Scavenging of ozone precursors in convective clouds observed during a SEAC^{4}RS case study

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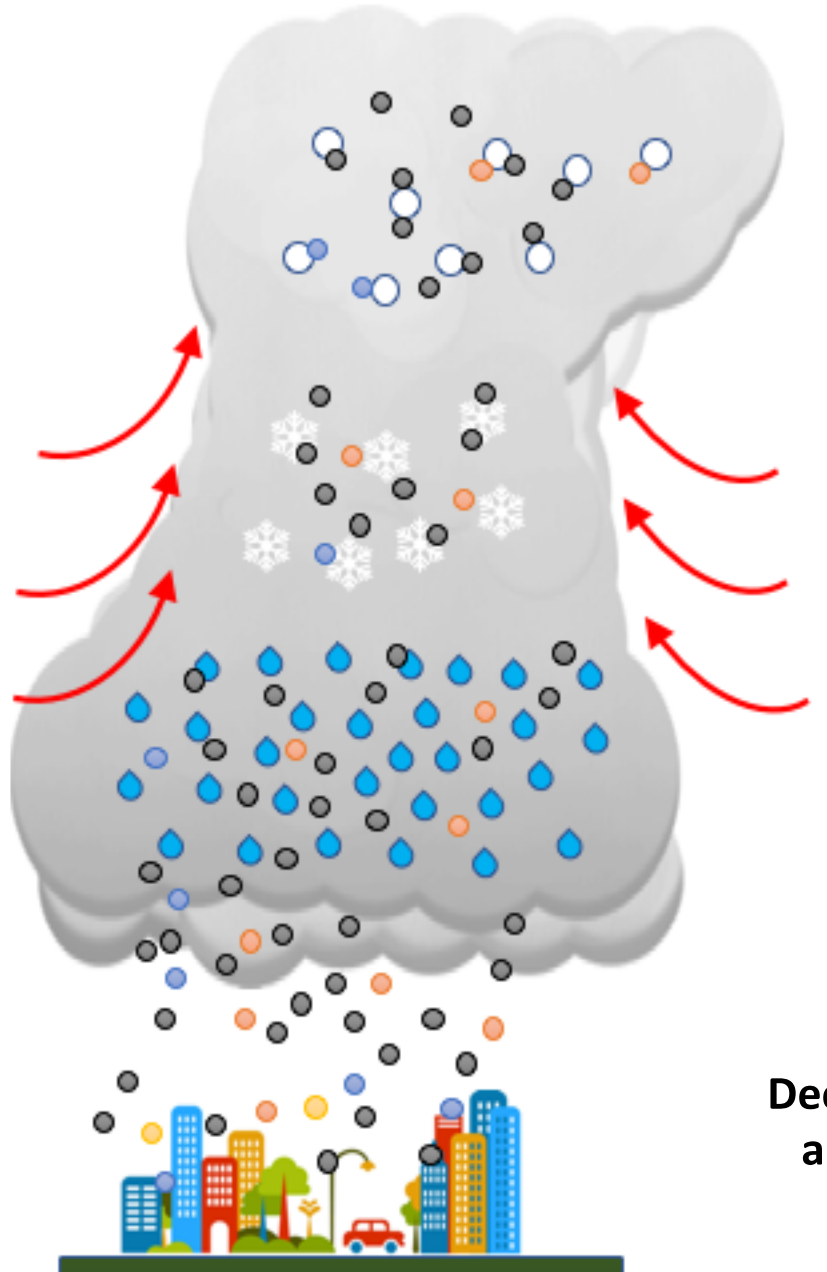
Motivation



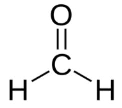
Many **chemical** and **physical** process within the convective core and anvil affect the net transport of **soluble species**:

- 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

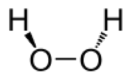
Scavenging efficiencies (SE) is defined as the amount of soluble gas removed by a storm during the transport of an air parcel from its inflow to the outflow.

Ozone precursors

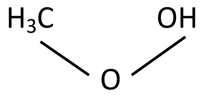
Formaldehyde



hydrogen peroxide



methyl hydroperoxide



Deep Convective Clouds and Chemistry (DC3) campaign

SEs 41-58% (Fried et al 2016)

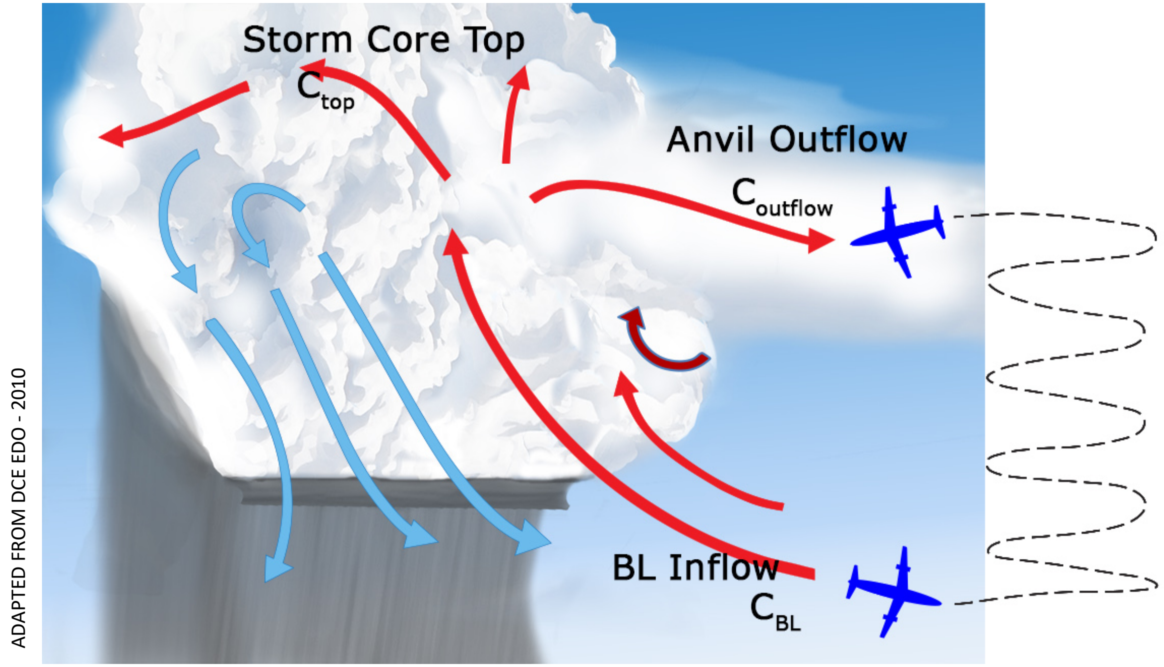
SEs 79-97% (Barth et al 2016)

SEs 12-84% (Barth et al 2016; Bela et al 2018)

(previous to DC3): <10% (Snow et at 2007;Barth et al 2007)

Scavenging Efficiency Calculations - Observations

Scavenging Efficiency using Entrainment Model



1. Find **entrainment rate (ER)** into storm from surrounding environment

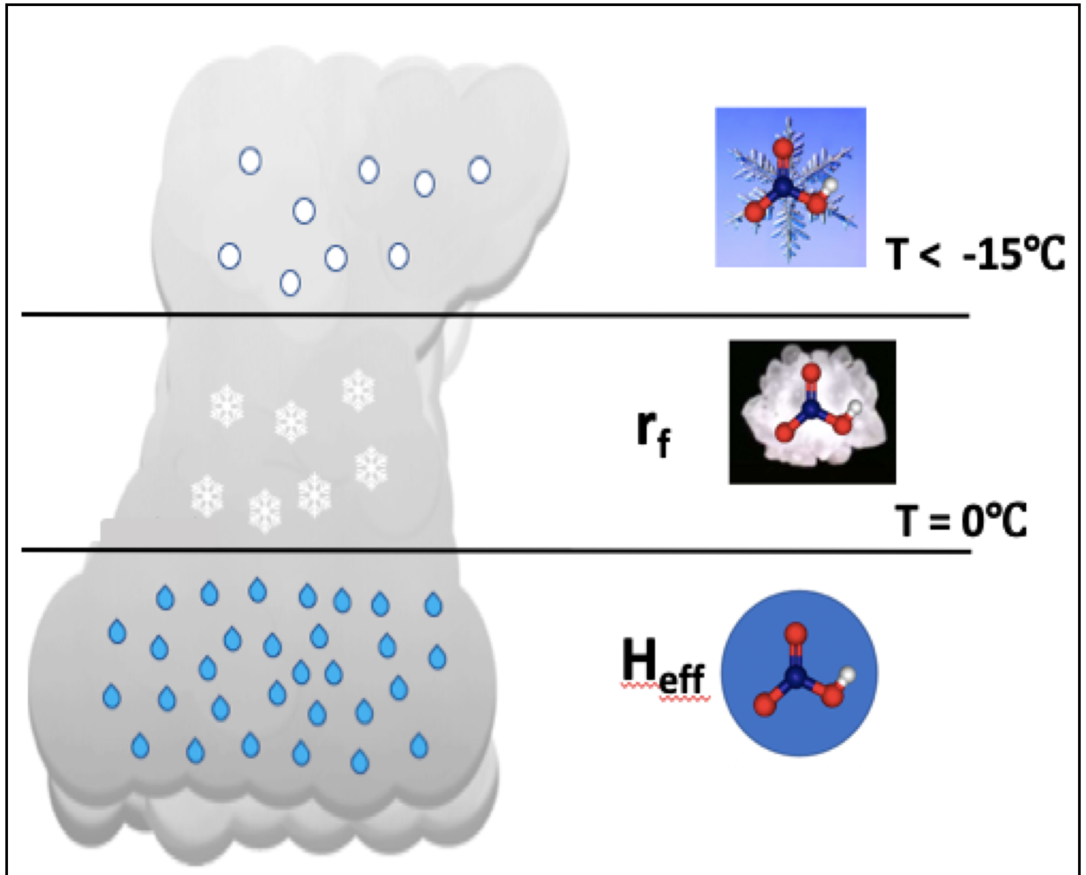
ER from **observations**	ER from **simulations**
CO or CO_2	WRF-tracer

2. Use ER to determine amount of soluble trace gas transported to top of storm
3. Compare measured mixing ratio in outflow to estimated value transported to top of storm

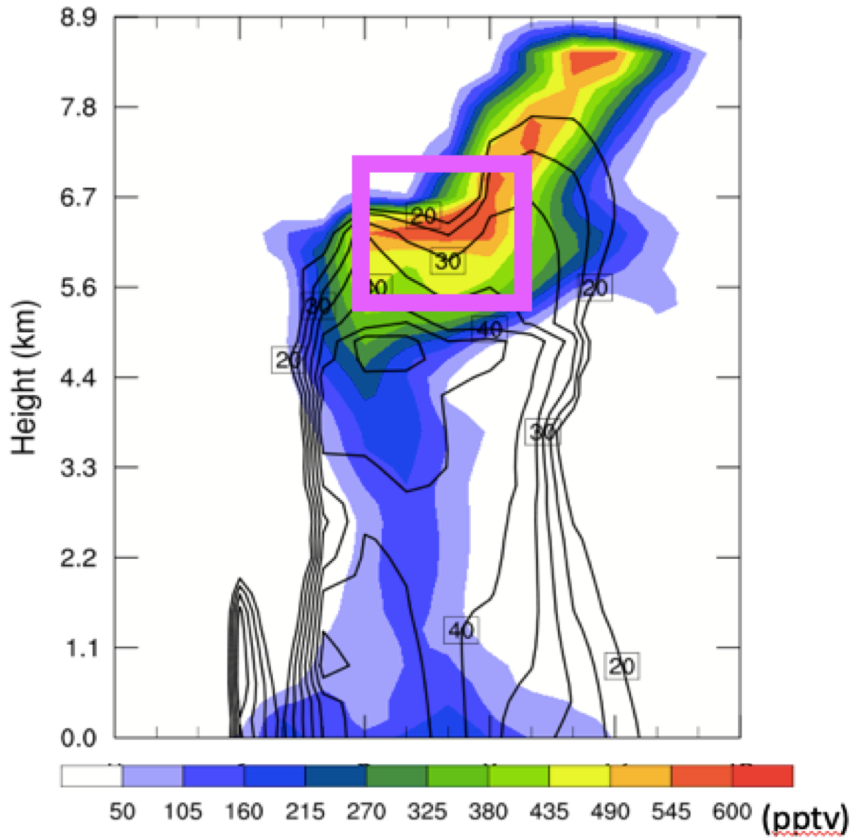
Fried et al. 2016

Scavenging Efficiency Calculations - Modeling

WRF-Chem



Absolute difference in CH_2O mixing ratios
(wet scavenging **ON** - wet scavenging **OFF**)



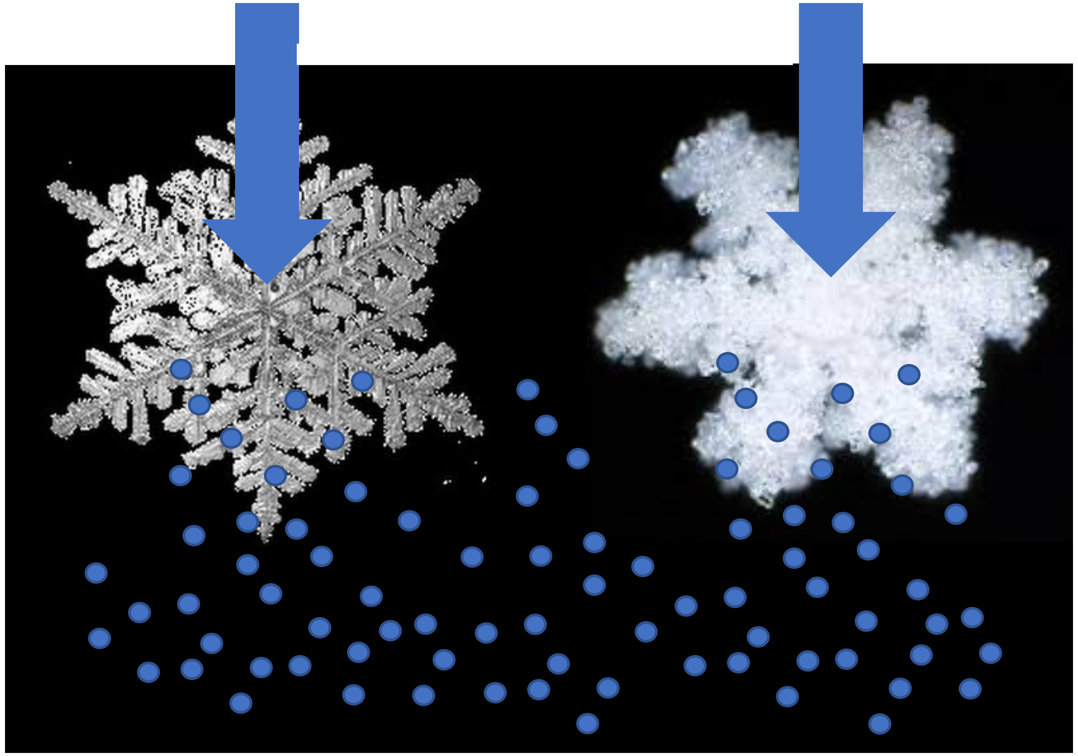
$$SE(\%) = 100 * \left(\frac{q_{i,noscav} - q_{i,scav}}{q_{i,noscav}}\right)$$

Where q_i = trace gas mixing ratio in **outflow box**

Bela et al. 2016; 2018

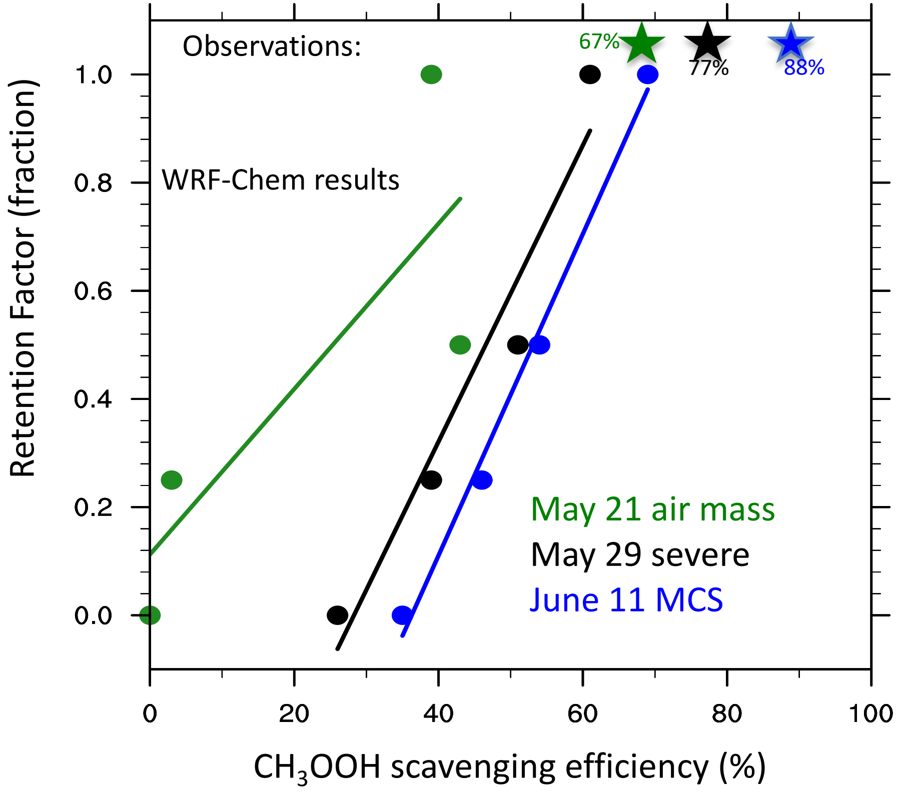
Cloud Physics vs Scavenging Efficiency

- when snow or graupel fall and collect cloud drops, the cloud drops freeze



What happens to the dissolved trace gases when freezing occurs ?

- retained in the frozen drops
- degassed during the freezing process



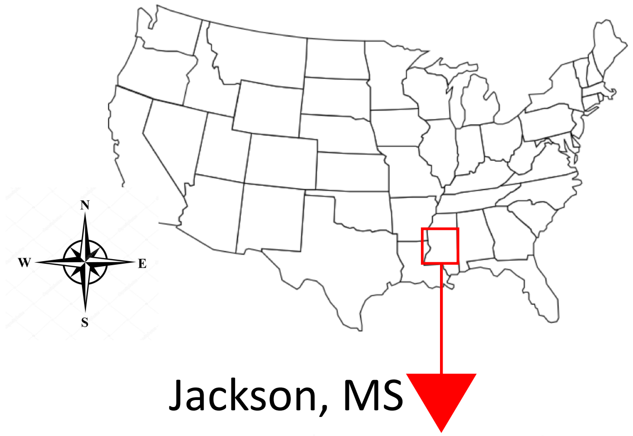
From Bela et al. (2018)

- WRF-Chem simulations of DC3 storms predict CH_3OOH SEs (12-84%) greater than expected (<10%)
- CH_3OOH SE varies with ice retention factor

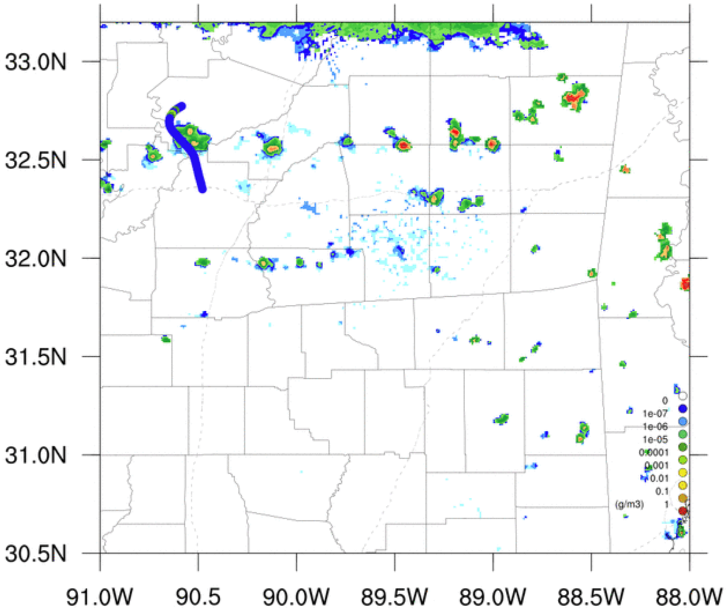
Case study

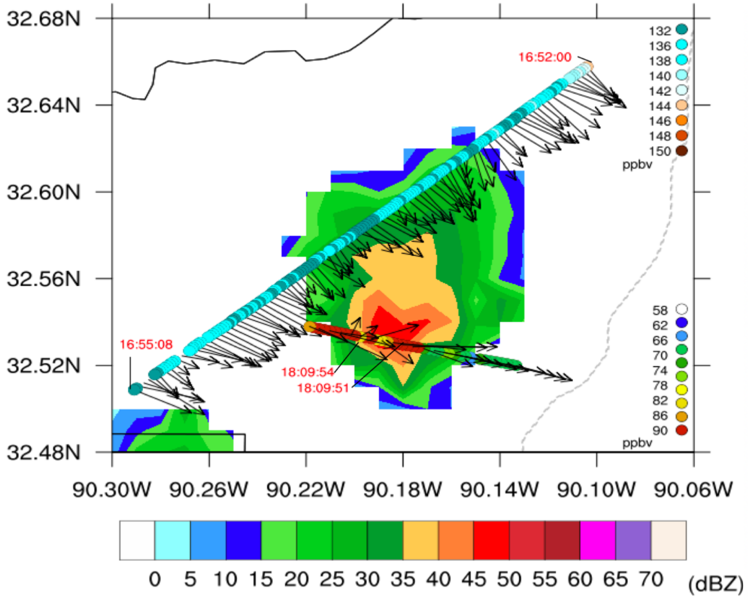
NASA SEAC⁴RS - Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys

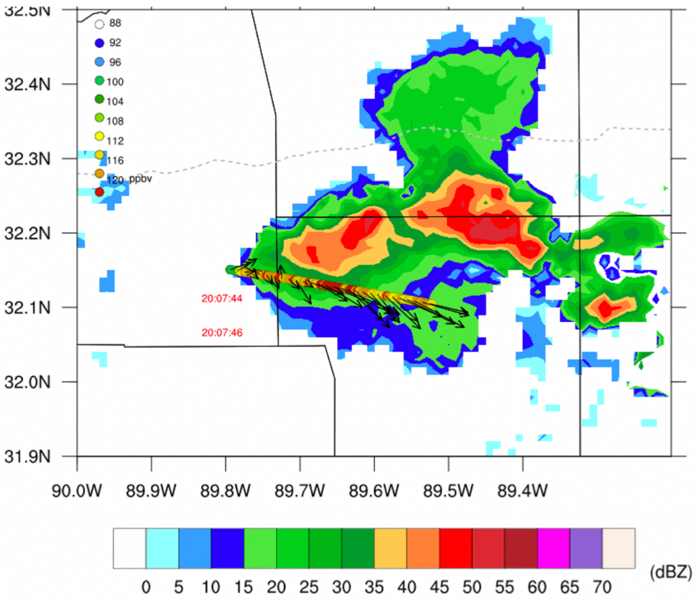
September 2, 2013 - Air mass thunderstorms



Reflectivity and Ice Water Content - 1735 (UTC)

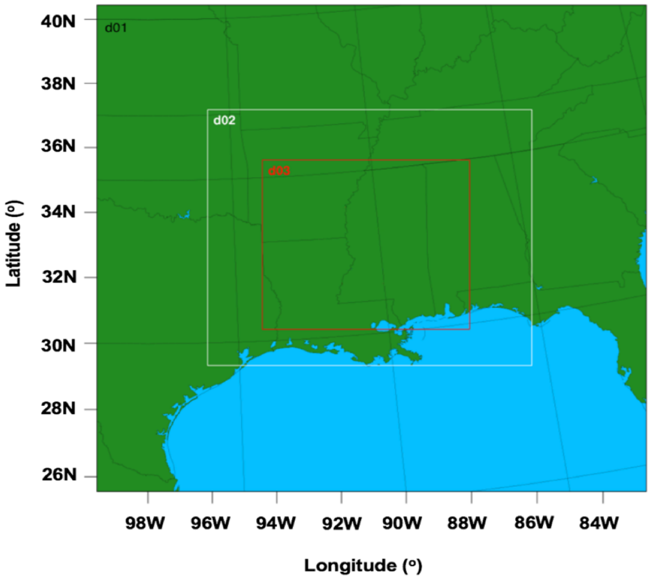


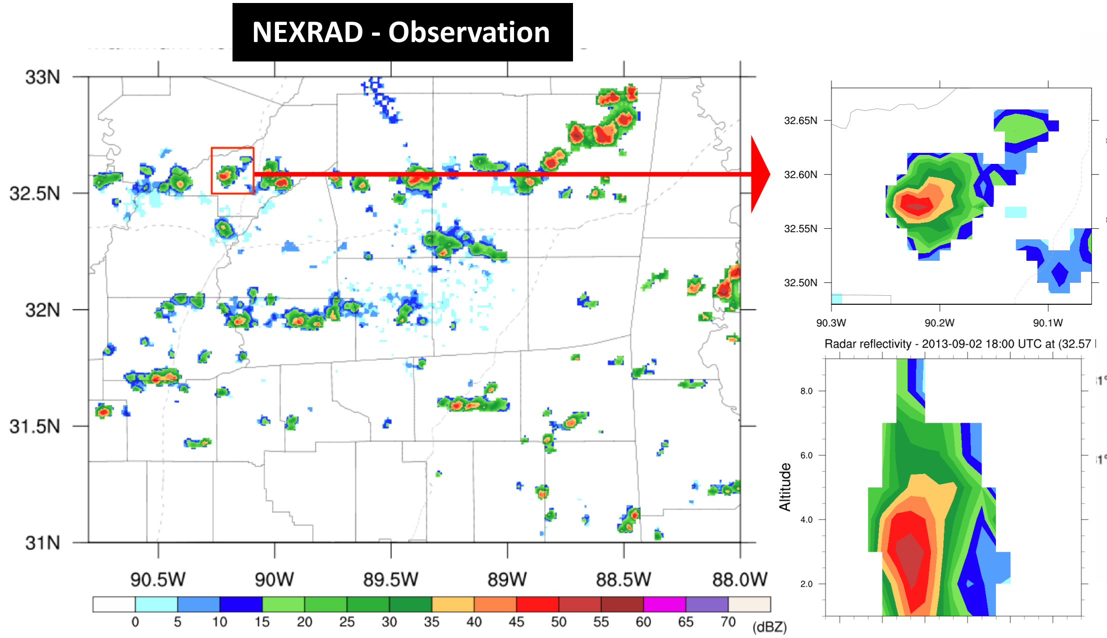


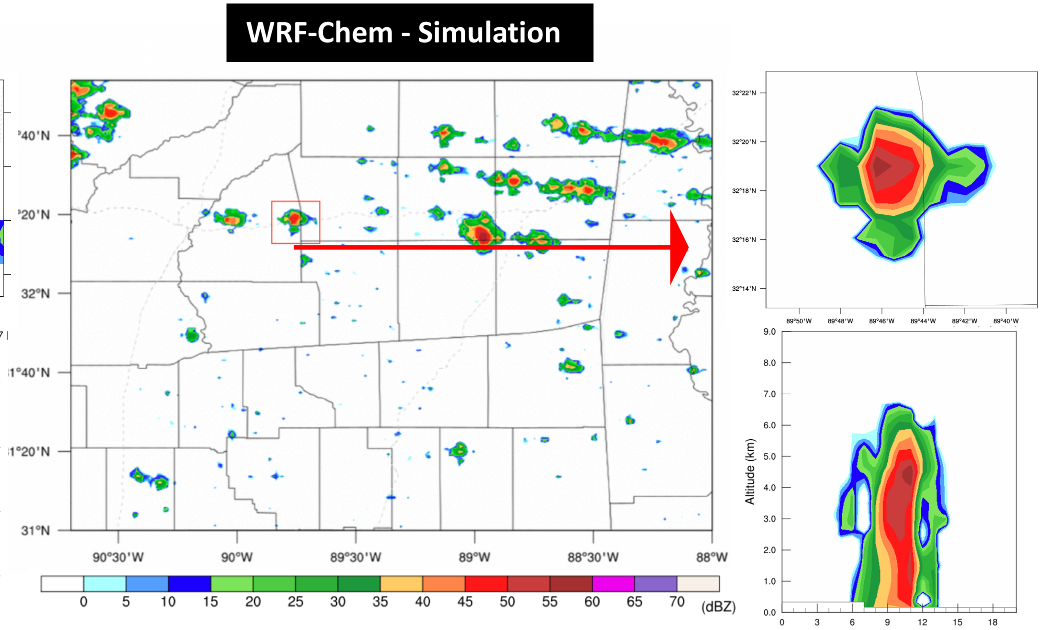


WRF-Chem simulation

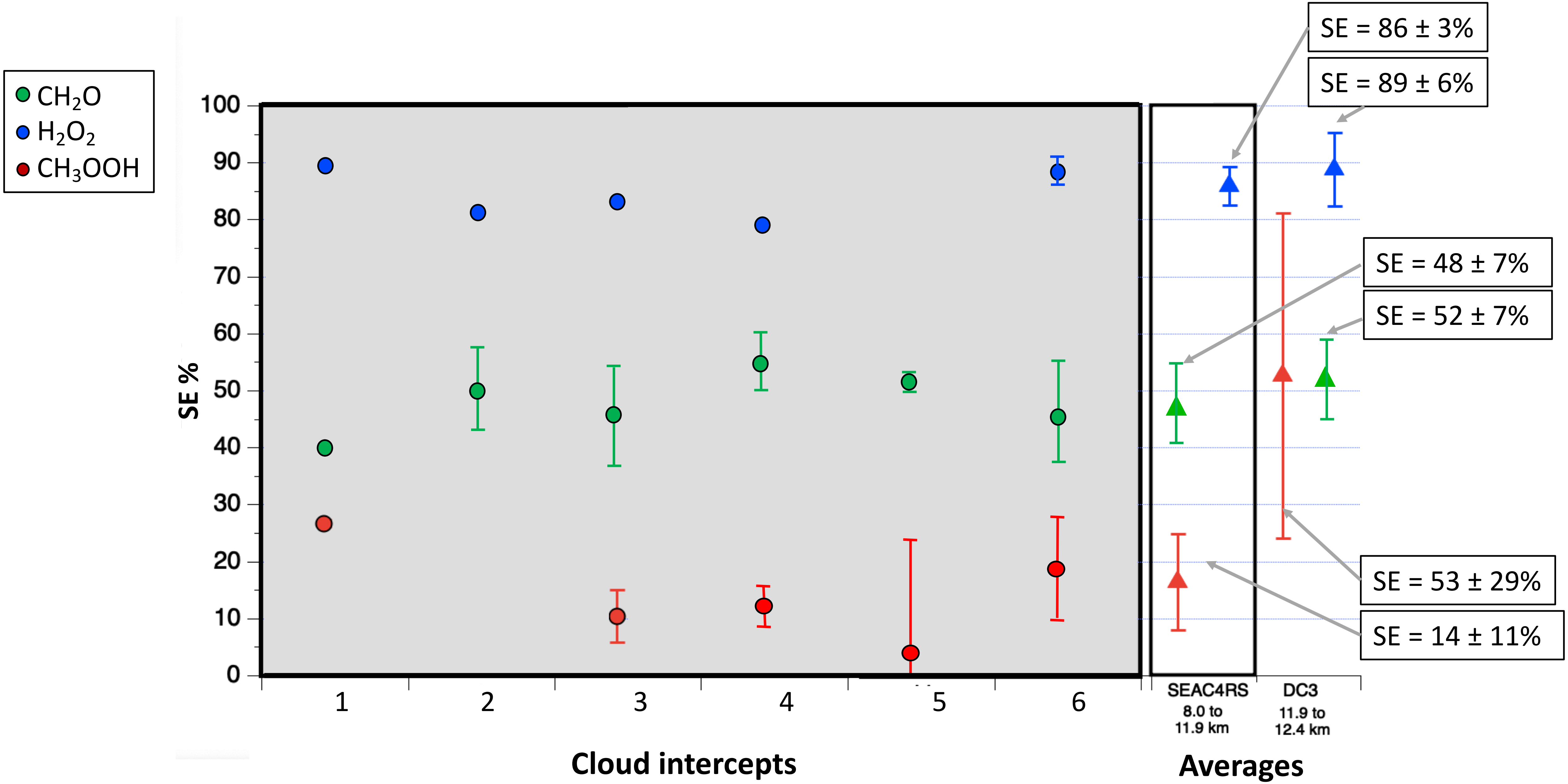
Domain	d01	d02	d03
WRF-chem Version	3.9.1 (released Feb 2018)		
Simulation period	From 09/02 at 06 UTC to 09/03 at 00 UTC		
Met. IB Cond.	North America Regional Reanalysis (NARR)		
Horizontal resol	12150m	4050m	1350m
Grid points (x,y)	145x136	256x214	490x424
Microphysics	Morrison two-moment scheme		
Short/Longwave rad	Rapid Radiative Transfer Model		
Land-surface	Noah Unified Land Surface Model (NOAH)		
Boundary layer	Yonsei University (YSU)		
Cumulus scheme	Kain-Fritsch	Kain-Fritsch	NONE
Initial cond. Chem.	CAM-chem		
Chem. mechanism	MOZART		
Biogenic emissions	MEGAN		
Anthropogenic emis.	NEI2011		
Wildfire emission	FINNv1		
Aerosols option	GOCART		





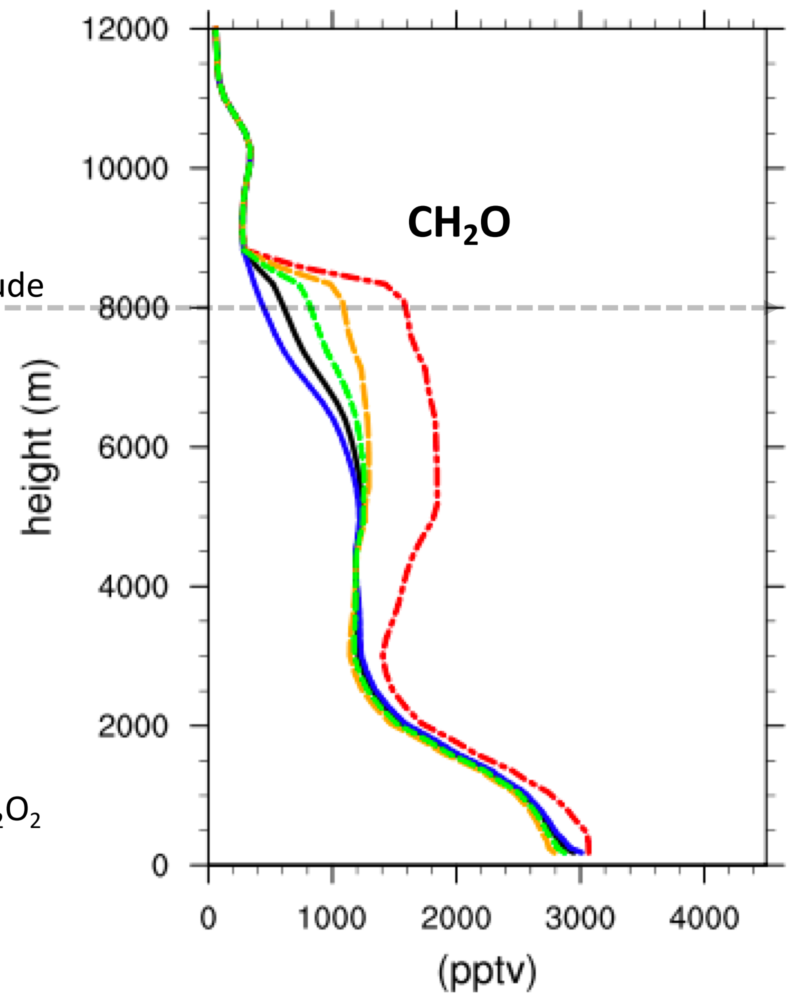


Observed Scavenging Efficiencies (SE) – CH_2O &Peroxides

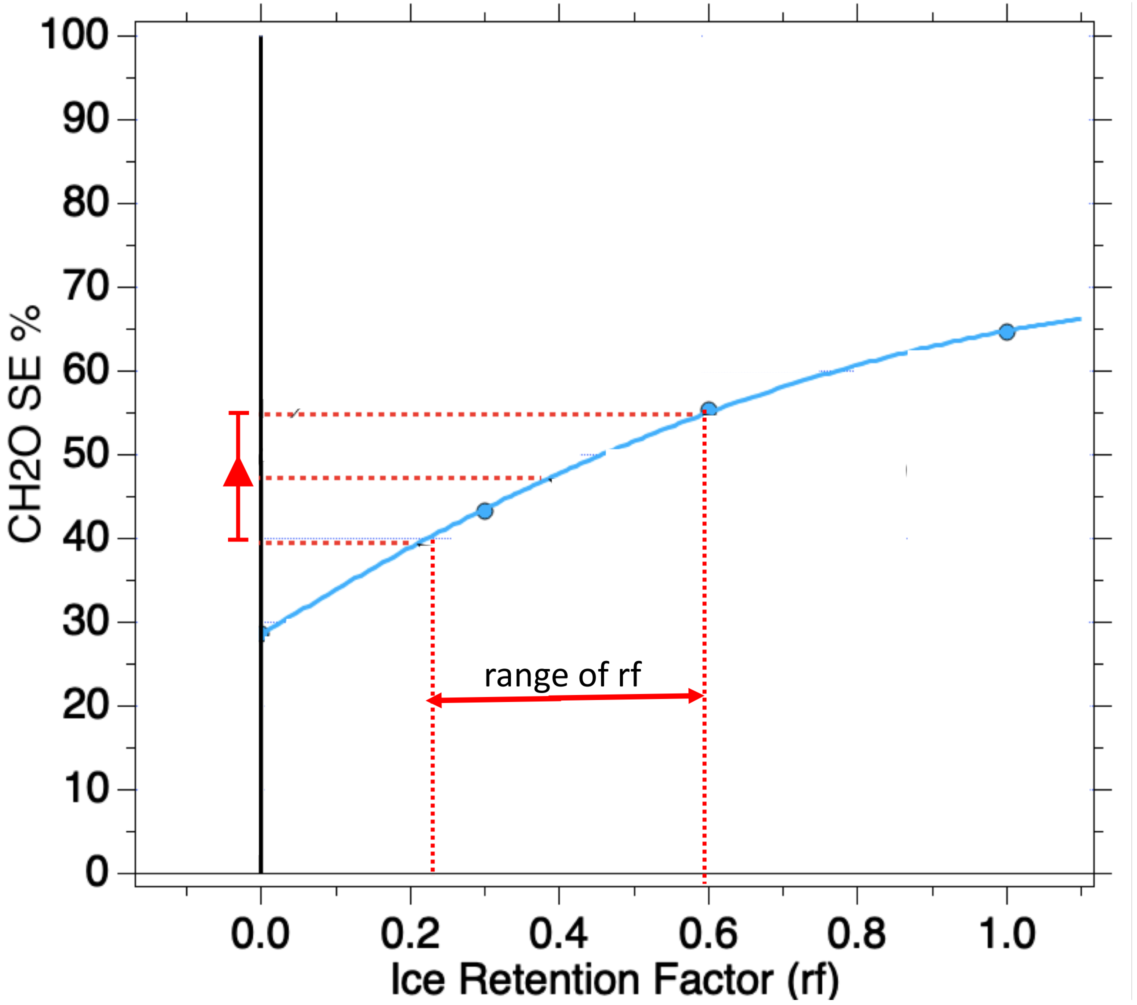


Ice retention, WRF-Chem

DC8 intercepts altitude



No scavenging
Scavenging, rf = 0
Scavenging, rf = 0.3
Scavenging, rf = 1
Scavenging,
rf = 0.6 for CH_2O and H_2O_2
rf = 0.02 for CH_3OOH



CH_2O **rf** is 0.3 - 0.6

DC3 found **rf** < 0.2 for severe storms

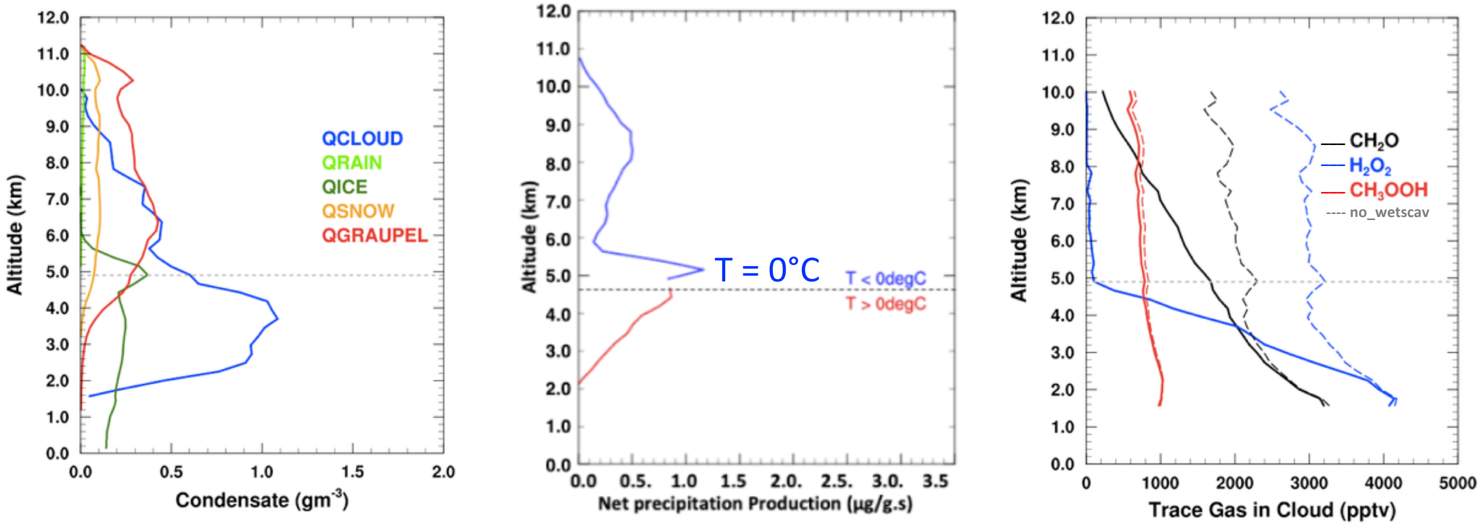
H_2O_2 **rf** is 0.2 - 0.4

DC3 found **rf** < 0.2 for severe storms

CH_3OOH **SE** is not sensitive to **rf** for SEAC4RS storms

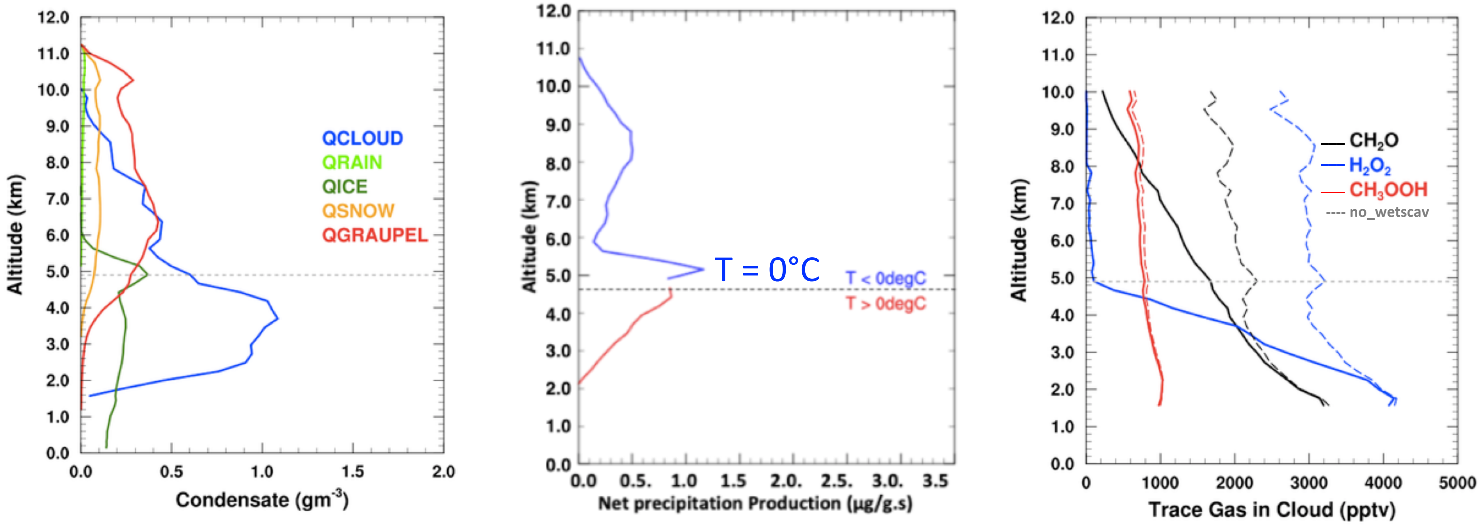
DC3 found **rf** = 1 for severe storms

Microphysics vs Scavenging Efficiency



- Although some differences in cloud physics between storms, modeled storms are not much different
  - Higher soluble trace gases are often removed below the freezing level

Microphysics vs Scavenging Efficiency



- Although some differences in cloud physics between storms, modeled storms are not much different
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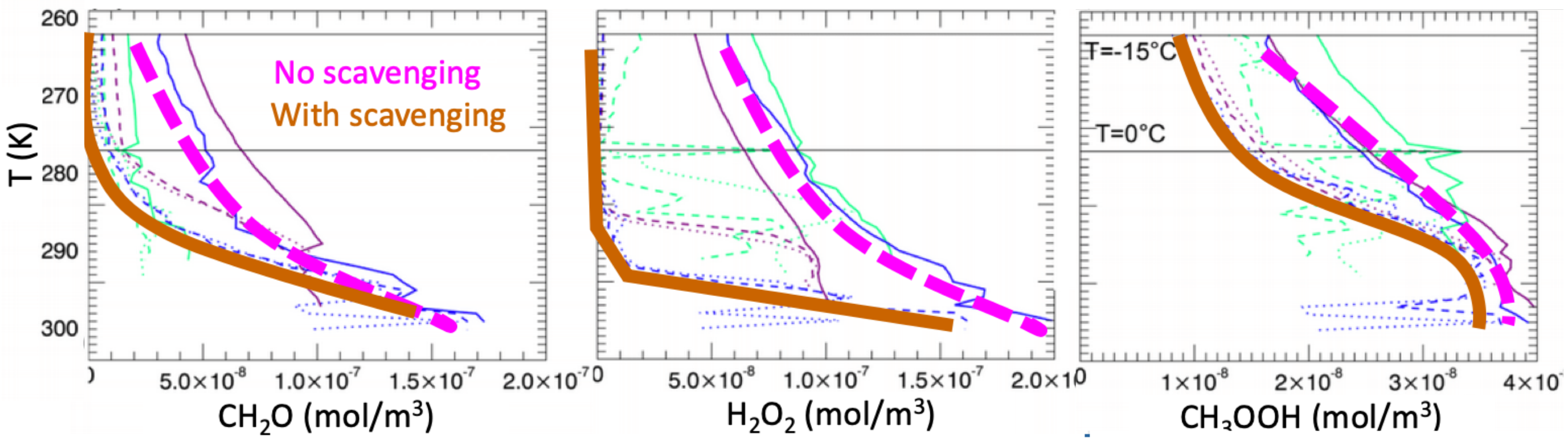
DC3 severe storms
Bela et al. (2018)



- Severe storms in DC3 removed more H_2O_2 and CH_2O below freezing level than SEAC[4]RS airmass and multicell storms

Conclusions

1. **WRF-Chem** satisfactorily represents small-scale convective storms and it is useful tool for **ER**, **SE**, and **rf** estimations.

	Observation	Modeling		
2. **CH_2O SEs**	42 – 54%	35 – 78%	similar to **DC3** results	**rf =** 0.3 - 0.6
H_2O_2 SEs	82 – 89%	69 – 100%	similar to **DC3** results	**rf =** 0.2 - 0.4
CH_3OOH SEs	3 – 25%	6 – 9%	smaller than **DC3** results but similar to earlier studies	**rf =** 0.02

3. **rf** for the **SEAC^{4}RS** storms differ slightly from those found in **DC3** severe storms. The smaller **SEAC^{4}RS** storms (**W** factors ~ 3 to 9 less) appear to have **less developed mixed phase regions** resulting in less production of precipitation from cloud water than more severe storms. This suggests that **rf** may be dependent on the **type of storm** or **stage of the storm development**.

4. **Retention** of dissolved trace gases in frozen precipitation more important to moderately soluble trace gases

Thank you!

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