WRF-Chem Simulations of Lightning-NO_x Production & Transport in an Oklahoma Storm during DC3

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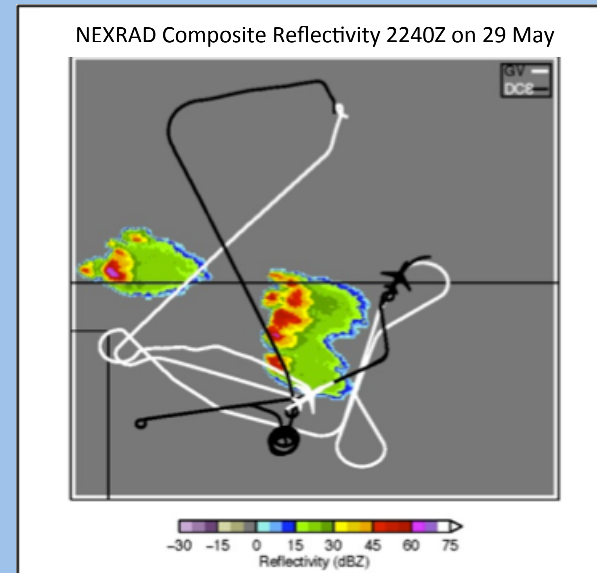
Key Objectives

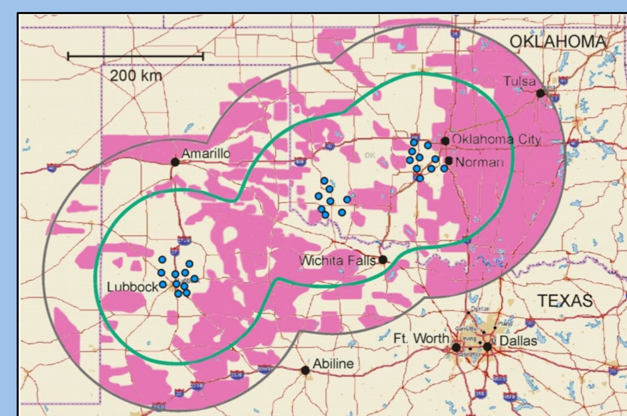
- Continuation of previous work, which:
  - Compared flashes generated by flash rate parameterization schemes (FRPSs) in a WRF-Chem model simulation with lightning observations:
    - Oklahoma Lightning Mapping Array (OK LMA)
    - National Lightning Detection Network (NLDN)
  - Tentatively concluded lightning-generated NO_x (LNO_x) production is around 125 moles $flash^{-1}$

- Current work objectives:
  - Define and incorporate new lightning flash channel vertical distributions and IC:CG ratios into the WRF-Chem model based on lightning data from a LMA for the storm of interest
  - Analyze distribution of observed and model-simulated trace gas species in storm inflow and outflow
  - Determine NO production scenario for IC and CG lightning

Background

- Severe convection developed ~21Z May 29 along KS/OK border and continued until 04Z May 30
- Aircraft sampled storm and its environment from 20Z May 29 to 01Z May 30
  - DC-8 focused on storm inflow & outflow
  - GV & Falcon concentrated on outflow
- Ground-based data included:
  - Dual-Doppler radar (NEXRAD level II regional)
  - Shared Mobile Atmospheric Research and Teaching Radar (SMART-Radar)
  - NLDN cloud-to-ground flash data
  - OK LMA flash initiation density data





Blue circles: LMA stations
Green outline: Extent of 3-D lightning mapping capability
Gray outline: Extent of 2-D lightning detection

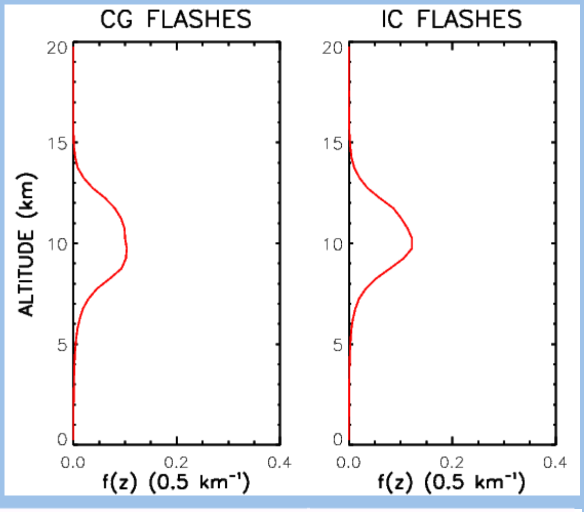
WRF-Chem Model V3.6.1

- Grid resolution: dx = dy = 1-km, dz = 50-250 m
- Initialized with 18Z NAM ANL (6-hr) for boundary conditions
- Lightning Data Assimilation from 18-21Z (*Fierro et al., 2012*)

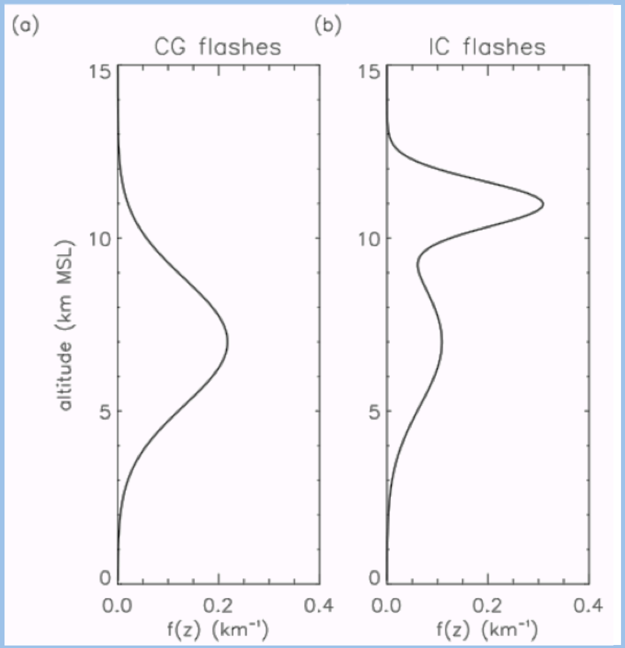
Type of Scheme	Selection for Simulation
Microphysics	Morrison
Planetary boundary layer	Yonsei University (YSU)
Land surface	Noah
Radiation (short & longwave)	Rapid radiative transfer model for GCMs (RRTMG)
Photolysis	F-TUV
Trace gas chemistry	MOZART
Flash rate	➢ Updraft volume based on AL supercells (UP510_S) ➢ Coarsely prescribed IC:CG ratios (*Boccippio et al., 2001*) replaced with IC:CG ratios based on LMA and NLDN obs
LNO_x	Flash segment vertical distribution based on observations

LNO_x Parameterization Scheme

- Replaced the typical lightning flash channel distributions (*DeCaria et al., 2000; 2005*) with observed IC & CG vertical distributions
  - Used flash channel segment data from observed storm's respective LMA network
  - IC & CG distributions for 29 May both appear to be single Gaussian where channels maximize at ~10km (-42°C)
  - Previous distributions were set to maximize the lightning channels at -15°C (IC & CG) and -45°C (IC), or 6km and 10.5km, respectively
- Found 125 moles flash^{-1} provided best fit with observed anvil NO_x when using *DeCaria et al.* vertical distributions. This scenario:
  - Is much smaller than mean value of 500 moles flash^{-1} found in previous mid-latitude simulations (*Ott et al., 2010*)
  - Will be tested using new distributions
- Horizontal placement of NO based on reflectivity ≥ 20 dBZ in each grid cell



New IC & CG distributions for 29 May case



DeCaria et al. (2000, 2005)

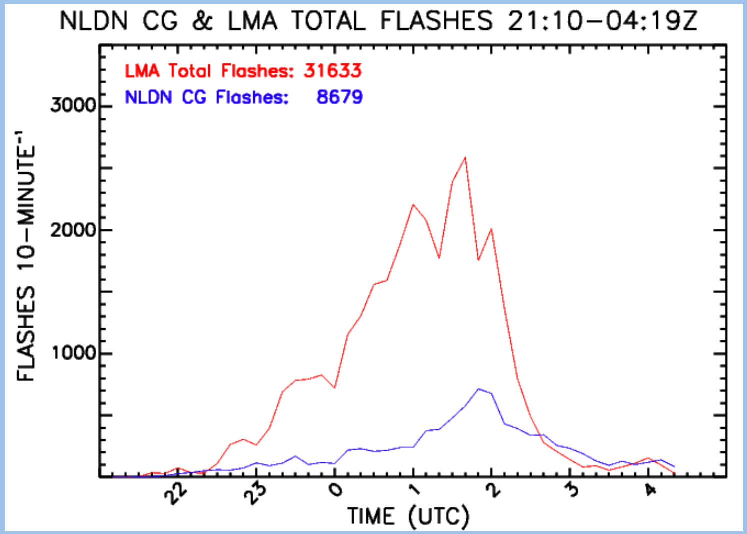
Methodology

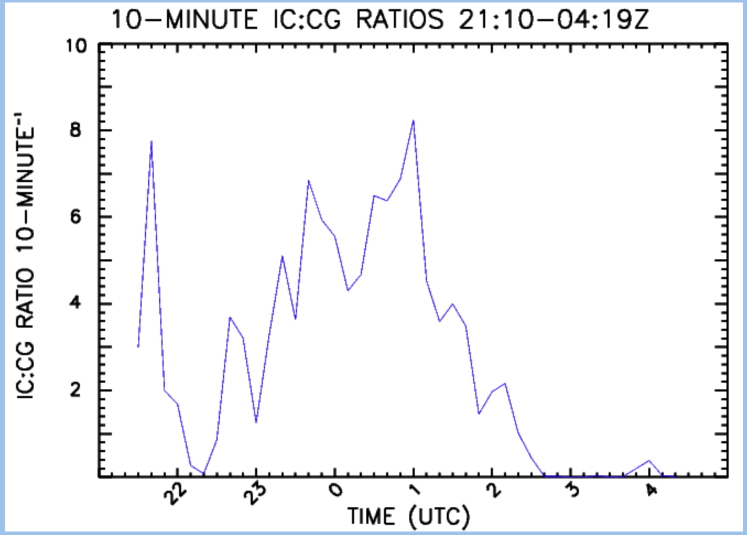
FRPS	Reference
Max vertical velocity (*Wmax*)	Price & Rind (1992)
Cloud top height (*CTH*)	Price & Rind (1992)
Updraft volume (*UpVol*)	Deierling & Petersen (2008)
Ice water path (*IWP*)	Petersen et al. (2005)
Precipitation ice mass (*PIM*)	Deierling et al. (2008)
Ice mass flux product (*IMFP*)	Deierling et al. (2008)
Graupel volume (*CSU_GEV*)	Basarab et al. (2015)
35-dBZ volume (*CSU_VOL35*)	Basarab et al. (2015)
Precipitation ice mass (*CSU_PIM*)	Basarab et al. (2015)
Graupel echo volume (-40°<T<-5°C; *ALGEV5*)	Carey et al. (2015)
ALGEV5 for supercells (*ALGEV5_S*)	L. Carey
Graupel echo volume (-40°<T<-10°C; *ALGEV10*)	Carey et al. (2015)
ALGEV10 for supercells (*ALGEV10_S*)	L. Carey
Updraft volume(w>5m s^{-1}, -40°C<T<-10°C; *ALUP510*)	Carey et al. (2015)
ALUP510 for supercells (*ALUP510_S*)	L. Carey

- Compared flash rate trends over the observed and model-simulated storm's lifetime
  - Used 15 different FRPS, including those from literature, as well as recently developed schemes from DC3 radar and LMA data
  - Selected the FRPS that reasonably represented the total observed flashes over the storm and the flash rate trends from the LMA
- Assumed LNO_x production is 125 moles $flash^{-1}$ and will adjust as necessary
- Analyzed trace gas species (i.e., CO, NO_x, O_3) using model-simulated values and aircraft (DC-8 & GV) observations to:
  - Create probability distribution function (PDF) plots in storm outflow
  - Evaluate convective transport
  - Determine best fit NO production scenario

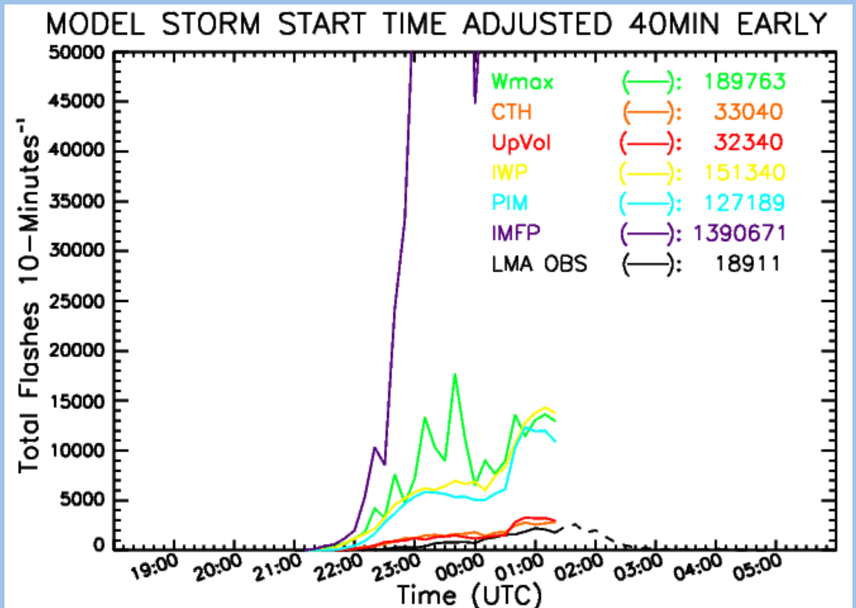
IC:CG Ratios

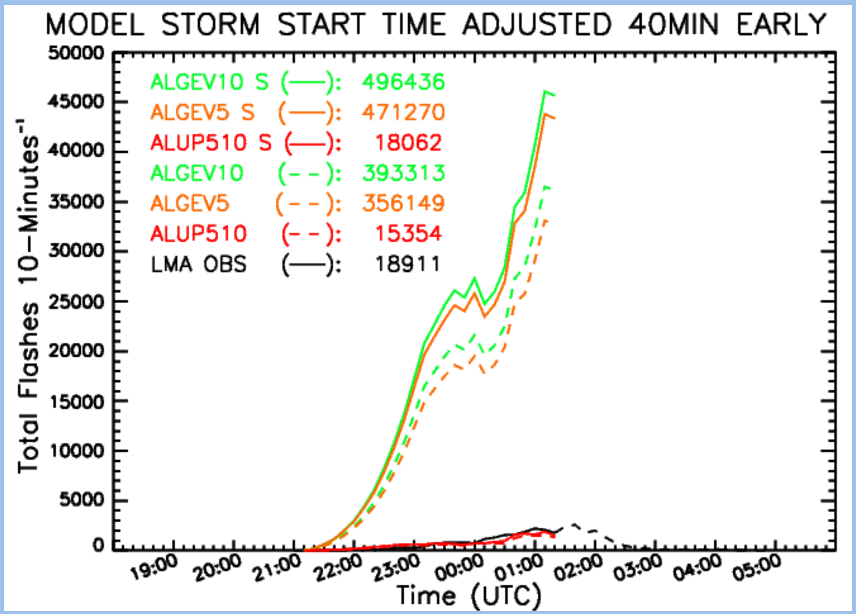
- Coarsely prescribed IC:CG ratios from *Boccippio et al. (2001)* provide a mean IC:CG of 3.90 ± 0.49 over the region where the severe convection occurred
- LMA total and NLDN CG flashes indicate the IC:CG ratio fluctuates over the lifetime of the convection on 29 May
  - Mean IC:CG ratio over storm lifetime is 2.73 ± 2.51
- Time evolving IC:CG ratios are applied in the model to the storm of interest, while climatological IC:CG values are used in the area surrounding the storm

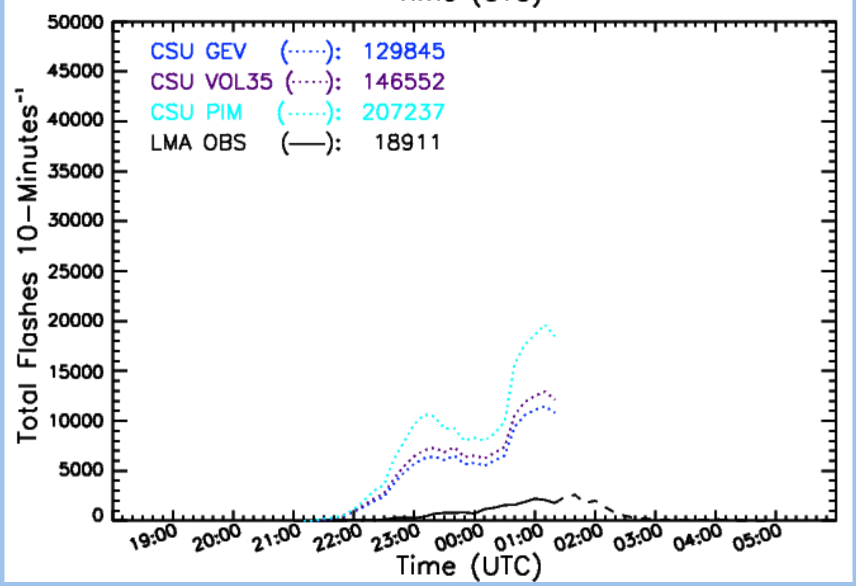




Model Flash Rates vs. Observations



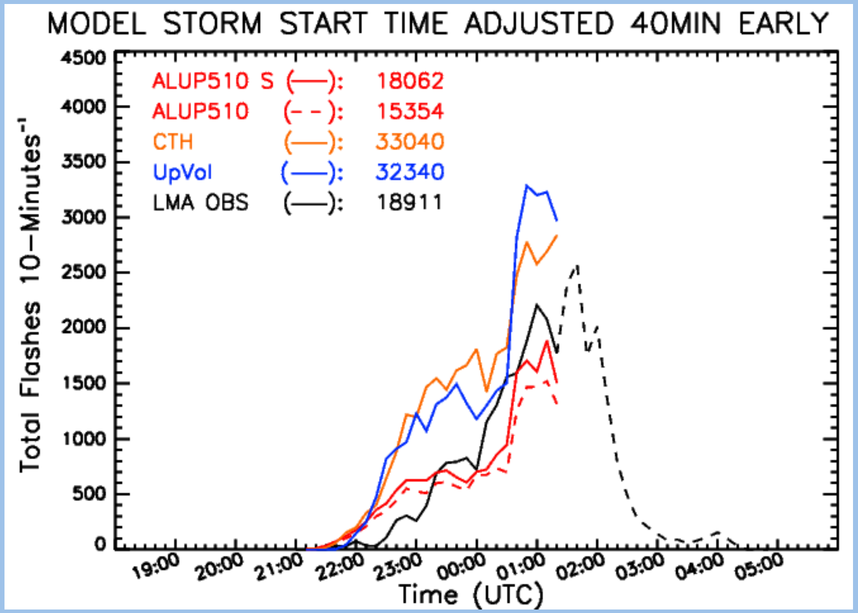




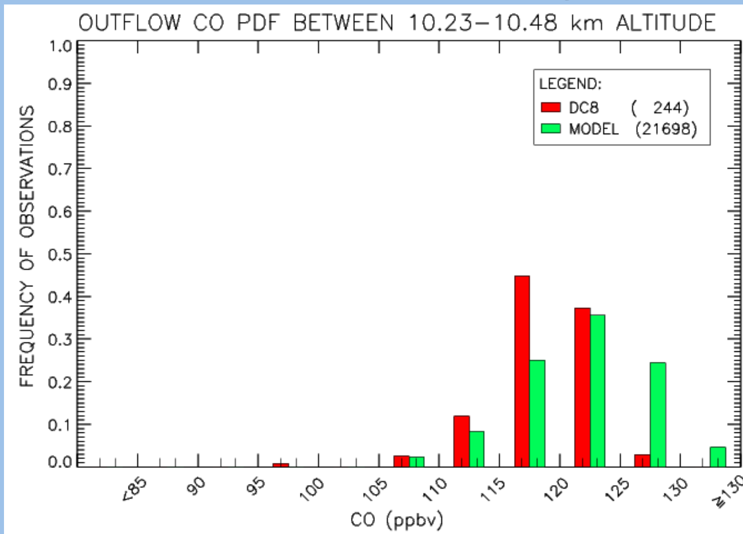
- Observed storm occurs 21:10-04:10 UTC
- Model-simulated storm onset is delayed 40 min (21:50 UTC)
- Plotted observed & model-simulated flash rates to both begin at 21:10 UTC

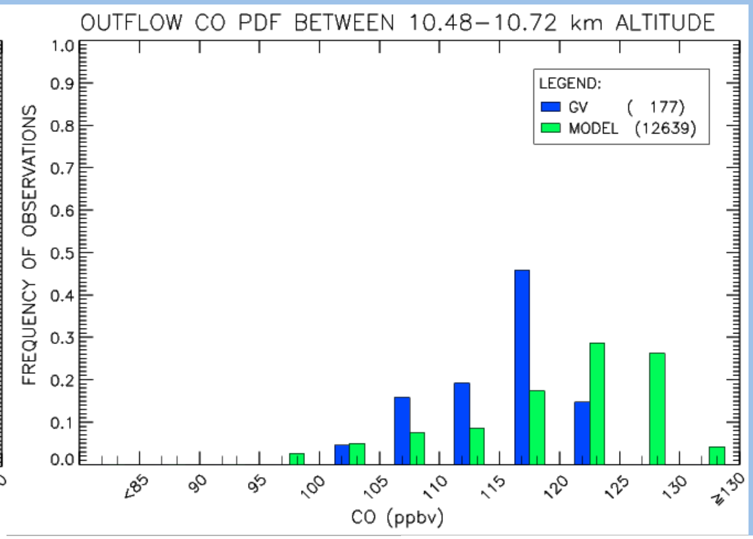
Model Flash Rates vs. Observations

- Selected the updraft volume FRPS for Alabama supercells (ALUP510_S) for use in model
  - Based on updraft ($w > 5$ m s^{-1}) volume and mixed-phase region (-40°C < T < -10°C)
- All FRPSs incorporating hydrometeors overestimate (*by 7-74x*) the total flash observations
- All FRPSs developed for the Colorado region overestimate (*by 7-11x*) the total flash observations
  - 35-dBZ volume was generally developed from storms with shallow warm cloud depths (< 1km), while the 29 May case has a deep warm cloud depth (2.5km)



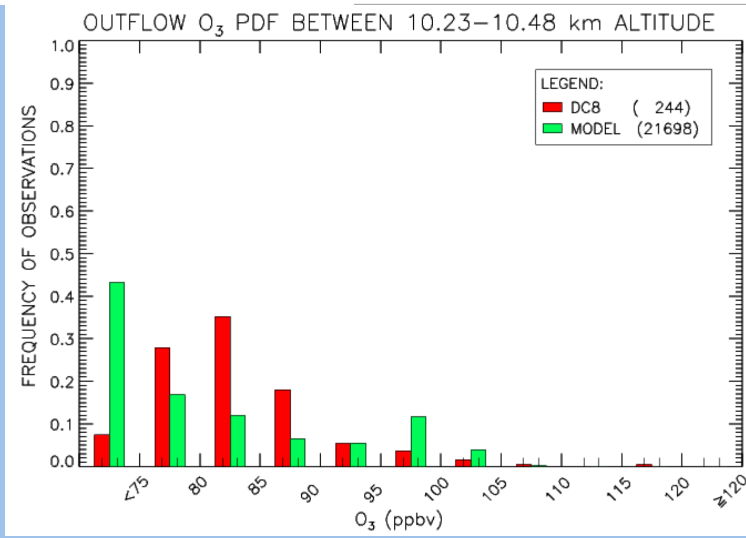
CO & O_3 PDFs in Storm Outflow

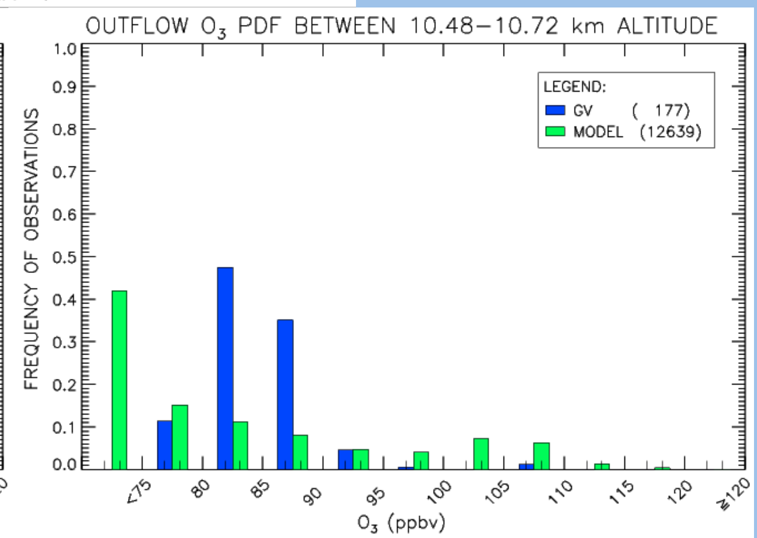




Model-simulated CO peaks at <u>larger</u> values than observations

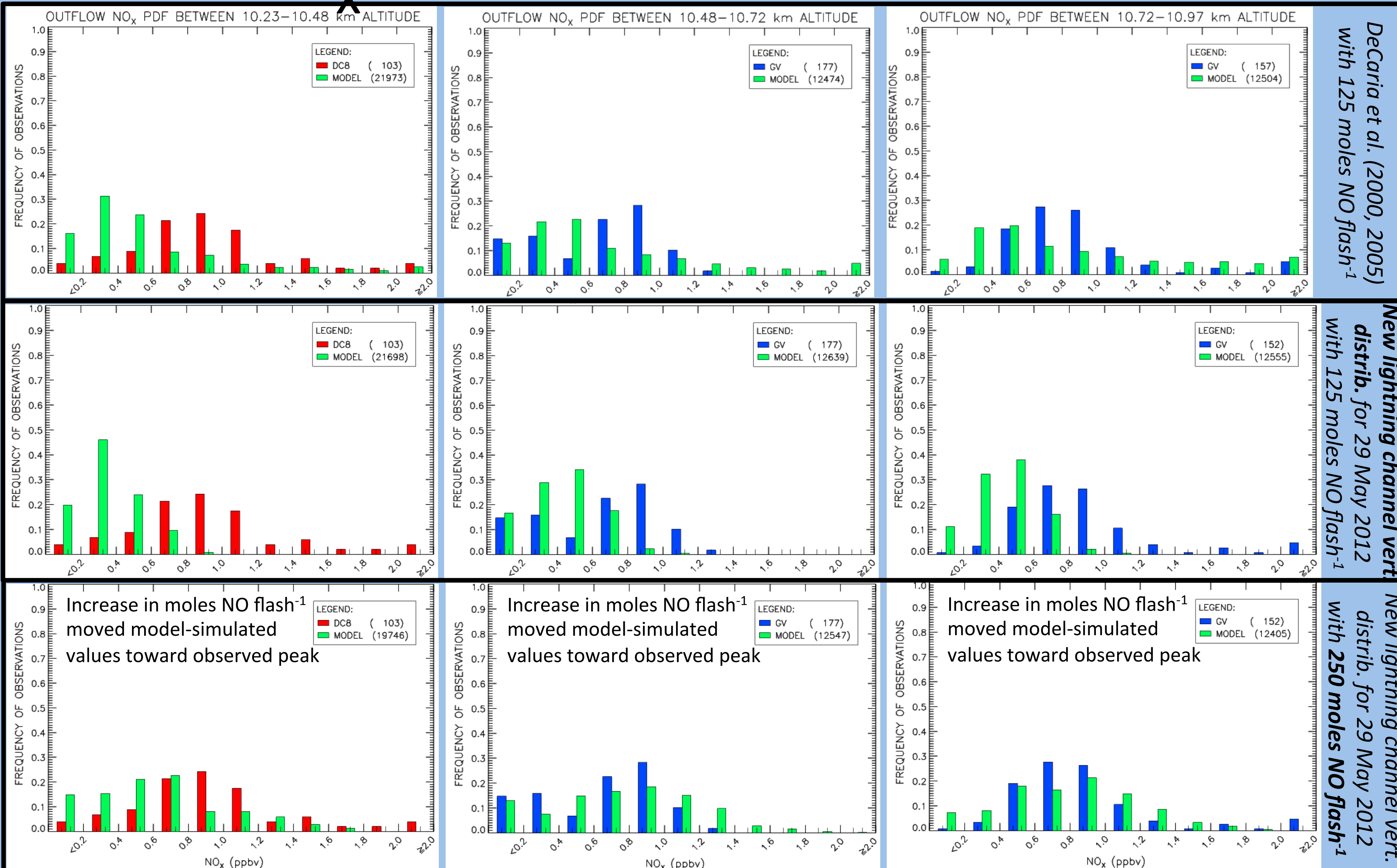
Model-simulated O_3 peaks at <u>smaller</u> values than observations





* Comparison of peak vertical velocities (*not shown*) suggests model-simulated values may be 20% greater than the SMART-Radar observations

NO_x PDFs in Storm Outflow



Conclusions

- A single model domain at fine resolution (1-km) produces a storm of roughly the same size and with similar characteristics as the observed
- FRPSs based on hydrometeors or Colorado storms are not ideal for the severe Oklahoma convection observed on 29 May
  - Selected a FRPS based on **updraft volume ($w > 5$ m s^{-1}) within the mixed-phase region of Northern Alabama supercells**
- LNO_x production may be closer to **250 moles flash^{-1}**
  - Removed influence of an IC upper lightning channel on NO_x by replacing the IC & CG vertical distributions (*DeCaria et al. 2000, 2005*) with observed lightning channel distributions from 29 May
  - May be less than the mean value for mid-latitude storms (*500 moles flash^{-1}*) due to presence of smaller flashes

Future Work

- 29-30 May 2012 Oklahoma severe convection:
  - Finalize NO production scenario for IC and CG LNO_x scheme
  - Test other NO production scenarios from the literature and compare against the scenario selected for 29 May
    - 500 moles $flash^{-1}$ (*Ott et al., 2010*)
    - Lightning Nitrogen Oxides Model (LNOM) results for IC & CG flashes (*Koshak, 2014*)
  - Investigate O_3 changes within the cloud and downwind of the storm
- 6-7 June 2012 Colorado squall line:
  - Test and select one of the 15 FRPSs in the WRF model
  - Determine NO production scenario for IC and CG LNO_x scheme
  - Investigate O_3 changes within the cloud and downwind of the storm
- Compare the results between the storms to:
  - Investigate which FRPSs are most appropriate for the two types of convection
  - Examine the variation in LNO_x production
- Compare simulated LNO_x results from WRF-Chem with other previously studied mid-latitude thunderstorms

Acknowledgements

- Regional NEXRAD level II data provided by Cameron Homeyer (NCAR)

- NLDN data collected by Vaisala, Inc. and archived by NASA MSFC

QUESTIONS?

Photo by C. Cantrell

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