Transport and Entrainment of Trace Gases in a Modeled and Observed SEAC^{4}RS case study of Air Mass Thunderstorms

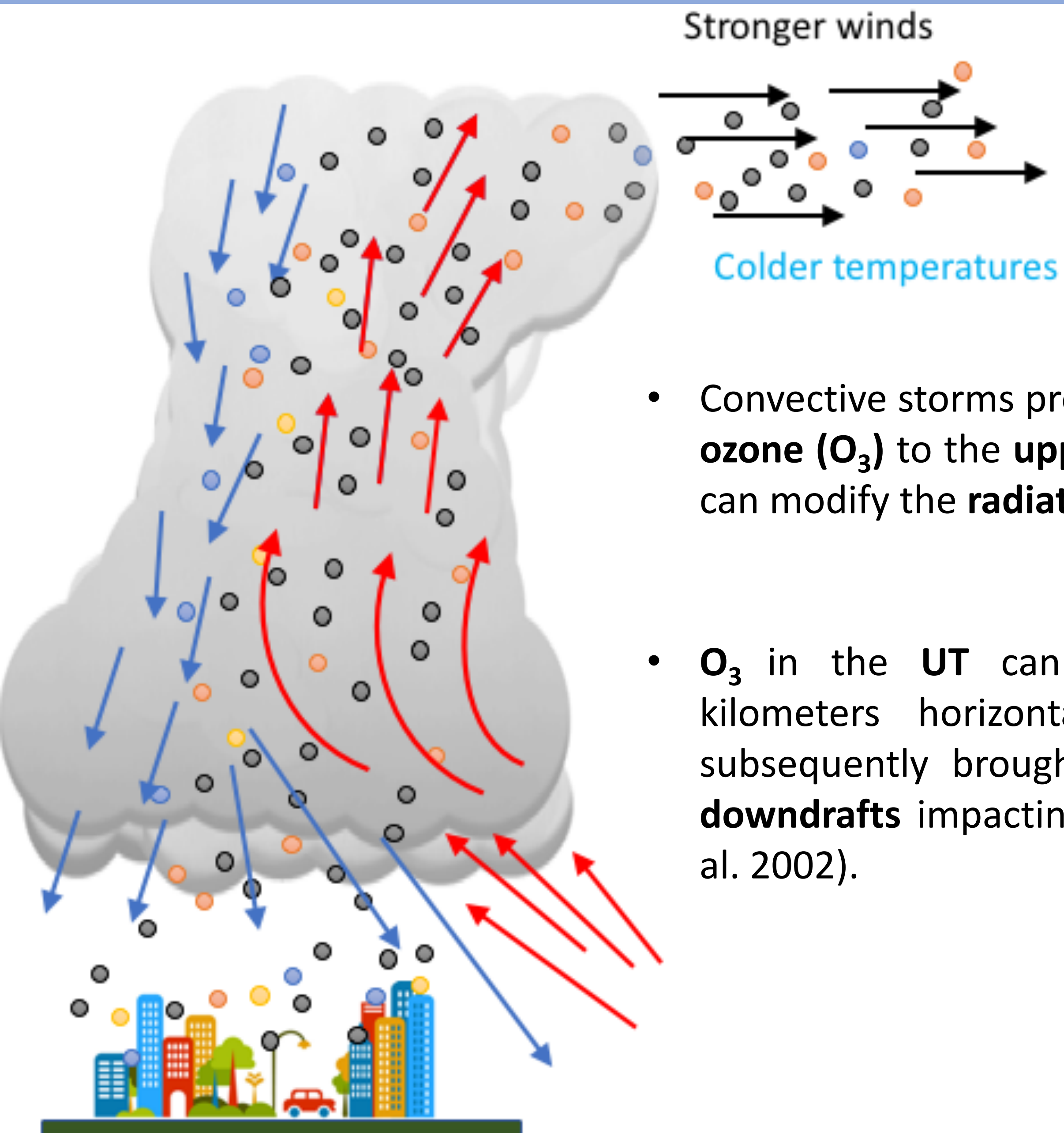
Gustavo Cuchiara [1,2], Mary Barth[1], Alan Fried[2], Cameron Homeyer[3], Megan Bela[4], Nicholas Heath[5]

[1]National Center for Atmospheric Research,
[2]University of Colorado, Institute of Arctic and Alpine Research
[3]University of Oklahoma, School of Meteorology
[4]National Oceanic and Atmosphere Administration, Chemical Science Division
[5]Air Force Technical Applications Center

Joint WRF/MPAS Users' Workshop • June 2018

gustavo.cuchiara@gmail.com

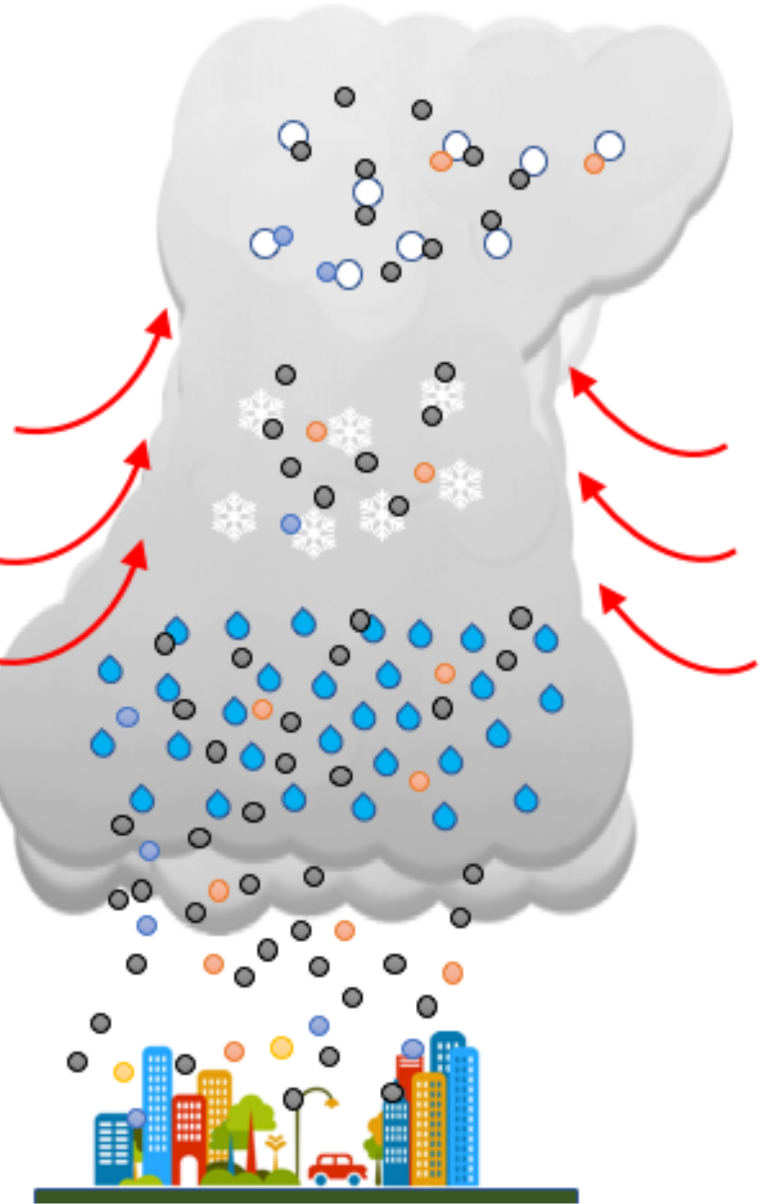
Motivation



- Convective storms produce and transport precursors of **ozone (O_3)** to the **upper troposphere (UT)**, where they can modify the **radiative forcing** (IPCC, 2001).

- **O_3** in the **UT** can be transported thousands of kilometers horizontally by **high-level winds** and subsequently brought to the surface by **convective downdrafts** impacting downwind **air quality** (Betts et al. 2002).

Motivation



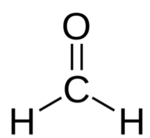
Many **chemical** and **physical** process within the convective core and anvil affect the net transport of soluble species:

- dissolution in cloud water or liquid phase precipitation (Seinfeld and Pandis, 2006)
- aqueous chemistry (Barth et al, 2007)
- ice deposition of HNO_3 and H_2O_2
- **Entrainment of air**

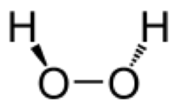
Objectives

- Understand better the scavenging, entrainment, and ice retention processes in convective clouds for selected tropospheric ozone precursors

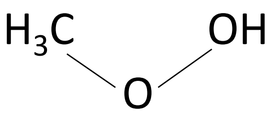
Formaldehyde



hydrogen peroxide



methyl hydroperoxide

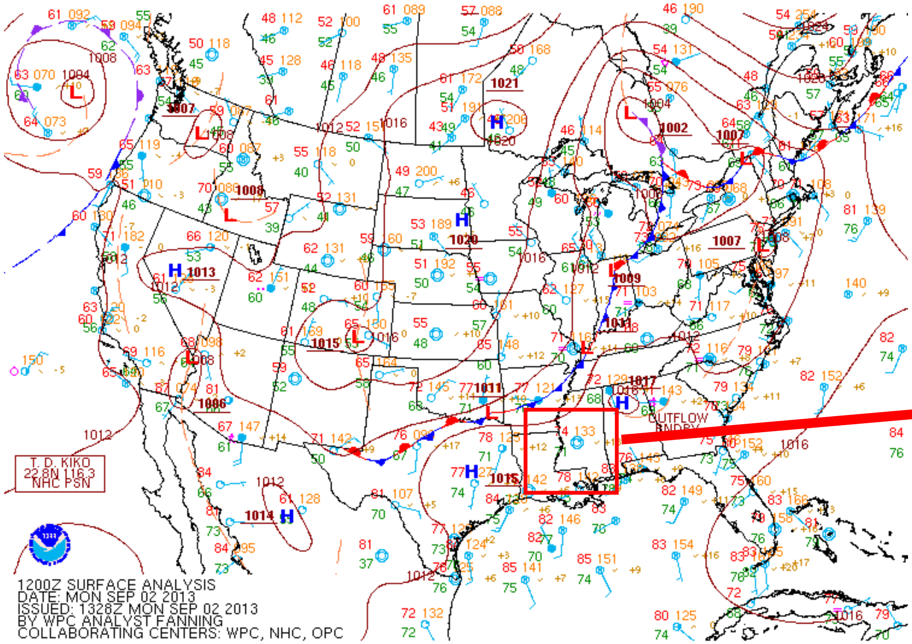


IN THIS WORK → evaluation of the WRF modeled storms compared to observations and an analysis of entrainment from WRF coupled with tracers.

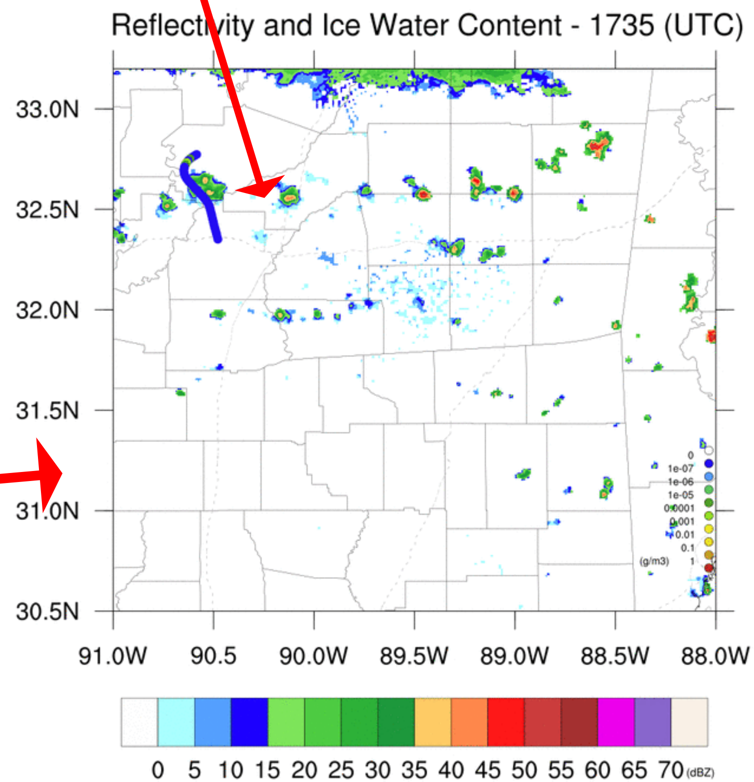
SEAC^{4}RS project - September 02, 2013

NASA's **DC-8 aircraft**

[NASA SEAC^{4}RS]() - Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys



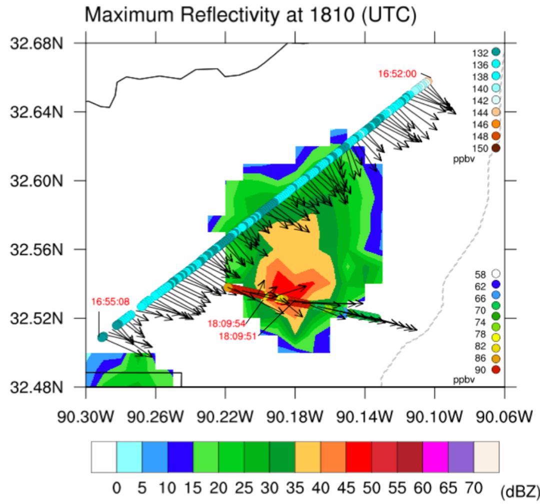
Jackson, MS

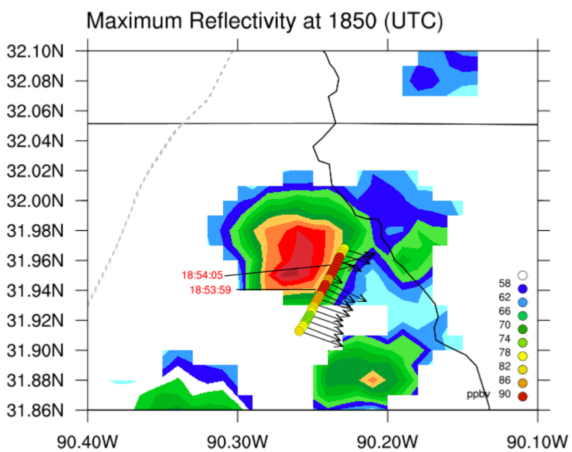


Observed clouds

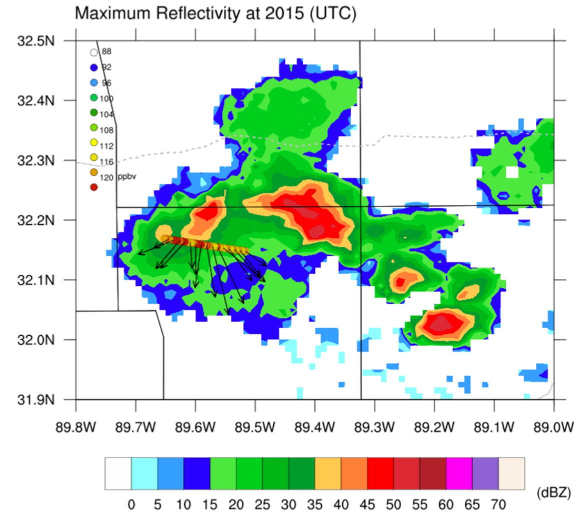
- **NEXRAD images vs DC-8 carbon monoxide**

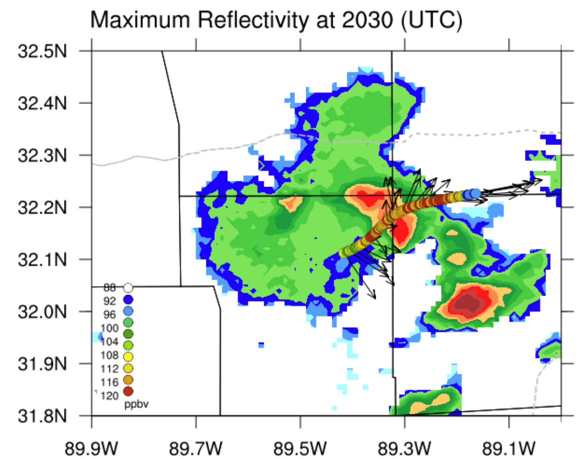
Single-cell clouds





Multicell clouds





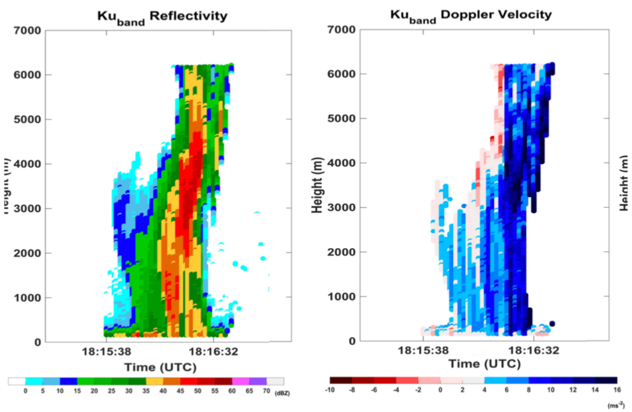
DC-8 aircraft:

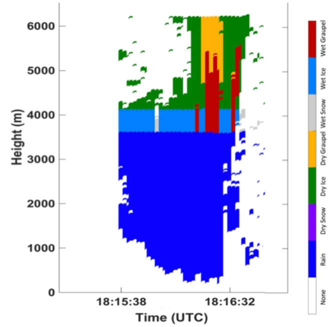
- 2 PBL samples
- 23 cloud intercepts
- 9 different clouds

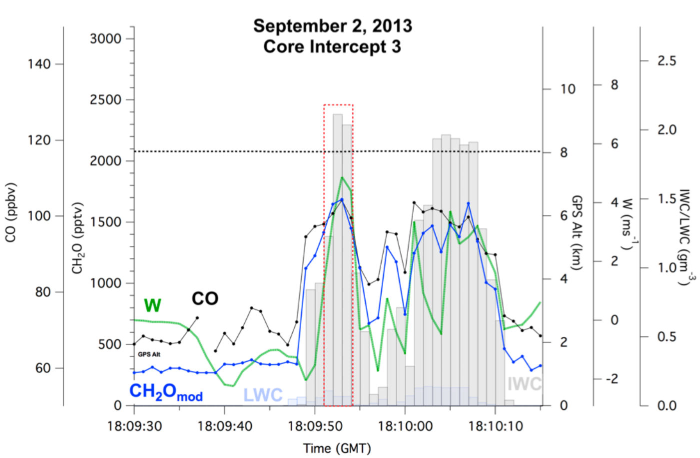
Observed clouds

- **Airborne Precipitation Radar – 2 (APR2)**

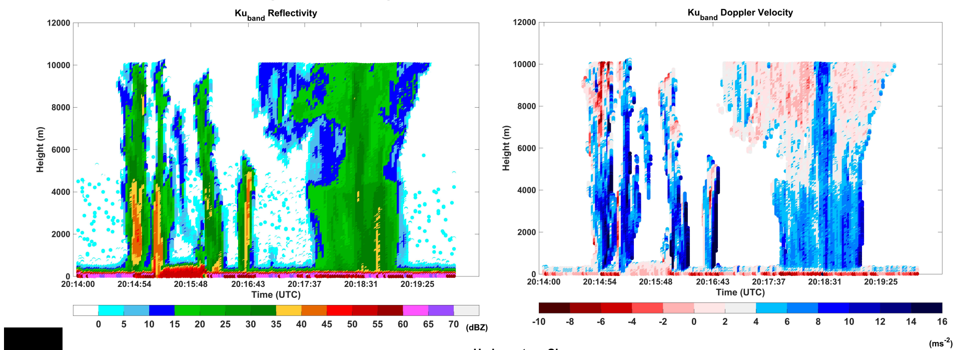
Single-cell clouds

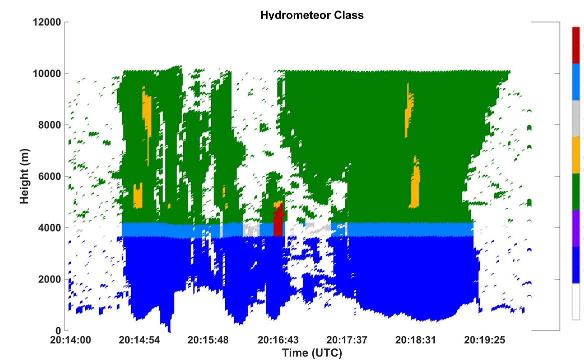


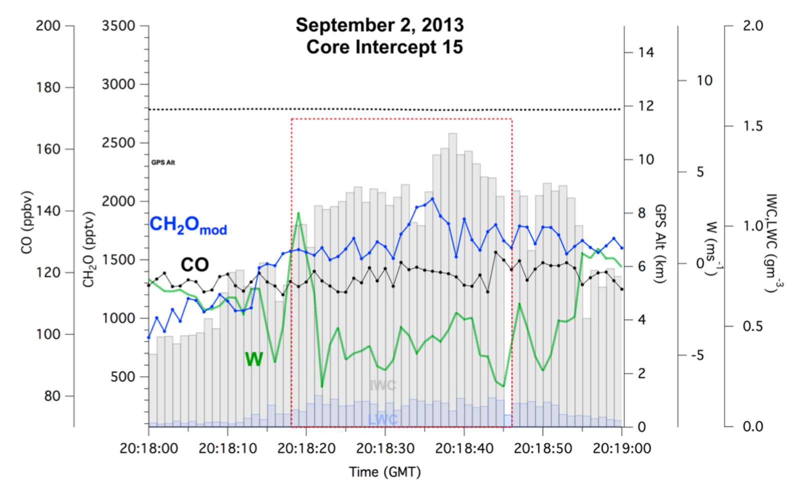




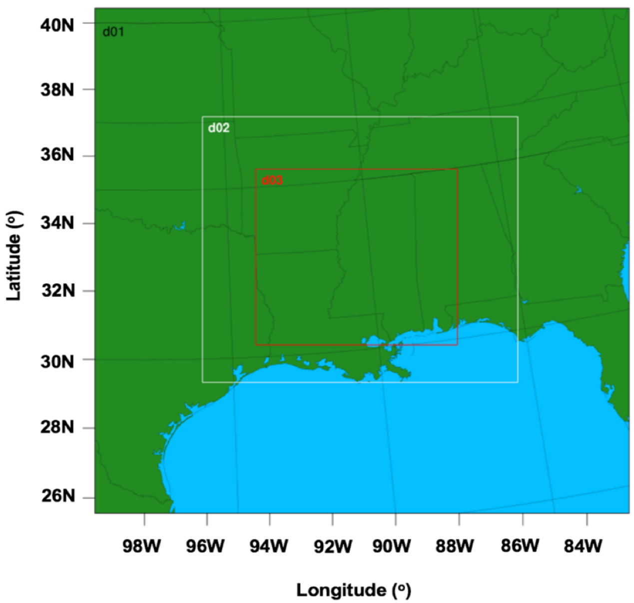
Multicell clouds



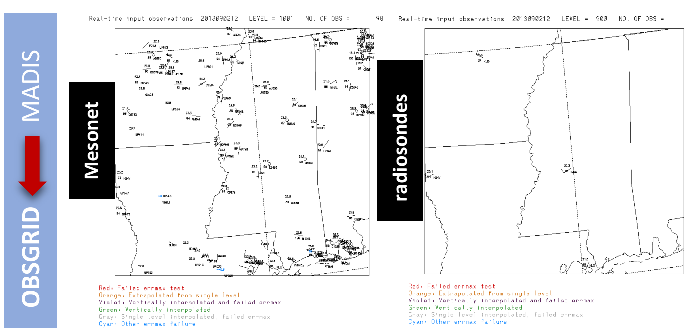




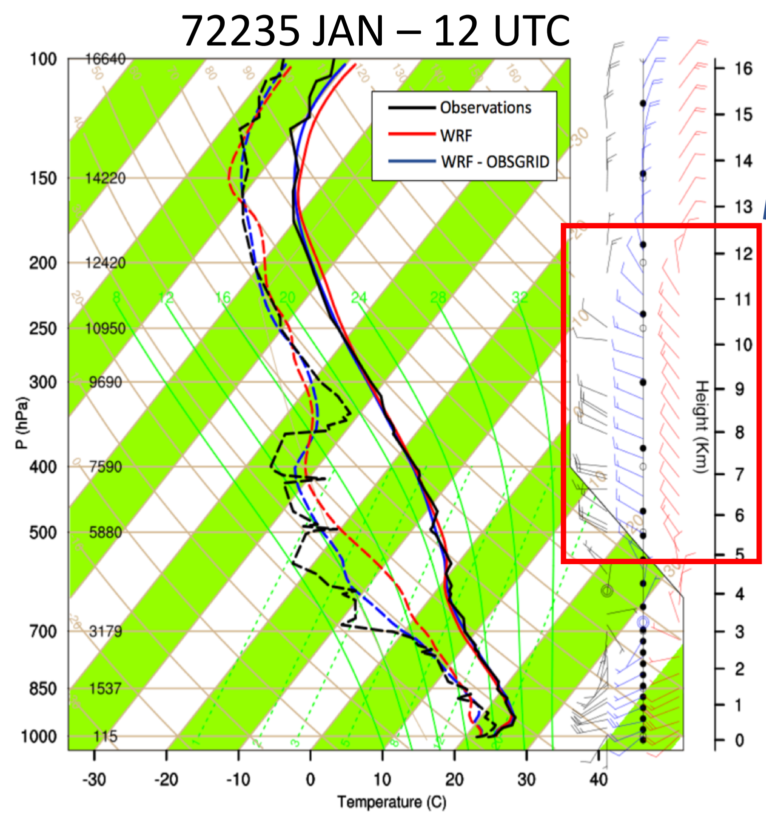
WRF configuration



Domain	d01	d02	d03
WRF Version	3.9.1 - released August 2017		
Simulation period	From 09/02 at 06 UTC to 09/03 at 00 UTC		
Met. IB Cond.	North America Regional Reanalysis (NARR)		
Horizontal resolution	12150 m	4050 m	**1350 m**
Grid points (x,y)	145x136	256x214	**490x424**
Microphysics	Morrison two-moment scheme		
Short/Longwave radiation	Rapid Radiative Transfer Model		
Land-surface	Noah Unified Land Surface Model		
Boundary layer	Yonsei University (YSU)		
Cumulus scheme	Kain-Fritsch	Kain-Fritsch	**None**



- Several choices of ICs and BCs, initialization times, and physical parameterization were tested.



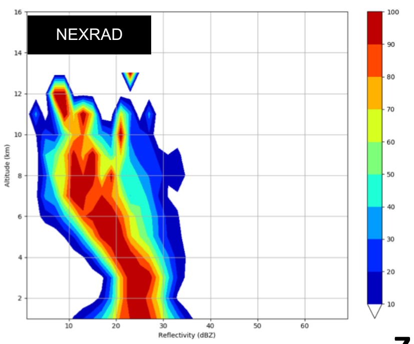
	WRF		WRF-OBSGRID	
Variable	Temp	Dew Point	Temp	Dew Point
R	0.998	0.994	0.998	0.998
RMSE (°C)	1.518	3.424	1.480	2.109
BIAS (°C)	0.247	1.275	-0.055	0.151

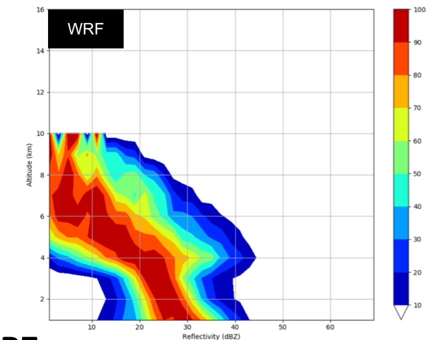
WRF validation

Contoured Frequency by Altitude Diagram (CFAD)

20 dBZ ≤ Z $_{1\text{-}4\ km}$ ≤ 30 dBZ

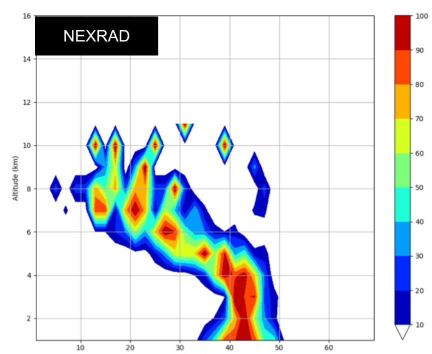
Moderate Rainfall
Reflectivities

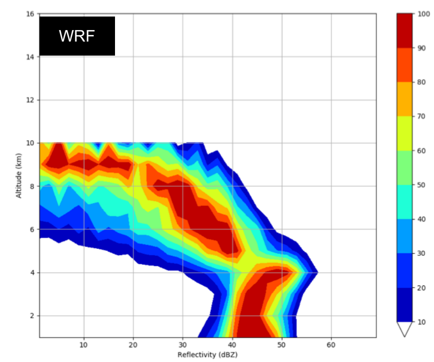




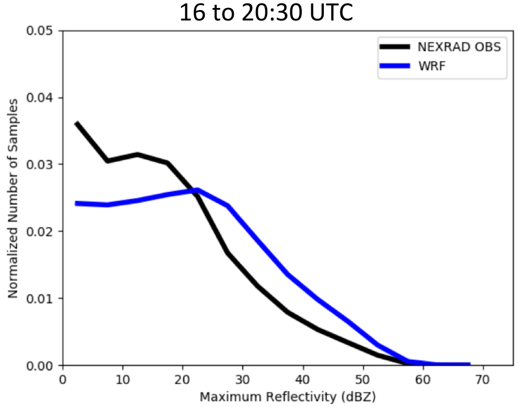
Z $_{1\text{-}4\ km}$ ≥ 40 dBZ

Heavy Rainfall
Reflectivities





16 to 20:30 UTC

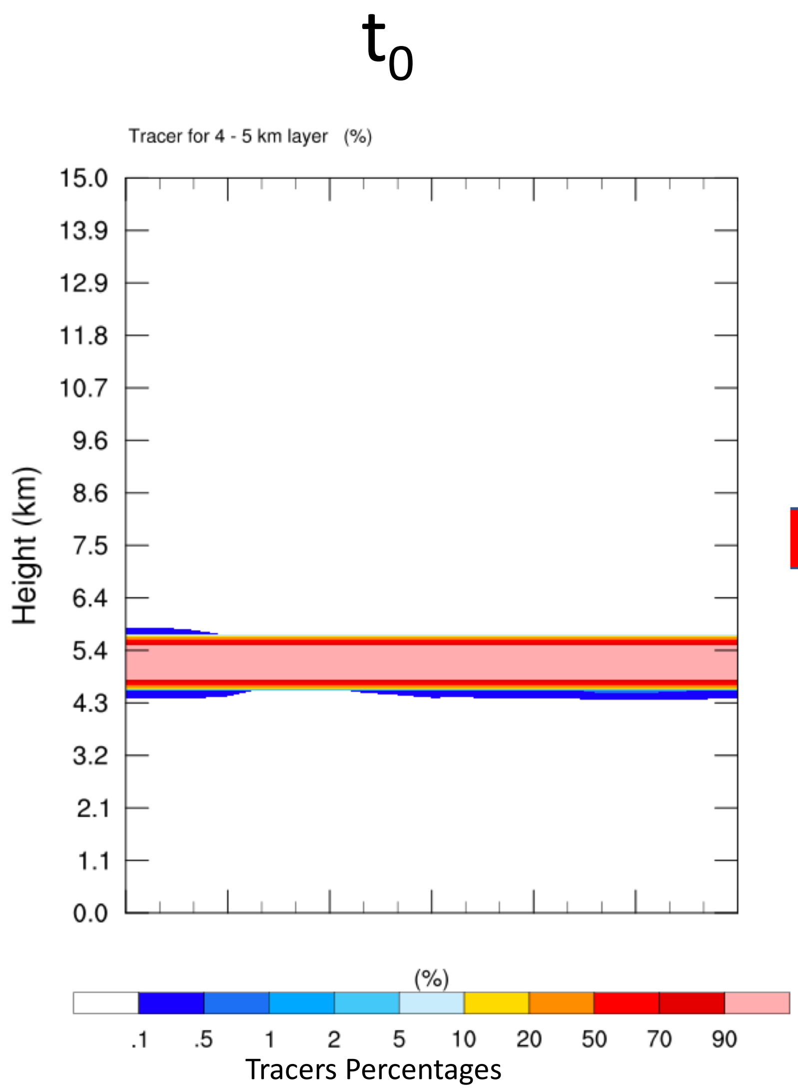


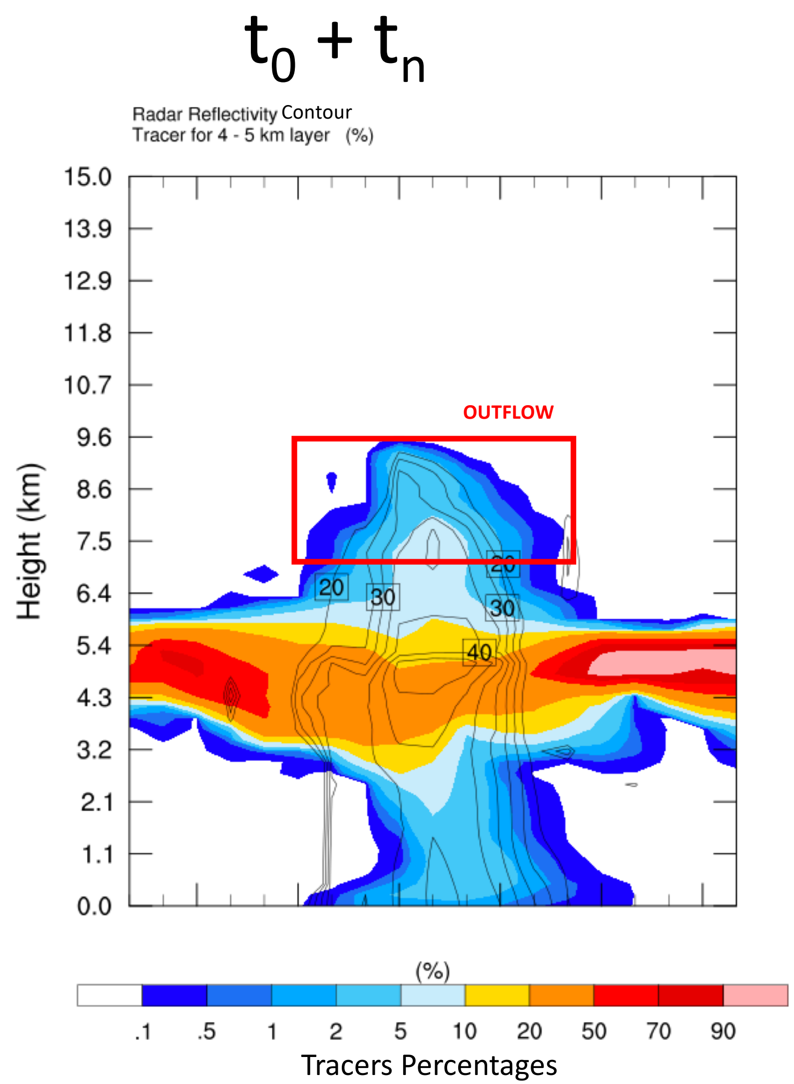
	OBS	WRF
Median	15.34	20.36
90 %	34.14	39.95
99 %	49.50	51.91

Heath et al. (2017)

Tracer experiment

- The tracers represent 1-km altitude layers to analyze the outflow region of the storm and learn how much of the outflow contains air from different altitude layers.



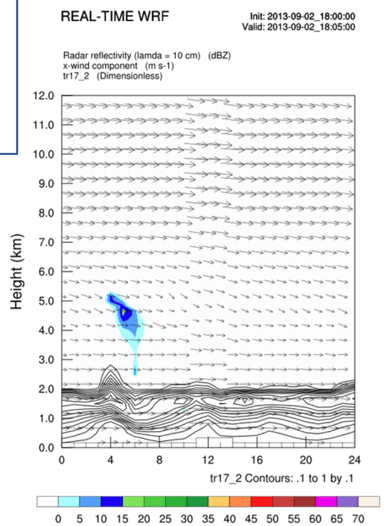


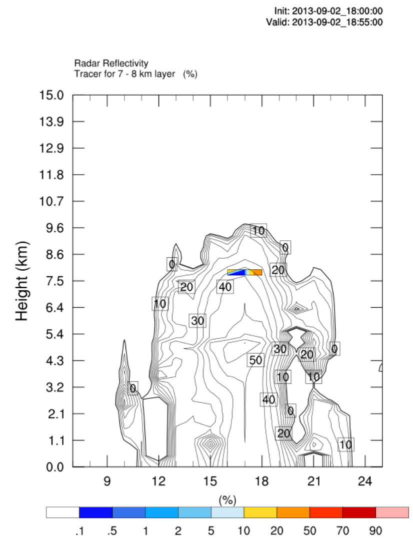
Bela et al., 2016; 2018 (accepted)

Tracer experiment

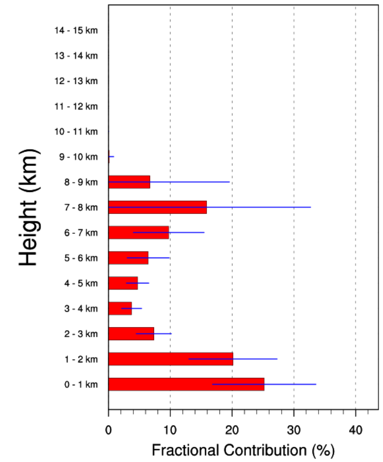
Single-cell clouds

Released: 18:00 UTC
Analysis: 18:55 UTC
layers **7** - **9 km**
dBZ > 20 and **W > 0**



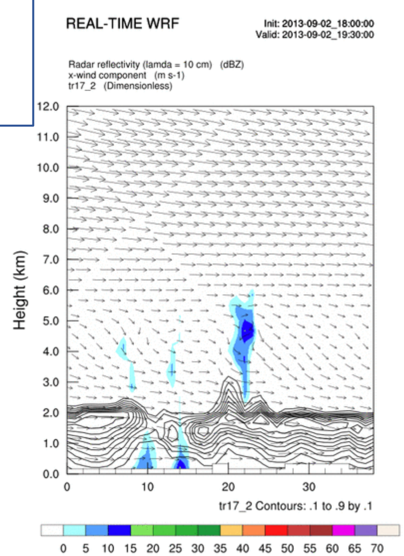


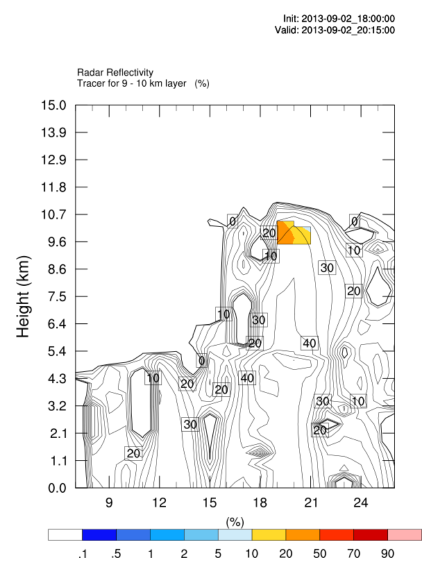
altitude-dependent entrainment



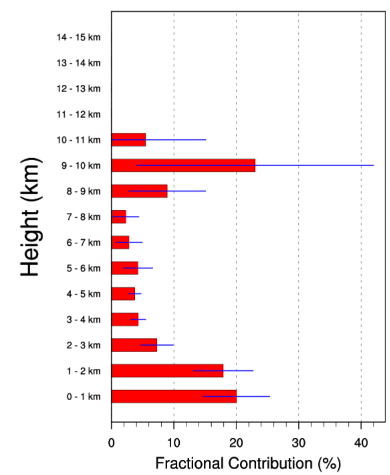
Multicell clouds

Released: 19:25 UTC
Analysis: 20:15 UTC
layers **9.5** - **11.5 km**
dBZ > 20 and **W > 0**



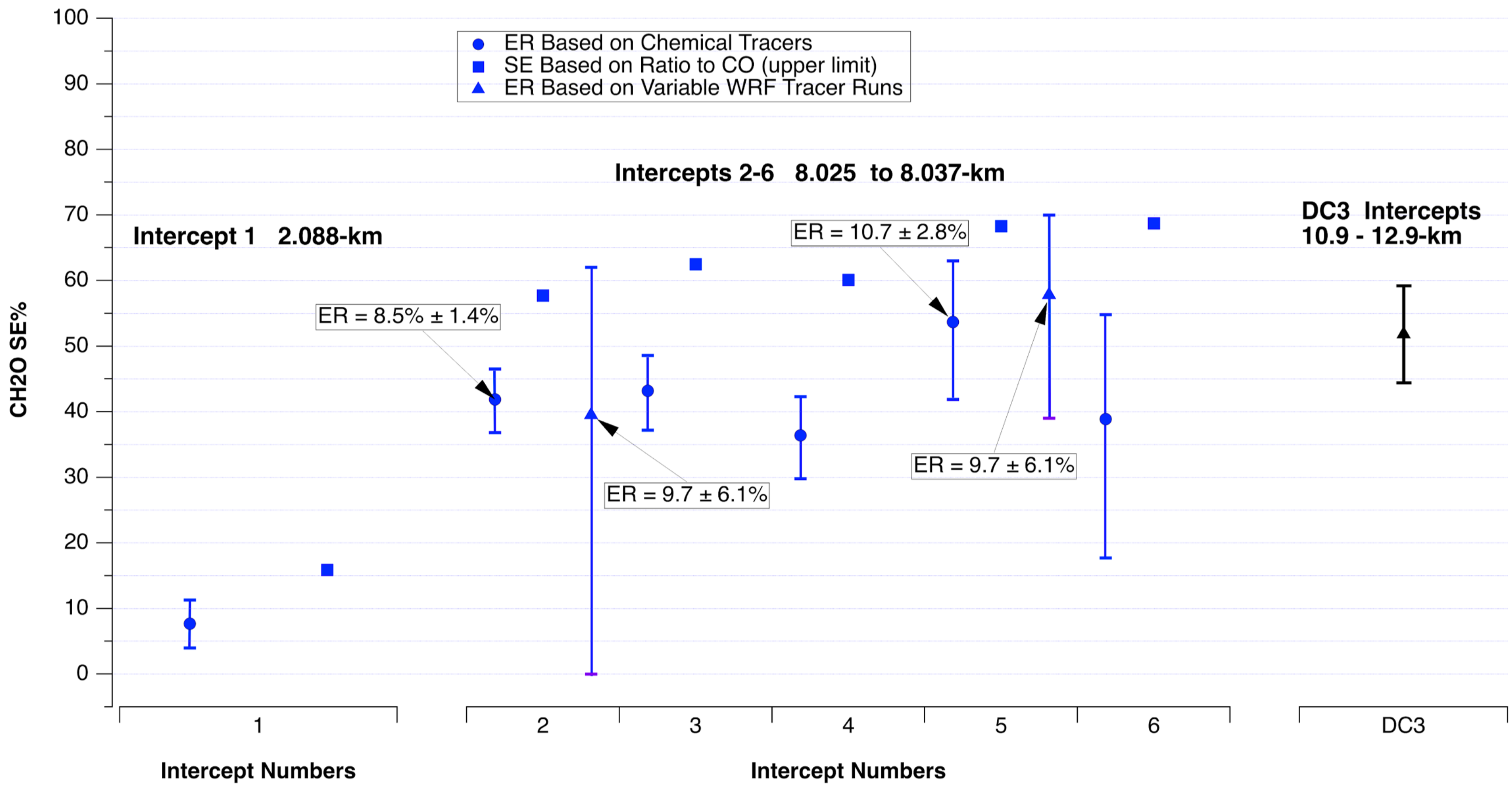


altitude-dependent entrainment



WRF Tracers vs Chemical Tracers

- The WRF coupled with tracers give support to methods of estimating entrainment rates based on chemical tracers such as CO, oxides of nitrogen, CO_2, n-butane, i-butane, etc.



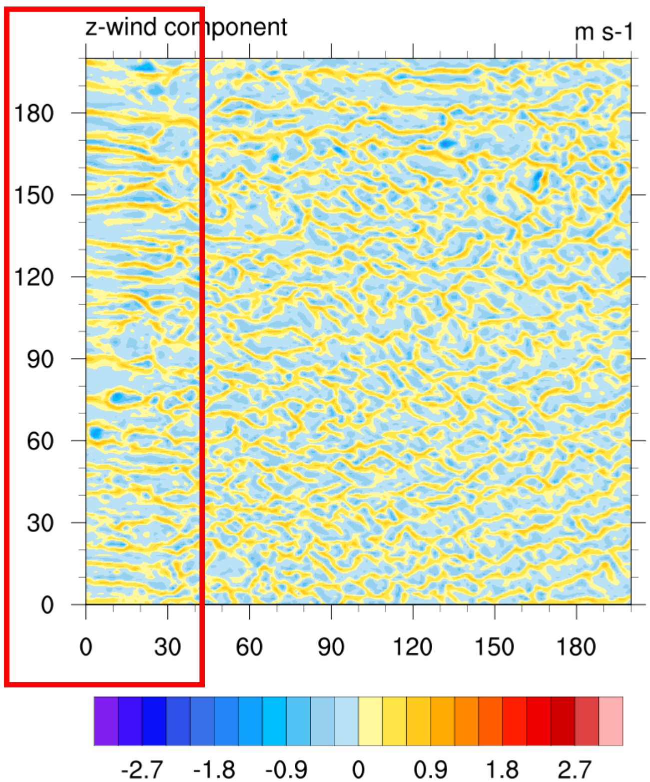
- entrainment rates are ultimately needed to calculate scavenging efficiencies

Fried et al., 2016

Future Work

LES

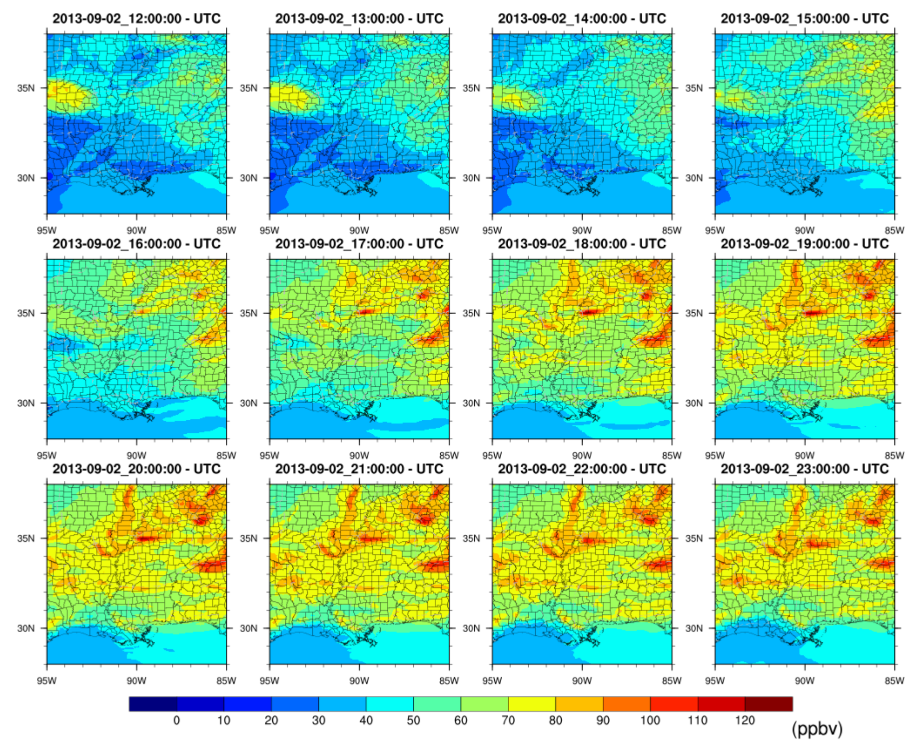
- Better entrainment estimation
- Real vs periodic BC
- Nesting LES-LES



WRF-chem

- Validation
- Turn on/off scavenging scheme

Preliminary - simulated O_3



Conclusions

1. The WRF model presented a satisfactory vertical structure of the atmosphere a few hours before the development of the storms, with slight differences in the timing, intensity and location of the convection as expected.

2. The results of the tracer experiment reveal that the inflow/outflow regions are responsible for the highest entrainment of air. However, there were different entrainment rates among clouds developing in a similar thermodynamic environment.

3. The altitude-dependent entrainment estimates provide a strong support to methods that derive entrainment rates from observed chemical species.

4. The WRF model coupled with tracer proves to be a good alternative to estimate entrainments in convective clouds.

Thank you!

We gratefully acknowledge the support of:

- Institute of Arctic and Alpine Research (INSTAAR) University of Colorado
- Atmospheric Chemistry Observation and Modeling (ACOM/NCAR)

This work is supported by NASA - Atmospheric Composition: Modeling and Analysis Program [grant NNX17AH52G]

gustavo.cuchiara@gmail.com