Connecting Soluble Trace Gas Vertical Distributions to Storm Properties

Mary C Barth

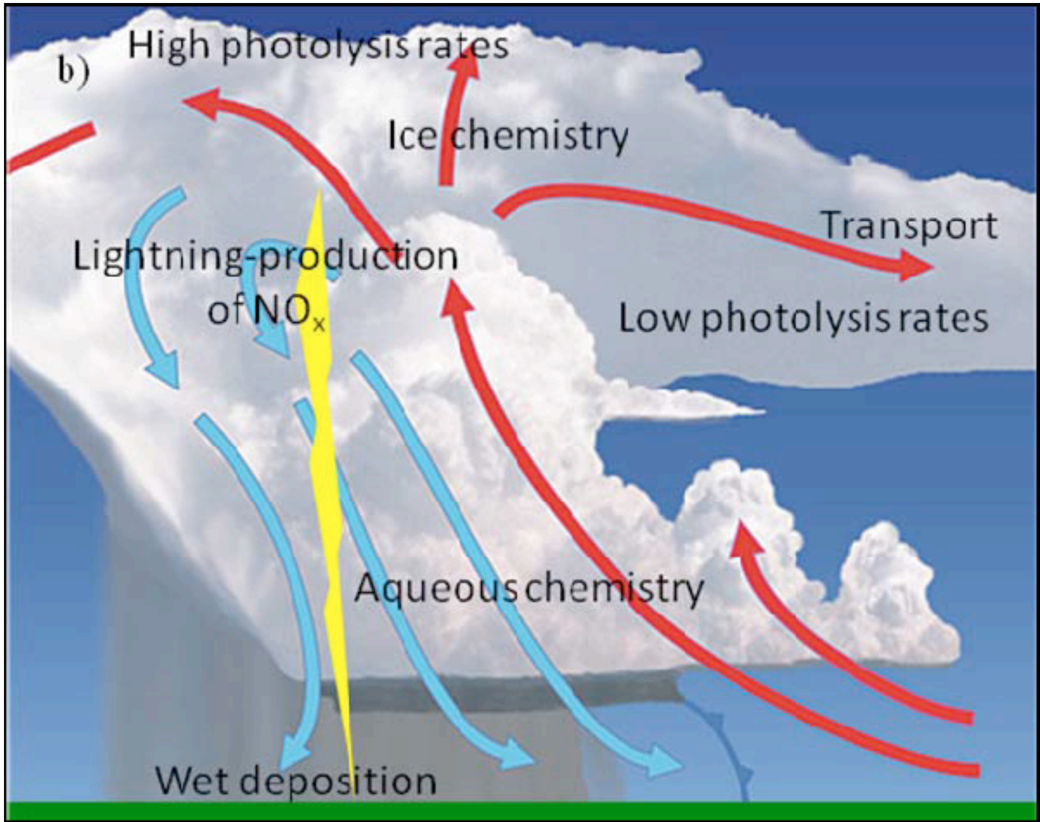
Megan M. Bela; Meghan Applegate; Alan Fried; *Petter Weibring; Thomas F. Hanisco; Heather L. Arkinson; Eric C. Apel; Daniel W. O'Sullivan; Brian Heikes; Paul O. Wennberg; John Crounse; Jason M. St Clair; Athanasios Nenes; Milos Z. Markovic; Jeffrey L. Stith; Teresa L. Campos; Steven A. Rutledge; Brett Basarab; Brody Fuchs; Lawrence D. Carey; Anthony L. Bain; Michael I. Biggerstaff; Armin Wisthaler; Glenn S. Diskin; Pedro Campuzano-Jost; Thomas B. Ryerson; Frank M. Flocke; Sara Lance*

Thanks to entire DC3 Science Team; NCAR/EOL for logistical support during DC3.
Thanks to NSF, NASA, DLR, NOAA,U. Oklahoma, U. Alabama-Huntsville for financial support.

Goals of the DC3 Field Campaign

1. ***To characterize thunderstorms and how they process chemical compounds that are ingested into the storm*** (transport, scavenging, lightning, production of NOx from lightning, chemistry)

2. ***To learn how the air that exits the storm in the upper troposphere (UT) changes chemically during the next day*** (chemical aging)



Additional topics: aerosols, halogens

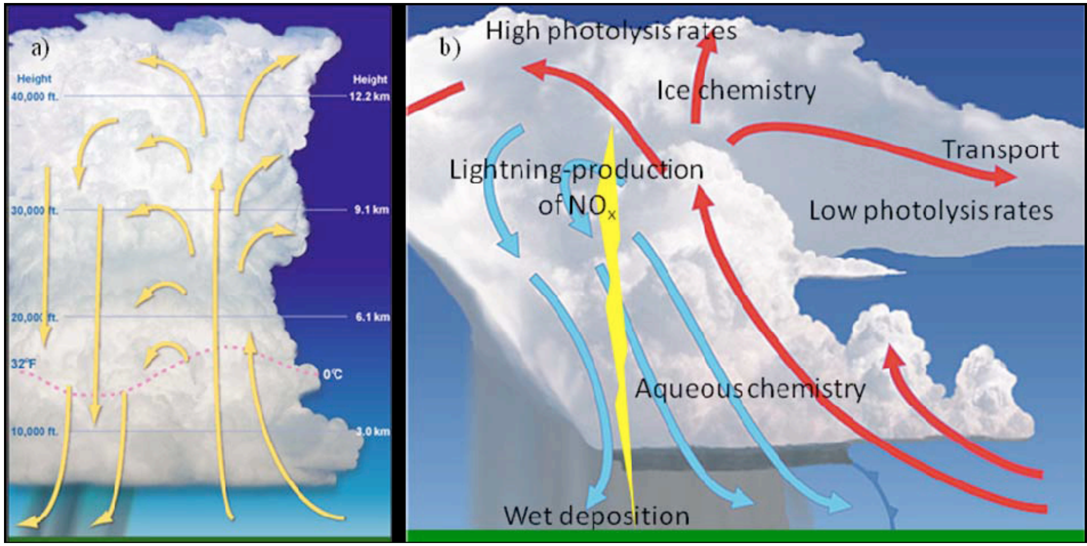
Goal of this paper

Contrast scavenging of trace gases for different types of storms

Colorado: High shear, moderate CAPE environments and high cloud base (→ ice dominated)

Oklahoma/Texas: High shear, high CAPE environments; sometimes low shear

Alabama: low shear, moderate CAPE environments (air mass thunderstorms)



Air Mass Thunderstorm High-Shear Thunderstorm

DC3 storms ranged from high-shear, high-CAPE to low-shear, low CAPE environments

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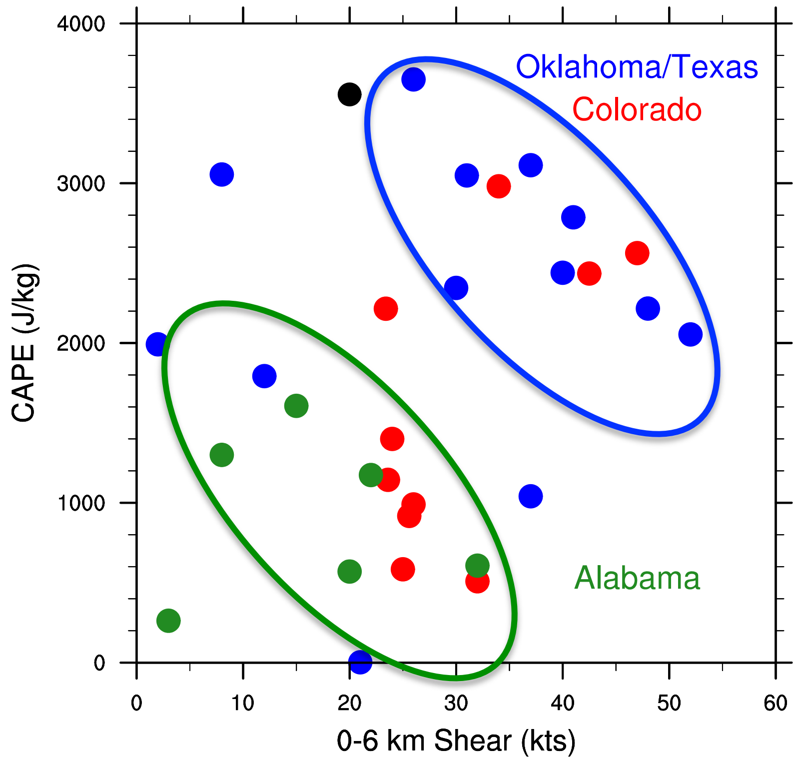

→ Generally true

Sounding Data : Oklahoma: C. Ziegler, T. Mansell; Colorado: W. Brown; Alabama: L. Carey; AND students for all 3 regions

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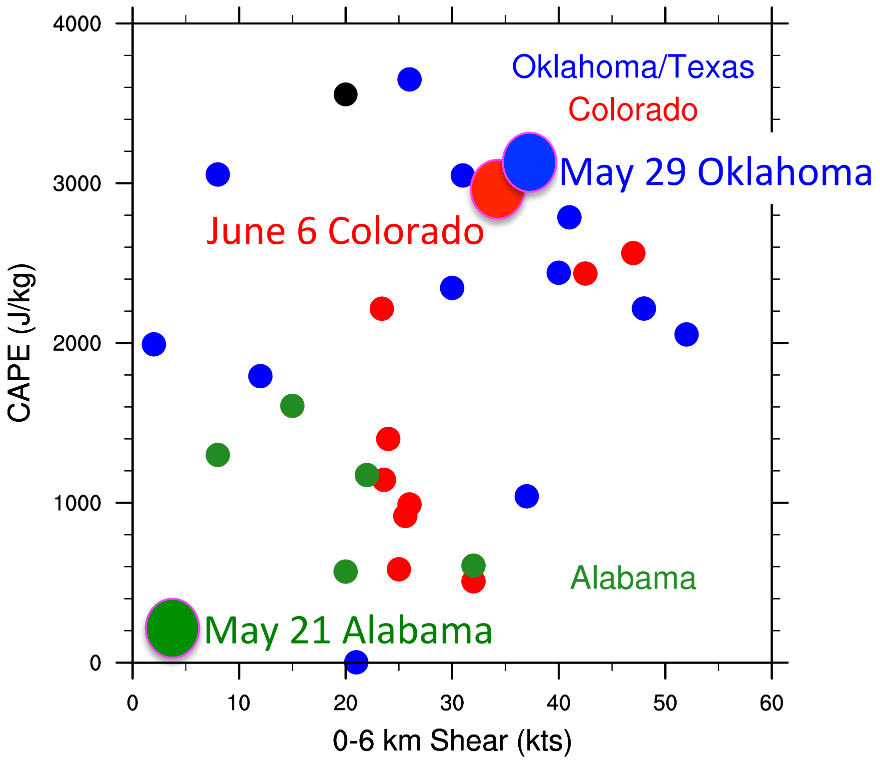

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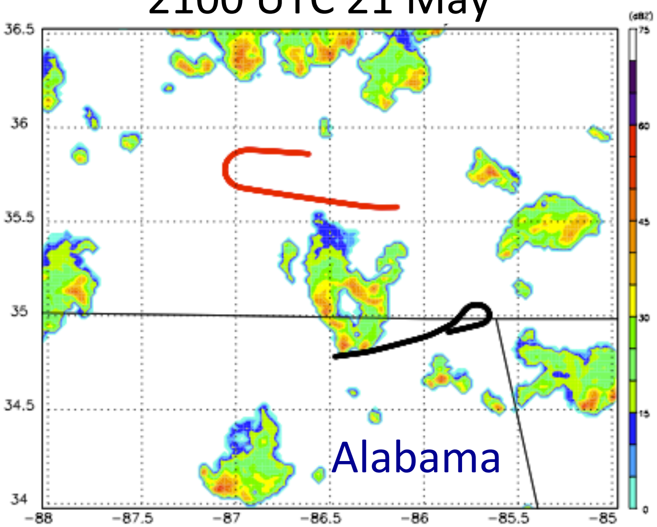
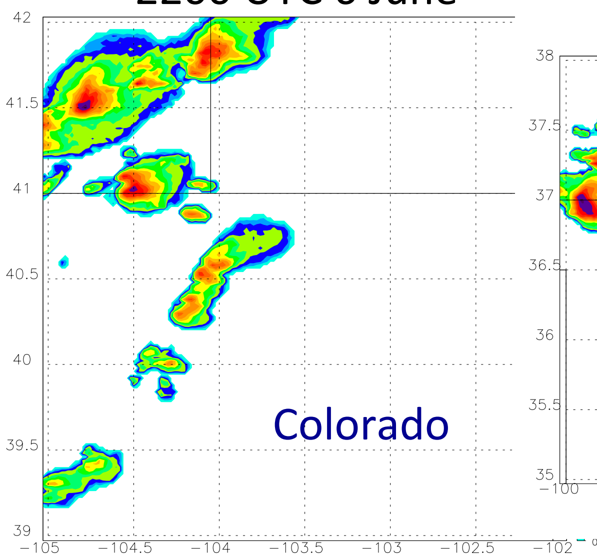
DC3 cases ranged from ordinary to severe thunderstorms

High-Shear Thunderstorms

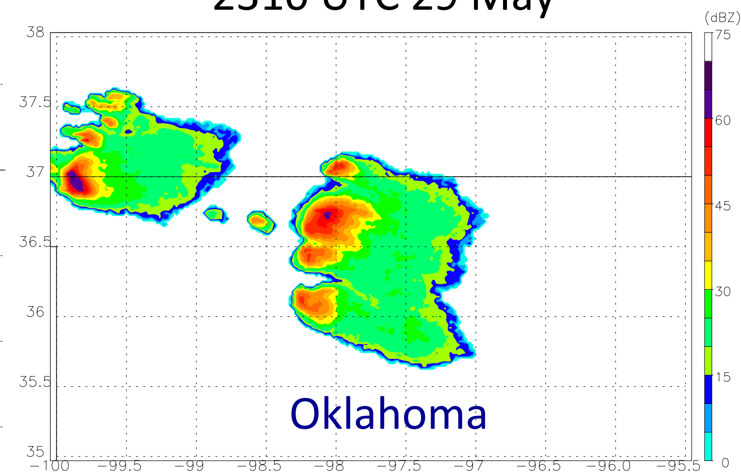
Air Mass Thunderstorm
2100 UTC 21 May



2200 UTC 6 June



2310 UTC 29 May



CAPE = 262 J/kg
0-6 km shear = 3 m/s

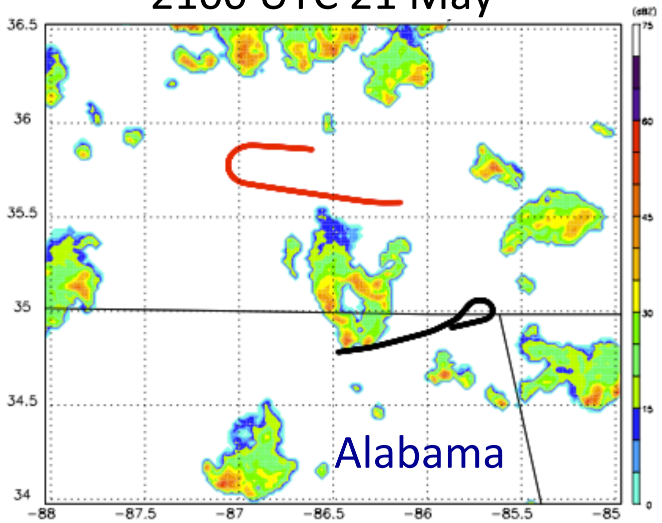
CAPE = 2981 J/kg
0-6 km shear = 34 m/s

CAPE = 3113 J/kg
0-6 km shear = 37 m/s

Decluttered NEXRAD radar data courtesy of Cameron Homeyer (NCAR)

DC3 cases ranged from ordinary to severe thunderstorms

Air Mass Thunderstorm
2100 UTC 21 May



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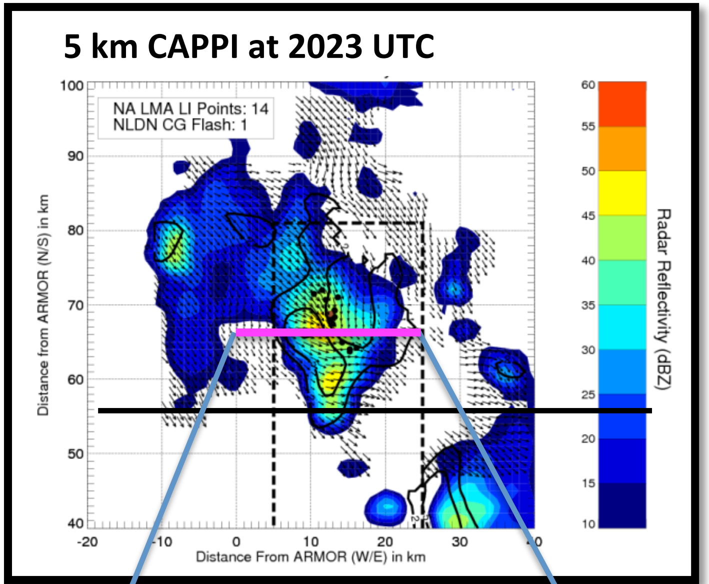
Decluttered NEXRAD radar data courtesy of Cameron Homeyer (NCAR)

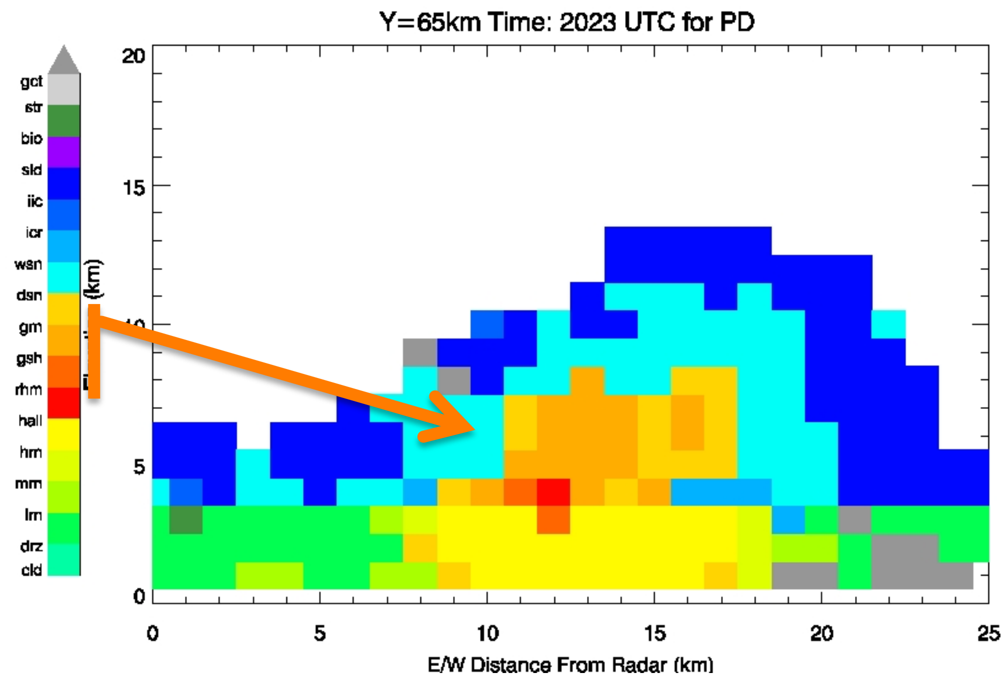
Alabama Case, 21 May 2012 at 2023 UTC



Vertical Cross-Section of radar reflectivity translated to cloud particle ID

Polarimetric Radar Reflectivity

Large quantity of hail and/or graupel particles found using the NCAR Particle Identification (PID)

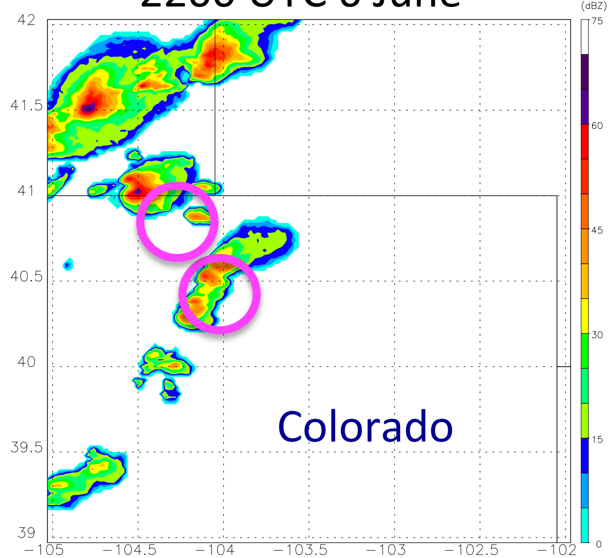


Courtesy of Larry Carey, Lamont Bain, Mariana Scott (U. Alabama – Huntsville)

DC3 cases ranged from ordinary to severe thunderstorms

2 storms examined in the Colorado 6 June case

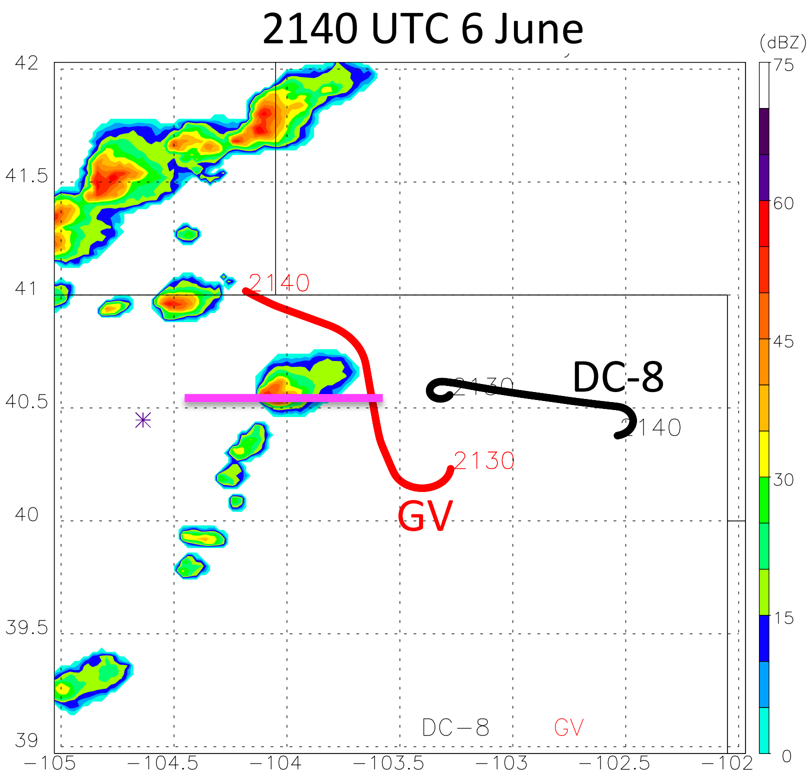
2200 UTC 6 June

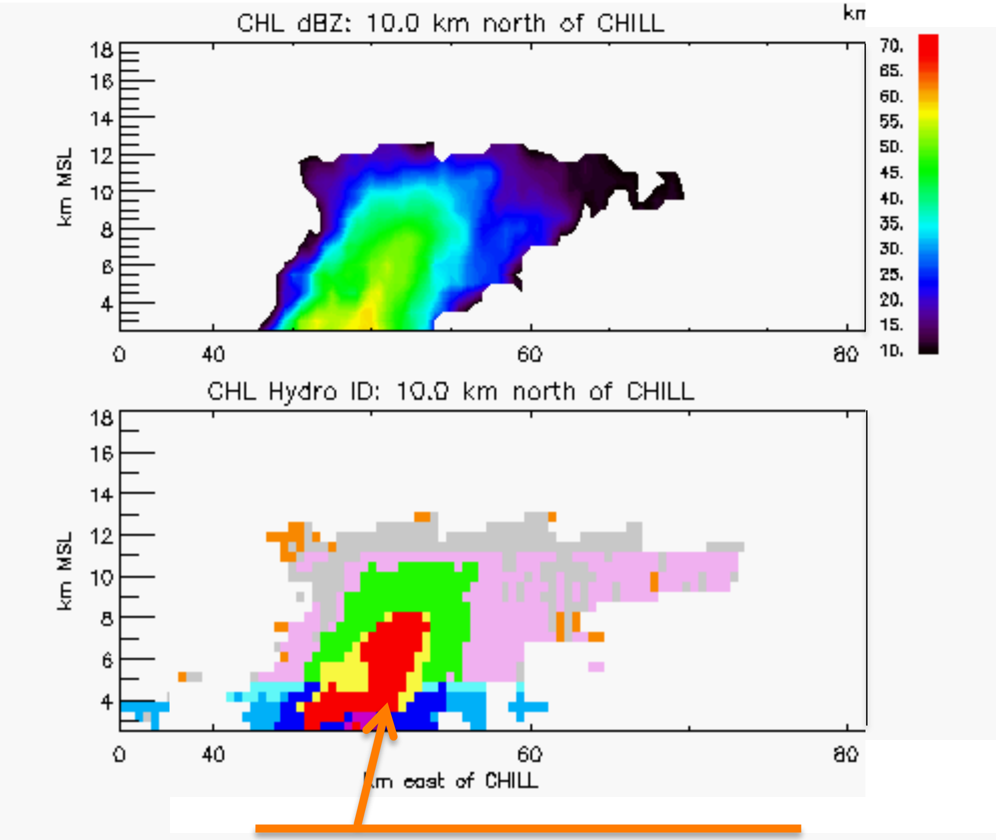


CAPE = 2981 J/kg
0-6 km shear = 34 m/s

Colorado Case, Early Storm, 6 June 2012

Extensive region of hail using the NCAR Particle Identification (PID)

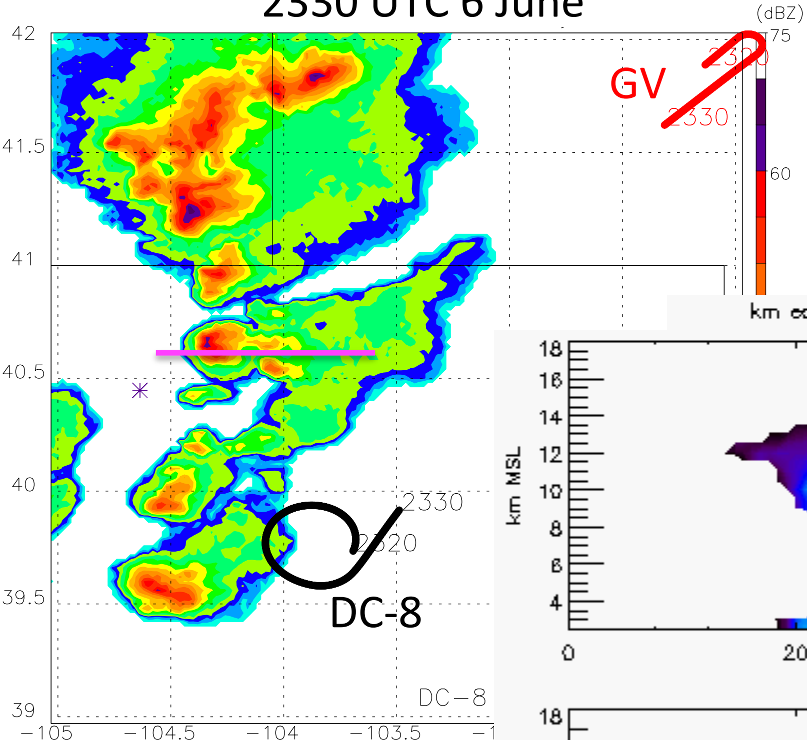




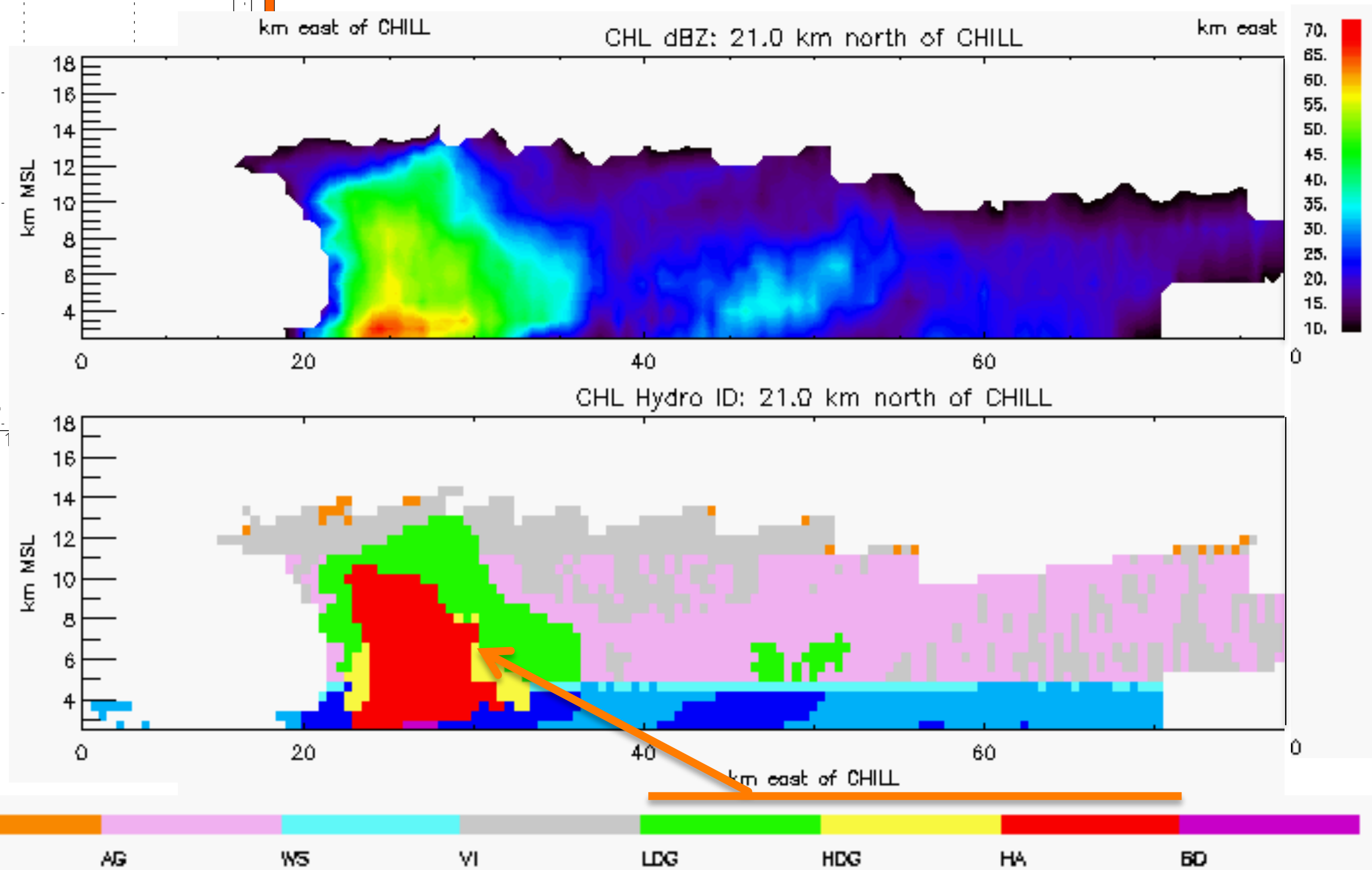
Courtesy of Brett Basarab, Steve Rutledge (Colorado State Univ.)

Colorado Case, Later Storm, 6 June 2012

2330 UTC 6 June



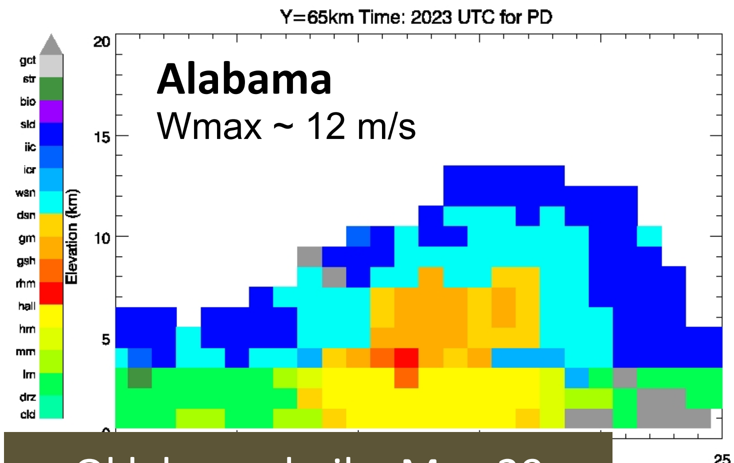
Extensive region of hail
Extensive snow anvil

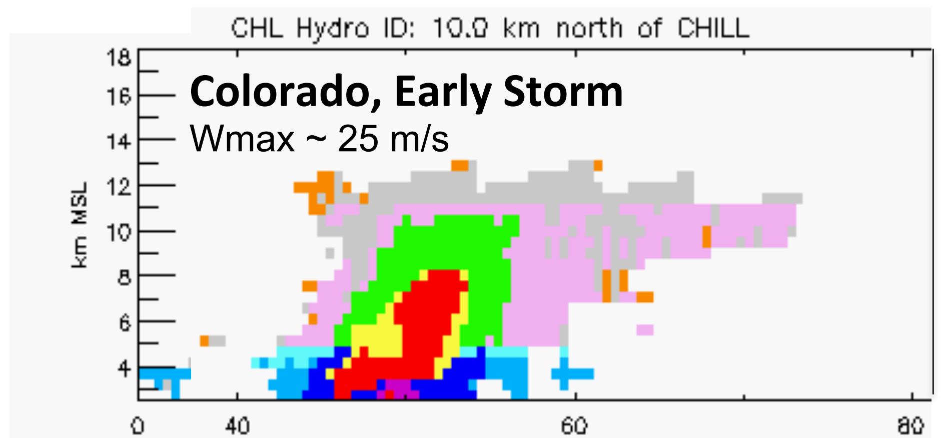


Courtesy of Brett Basarab, Steve Rutledge (Colorado State Univ.)

Alabama versus Colorado Storm Structure

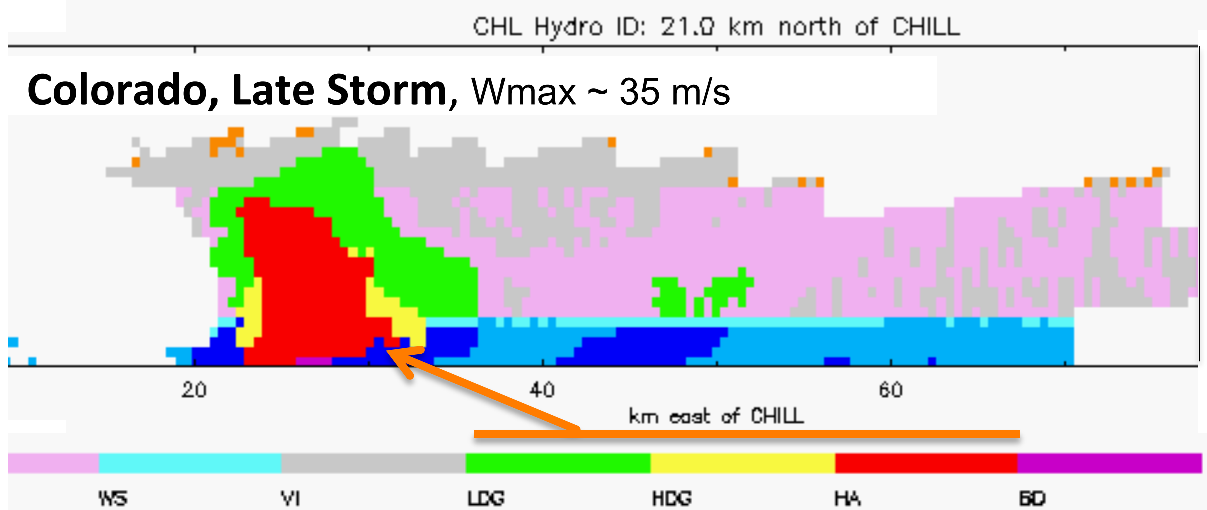
- All have graupel/hail, but Colorado storms have a larger amount
- Vertical velocities larger in Colorado storms





Oklahoma hail – May 29

IMAGE 2.12c (Photo Helge Tuschy)



and Colorado State Univ.

Convective Transport and Scavenging

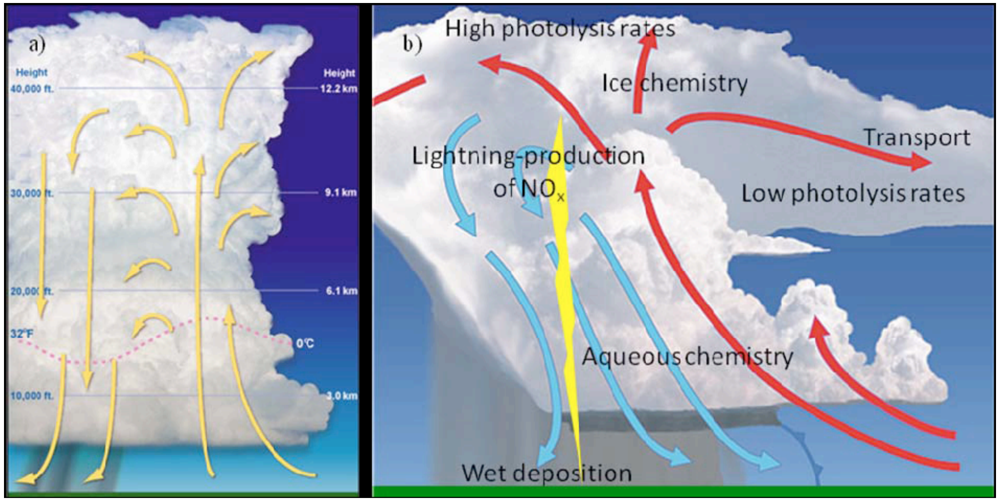
DC3 Hypothesis:

Transport to near tropopause in high-shear storms

Transport throughout the troposphere in low-shear storms

Scavenging in Colorado storms would be less efficient

Scavenging in OK/TX and Alabama storms would be more efficient



Air Mass Thunderstorm

High-Shear Thunderstorm

Convective Transport of Passive Species

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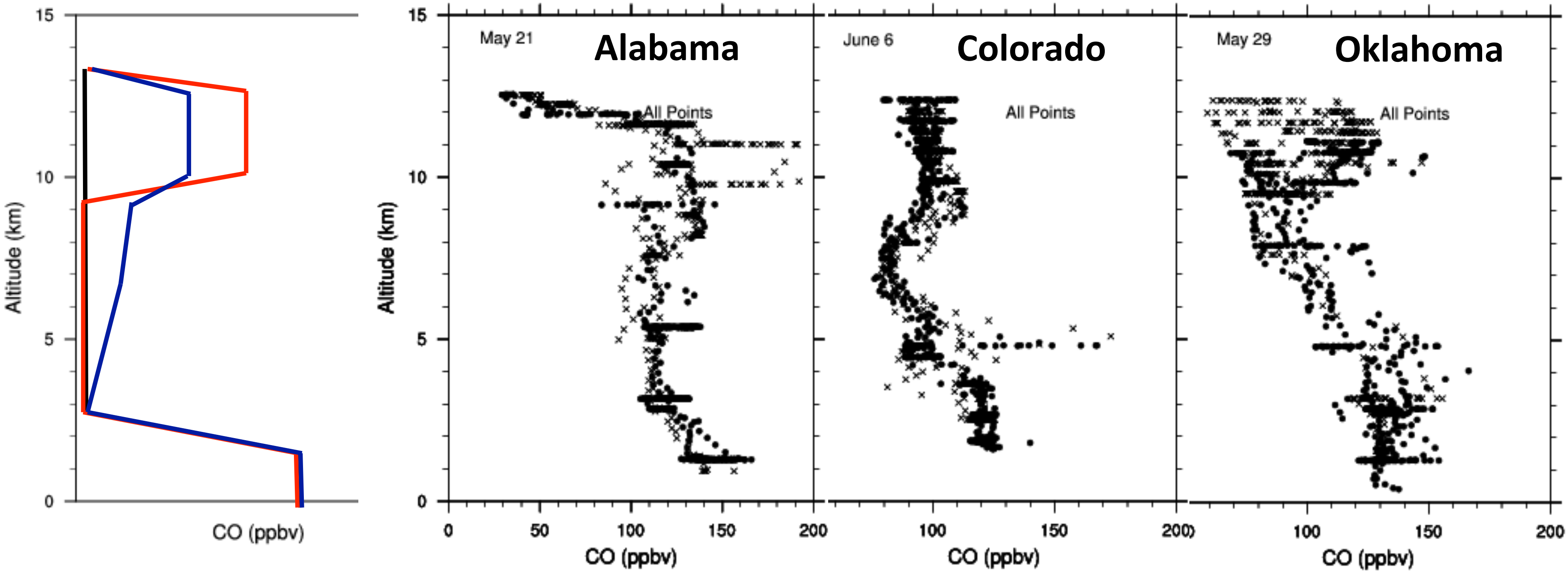

DC-8 data: Glenn Diskin, Glenn Sachse, James Podolske (NASA)

GV data: Teresa Campos, Frank Flocke, Daniel Stechman, Carolyn Farris, and Melodye Rooney (NCAR)

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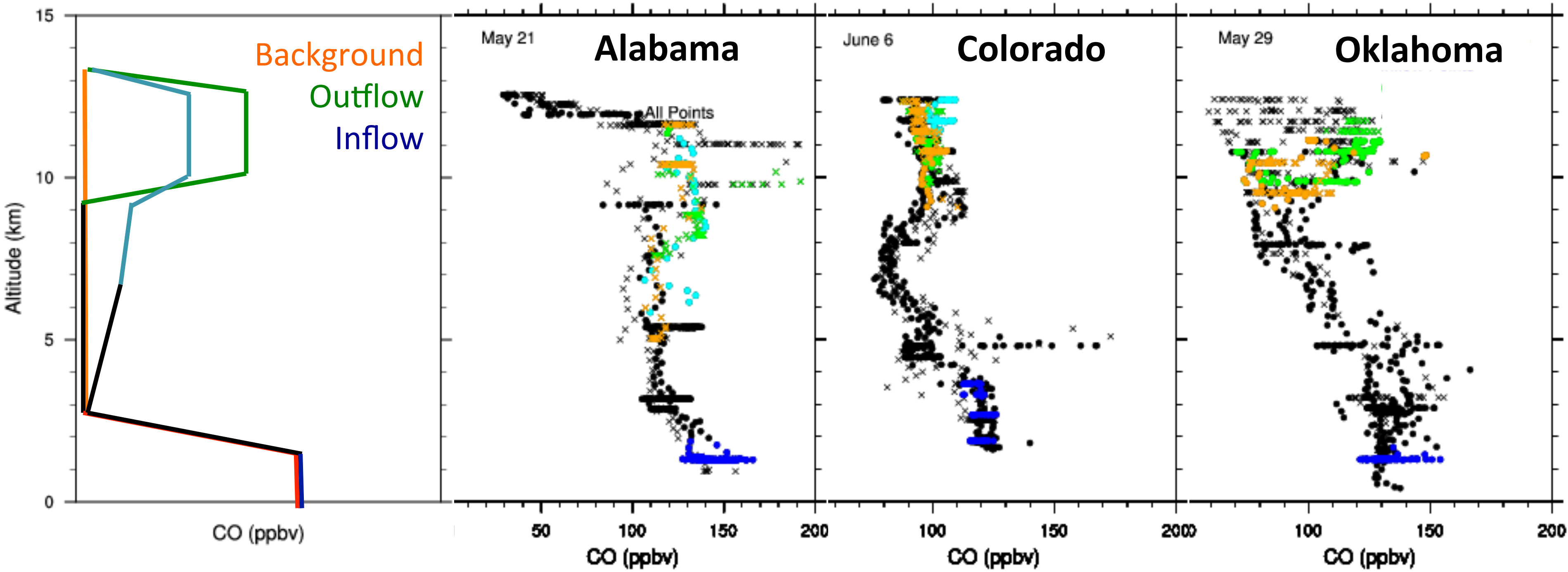


→ Background data points are not very different than convective outflow

→ Also true for non-methane hydrocarbons, e.g. toluene

Convective Transport of H_2O_2

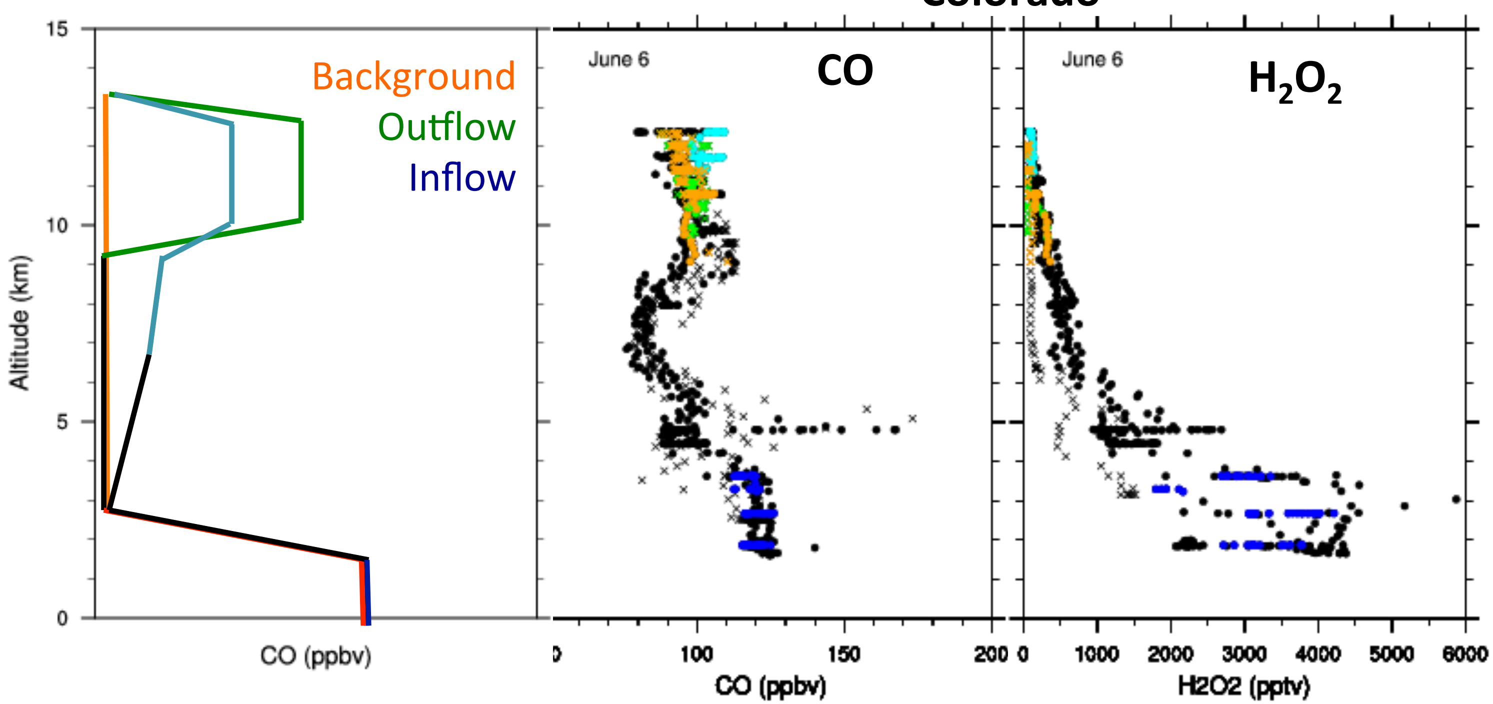
- H_2O_2 is a very soluble species ($K_H = 8x10^4$ M/atm)

→ **Vertical profiles show substantial scavenging in Colorado storm**

→ **Early Colorado storm had a weak convective transport signal**

  - **may be due to entrainment**

Colorado



DC-8 H2O2 data: Paul Wennberg, John Crounse, Jason St. Clair (CIT)

GV H2O2 data: Dan O'Sullivan (USNA), Brian Heikes (URI)

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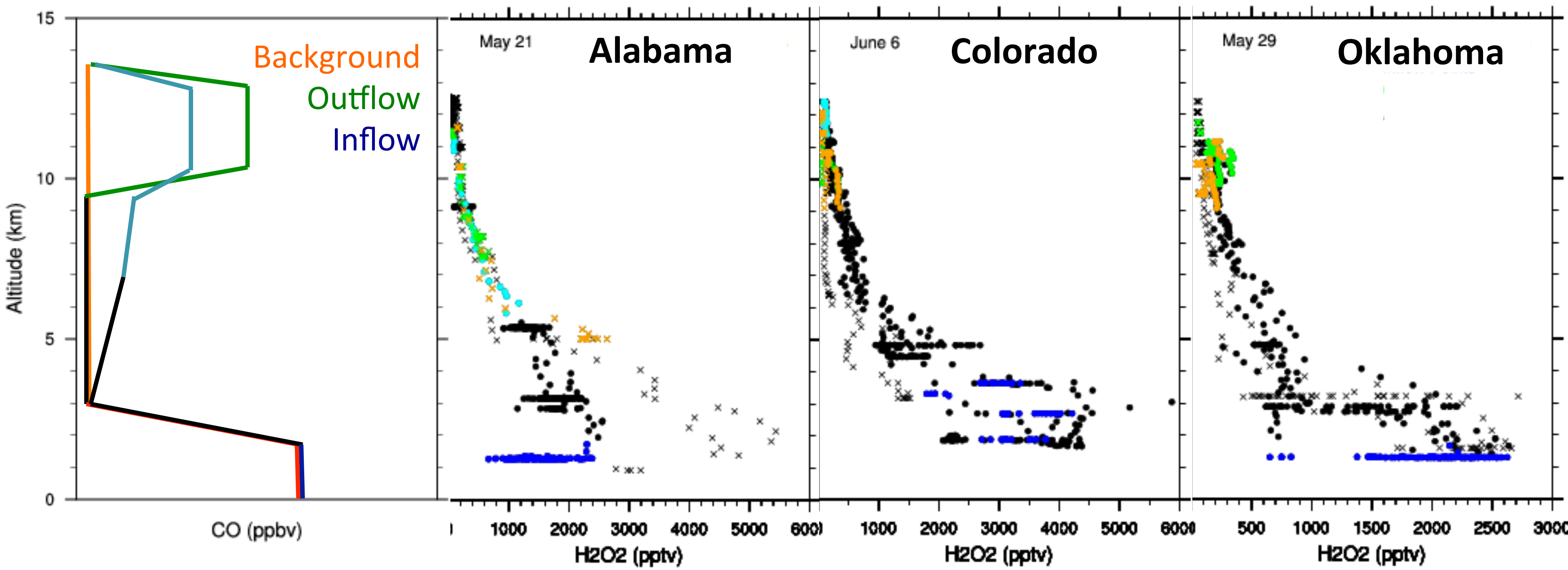


→ H_2O_2 appears to be scavenged similarly in all storms

- except, perhaps, the Oklahoma storm

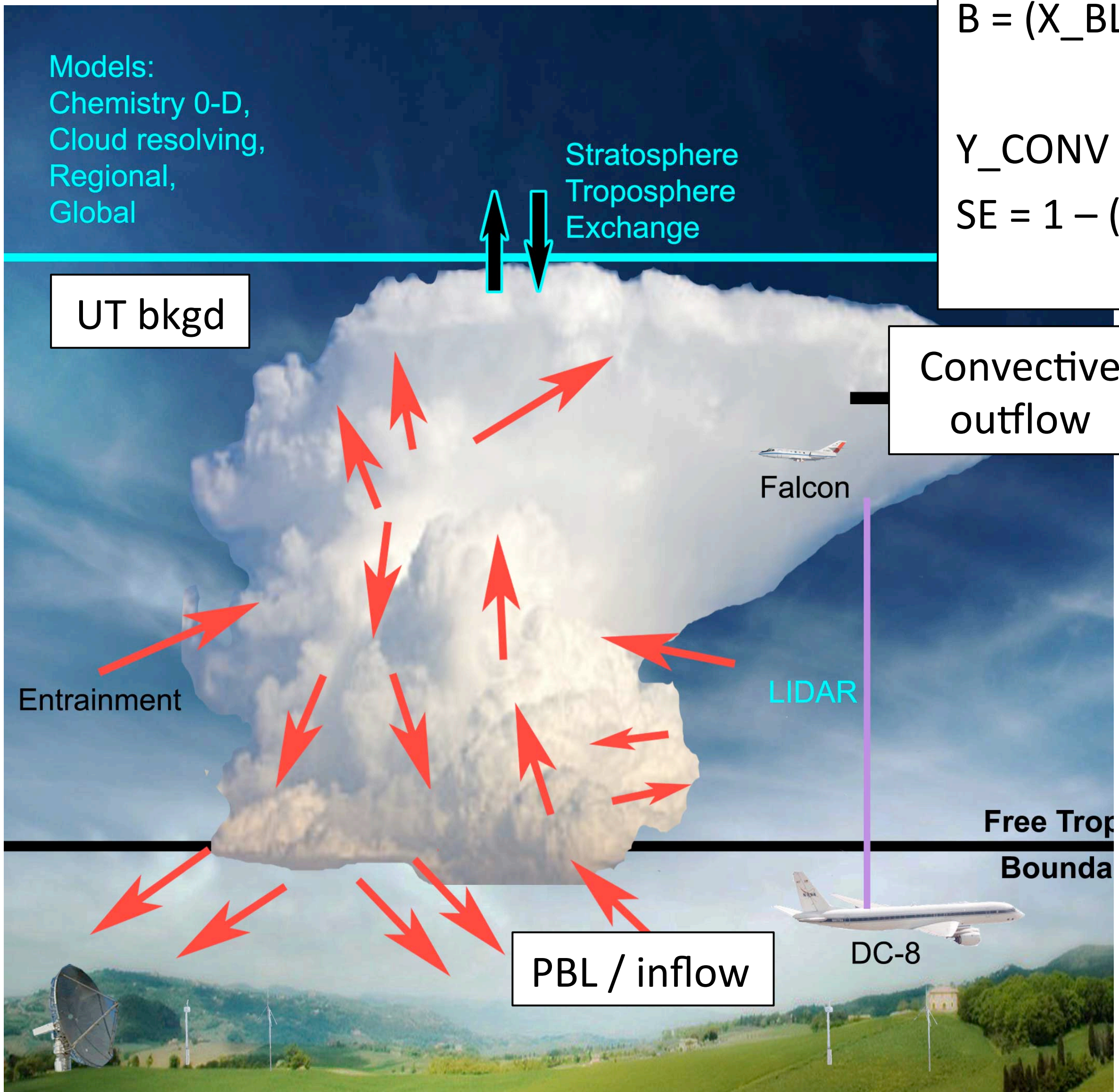
Quantifying Scavenging Efficiency of Soluble Species

X = passive species   Y = soluble species

B = (X_BL – X_CONV) / (X_BL – X_UT)

Y_CONV = (1-SE) β Y_BL + (1-β) Y_UT

SE = 1 – (Y_CONV - β Y_UT) / ((1-β) Y_BL)



Passive species:

CO, alkanes, alkenes:

toluene, isoprene,

MVK+MACR, C_2H_6, C_3H_8,

n-C_4H_{10}

Soluble species:

HNO_3, H_2O_2, CH_2O, CH_3OOH

Scavenging Efficiencies for Different Storms and Species

Storm	Type	CH_3OOH		CH_2O		H_2O_2		HNO_3	
		CO	Toluene	CO	Toluene	CO	Toluene	CO	Toluene
Alabama	Low shear	0.67	0.10	0.84	0.40	0.65	1.0	0.32	1.0
Colorado 1	High shear	0.91	0.93	0.64	0.78	0.94	0.96	0.94	0.92
Colorado 2	High shear	0.75	0.87	0.43	0.72	0.94	0.96	0.94	1.0
Oklahoma	High shear	0.83	0.83	0.68	0.45	0.92	0.90	0.94	1.0

DC-8 CH_3OOH, H_2O_2, HNO_3 data: Paul Wennberg, John Crounse, Jason St. Clair (CIT)
GV CH_3OOH, H_2O_2 data: Dan O'Sullivan (USNA), Brian Heikes (URI)
DC-8 and GV CH2O data: Alan Fried, Jim Walega, Dirk Richter, Petter Weibring (U. Colorado)
DC-8 CH2O data: Tom Hanisco (NASA/GSFC), Heather Arkinson (U. Maryland)
GV HNO_3 data: Greg Huey, Dave Tanner (GaTech)
DC-8 data: Glenn Diskin, Glenn Sachse, James Podolske (NASA)
GV data: Teresa Campos, Frank Flocke, Daniel Stechman, Carolyn Farris, and Melodye Rooney (NCAR)
DC-8 Toluene data: Don Blake, Nicola Blake (U. California – Irvine)
GV Toluene data: Eric Apel, Rebecca Hornbrook, Alan Hills (NCAR), Dan Riemer (U. Miami)

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Oklahoma	High shear	0.74	0.81	0.67	0.45	0.95	0.98	0.89	0. 90

- **CH_2O consistently has scattered results**
- Alabama storm consistently has scattered results
- Alabama storm has less scavenging than high-shear storms
- Scavenging in the two Colorado storms is not the same

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Scavenging Efficiencies for Different Storms and Species

- This work: more scavenging in high shear storms, less in low-shear, Alabama case
  - **Mixing of free tropospheric air into storm is a critical factor**
  - **Recommend a multi-component model**
- Uncertainties
  - Photochemistry occurring along air parcel trajectory
  - **Should strive to connect inflow points measured to outflow points measured using radar wind observations**
- **Bela et al. poster** (Thursday) shows scavenging results from cloud-resolving model simulations
- **Fried et al. poster** (Thursday) shows scavenging efficiency estimates for May 29 case using a 3-component model and considering photochemistry

Convective Transport and Scavenging in 3 DC3 Storms

- Pre-convective (background) UT air found to often be affected by previous day convection or biomass burning plumes
- Smaller (or younger) storms had a weak convective transport signal – may be due to entrainment
- Scavenging occurred more for high-shear storms, less for low-shear storm
- Next: Place scavenging into context of other storm parameters, e.g. amount of graupel or hail

Thank you!