Rain-vapor isotopic equilibration in central Kenya

Cynthia Gerlein[1], Keir Soderberg[2], Preston C. Kemeny[1], Kelly K. Caylor[1]

[1]Princeton University, [2]S. S. Papadopulos & Associates, Inc.

First International Workshop on Advances in Observations, Models and Measurement Techniques of Atmospheric Water Vapor Isotopes

October 17th 2013

Motivation

esa

ECOSPHERE

SPECIAL FEATURE: ISOSCAPES

Using atmospheric trajectories to model the isotopic composition of rainfall in central Kenya

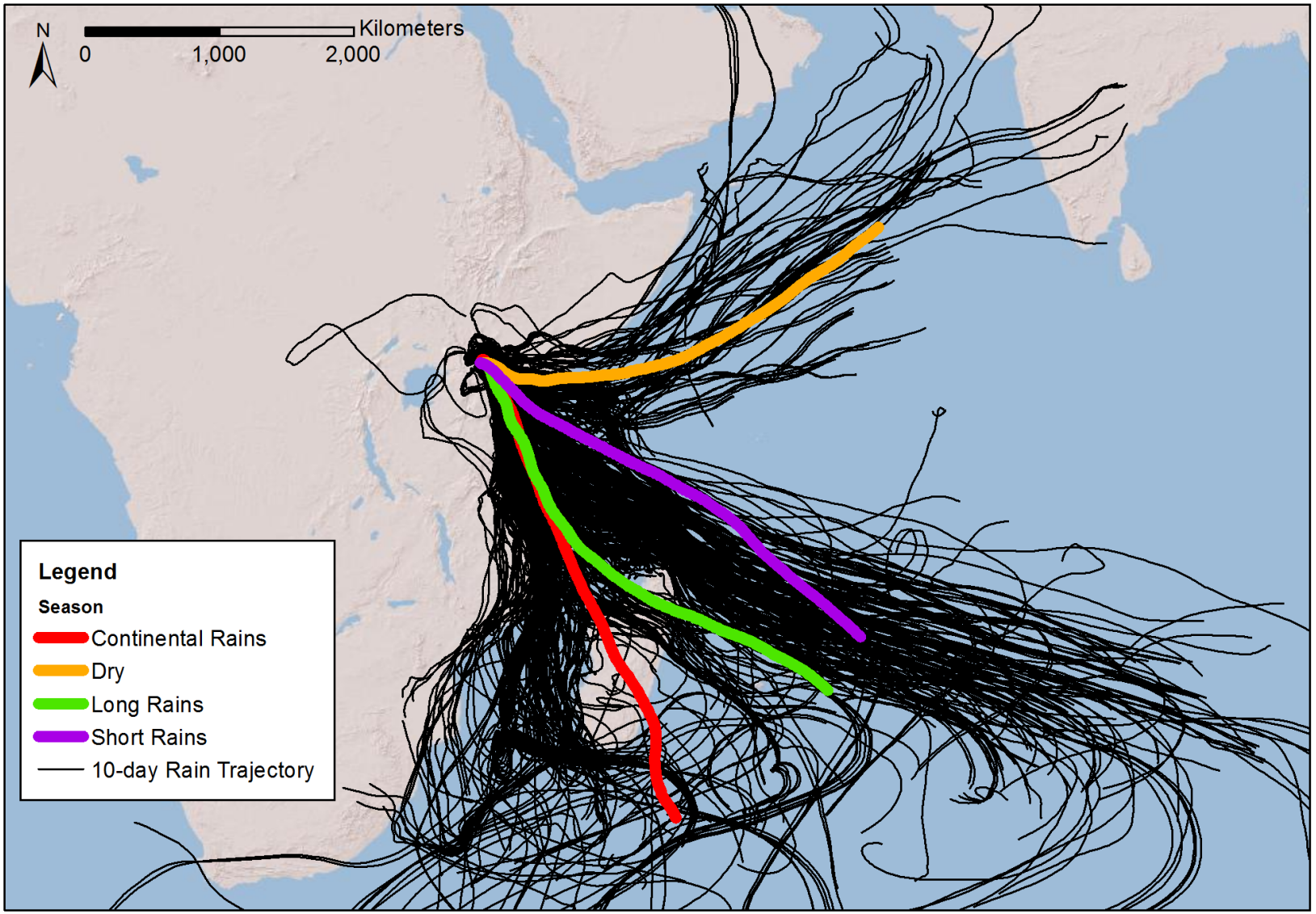
Keir Soderberg,[1,2,†] Stephen P. Good,[1] Molly O'Connor,[1] Lixin Wang,[3,4] Kathleen Ryan,[1] and Kelly K. Caylor[1]

[1]*Department of Civil and Environmental Engineering, Princeton University, Princeton, New Jersey 08544 USA*
[2]*S. S. Papadopulos & Associates, Inc., Bethesda, Maryland 20814 USA*
[3]*Department of Earth Sciences, Indiana University-Purdue University, Indianapolis (IUPUI), Indianapolis, Indiana 46202 USA*
[4]*Water Research Centre, School of Civil and Environmental Engineering, University of New South Wales, Sydney, New South Wales 2052 Australia*

Citation: Soderberg, K., S. P. Good, M. O'Connor, L. Wang, K. Ryan, and K. K. Caylor. 2013. Using atmospheric trajectories to model the isotopic composition of rainfall in central Kenya. Ecosphere 4(3):33. http://dx.doi.org/10.1890/ES12-00160.1

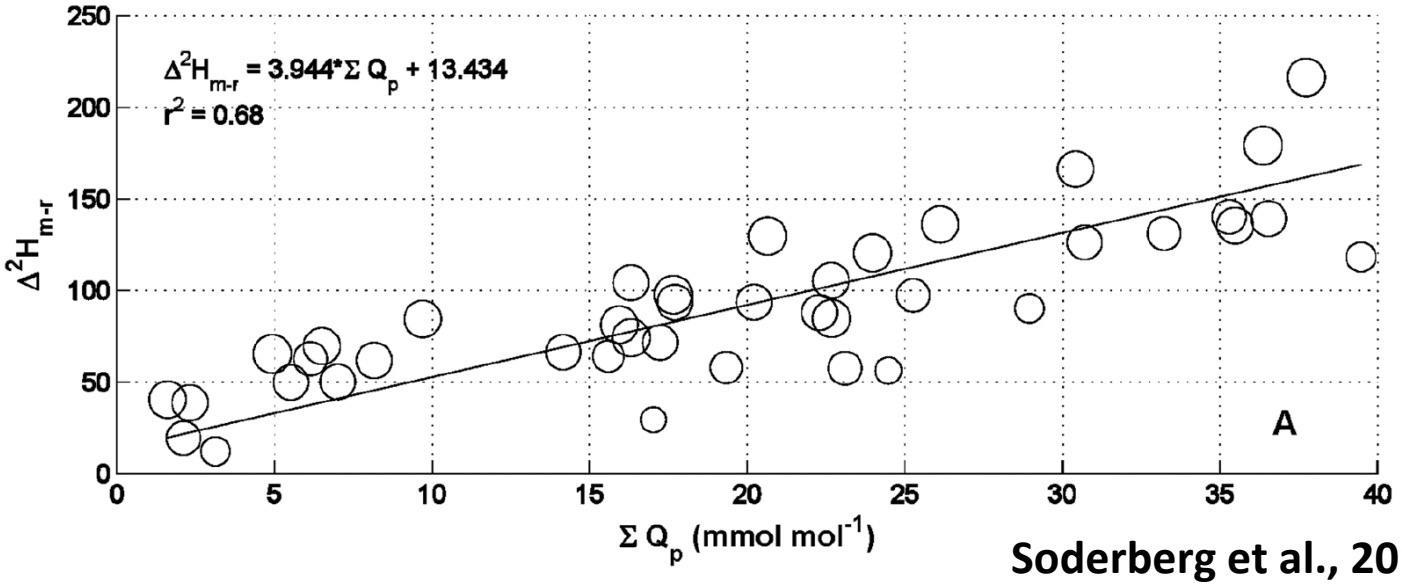
Abstract. The isotopic composition of rainfall (δ^2H and $\delta^{18}O$) is an important tracer in studies of the ecohydrology, plant physiology, climate and biogeochemistry of past and present ecosystems. The overall continental and global patterns in precipitation isotopic composition are fairly well described by condensation temperature and Rayleigh fractionation during rainout. However, these processes do not fully explain the isotopic variability in the tropics, where intra-storm and meso-scale dynamics may dominate. Here we explore the use of atmospheric back-trajectory modeling and associated meteorological variables to explain the large variability observed in the isotopic composition of individual rain events at

Motivation



Soderberg et al., 2013, Ecosphere

Motivation



Soderberg et al., 2013, Ecosphere

Positive intercept (0 positive humidity excursions along the trajectory) in both Δ^2H and $\Delta^{18}O$.

With no substantial advection or surface flux input, the Rayleigh fractionation predicts depleted rainfall isotopic composition relative to the measured values.

Possible explanation:
post-condensation process, such as evaporation of falling raindrops

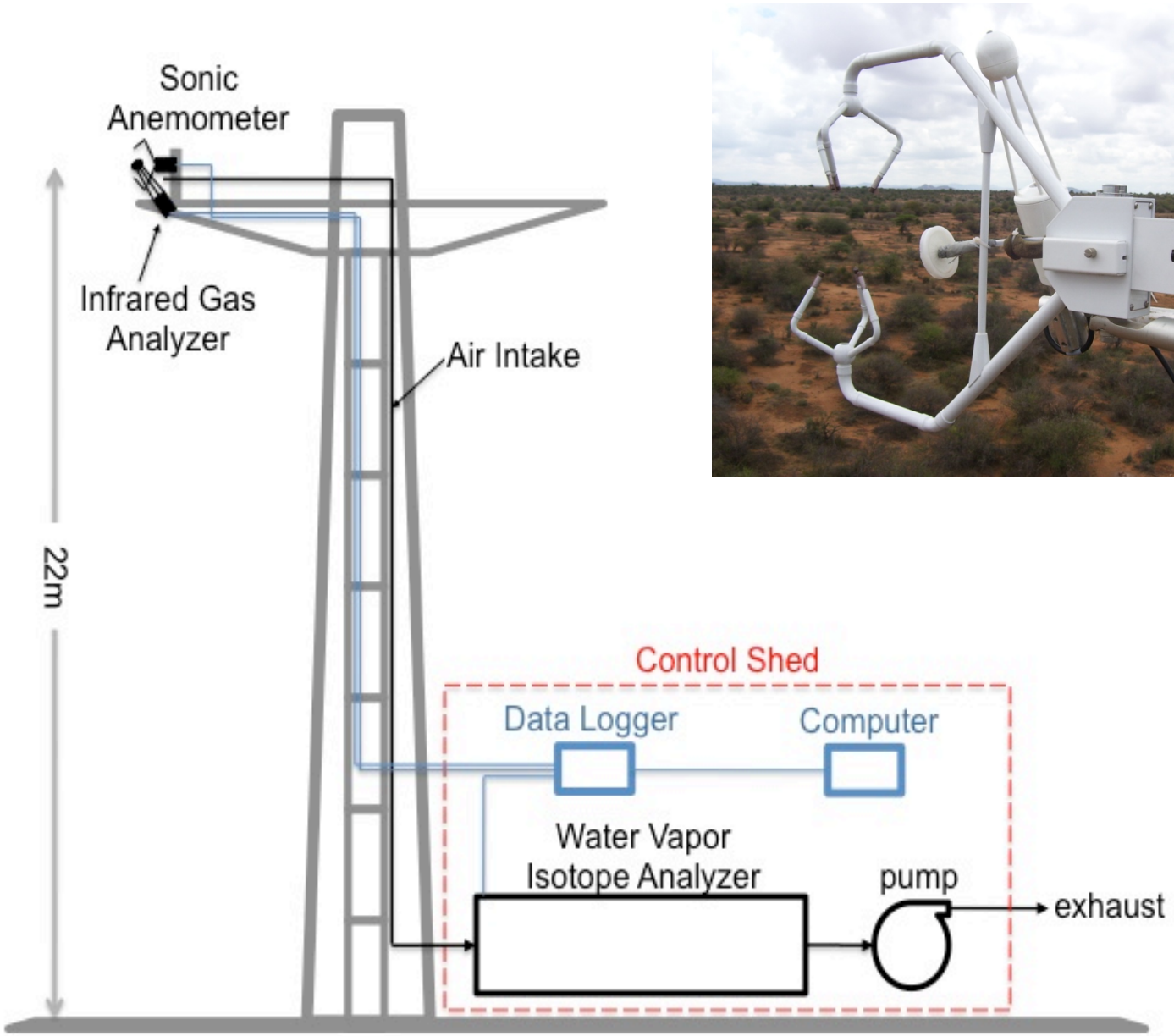
Motivation

- Determine the degree of isotopic equilibrium between raindrops and the surrounding vapor

- Relate this degree of equilibration to the intensity of convection determined from sequential rainfall

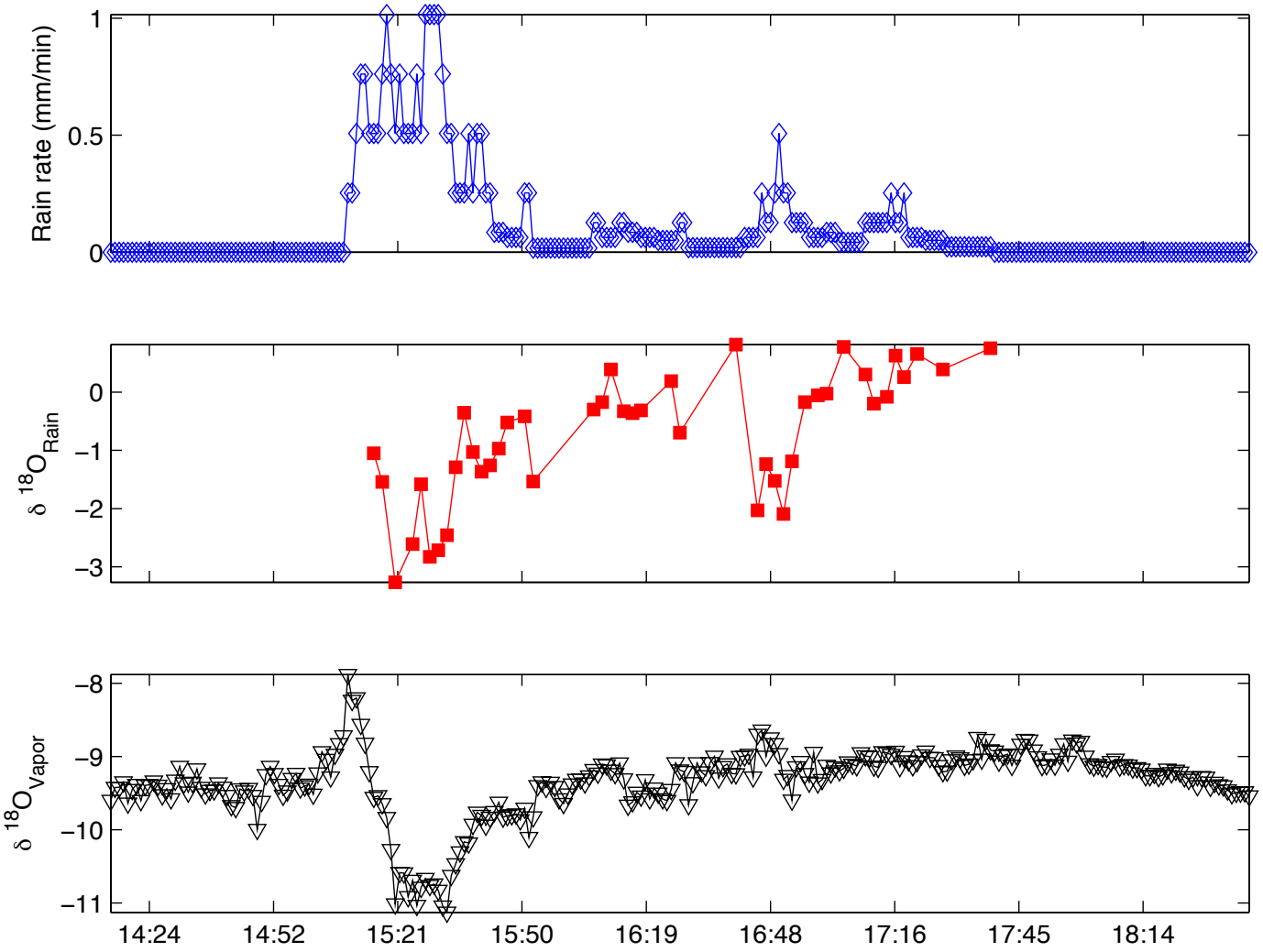
Study site and data collection

- Mpala Research Center, Laikipia district, Central Kenya
- Data collection:
  - Temperature
  - Relative humidity
  - Rain rate
  - Continuous vapor isotopic composition
  - High resolution rain sampling for isotopic composition from 17 rain events

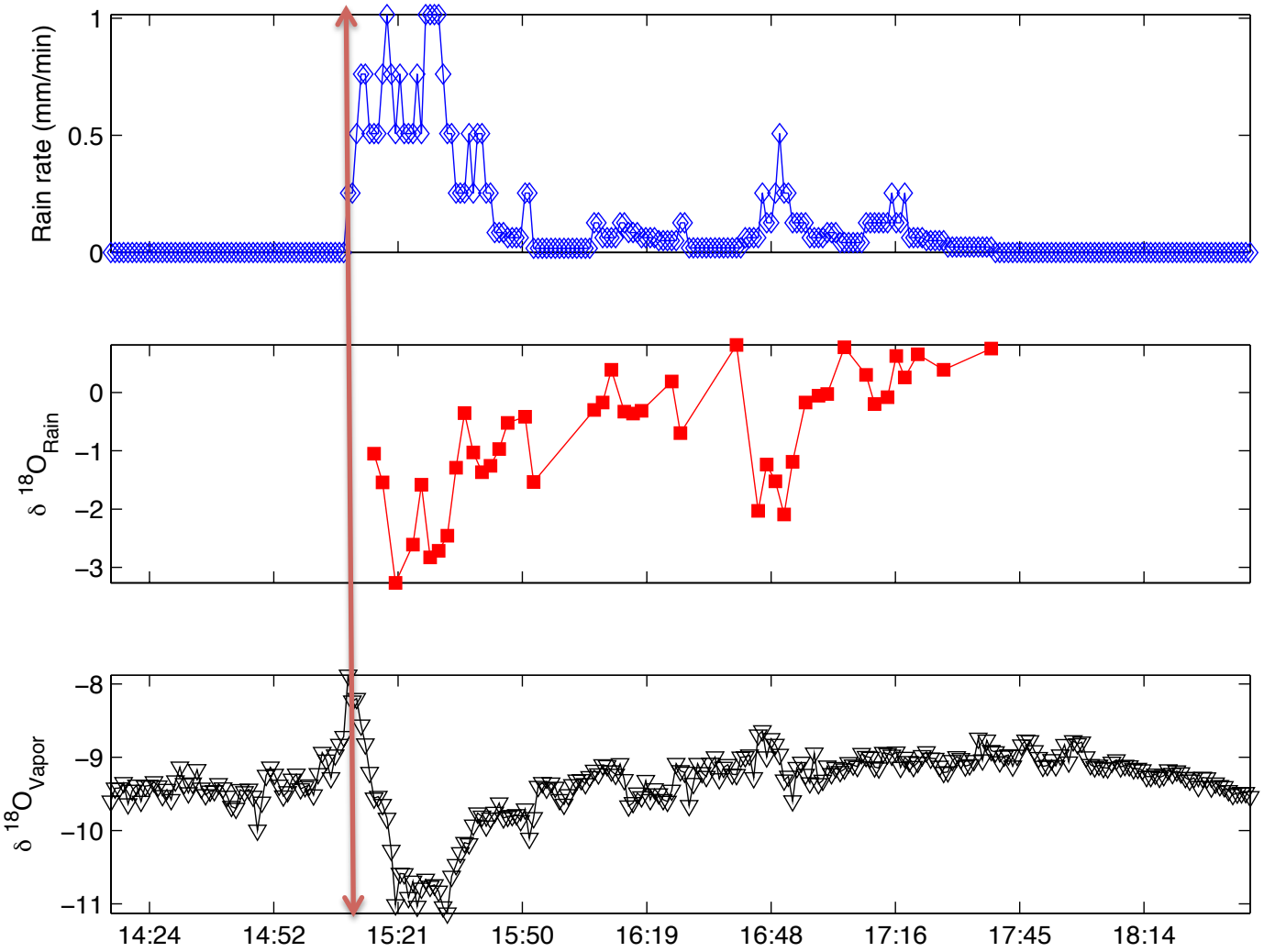


Eddy covariance tower configuration

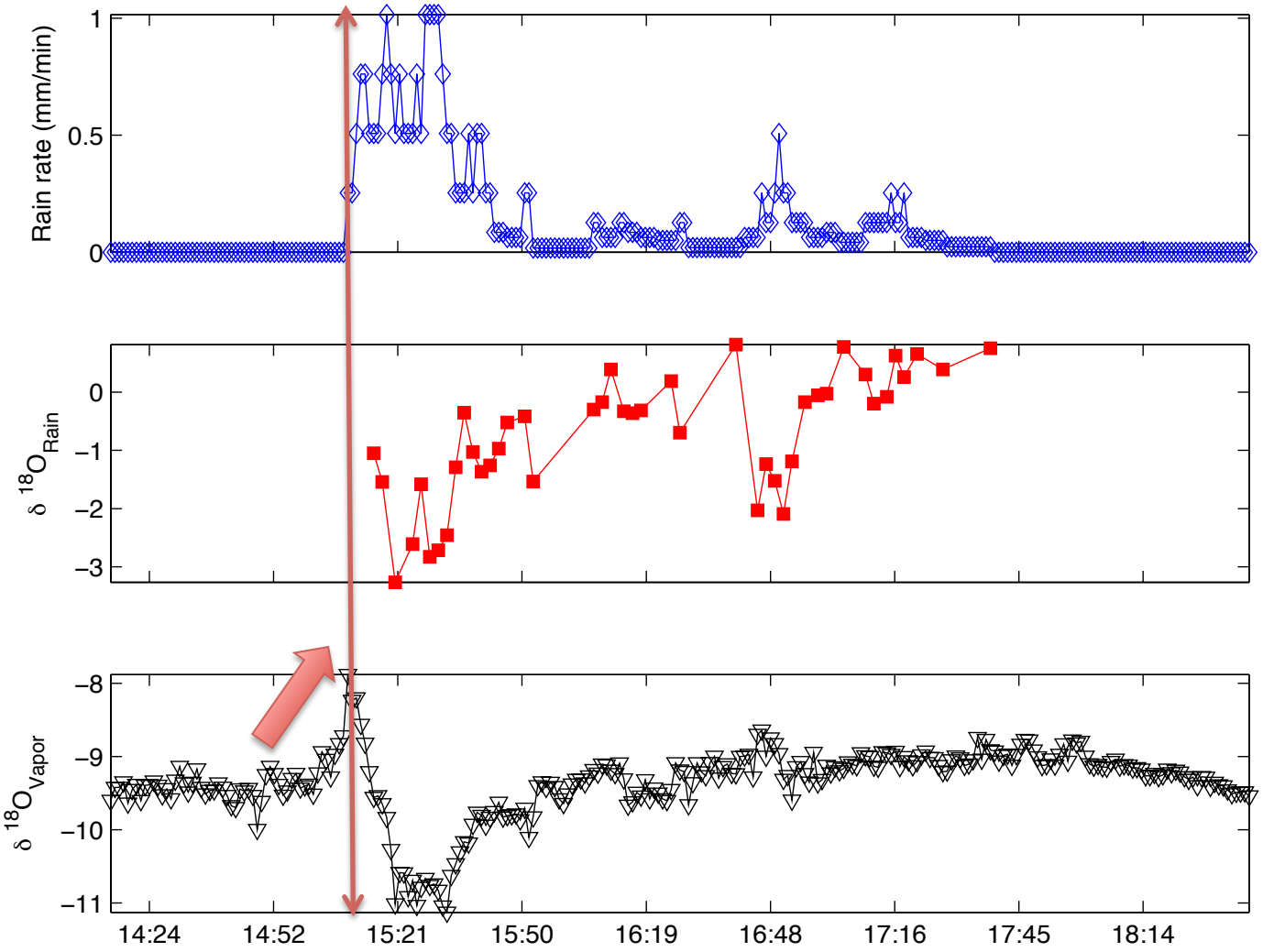
Storm evolution: rain rate and $\delta^{18}O$



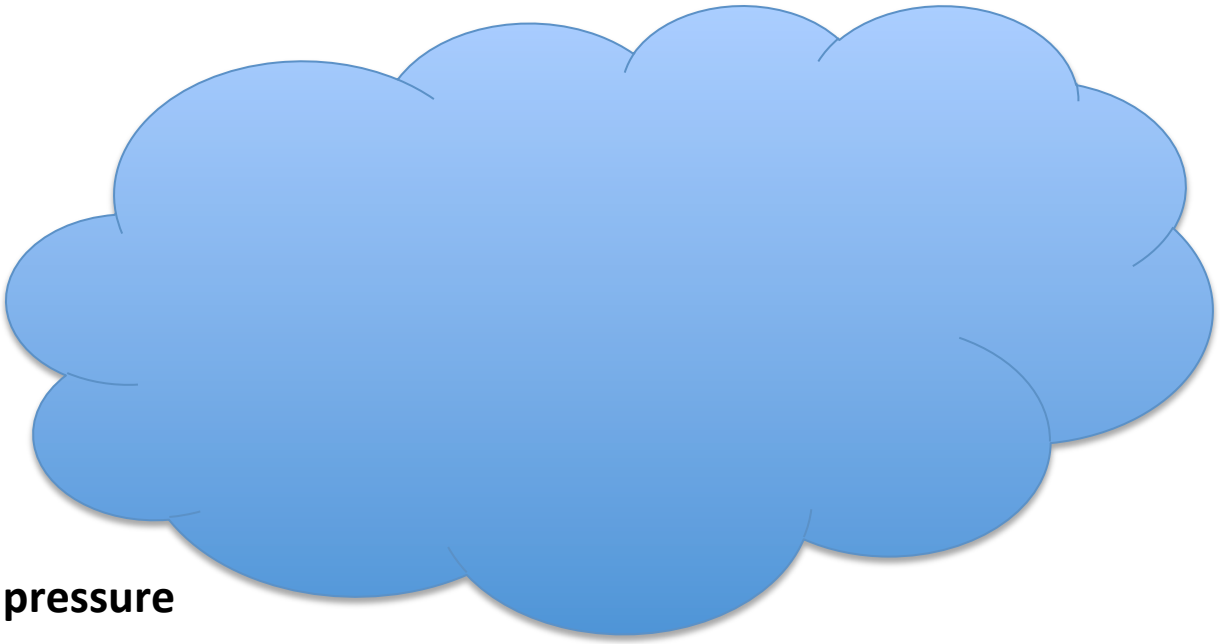
Storm evolution: rain rate and $\delta^{18}O$



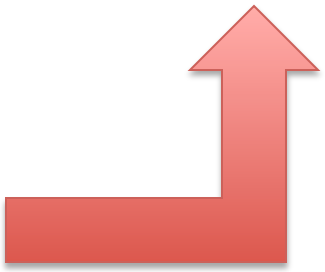
Storm evolution: rain rate and $\delta^{18}O$



Storm evolution: rain rate and $\delta^{18}O$

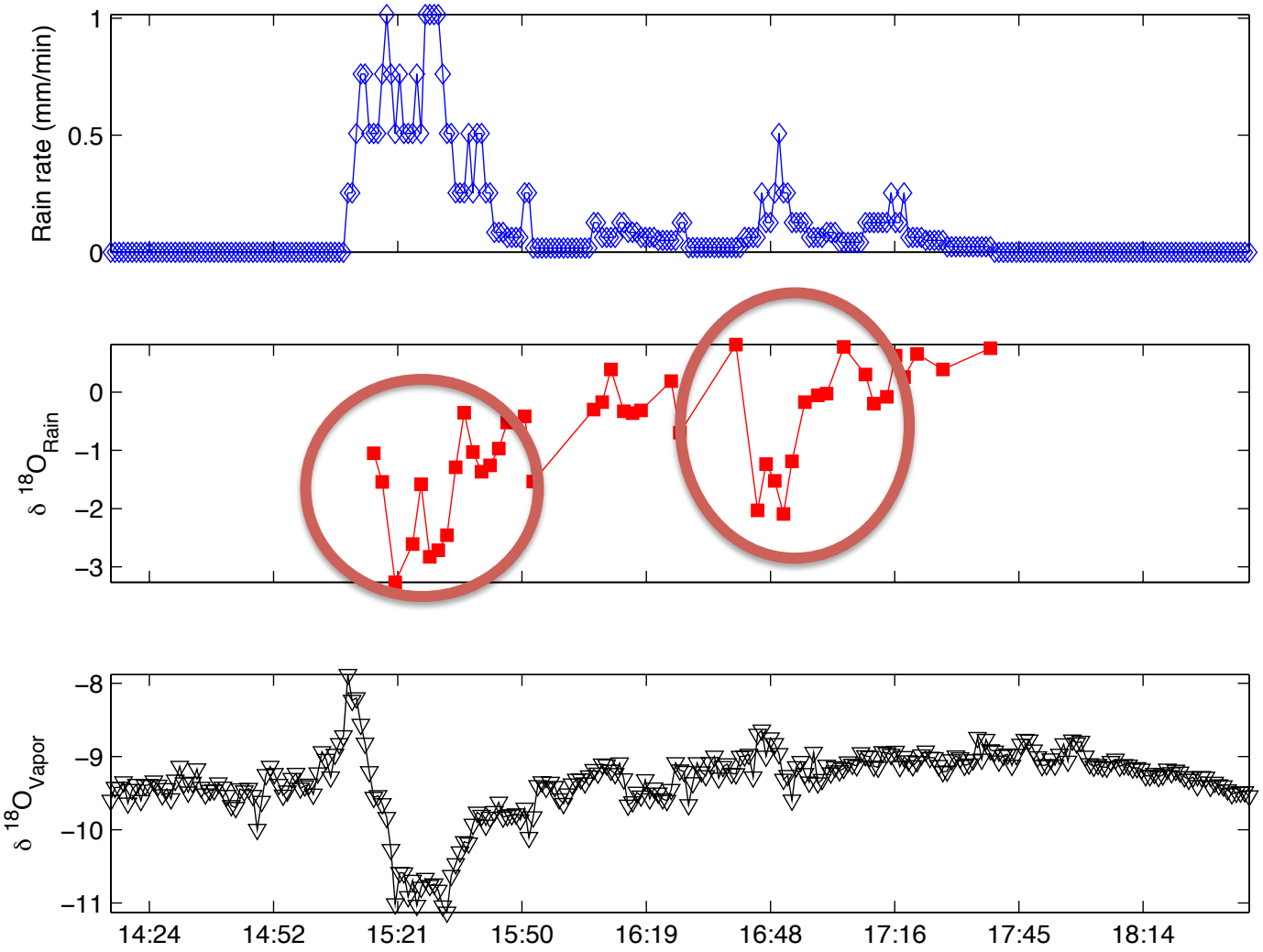


Low pressure

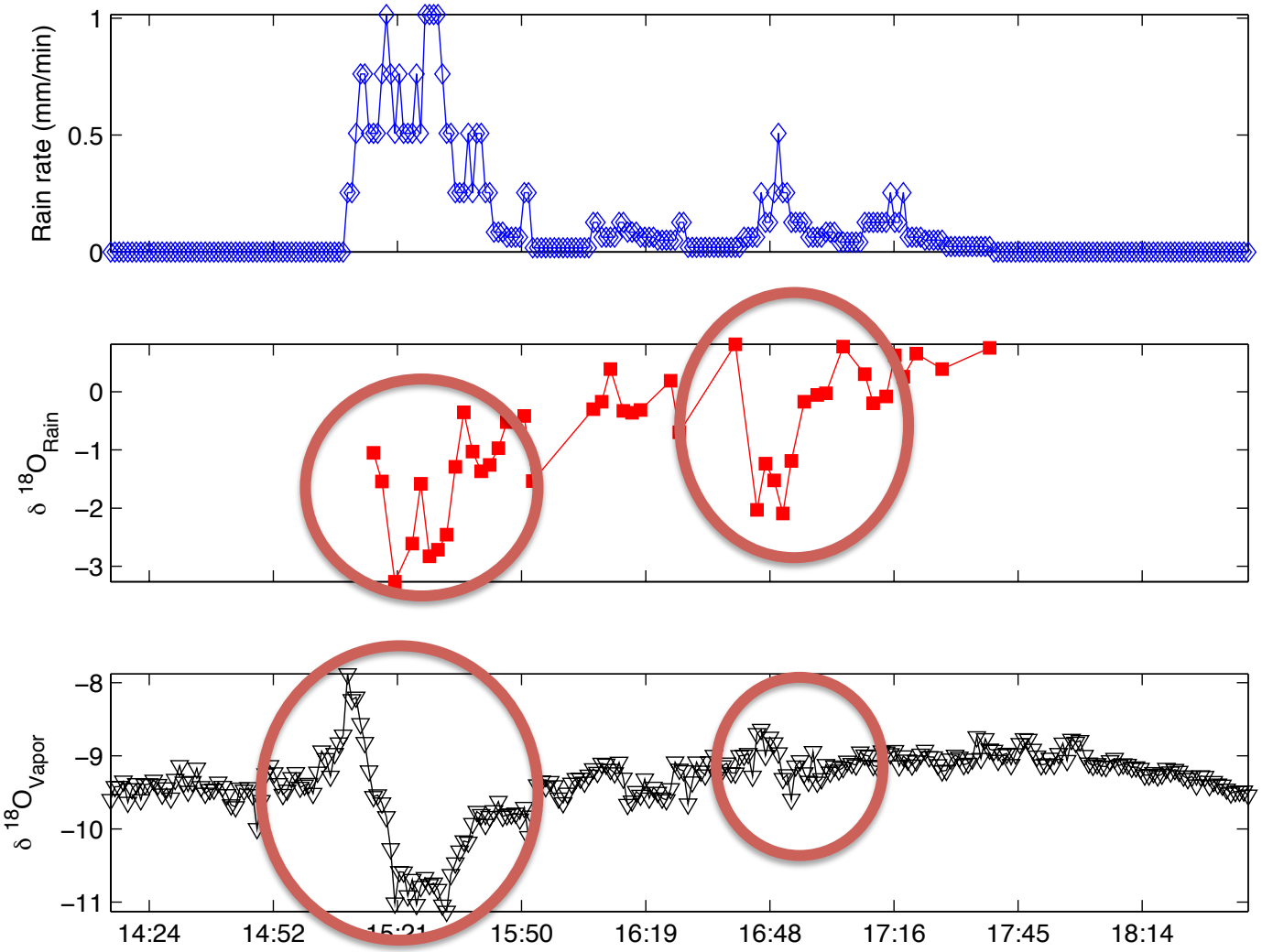


Surface air (heavier) sucked up

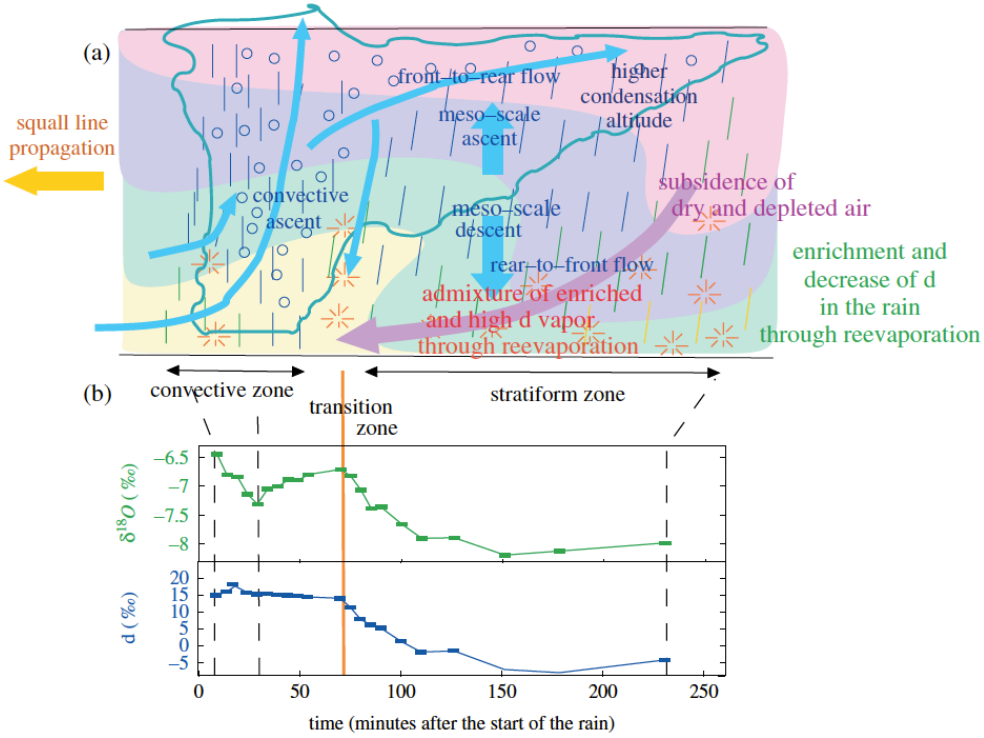
Storm evolution: rain rate and $\delta^{18}O$

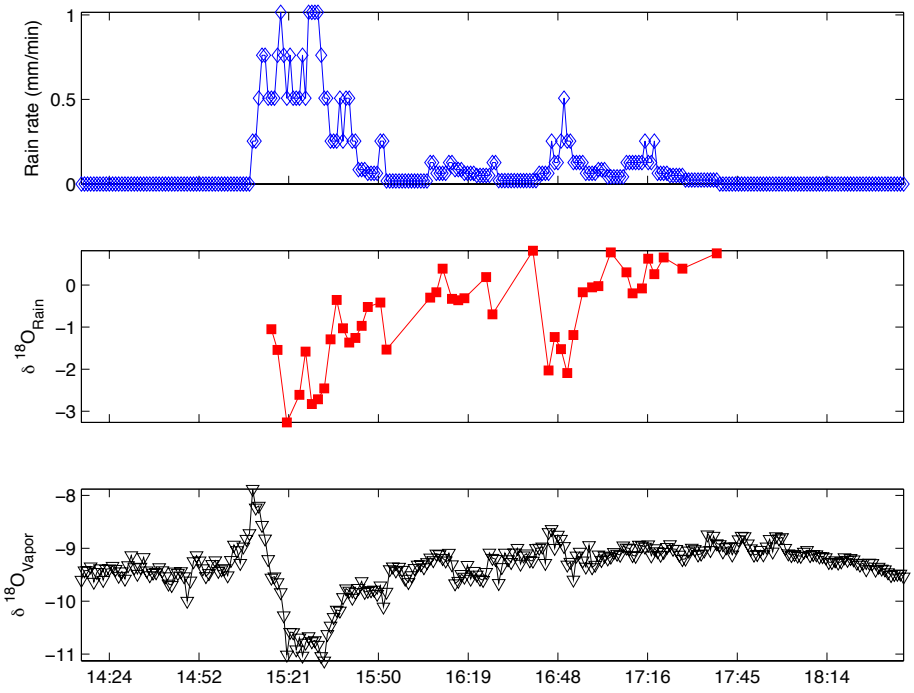


Storm evolution: rain rate and $\delta^{18}O$



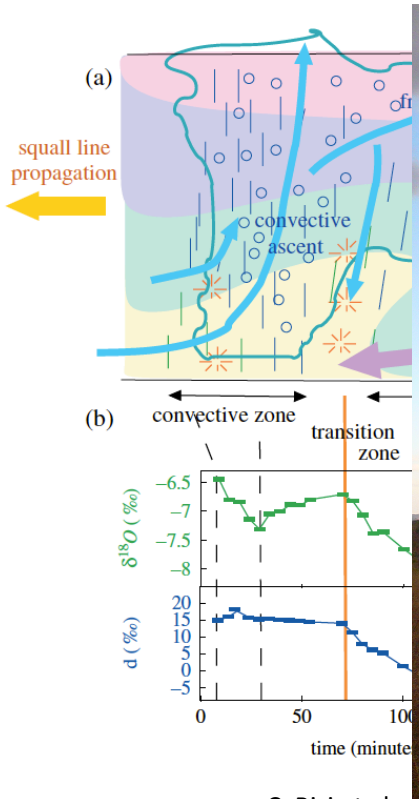
A proof of convective rainfall ?



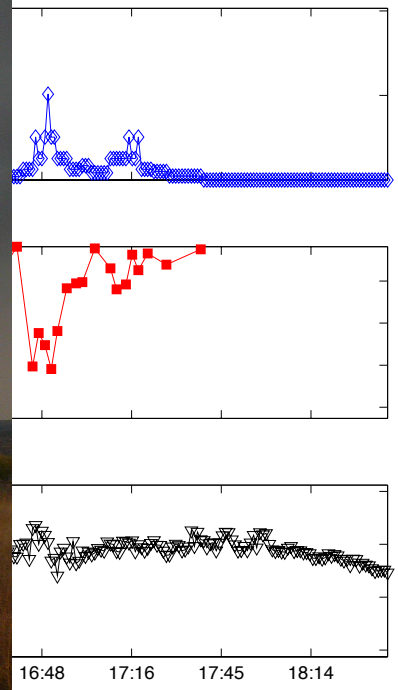


C. Risi et al., Q. J. R. Meteorol. Soc. 136(s1): 227–242 (2010)

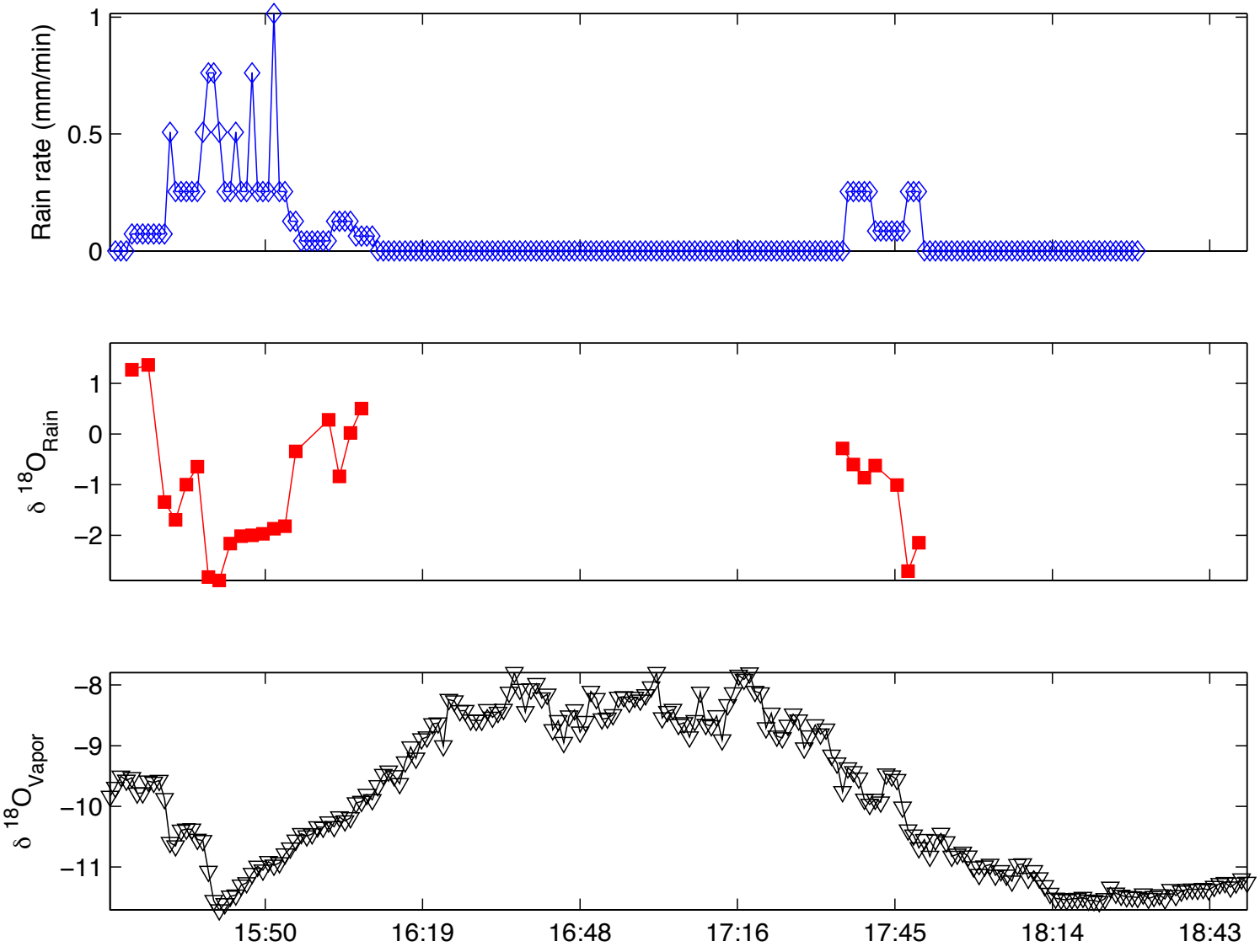
A proof of convective rainfall ?



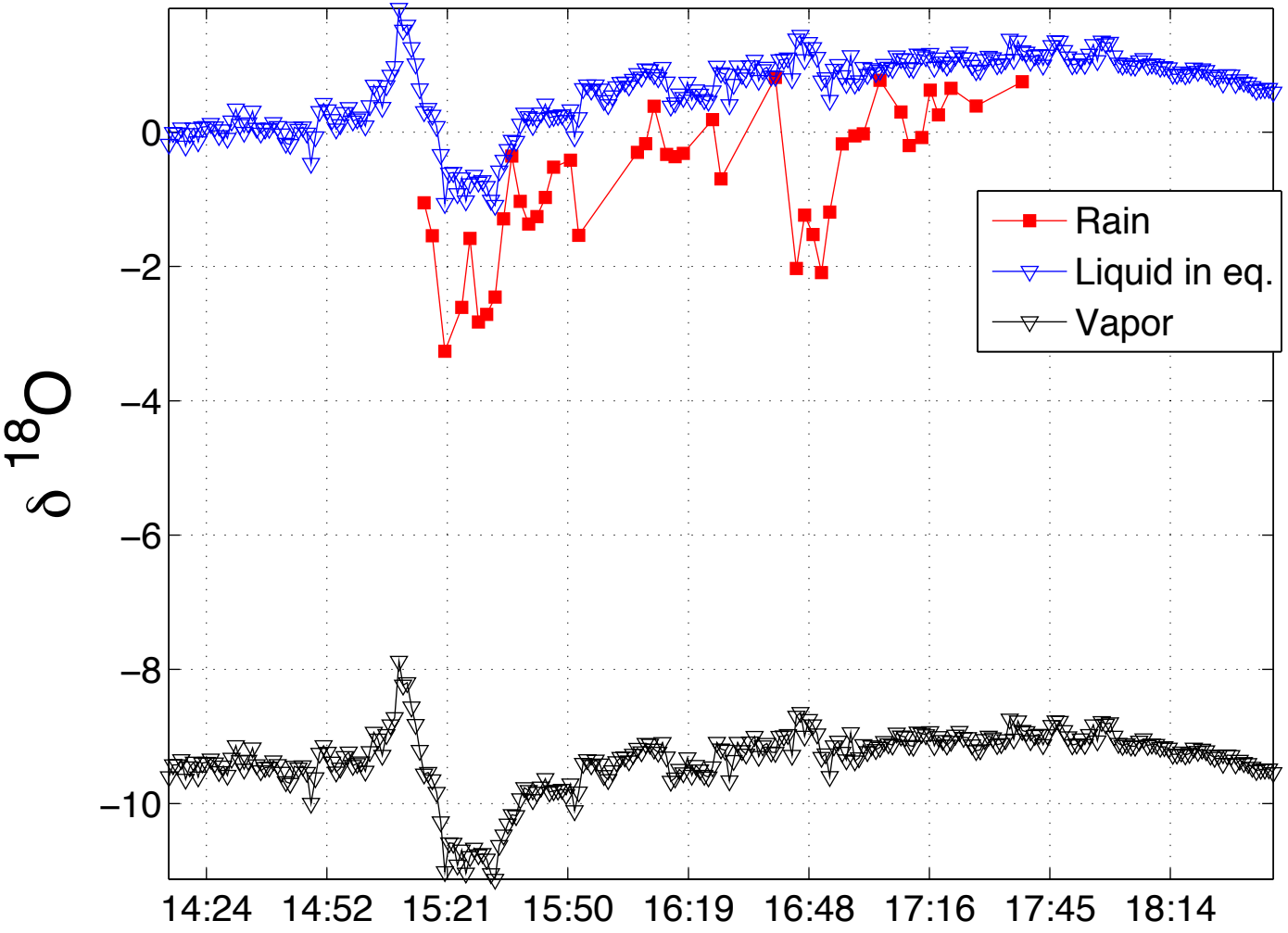
C. Risi et al.,



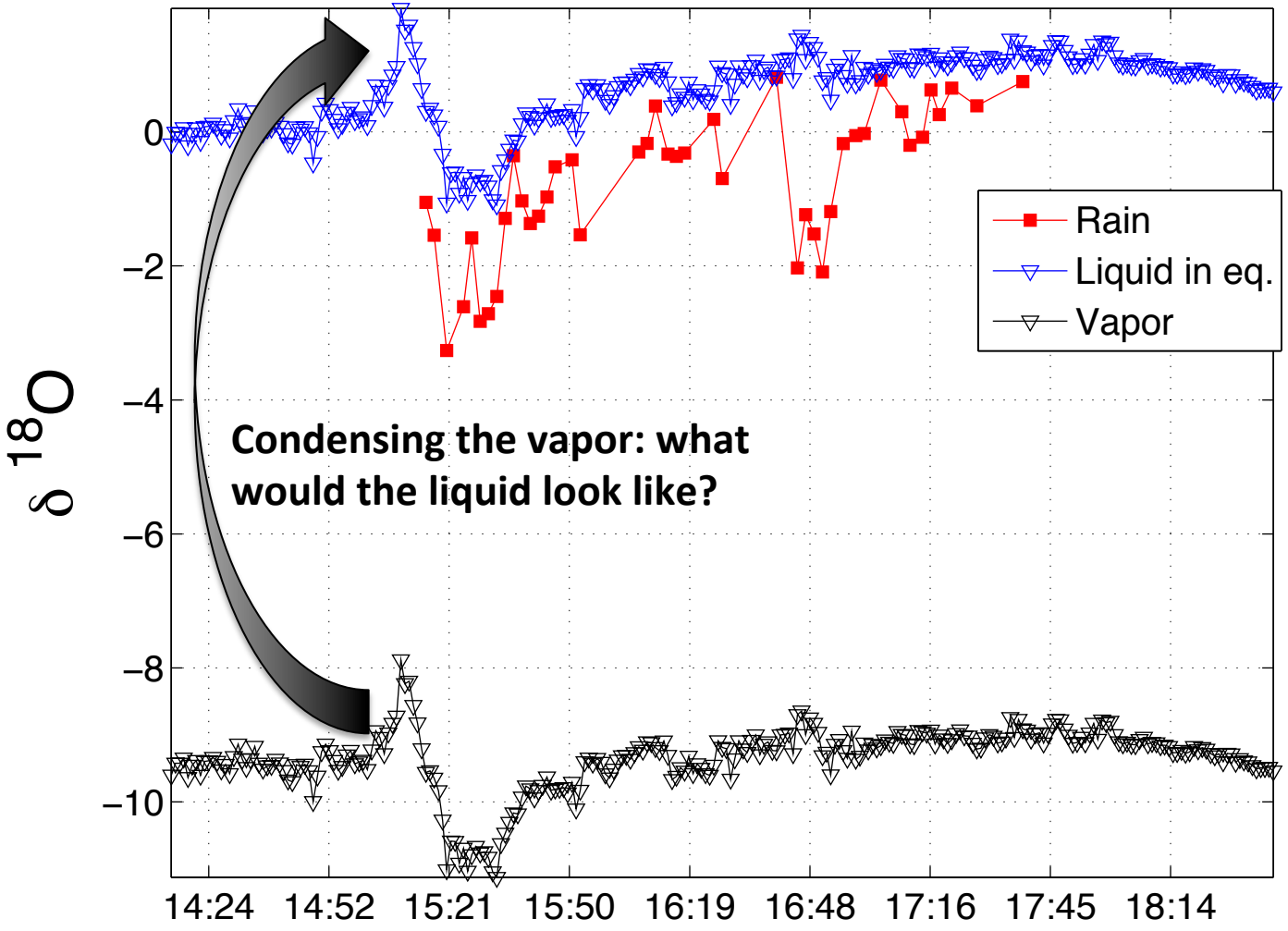
$\Delta\ ^{18}O$


Rain rate (mm/min)
1
0.5
0
δ 18O Rain
1
0
−1
−2
δ 18O Vapor
−8
−9
−10
−11
15:50
16:19
16:48
17:16
17:45
18:14
18:43

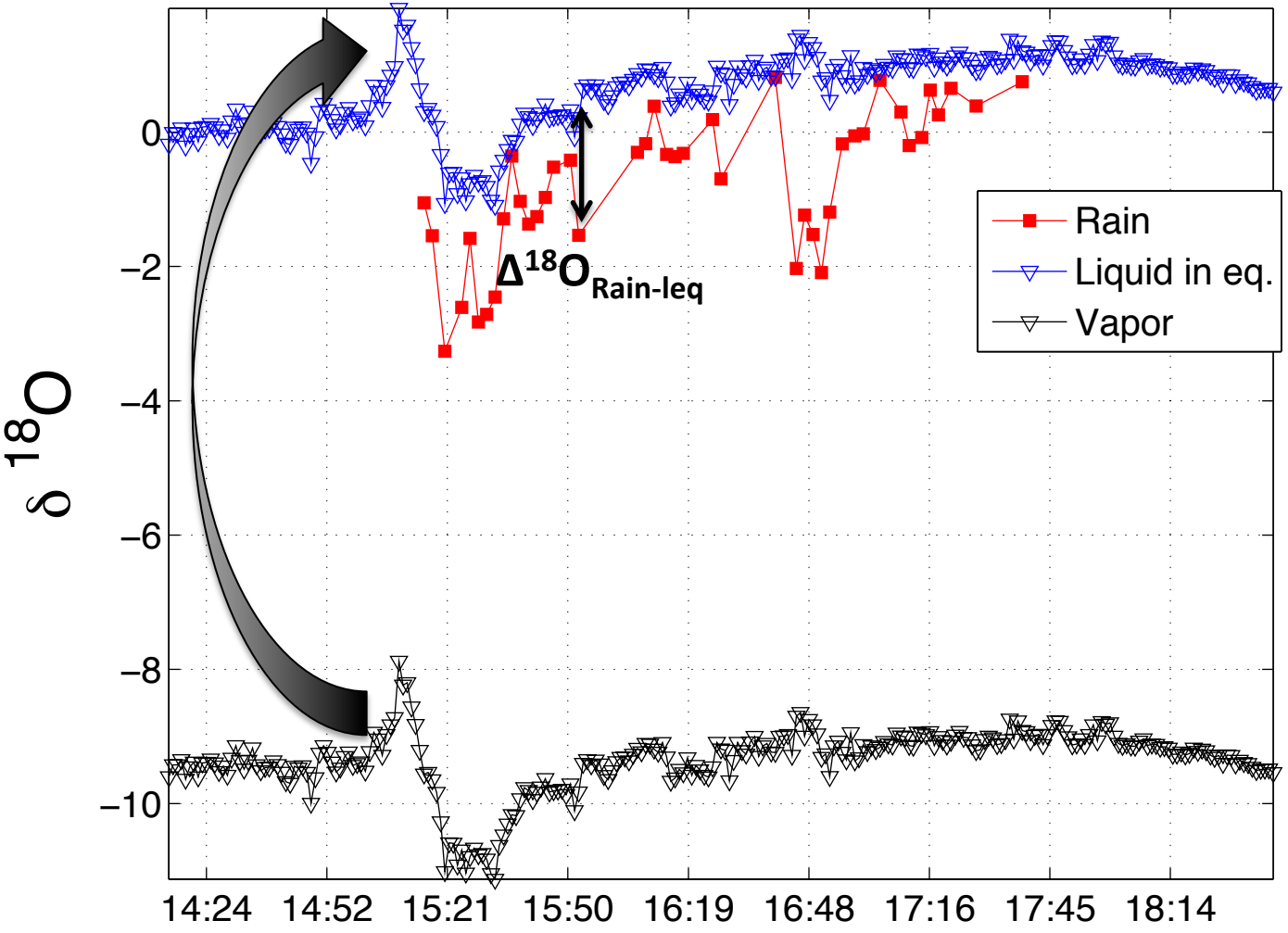
Δ Notation


δ 18O
0
−2
−4
−6
−8
−10
14:24
14:52
15:21
15:50
16:19
16:48
17:16
17:45
18:14
Rain
Liquid in eq.
Vapor

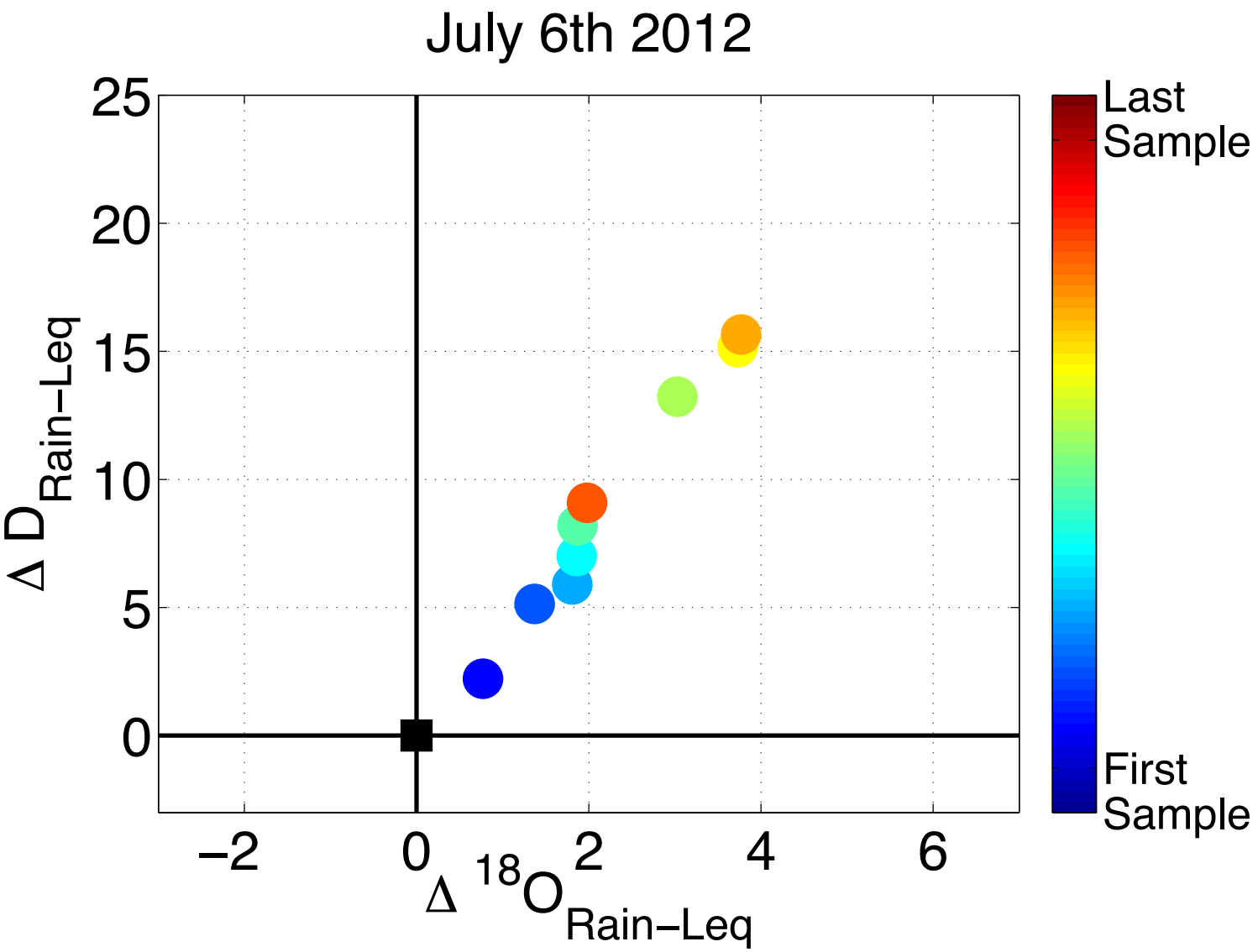
Δ Notation


δ 18O
0
−2
−4
−6
−8
−10
14:24
14:52
15:21
15:50
16:19
16:48
17:16
17:45
18:14
Rain
Liquid in eq.
Vapor
Condensing the vapor: what would the liquid look like?

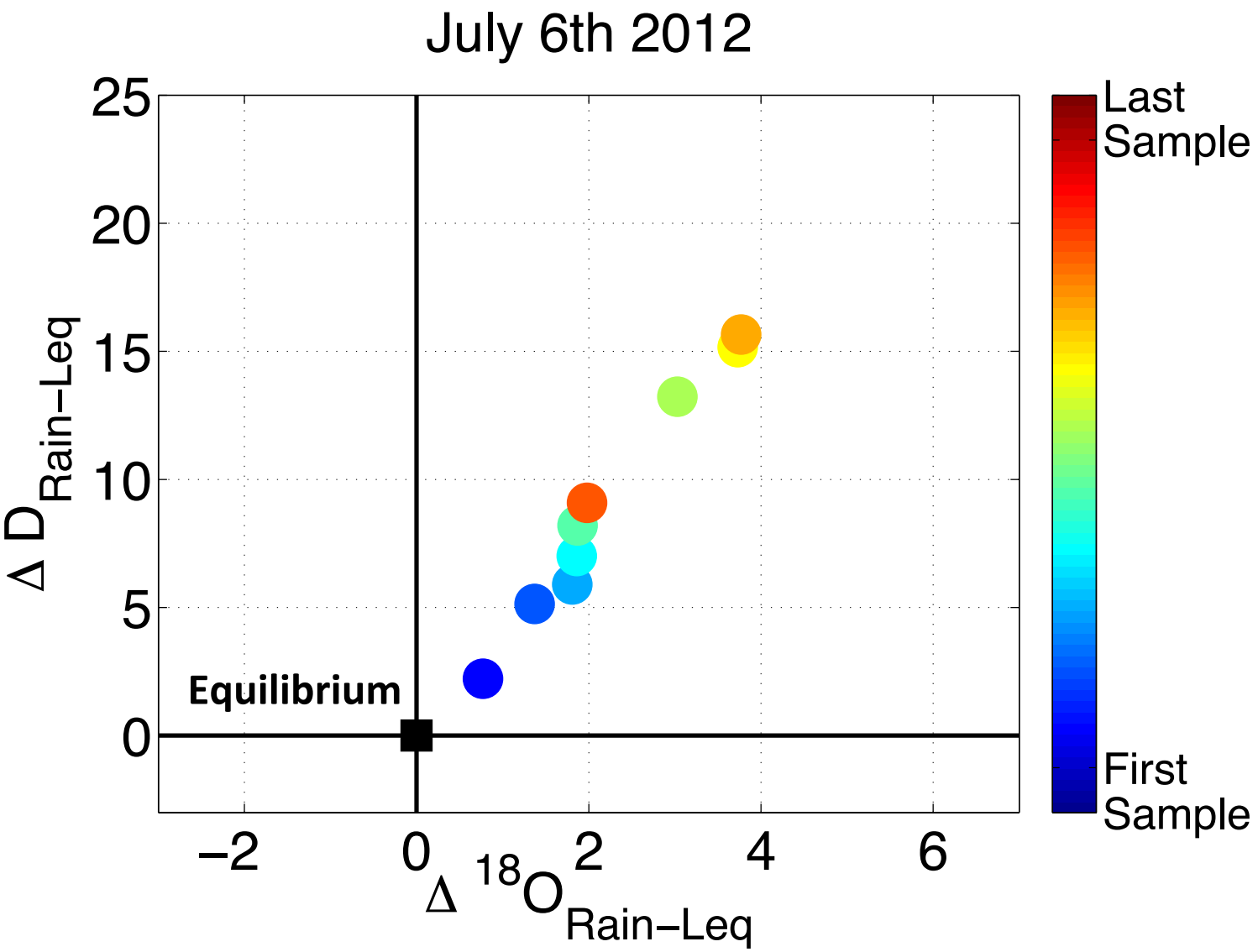
Δ Notation


δ 18O
0
−2
−4
−6
−8
−10
14:24
14:52
15:21
15:50
16:19
16:48
17:16
17:45
18:14
Δ18ORain-leq
Rain
Liquid in eq.
Vapor

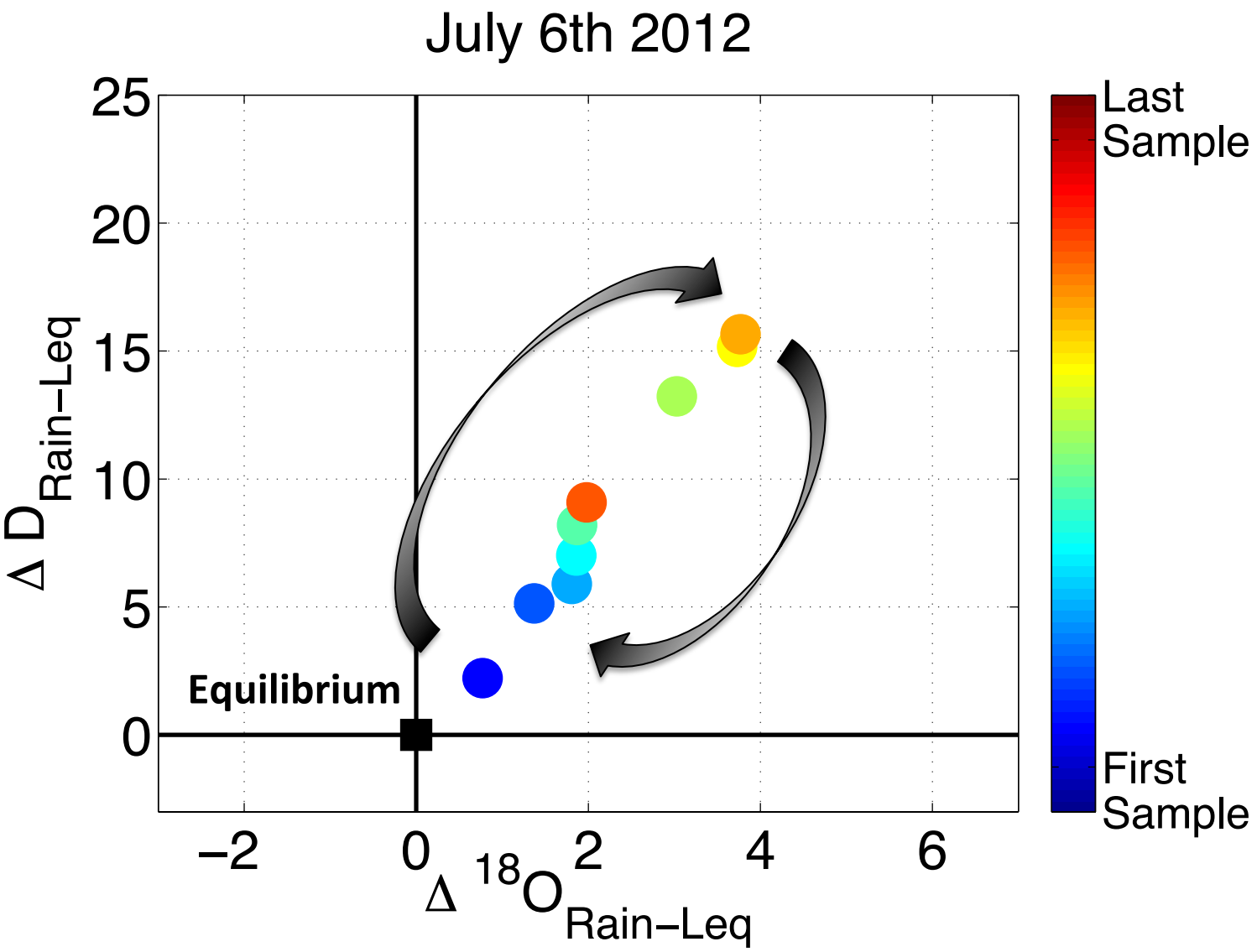
Intra-storm evolution

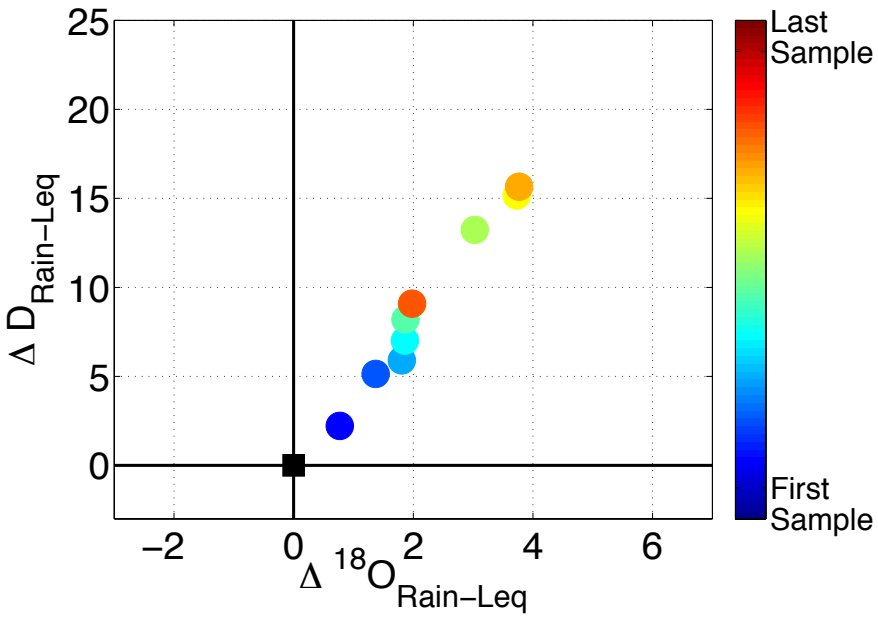


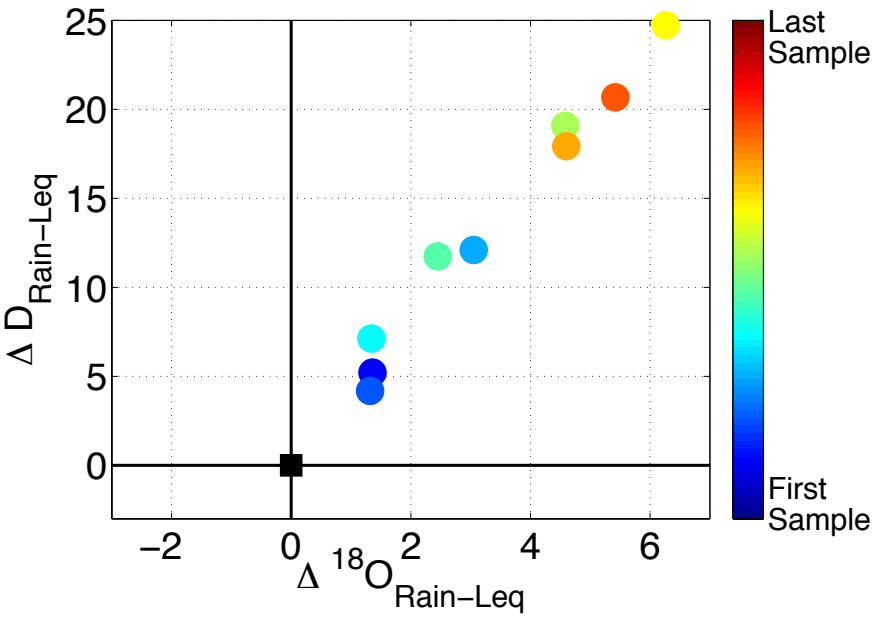
Intra-storm evolution

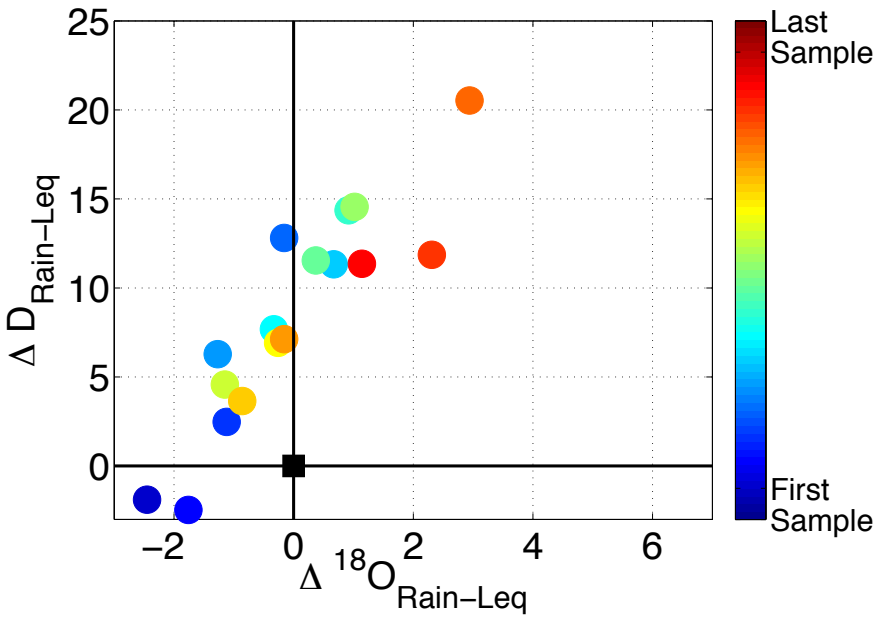


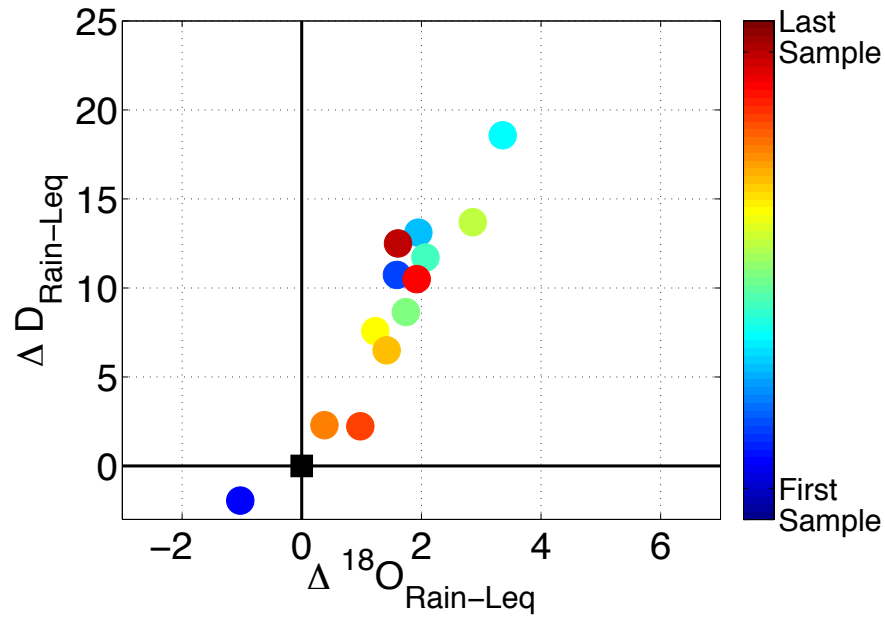
Intra-storm evolution



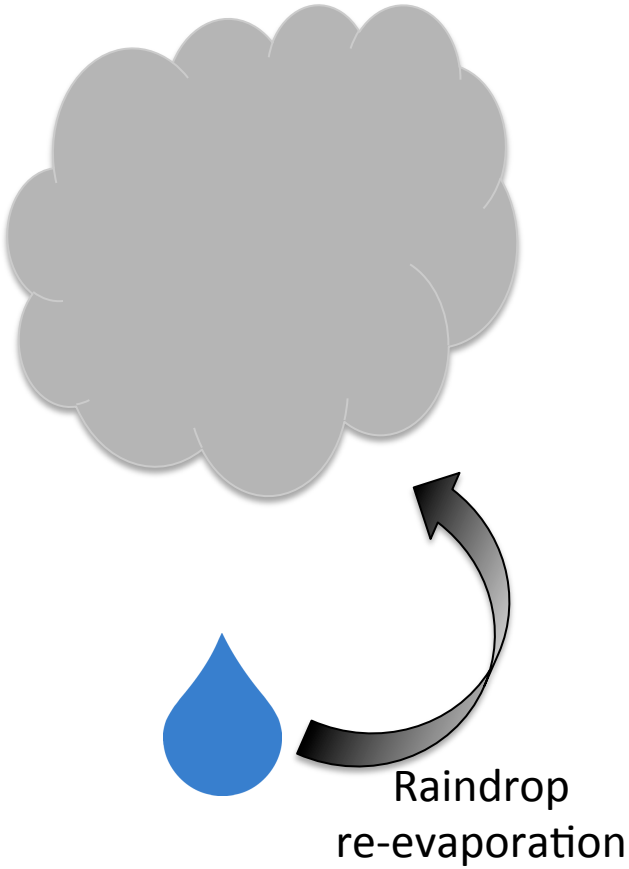

July 6th 2012
Δ D Rain−Leq
Δ 18O Rain−Leq
Last Sample
First Sample


June 27th 2012
Δ D Rain−Leq
Δ 18O Rain−Leq
Last Sample
First Sample

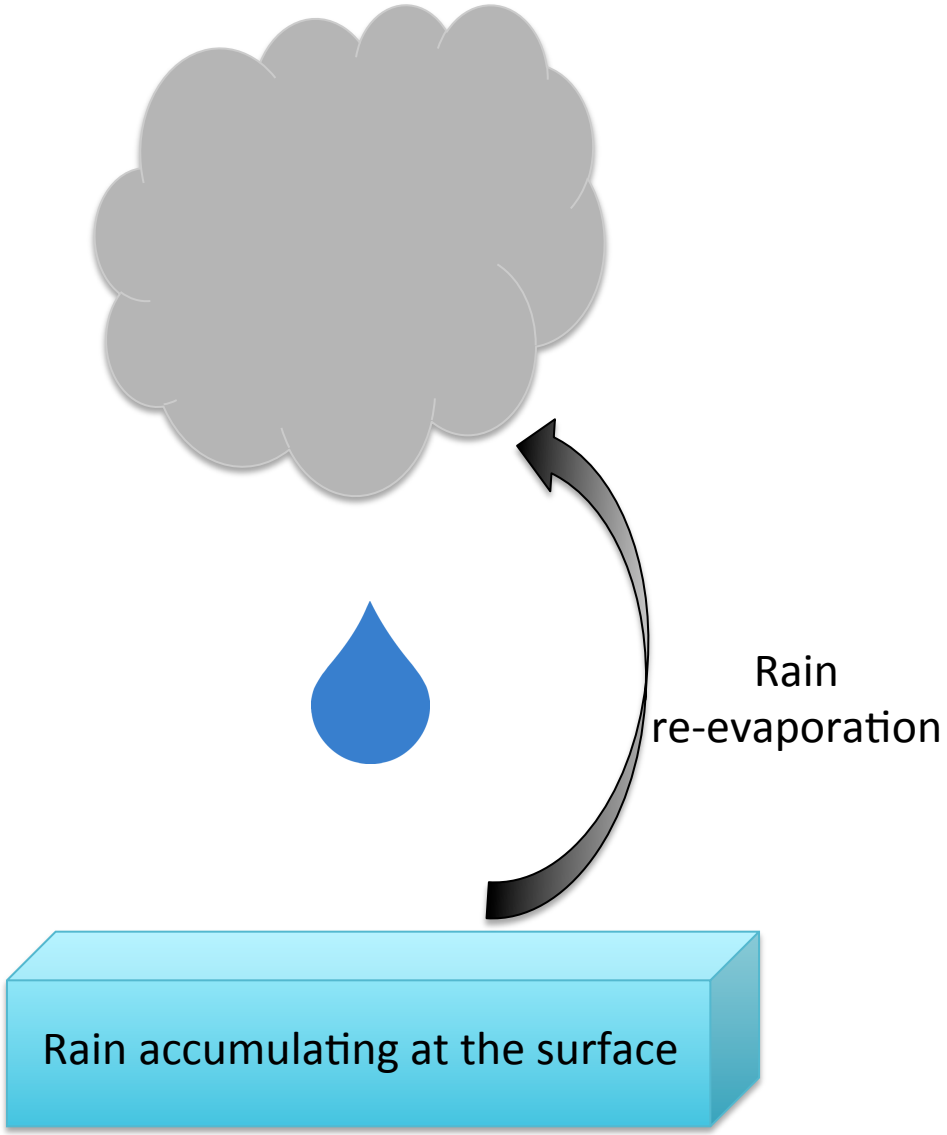

July 17th 2012
Δ D Rain−Leq
Δ 18O Rain−Leq
Last Sample
First Sample


August 23rd 2012
Δ D Rain−Leq
Δ 18O Rain−Leq
Last Sample
First Sample

Early rain
Low relative humidity



Late rain
High relative humidity



Conclusion / Perspective

- First part of the evolution of the isotopic composition of the rain throughout an event is in agreement with re-evaporation of raindrops.
- Rain goes back towards equilibrium as a result of evaporation from the soil: large amount of water with approx. same composition gives a stable signal (fractionation with transport)
- Need for a model of re-evaporation to explain the mechanisms of the evolution observed.

MONDAY, DECEMBER 09, 2013,

1:40 PM – 6:00 PM, Hall A-C (Moscone South)

GC13A-1057. Isotopic equilibrium between precipitation and water vapor: evidence from continental rains in central Kenya

Keir Soderberg, Cynthia Gerlein, Preston C. Kemeny, Kelly K. Caylor


Questions ?
cgerlein@princeton.edu