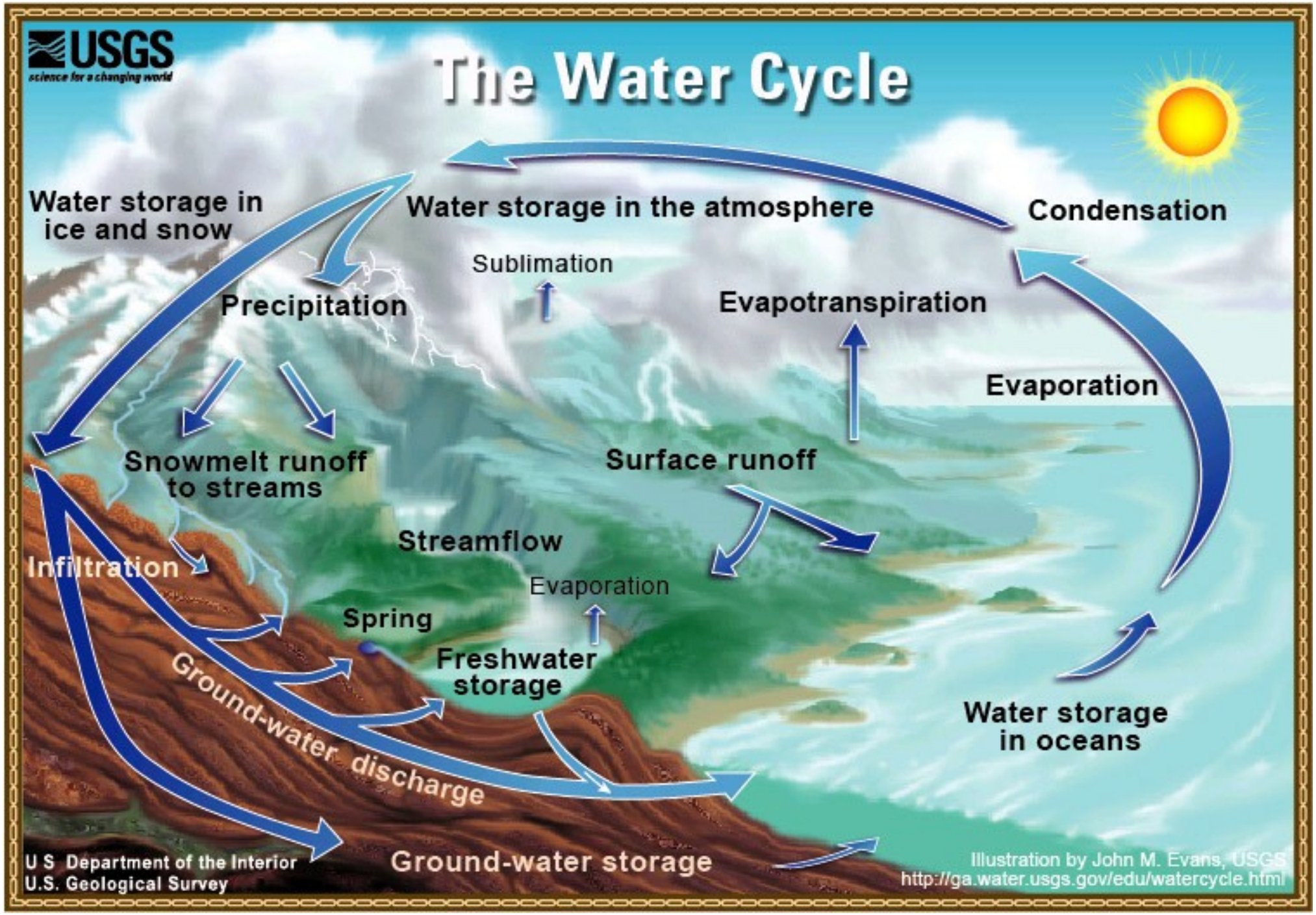
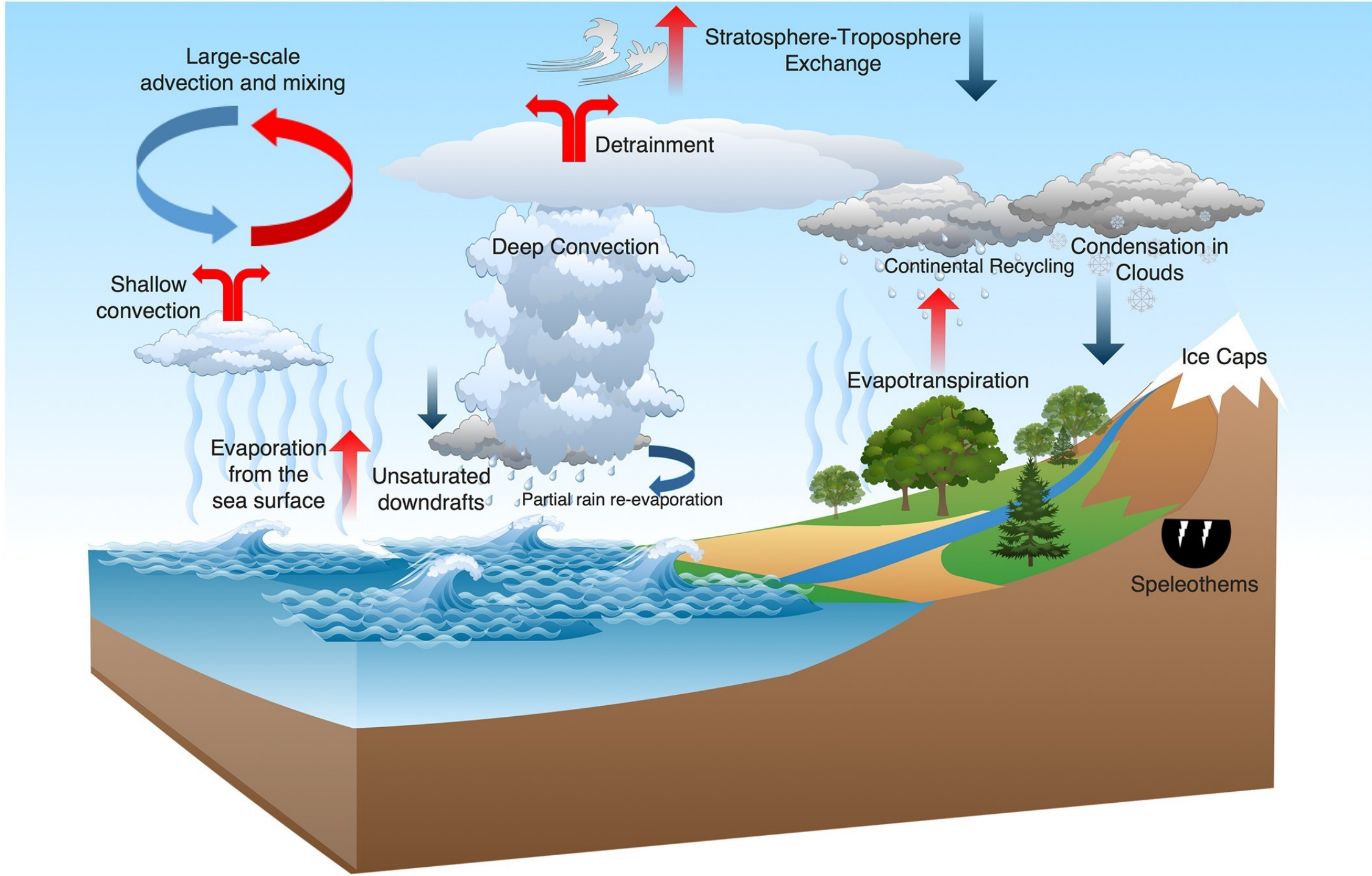
Mysteries in the Mist: Atmospheric Aerosols and Water Vapor Isotopes

Dr. Joseph Galewsky
Department of Earth and Planetary Sciences
University of New Mexico


USGS
science for a changing world
The Water Cycle
Water storage in ice and snow
Water storage in the atmosphere
Condensation
Sublimation
Precipitation
Evapotranspiration
Evaporation
Snowmelt runoff to streams
Surface runoff
Streamflow
Infiltration
Evaporation
Spring
Freshwater storage
Ground-water discharge
Water storage in oceans
Ground-water storage
U S Department of the Interior
U.S. Geological Survey
Illustration by John M. Evans, USGS
http://ga.water.usgs.gov/edu/watercycle.html


Large-scale
advection and mixing
Stratosphere-Troposphere
Exchange
Detrainment
Deep Convection
Shallow
convection
Continental Recycling
Condensation in
Clouds
Evapotranspiration
Ice Caps
Evaporation
from the
sea surface
Unsaturated
downdrafts
Partial rain re-evaporation
Speleothems

Delta notation

$$R = \frac{rare\ isotope\ abundance}{abundant\ isotope\ abundance}$$

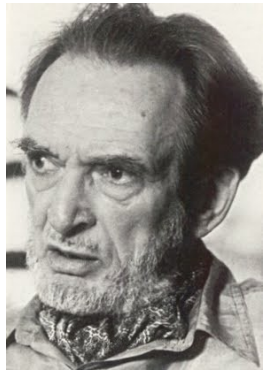
$$\delta = \left(\frac{R_{sample}}{R_{standard}} - 1\right) \times 1000$$

1931: Harold Urey discovered Deuterium

The Isotopic Composition of Sea Water

By Edward Smith Gilfillan, Jr.[1]

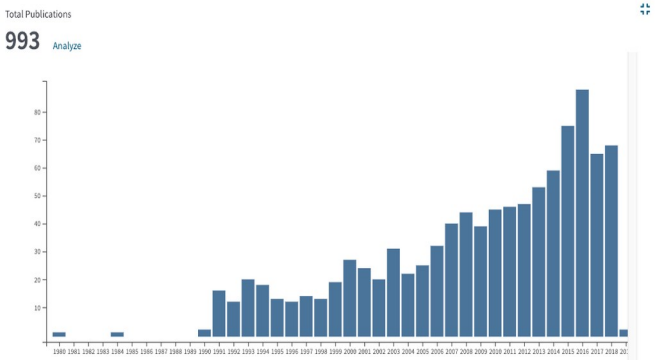
1934: The first isotopic analyses of natural water



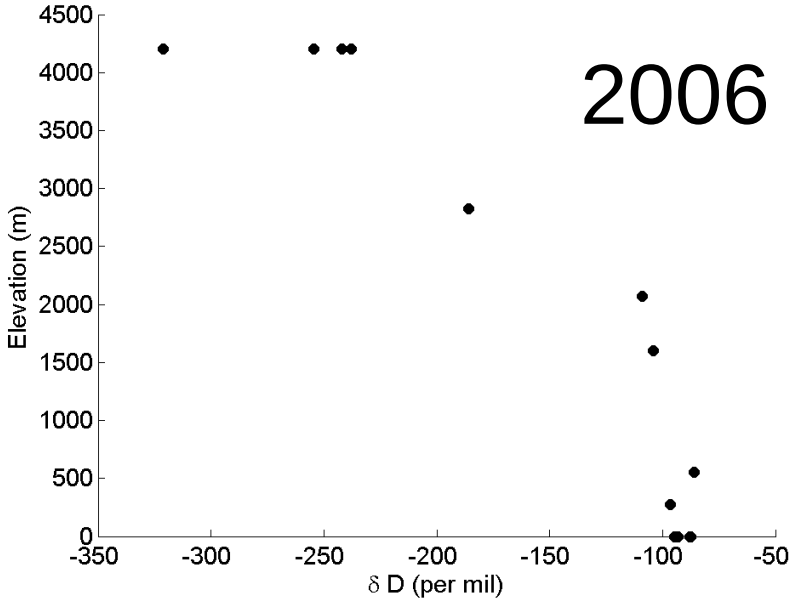
1953: Dansgaard, first isotopic analyses of natural water vapor

1984: Gedzelman continued several pioneering studies

Timeline of water vapor isotopic measurements

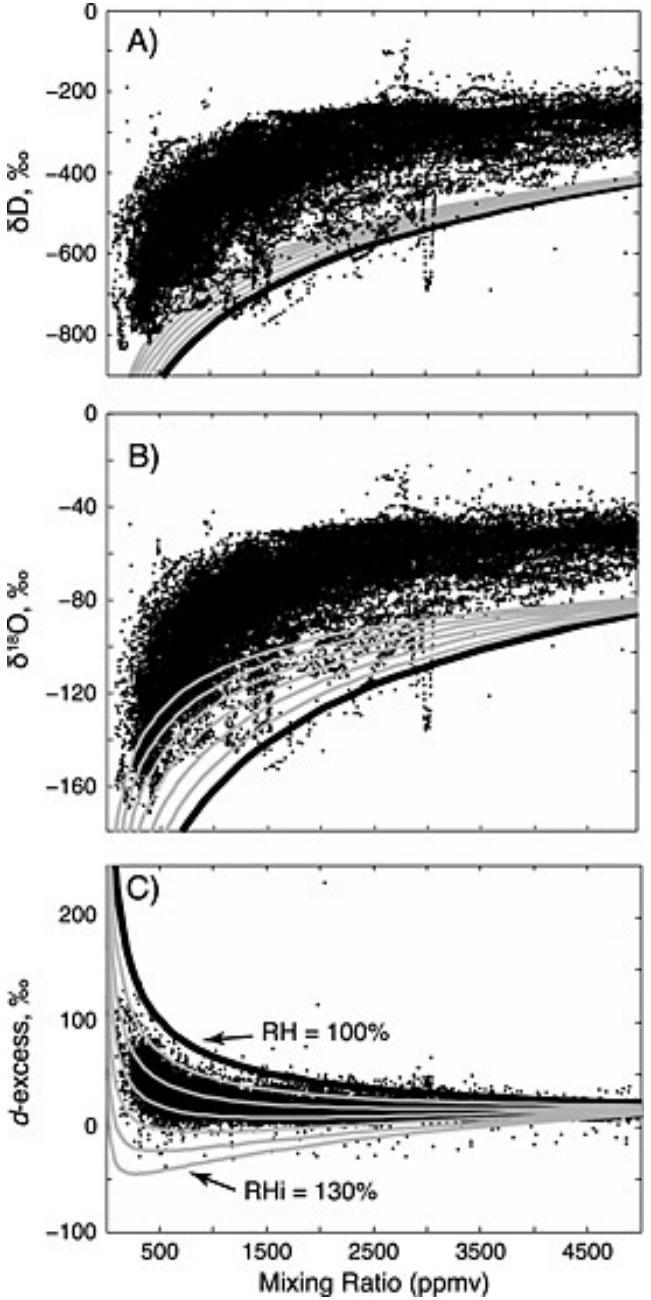


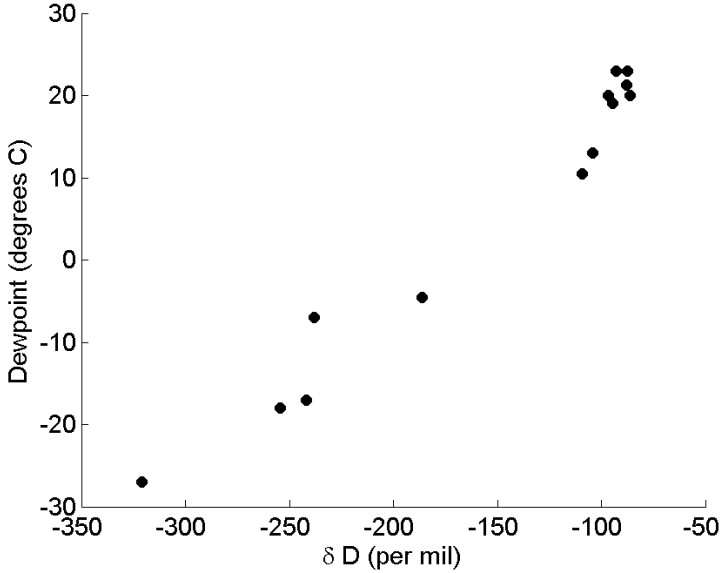
2008-Present : there has been an explosion of studies of water vapor isotopic composition over the last decade.



2006

2012

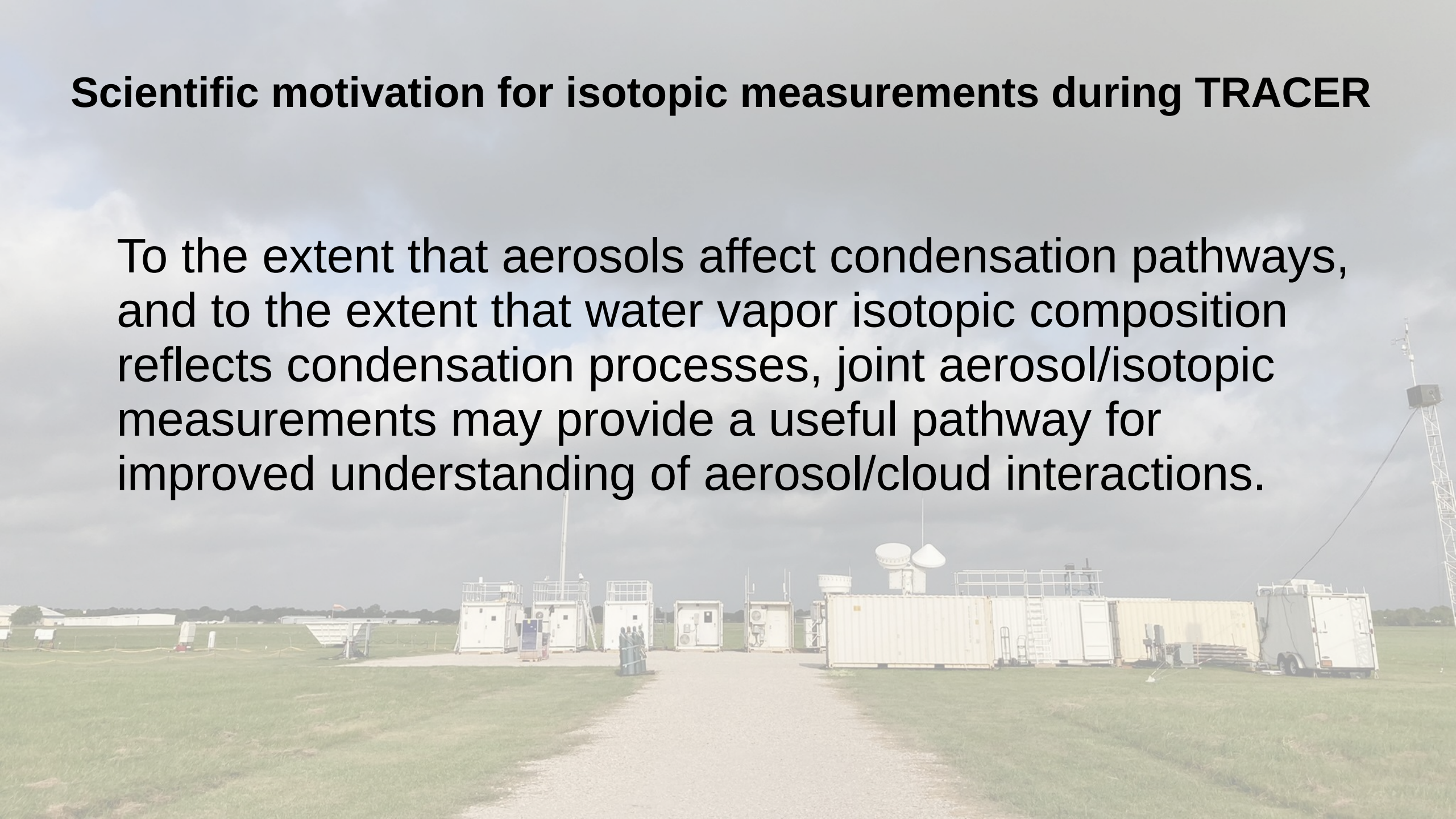




Commercial cavity ringdown spectrometers enabled a dramatic expansion of the measurement of water vapor isotopic composition after 2008.

Scientific motivation for isotopic measurements during TRACER

To the extent that aerosols affect condensation pathways, and to the extent that water vapor isotopic composition reflects condensation processes, joint aerosol/isotopic measurements may provide a useful pathway for improved understanding of aerosol/cloud interactions.

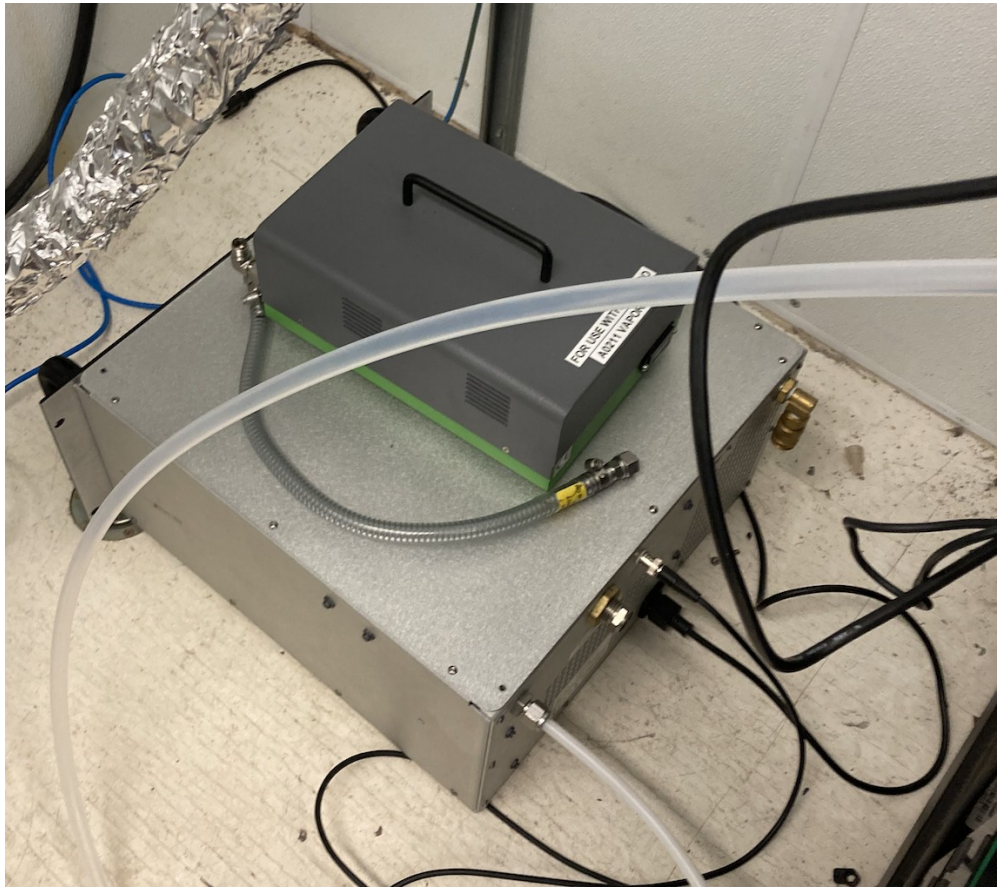


Configuring a CRDS installation for real-time measurements

Inlet protected from rain and dust

Heated and insulated tubing to prevent condensation

Standards delivery module and dry air source



CRDS with external pump

Processing Steps for CRDS Data

(1) Humidity-induced bias

(2) VSMOW-SLAP Calibration

(3) Drift Correction

(4) Humidity Calibration

VISST > MINNIS CLOUD PRODUCTS USING VISST ALGORITHM

VAP TYPE(S) > EXTERNAL • GUEST

Satellite-based retrievals of cloud and radiation properties are available in this value-added product provided by Bill Smith's group at NASA/Langley using the VISST (Visible Infrared Solar-Infrared Split Window Technique) algorithm. These datastreams are both pixel-level (4-km) retrievals and averages on a 0.3 or 0.5 degree latitude-longitude grid and replace earlier satellite-based retrievals on the Layered Bispectral Threshold Method (LBTM).

CSPHOT > SUNPHOTOMETER

INSTRUMENT TYPE(S) > BASELINE • EXTERNAL • GUEST

The Cimel sunphotometer (CSPHOT) is a multi-channel, automatic sun-and-sky scanning radiometer that measures the direct solar irradiance and sky radiance at the Earth's surface. It takes measurements at predetermined discrete wavelengths in the visible and near-infrared parts of the spectrum to determine atmospheric transmission and scattering properties. The CSPHOT only operates during daylight (sun above horizon).

UHSAS > ULTRA-HIGH SENSITIVITY AEROSOL SPECTROMETER

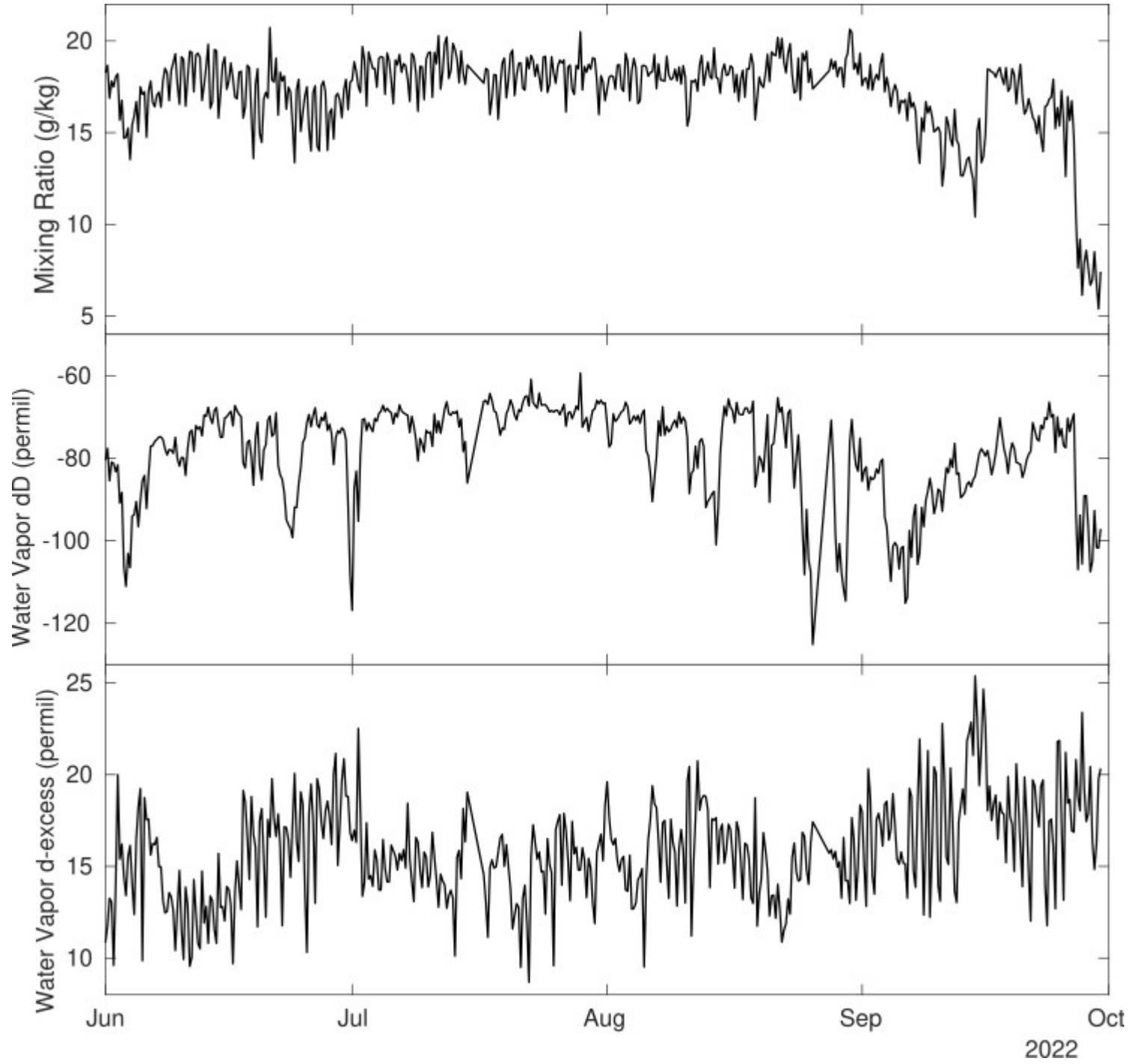
INSTRUMENT TYPE(S) > BASELINE • GUEST

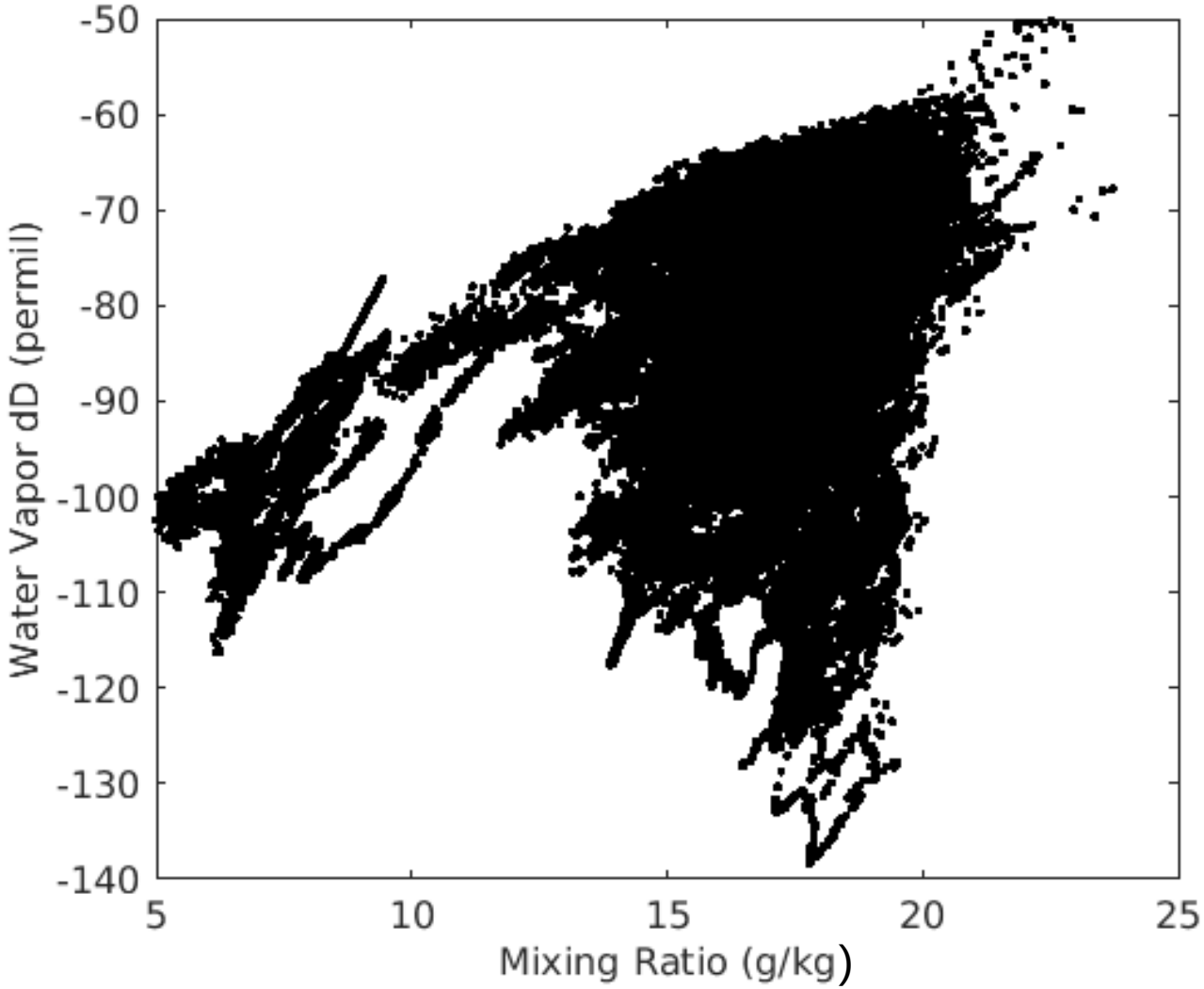
The ultra-high-sensitivity aerosol spectrometer (UHSAS) is an optical-scattering, laser-based, aerosol particle spectrometer system for sizing particles in the 60 to 1000 nanometer (nm) range [1–3].

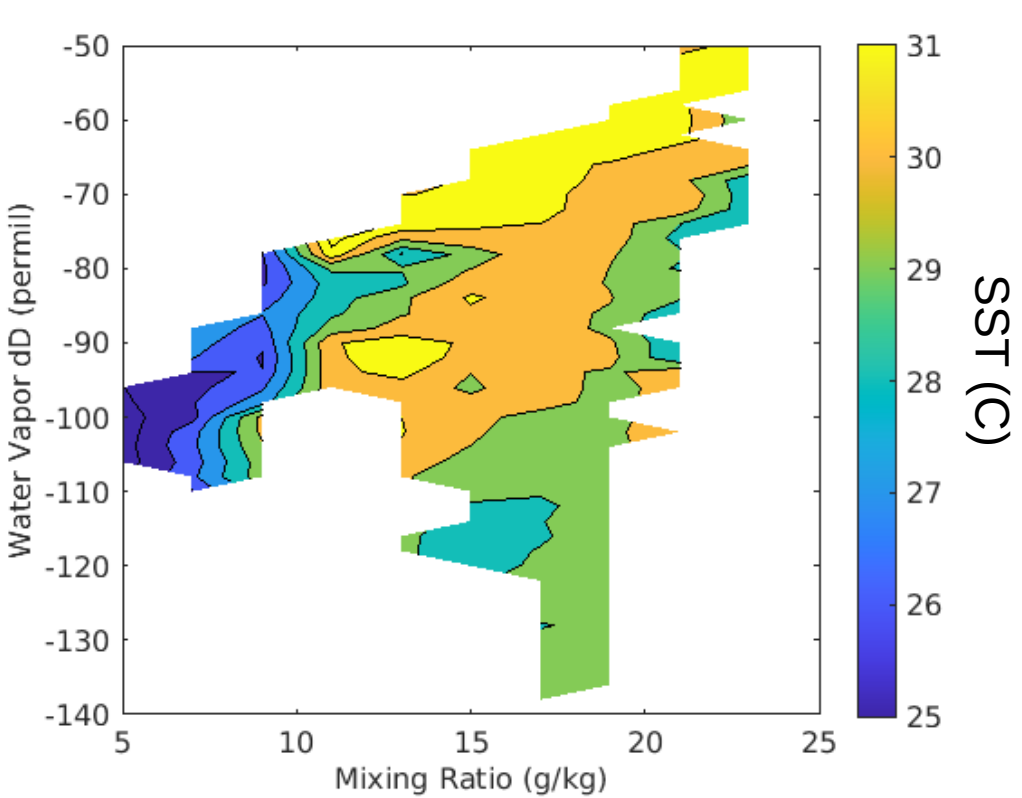
CCN > CLOUD CONDENSATION NUCLEI PARTICLE COUNTER

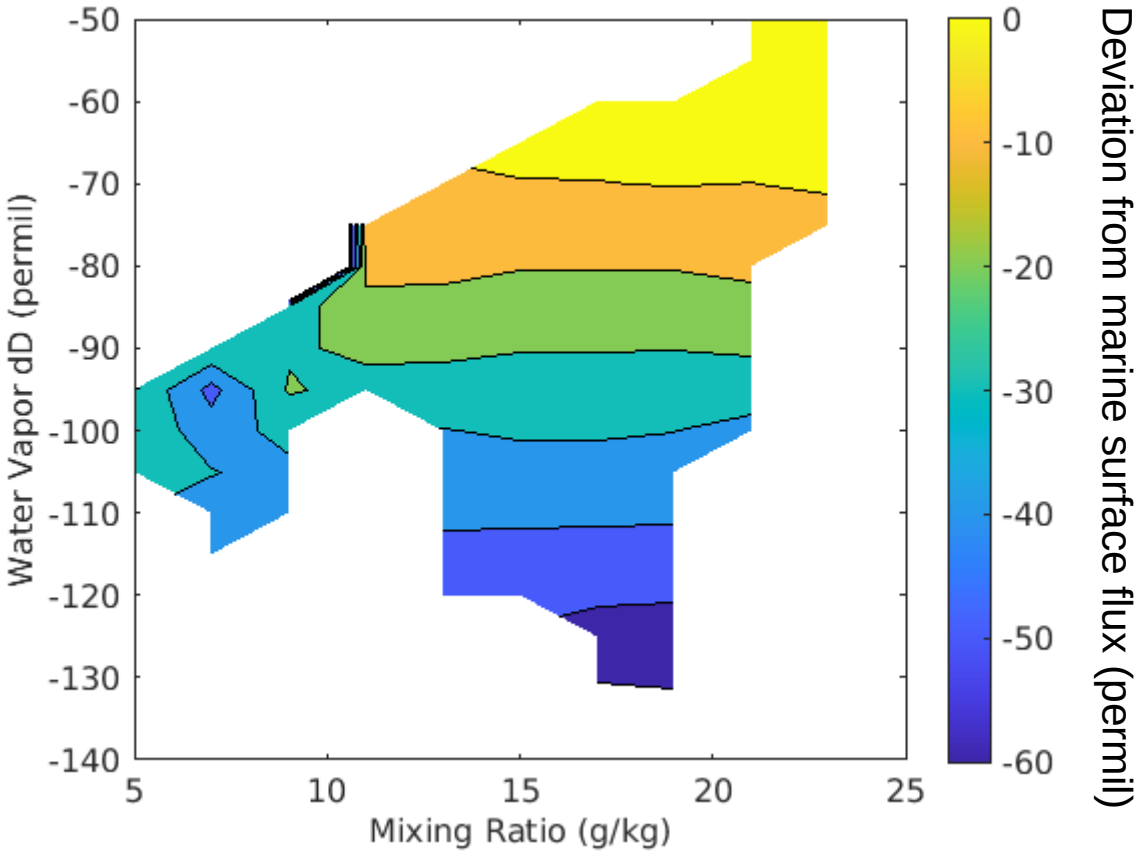
INSTRUMENT TYPE(S) > BASELINE • EXTERNAL • GUEST

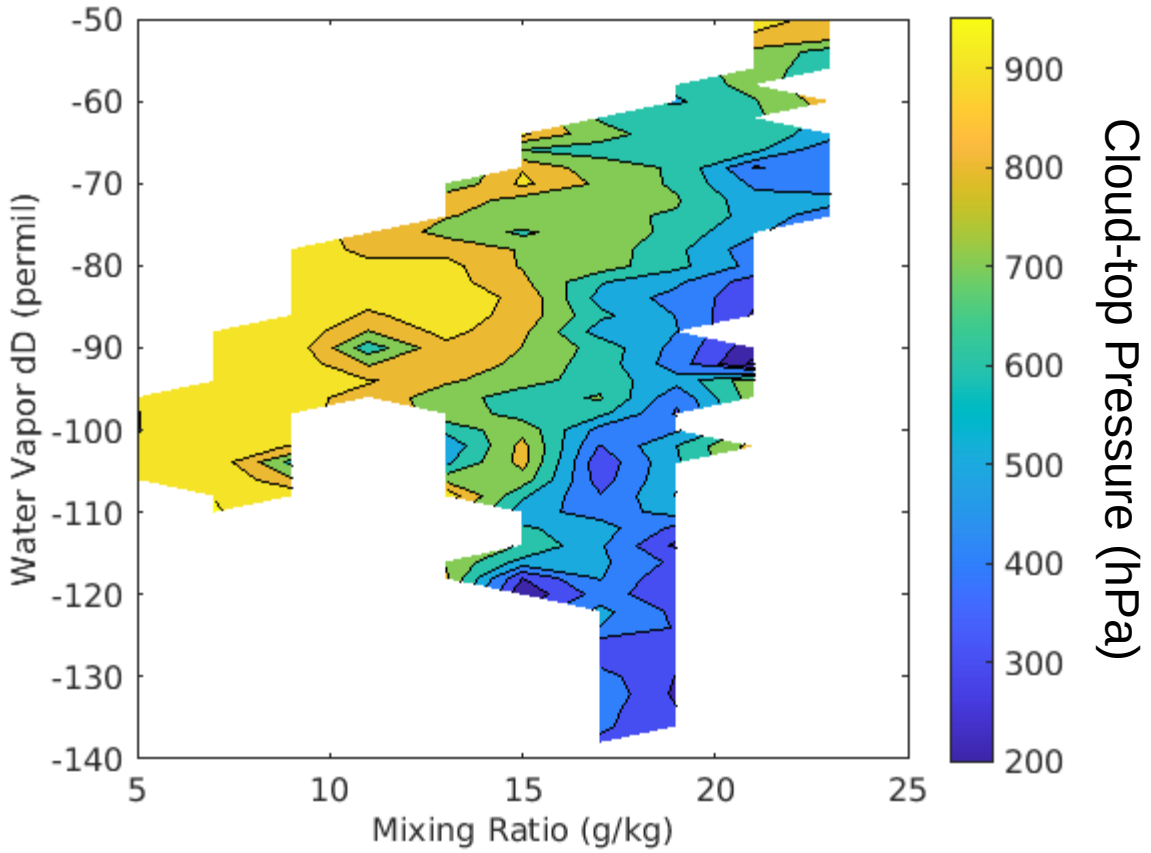
The cloud condensation nuclei counter measures the concentration of aerosol particles by drawing an air sample through a column with thermodynamically unstable supersaturated water vapor that can condense onto aerosol particles. Particles that are activated, i.e., grown larger in the process, are counted and sized by an optical particle counter (OPC). In this way the CCN measures activated ambient aerosol particle number concentration as a function of supersaturation.

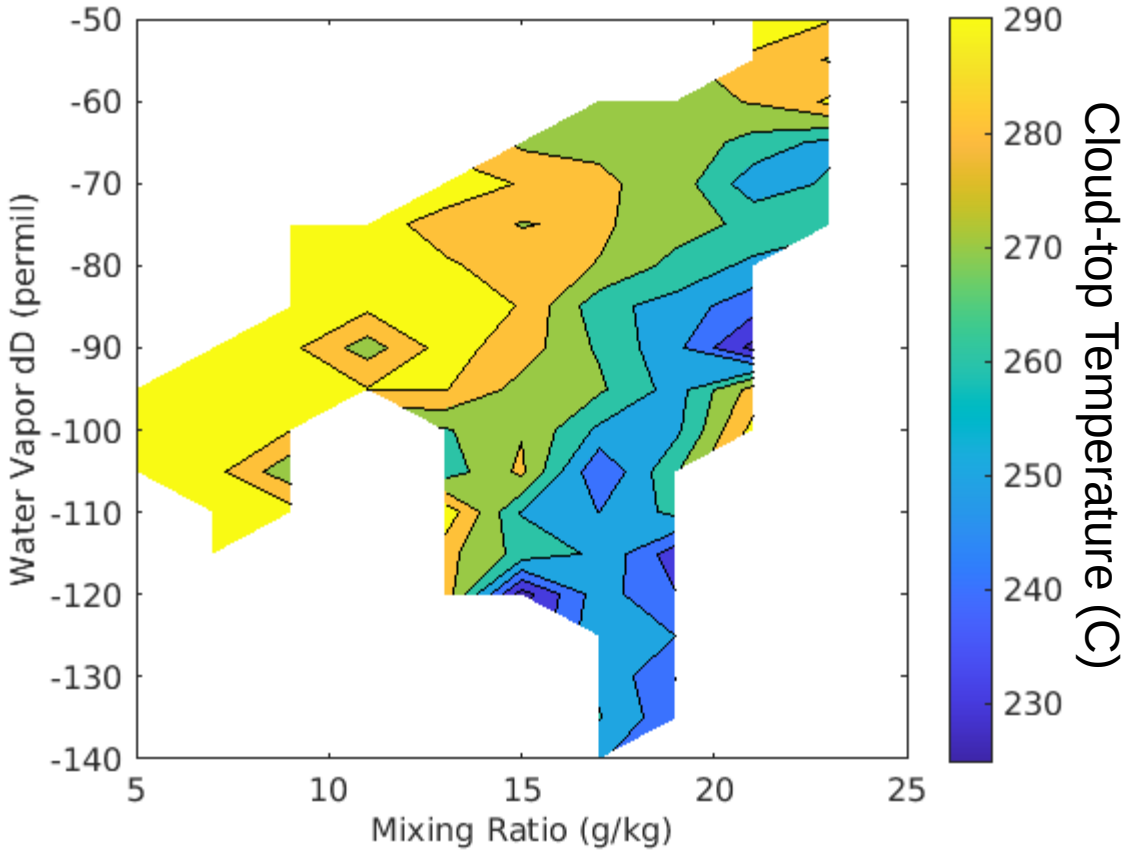

Mixing Ratio (g/kg)
20
15
10
5
Water Vapor dD (permil)
-60
-80
-100
-120
Water Vapor d-excess (permil)
25
20
15
10
Jun
Jul
Aug
Sep
Oct
2022

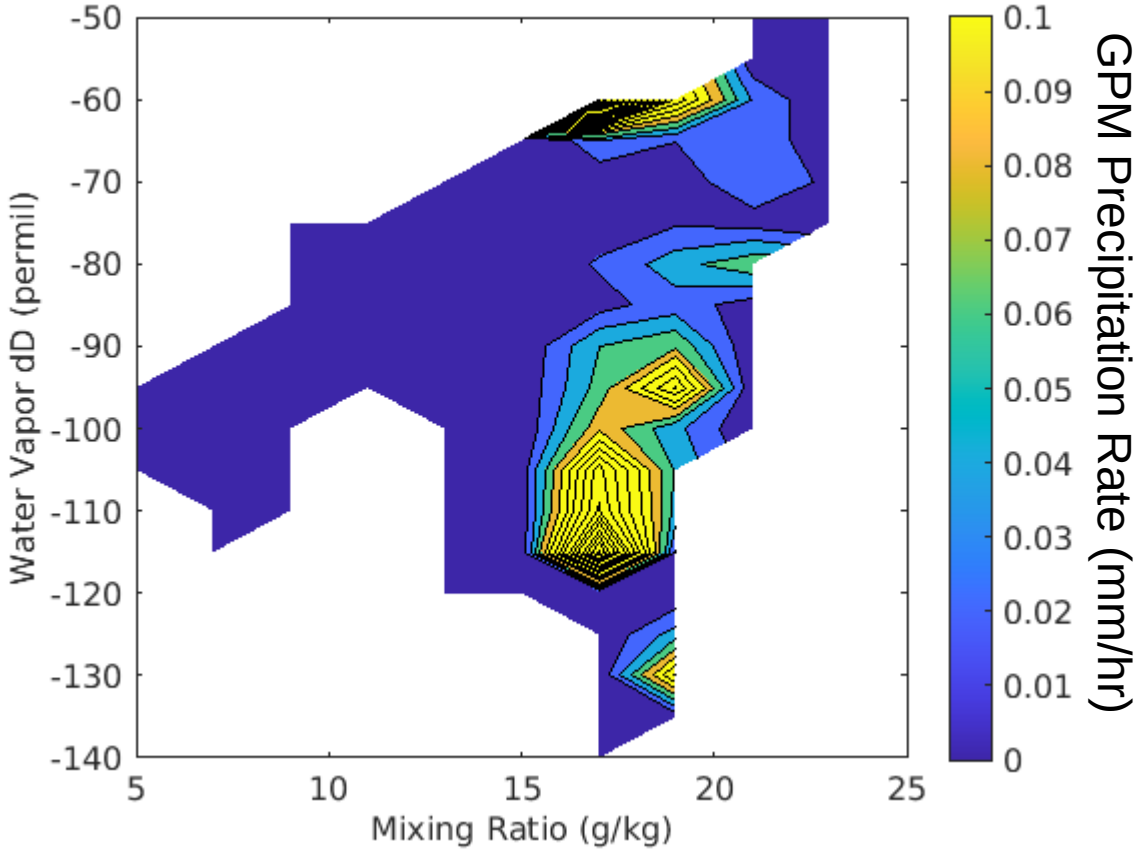

-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
Water Vapor dD (permil)
5
10
15
20
25
Mixing Ratio (g/kg)

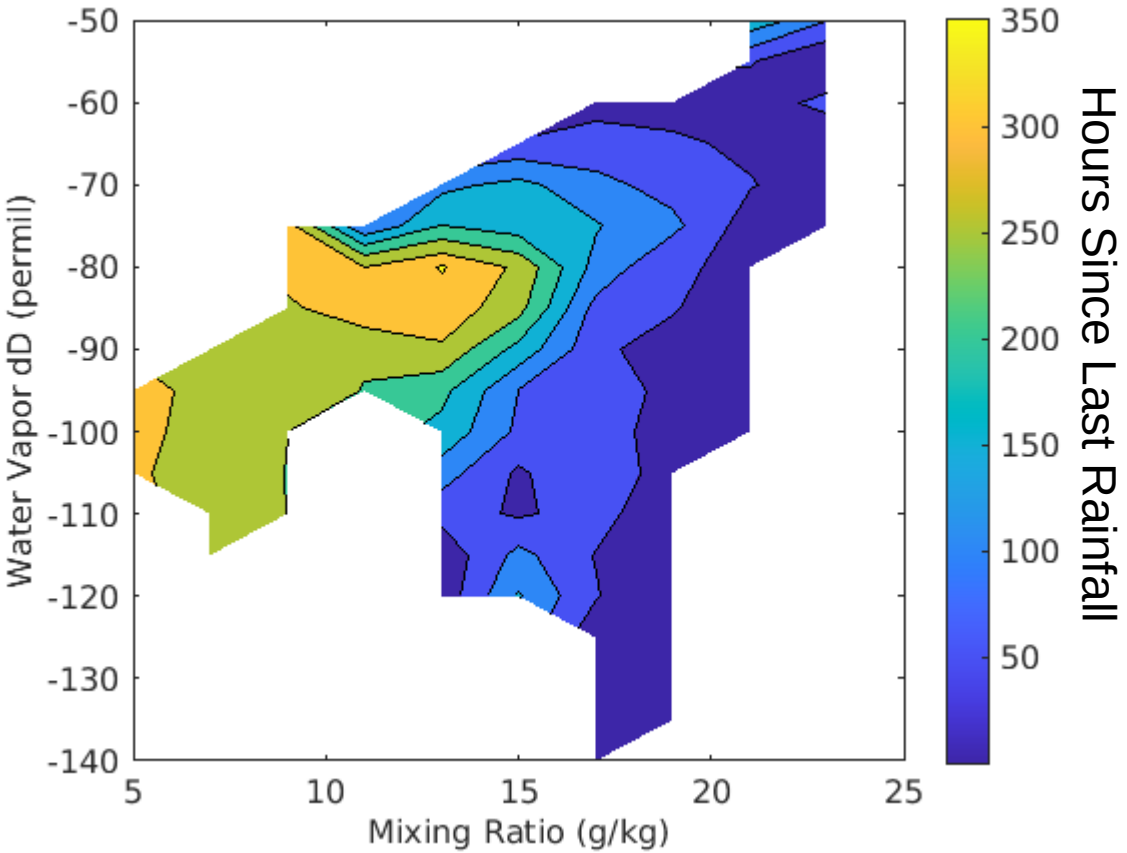

Water Vapor dD (permil)
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
5
10
15
20
25
Mixing Ratio (g/kg)
31
30
29
28
27
26
25
SST (C)

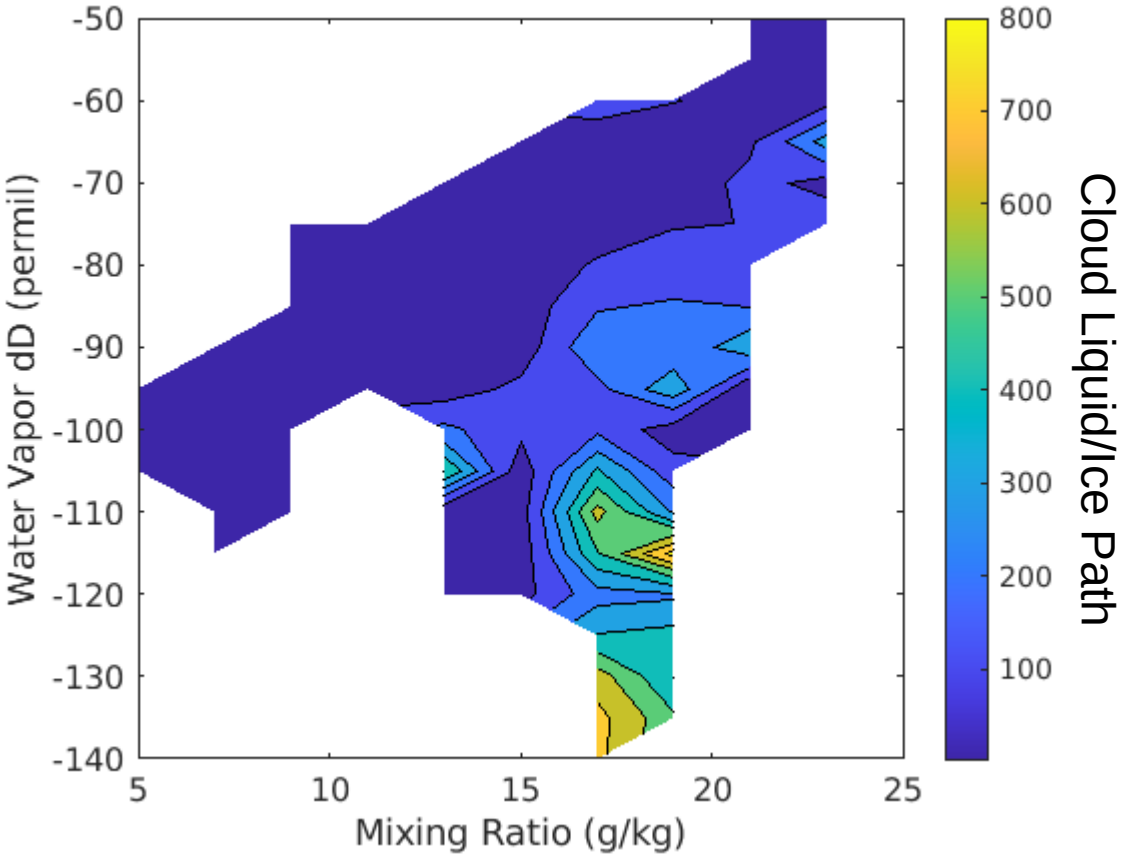

Water Vapor dD (permil)
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
5
10
15
20
25
Mixing Ratio (g/kg)
0
-10
-20
-30
-40
-50
-60
Deviation from marine surface flux (permil)

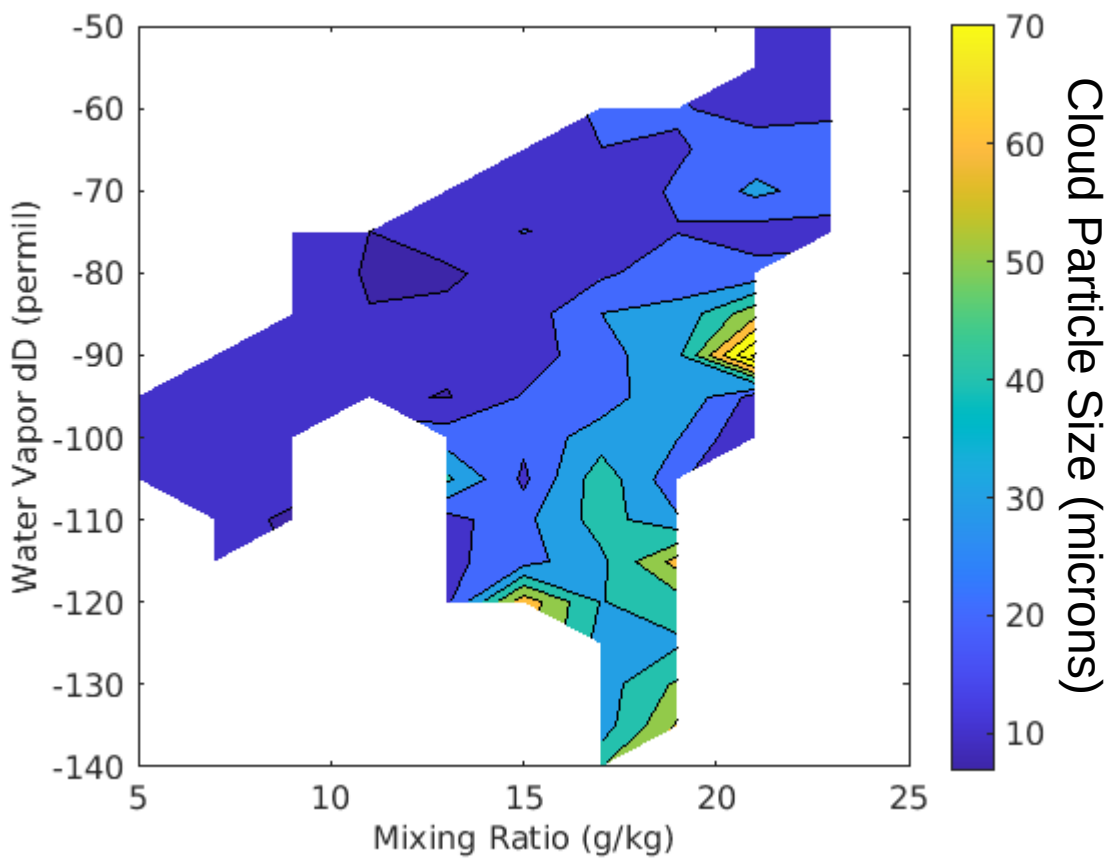

-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
Water Vapor dD (permil)
5
10
15
20
25
Mixing Ratio (g/kg)
900
800
700
600
500
400
300
200
Cloud-top Pressure (hPa)

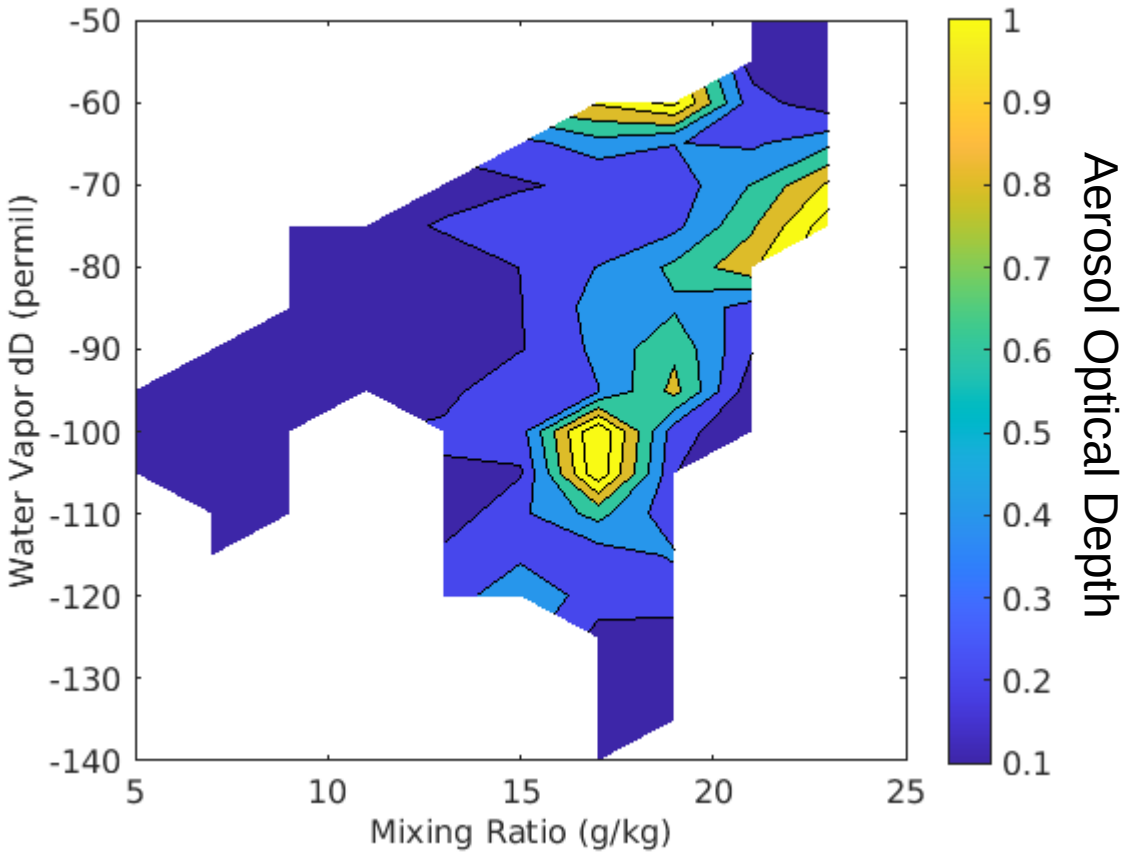

-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
Water Vapor dD (permil)
5
10
15
20
25
Mixing Ratio (g/kg)
290
280
270
260
250
240
230
Cloud-top Temperature (C)

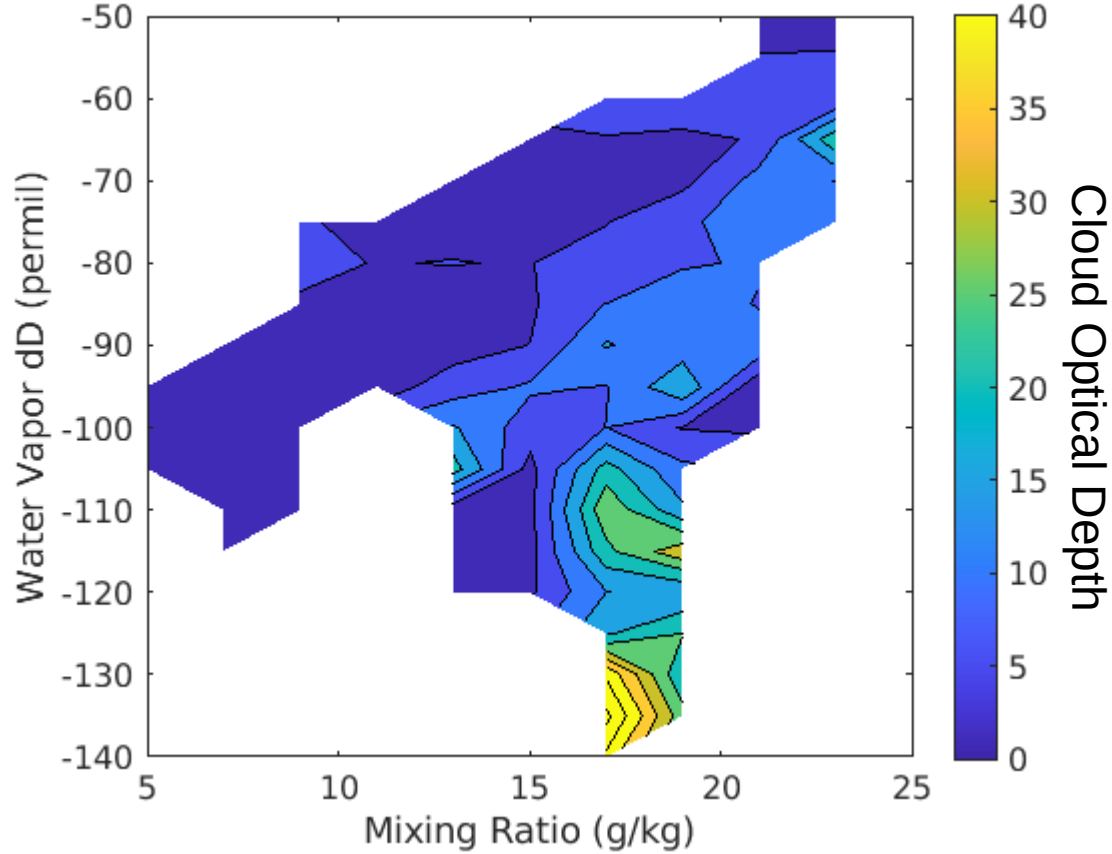

-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
Water Vapor dD (permil)
5
10
15
20
25
Mixing Ratio (g/kg)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
GPM Precipitation Rate (mm/hr)

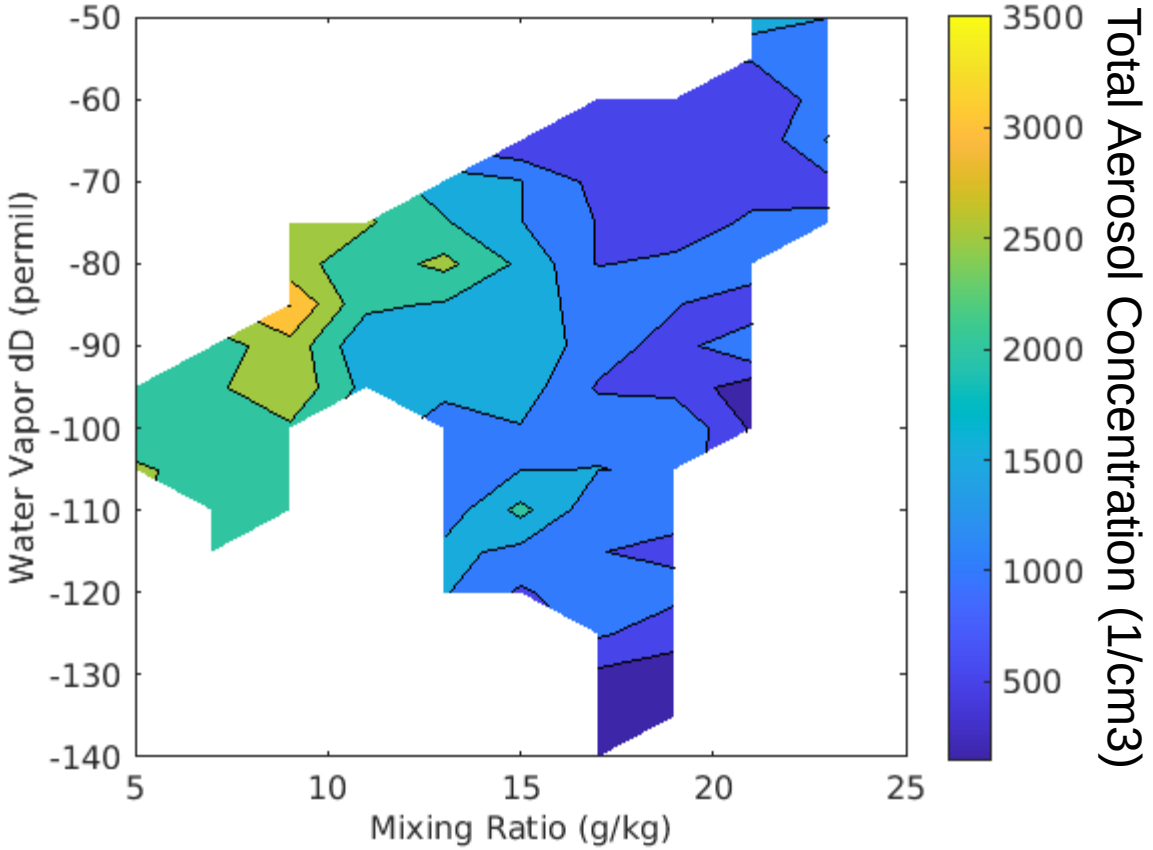

-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
Water Vapor dD (permil)
5
10
15
20
25
Mixing Ratio (g/kg)
350
300
250
200
150
100
50
Hours Since Last Rainfall

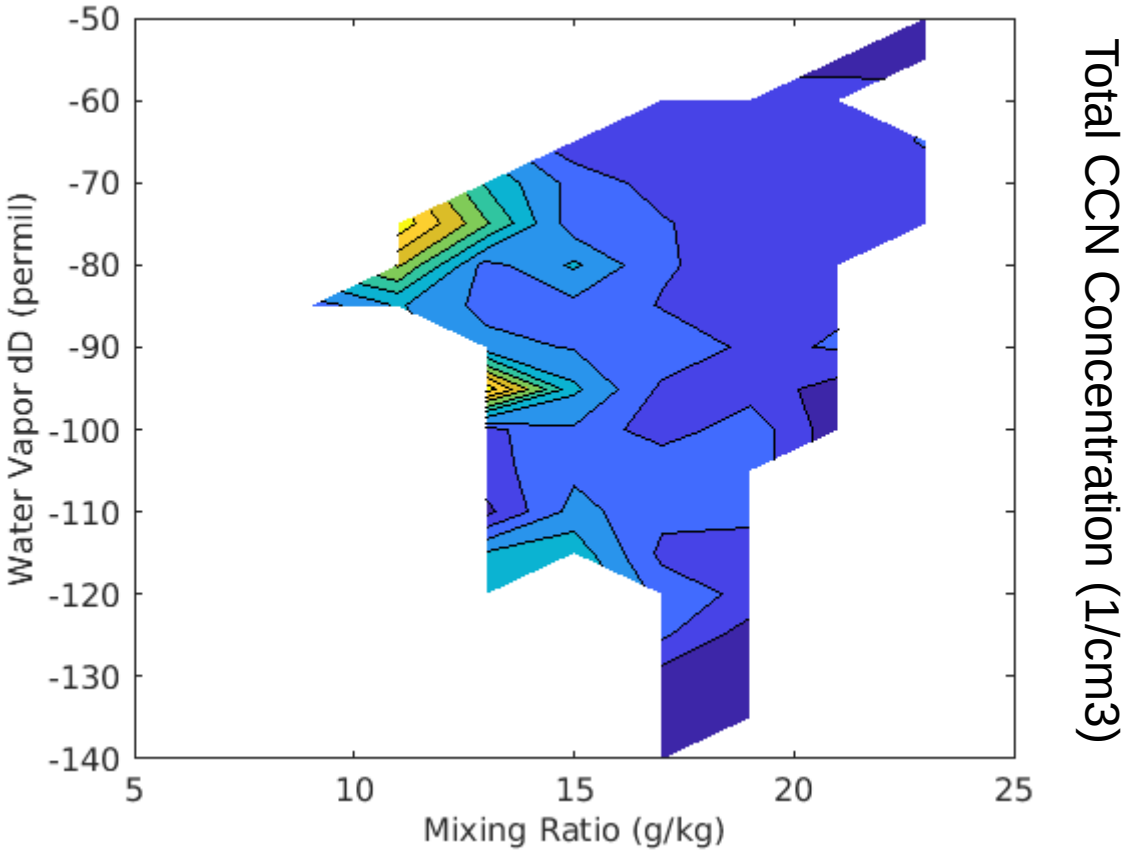

Water Vapor dD (permil)
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
5
10
15
20
25
Mixing Ratio (g/kg)
800
700
600
500
400
300
200
100
Cloud Liquid/Ice Path


Water Vapor dD (permil)
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
5
10
15
20
25
Mixing Ratio (g/kg)
70
60
50
40
30
20
10
Cloud Particle Size (microns)


-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
Water Vapor dD (permil)
5
10
15
20
25
Mixing Ratio (g/kg)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Aerosol Optical Depth


-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
Water Vapor dD (permil)
5
10
15
20
25
Mixing Ratio (g/kg)
40
35
30
25
20
15
10
5
0
Cloud Optical Depth


-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
Water Vapor dD (permil)
5
10
15
20
25
Mixing Ratio (g/kg)
3500
3000
2500
2000
1500
1000
500
Total Aerosol Concentration (1/cm3)


-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
Water Vapor dD (permil)
5
10
15
20
25
Mixing Ratio (g/kg)
Total CCN Concentration (1/cm3)

Conclusions and Research Questions

(1) Measurements during the TRACER IOP show a coherent association between the isotopic composition of water vapor, cloud properties, aerosols, and precipitation.

(2) Deep convection is associated with lower delta values, high cloud liquid/ice path, high cloud optical depth, and large cloud particle size, all of which are consistent with a large amount of condensation aloft.

(3) High aerosol optical depth is associated with high precipitation rates and with moderate isotopic depletion; however, the lowest delta values are associated with low values of AOD.

(4) Surface measurements of aerosol and CCN concentrations are highest at longer time scales after rainfall events, and occur under drier and moderately isotopically depleted conditions.

Conclusions and Research Questions

Are these relationships consistent across different settings? Measurements from SAIL, EPCAPE, and CAPE-K, along with older measurements from ENA will answer this question.

The links between isotopic measurements and cloud microphysical properties are not surprising, but how are the condensation processes aloft communicated to the surface?

What processes link AOD and COD to isotopic composition?


LA SCIENCE
C'EST DE
LA BOMBE