Investigating below-cloud rain evaporation and boundary layer moisture recycling by coupling stable water isotopes in vapor and precipitation to raindrop size distributions at the Boulder Atmospheric Observatory site

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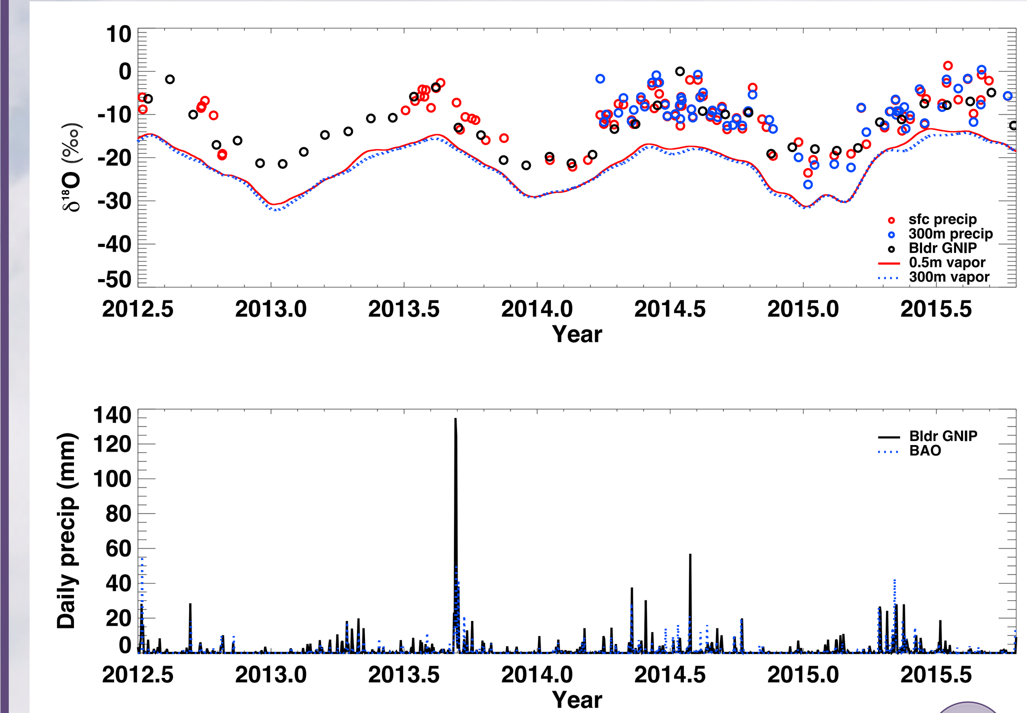
Summary

An observational data set of stable water isotopes in water vapor and precipitation is presented over a 2-year period at the BAO tall-tower site, coupled with raindrop size and velocity distributions from the surface and 300m. Our goals are to: (**1**) *use the observations to constrain the degree of rain evaporation during rain events*, and (**2**) *use this formulation to refine climate model parameterizations used for boundary layer moisture recycling.*

1. Local meteoric water lines show continental recycling over semi-arid regions; Boulder GNIP vs BAO reflects west-east gradient in rain amount
2. Surface-300m differences more prominent on sub-seasonal time scales; less isotope equilibration during convective events
3. Modeled isotope kinetic fractionation parameters must be modified to better capture boundary layer moisture cycling



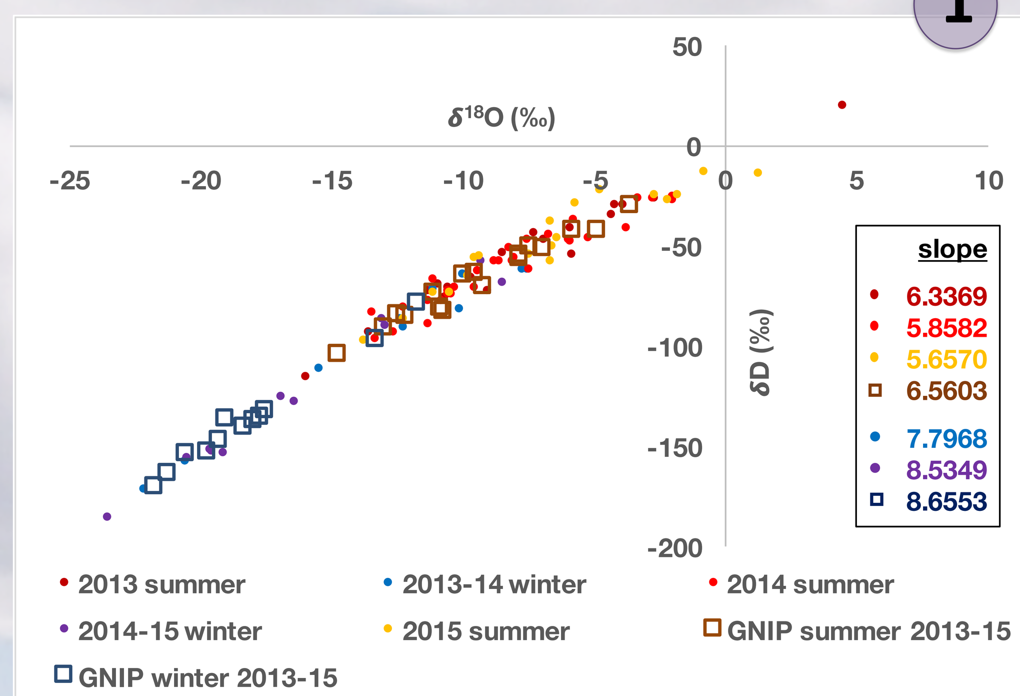
Location/Season	Avg δD	Avg $\delta^{18}O$	Avg dxs*
BAO Sfc/May-Oct	-56.93	-8.73	12.91
BAO 300m/May-Oct	-56.9	-8.53	11.34
Bldr GNIP May-Oct	-66.99	-9.95	12.61
BAO Sfc/Nov-Apr	-102.1	-14.31	12.38
BAO 300m/Nov-Apr	-102.6	-14.55	13.8
Bldr GNIP Nov-Apr	-109.3	-15.13	11.74

*dxs = $\delta D - 8*\delta^{18}O$

a. Bldr GNIP significantly more depleted than BAO due to higher rain amounts;

b. BAO 300m rain not significantly different from sfc rain on seasonal time scale, vapor at 300m slightly more depleted in summer;

c. Slope deviation from global meteoric water line ($\delta D = 8*\delta^{18}O + 10$) indicative of rainfall over semi-arid regions; more pronounced in summer



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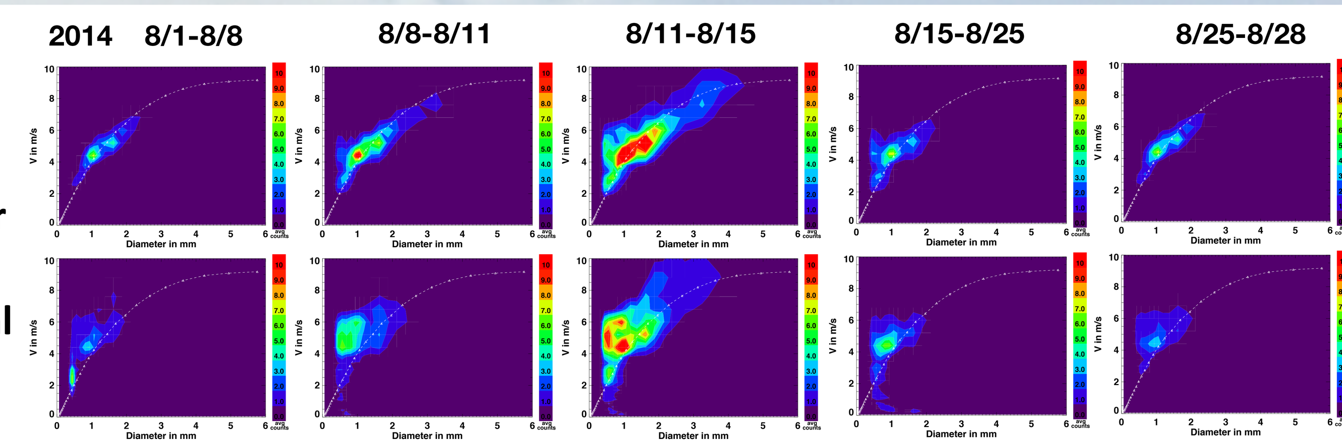
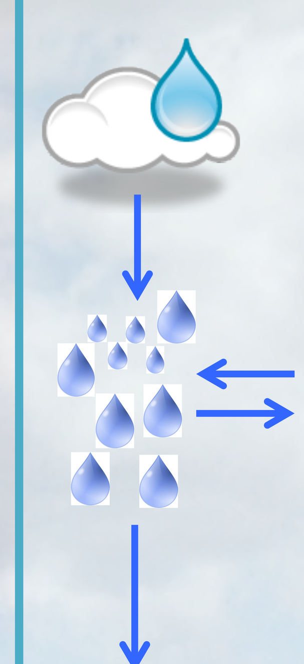
Sfc-300m differences appear in rain & vapor isotopes on sub-seasonal time scales



	2014 8/1-8/8	8/8-8/11	8/11-8/15	8/15-8/25	8/25-8/28
Rain Amt (sfc/300m)	3.47/3.06	4.06/1.71	13.85/9.94	23.31/35.88	7.18/5.05
δD_{rain} (sfc/300m)	-26.2/-21.2	-48.46/-49.60	-37.22/-33.44	-72.85/-70.49	-71.45/-69.83
$\delta^{18}O_{rain}$ (sfc/300m)	-1.99/-0.76	-5.91/-6.05	-5.77/-4.91	-10.55/-10.19	-9.52/-9.05
dxs_{rain} (sfc/300m)	-10.28/-15.09	-1.19/-1.21	8.96/5.82	11.57/11.02	4.73/2.58
δD_{vap} (sfc/300m)	-112.9/-116.6	-136.9/-141.8	-117.4/-117.6	-130.1/-129.6	-151.0/-159.8
$\delta^{18}O_{vap}$ (sfc/300m)	-15.1/-15.9	-18.9/-19.6	-14.7/-15.6	-17.7/-17.8	-19.7/-21.5
dxs_{vap} (sfc/300m)	7.85/10.9	14.2/14.9	0.36/7.47	11.3/12.5	6.68/12.4



a. 300m rain: small drops (more enriched) + large drops (less enriched) vs. sfc rain: larger drops only (less enriched), smaller drops have evaporated before they reach the sfc;

b. 3 of 5 rain periods had significantly depleted rain dxs at 300m station (δD and $\delta^{18}O$ more enriched) compared to sfc station; vapor significantly more enriched at 300m vs sfc;

c. Convective rain (8/15-8/25) leads to more uniform isotope signatures at both sfc & 300m – less/no drop evaporation;

d. Rain dxs negative and <9 indicative of predominantly stratiform events – more drop evaporation

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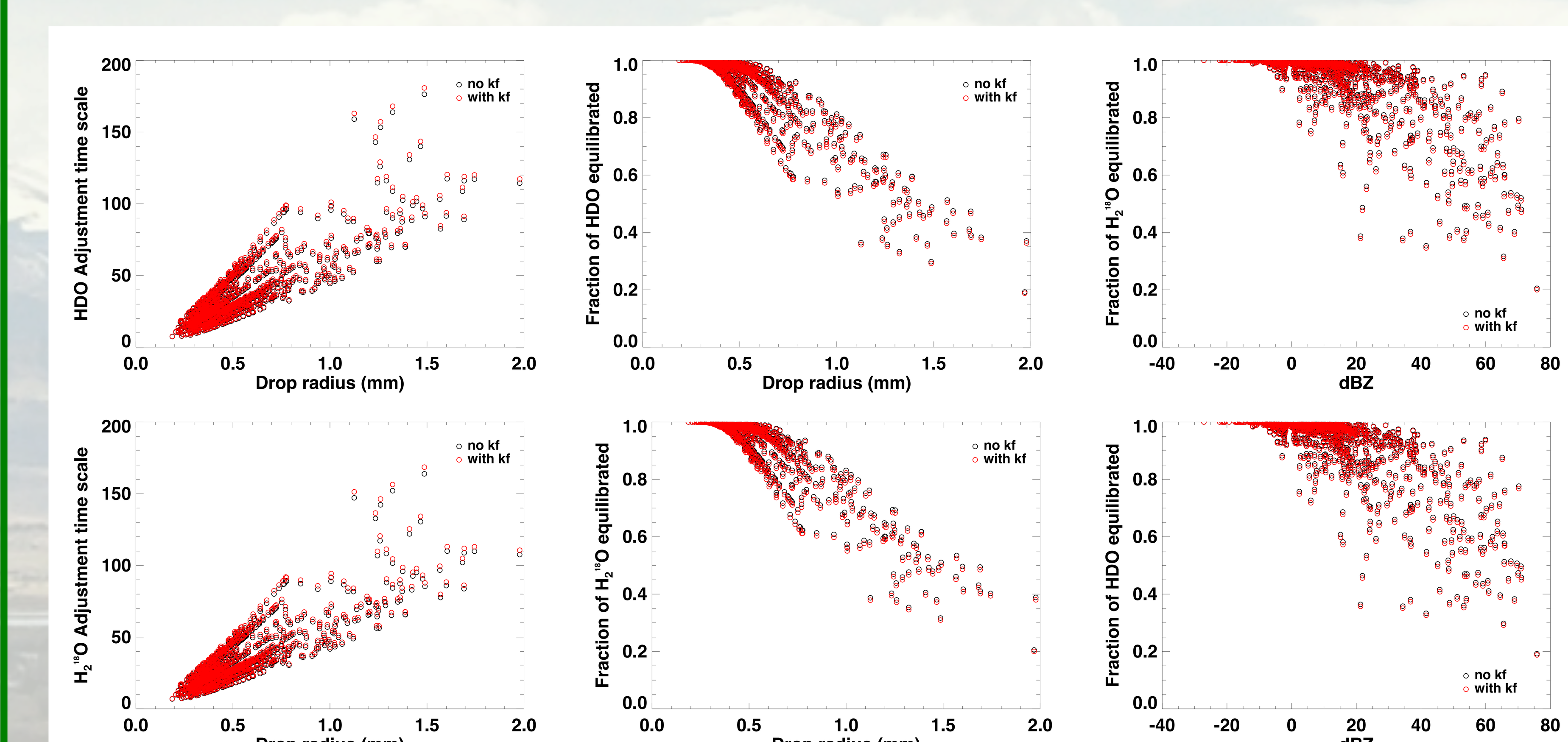
Coupling meteorological, disdrometer and isotope model fractionation parameters to predict isotopic equilibration time



a. Adjustment time scale on the order of minutes; rain at BAO is ~90% equilibrated for smaller drops;

b. Including simple kinetic fractionation (kf) predicts longer time scales for equilibration, more pronounced for larger drop sizes;

c. Fraction of isotopes equilibrated decreases with inclusion of kinetic fractionation, more pronounced for larger drop sizes;

d. 6% longer adjustment time required for 18O vs D;

e. Equilibration fraction is about the same for 18O vs D;

f. Our observations show that the degree of equilibration is less with higher rain rate (higher dBZ), agree with Lee & Fung (2007) model

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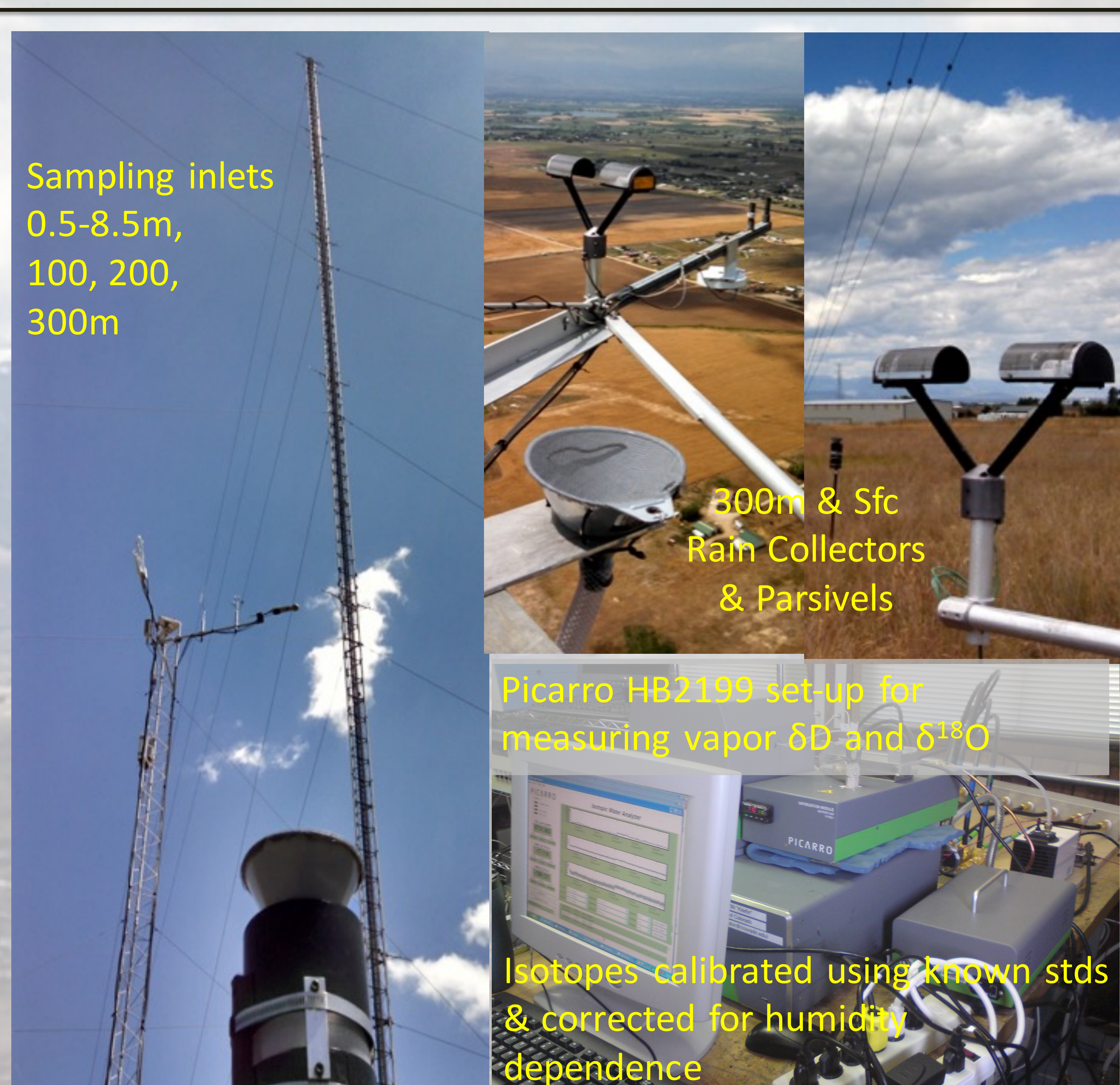
Rain drop model details taken from Nusbaumer et al. (2016); kinetic fractionation factor taken from Stewart (1975)



Conclusions & Future work

- Seasonal cycles of water isotopes in vapor and precipitation show clear east-west gradients along the Front Range; sub-seasonal time scales & drop size observations reveal evaporative enrichment processes during rain events at the BAO site
- Existing method in iCAM5 results in raindrops that are very close to fully equilibrated & predicts rain drop sizes that are too small; our results suggest modification of kinetic fractionation factor is required to better capture drop size-related isotope changes
- New parameterizations will be tested with an isotope-enabled single column model, which will also include contributions from surface recycling of evapotranspiration

References

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Lee, J.-E. and I Fung (2007) "Amount effect" of water isotopes and quantitative analysis of post-condensation processes. *Hydrol. Proc.*, doi: 10.1002/hyp.6637

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Acknowledgements and Funding

We would like to thank Bruce Bartram, Daniel Wolfe & William Otto for on-site help at the Boulder Atmospheric Observatory. This work was supported by NSF Career program Grant AGS-0955841.