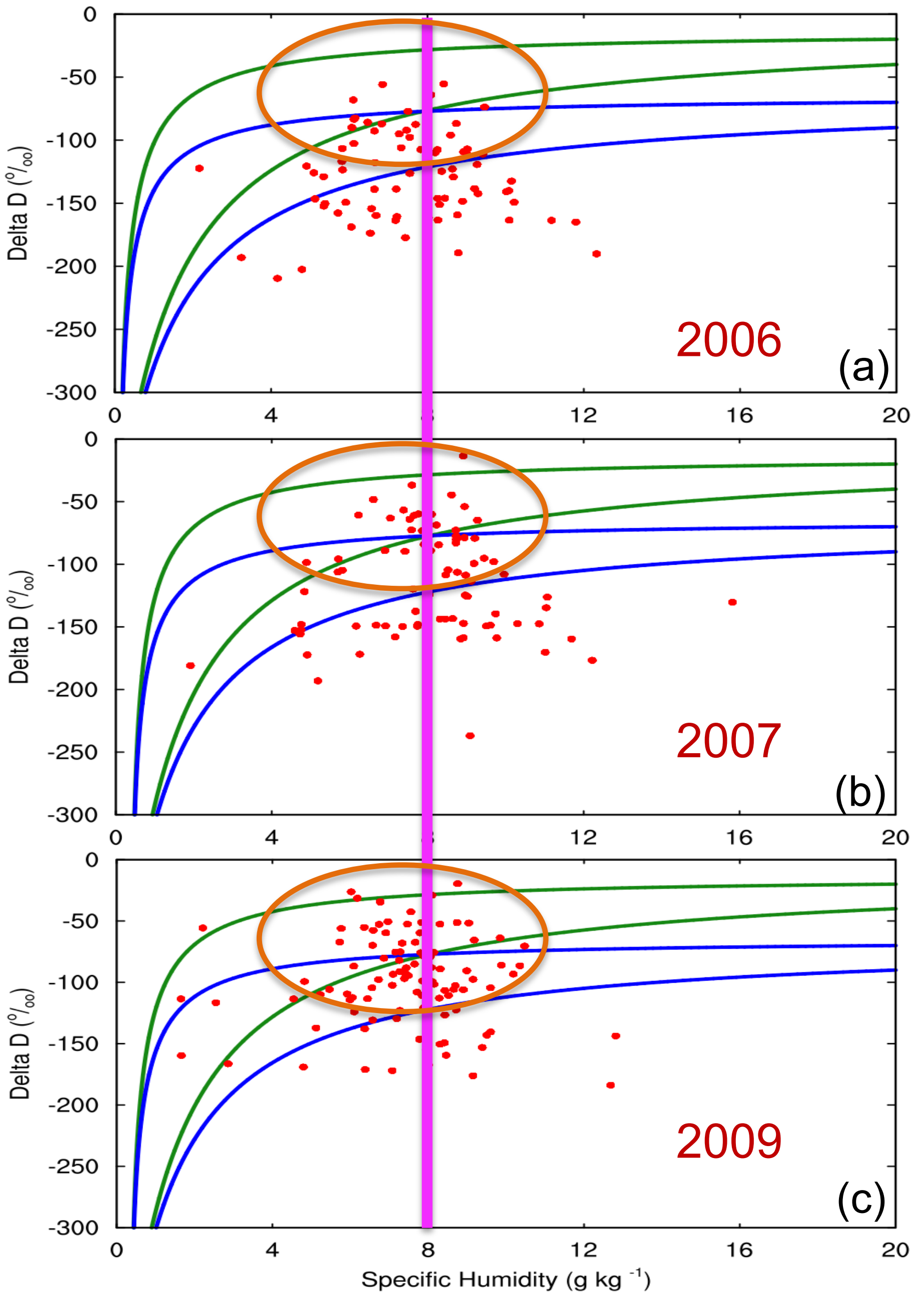
TES δD (825–600 hPa) is sampled to 4° latitude x 4° longitude spatial resolution.





The mean δD value of 2006 (-119.4±9.3‰) is relatively lower to those of 2007 (-110.0±13.1‰) and 2009 (-110.2±8.4‰).

TES observed HDO indicates reduced local ET in 2006



Larger specific humidity is associated with lower δD values in 2006 than in the other two years, as there are fewer observations (i.e., red dots) between the green lines.

ECMWF-ERA 500 hPa vertical velocities:

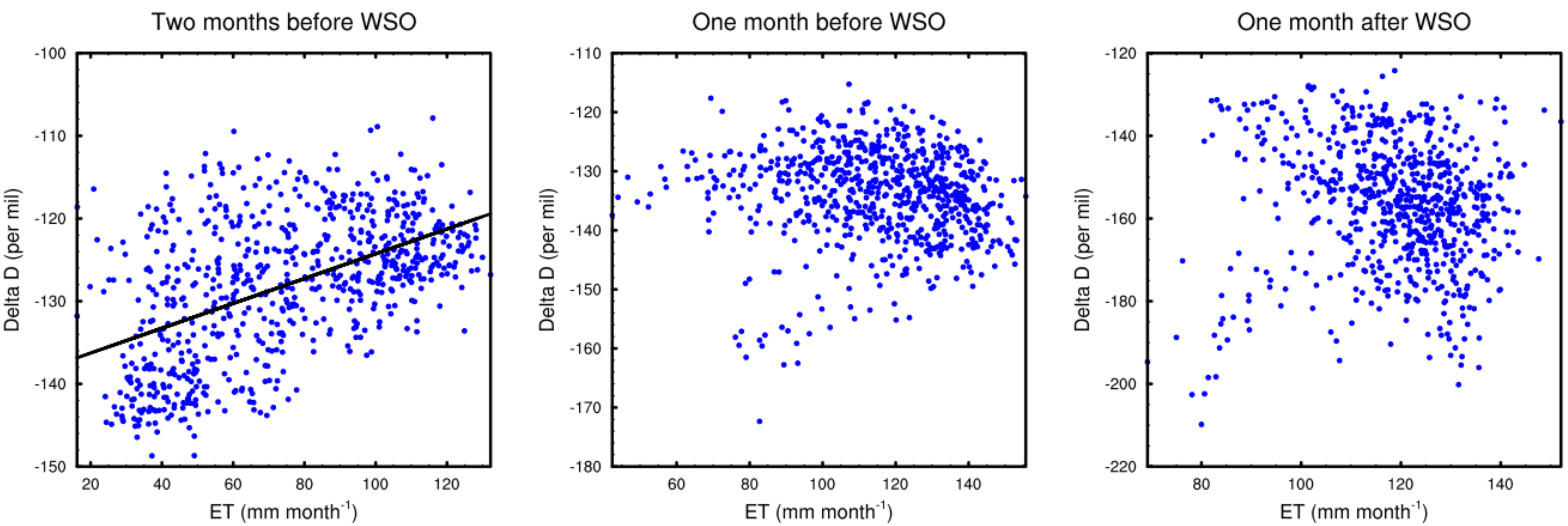
Year	Unit (Pa s^{-1})
2006	0.012
2007	0.018
2009	0.016
$Mean_{2001–2015}$	0.015 ± 0.003

This result suggests a smaller relative contribution from local ET in 2006.

(Shi *et al*., GRL, 2019)

ICAM suggested delta-D variations

- Water isotope-enabled Community Atmosphere Model (ICAM) is used to study δD variations associated with ET change.
- ICAM was driven by sea surface temperature (SST) during 2002–2017.



- δD increases with ET 60 days before the climatological WSO.
- The relationship between ET and δD starts turning over 30 days before the WSO, indicating that δD is more regulated by convective processes.
- This result is consistent with the observational-based result from Wright *et al* (2017).

Discussion and Conclusions

1) Wet season onset in southern Amazonia is delayed in 2006 as shown by TRMM precipitation.
2) Compared to 2007 and 2009, the relative contribution of local ET to precipitation is reduced during the 2006 late transition.
3) The results in this study imply an important land–atmosphere feedback due to the drought legacy.
4) ICAM has the capability in further testing the drought legacy effect and associated land–atmosphere feedback.

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Thanks for your attention!