A WRF-Chem Flash Rate Parameterization Scheme & LNO_x Analysis of the 29-30 May 2012 Convective Event in Oklahoma during DC3

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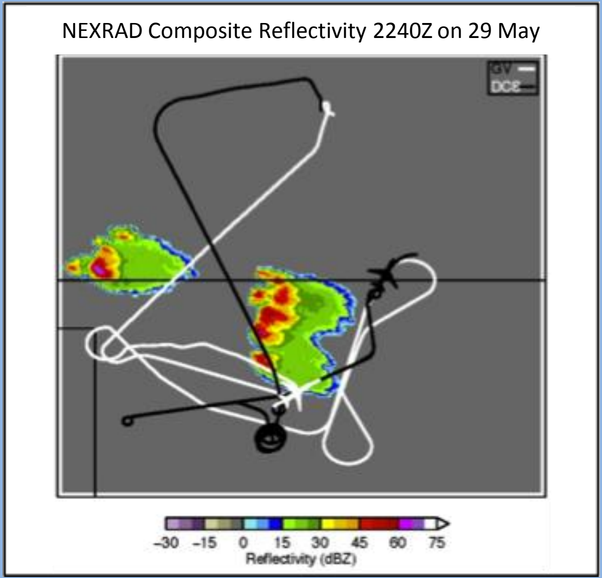
Photo by C. Cantrell

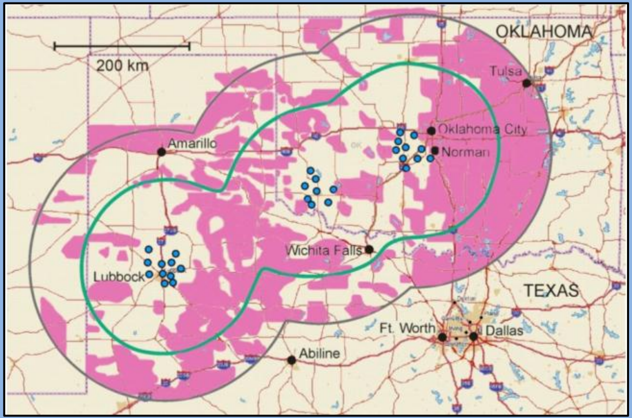
Key Objectives

- To study the 29-30 May 2012 deep convective storm observed during the Deep Convective Clouds and Chemistry (DC3) experiment over Oklahoma, including its:
  - Convective transport of trace gases
  - Associated lightning occurrence and nitrogen oxide (NO_x) production
- Simulate the observed storm using WRF-Chem
- Compare the physical features of the simulated storm against aircraft and ground-based observations
- Add flash rate parameterization schemes (FRPSs) to the model and identify the best match to observations
- Determine NO production scenario for IC and CG flashes following a lightning-generated NO_x (LNO_x) scheme

Background

- Storm system 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 and outflow
  - GV and Falcon concentrated on outflow
- Ground-based instrumentation included:
  - Dual-Doppler radar (NEXRAD level II regional)
  - National Lightning Detection Network (NLDN) cloud-to-ground flash data
  - Oklahoma Lightning Mapping Array (LMA) flash initiation density data

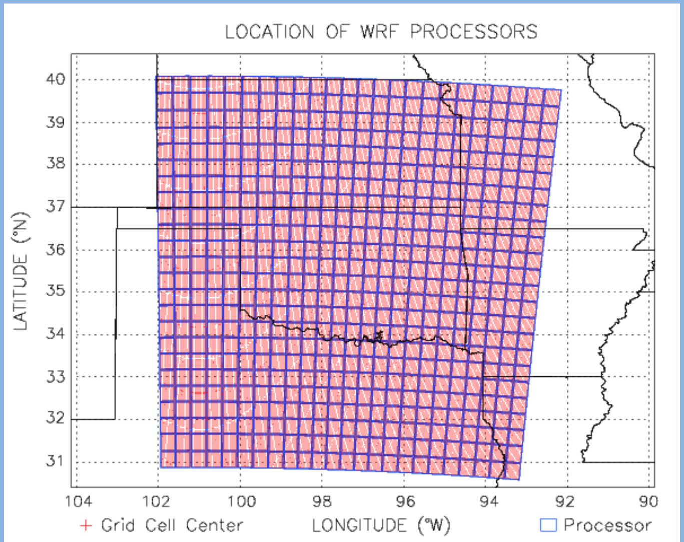




Blue circles: LMA stations
Green outline: Extent of 3-D lightning mapping capability
Gray outline: Extent of 2-D lightning detection

WRF-Chem Model V3.5

- Nested domains: 15-km and 3-km
- Initialized with DART and GFS for boundary conditions
- Used coarsely prescribed IC:CG ratios (*Boccippio et al., 2001*)



Type of Scheme	Selection for Simulation
Microphysics	Morrison
Planetary boundary layer	Mellor-Yamada-Janjic (MYJ)
Radiation	Rapid radiative transfer model for GCMs (RRTMG)
Flash rate	Maximum vertical velocity (W_{max})
Lightning-generated NO_x (LNO_x)	DeCaria et al. (2000, 2005)

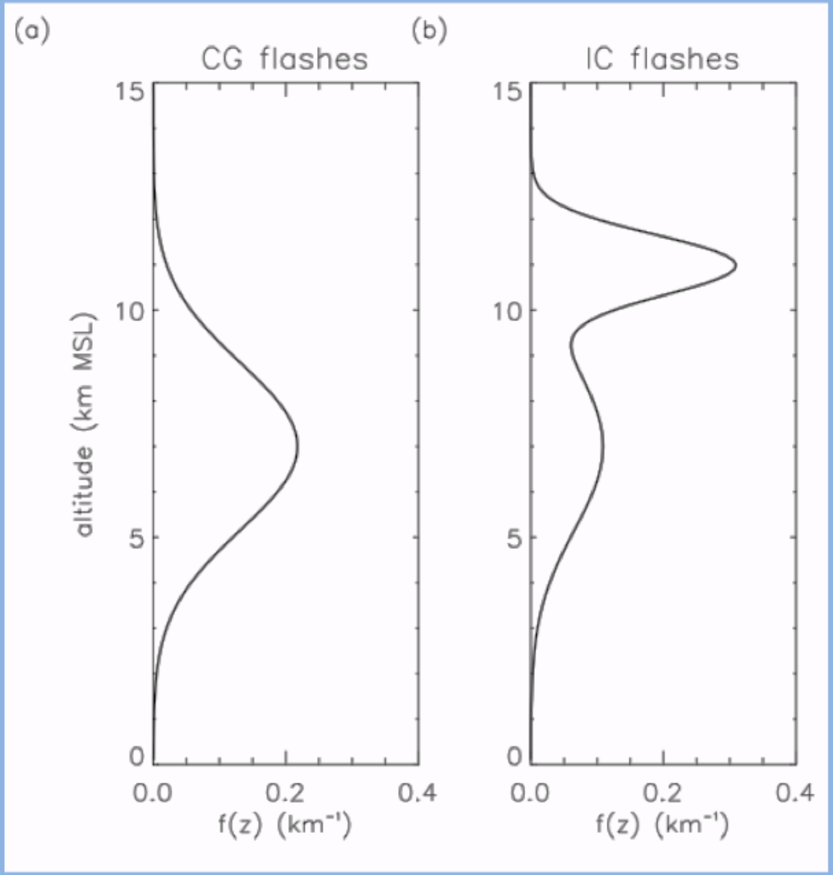
Flash Rate Parameterization Schemes

- Based on simulated thunderstorm's physical features
- Six types have previously been used in cloud-resolving models:

Type of FRPS	Equation (flashes min^{-1})	References
Maximum vertical velocity	$5.0 \times 10^{-6} \times W_{max}^{4.5}$	Price & Rind, 1992
Cloud top height	$3.44 \times 10^{-5} \times H^{4.9}$	Price & Rind, 1992
Updraft volume	$6.75 \times 10^{-11} \times w_5 - 13.9$	Deierling & Petersen, 2008
Ice water path	$33.33 \times IWP - 0.17$	Petersen et al., 2005
Ice mass flux product	$9.0 \times 10^{-15} \times (f_p \times f_{np}) + 13.4$	Deierling, 2006; Deierling et al., 2008
Precipitation ice mass	$3.4 \times 10^{-8} \times p_m - 18.1$	Deierling et al., 2008

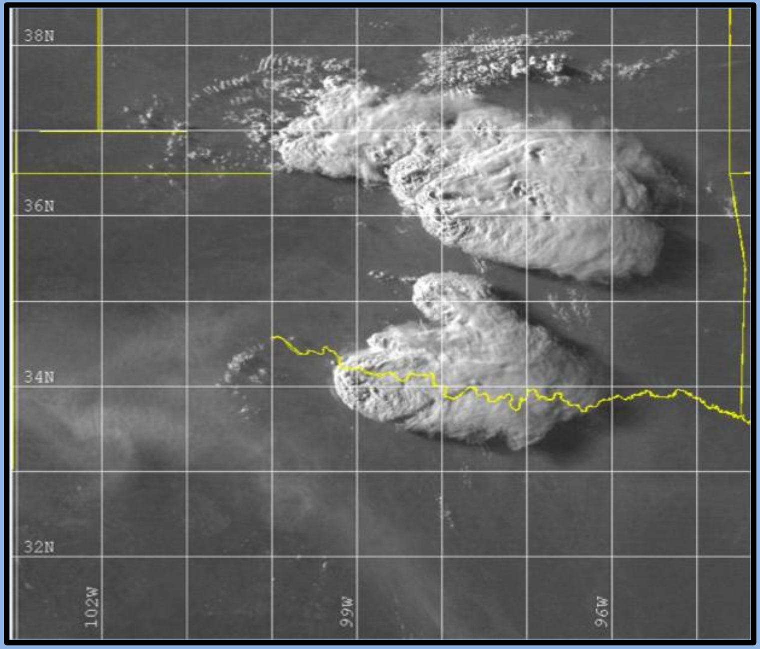
LNO_x Parameterization Scheme (DeCaria et al., 2005)

- Gaussian vertical distribution of IC (bimodal) and CG (single mode) NO production based on typical lightning flash channel distributions
- Lightning channels set to maximize at -15°C (CG and IC) and -45°C (IC)
- 500 moles NO per IC and CG flash (*Ott et al., 2010*)
- Horizontal placement of NO based on reflectivity ≥ 20 dBZ in each grid cell



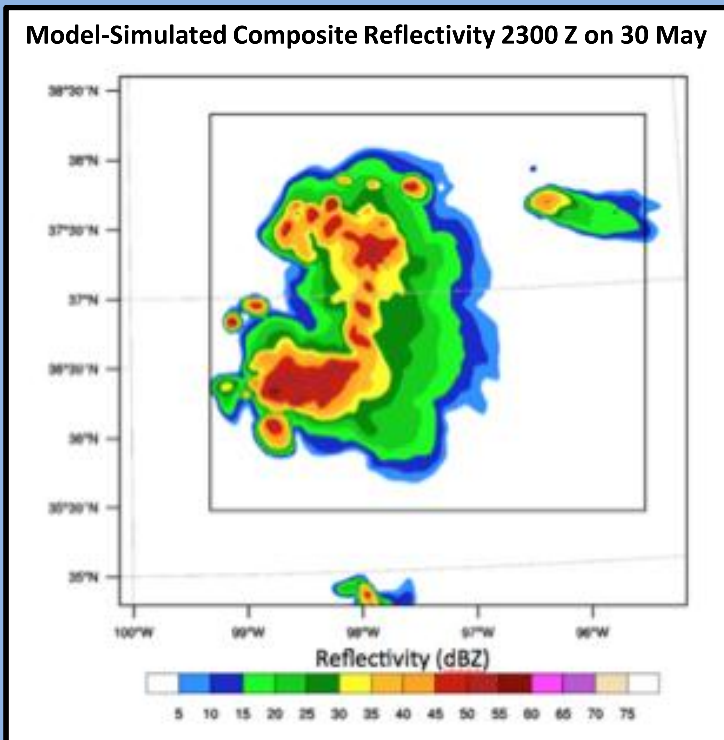
Methodology

- Compared flash rate trends over the observed (OK LMA and NLDN) and model-simulated storm's lifetime
- Created moving spatial masks at 10-min intervals for comparison of observed and model-simulated storms
- Used offline calculations, with adjustment factors, to analyze the six FRPS trends
- Calculated NLDN total flashes given NLDN CG flashes and mean IC:CG ratio for the storm region (3.9 ± 0.49), which is based on Boccippio et al. (*2001*)

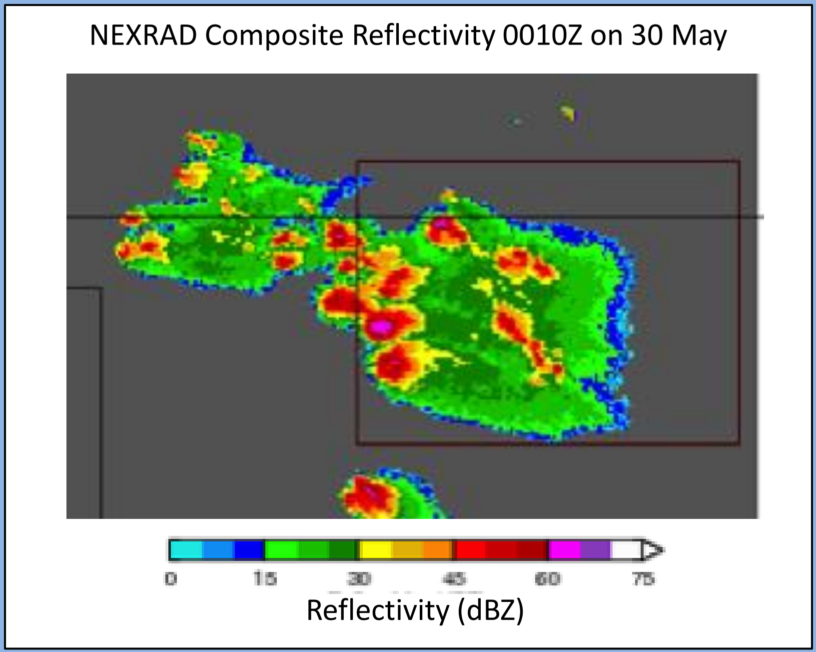


GOES-13 1-km Visible at 0008Z (NCAR/EOL)

Comparison of Storm Features from Initial Simulation



Black rectangle represents the spatial mask surrounding the model-simulated cell of interest at 2300Z May 30



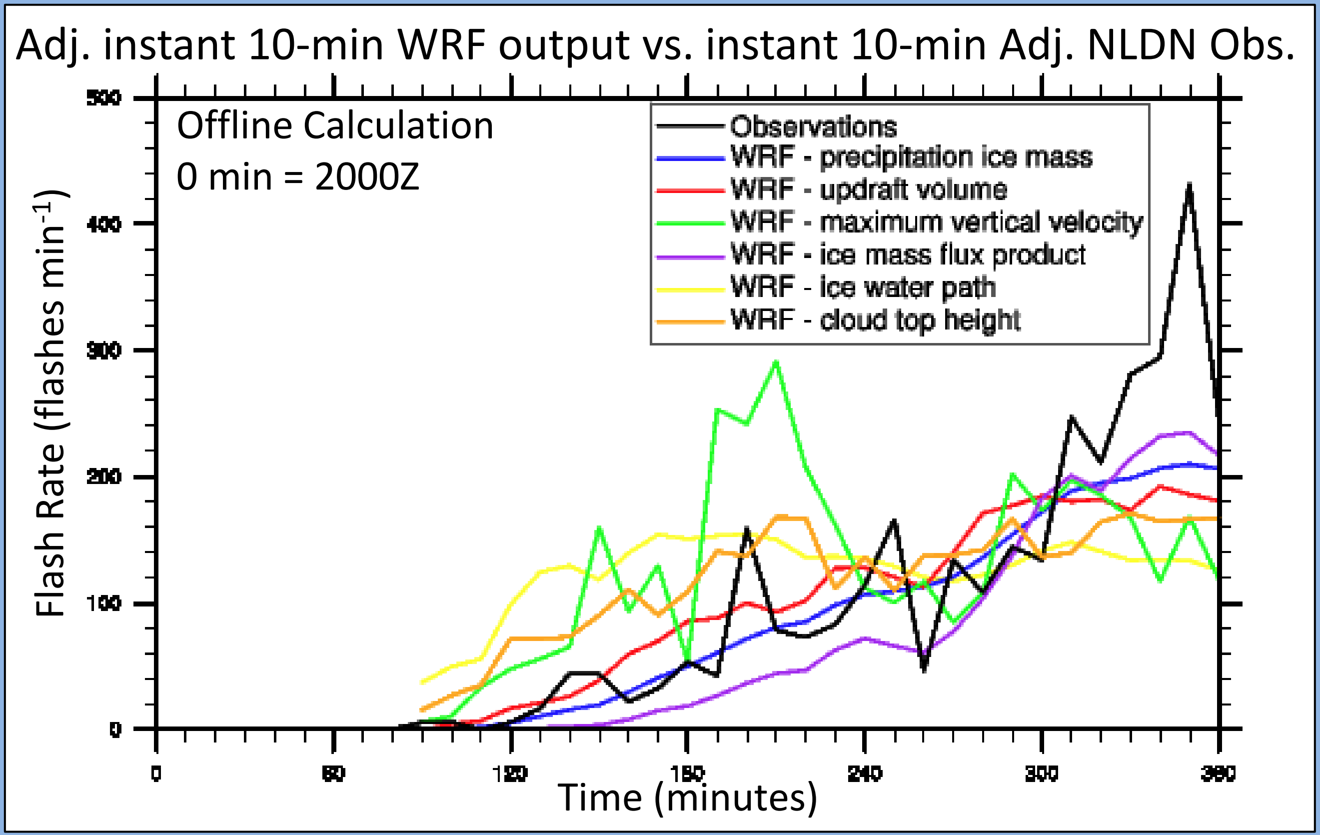
Red rectangle represents the spatial mask surrounding the cell of interest at 0010Z May 30

Model-simulated storm:

- Began ~1-1.5 hour before observed storm
- ***Exceeds*** area of observed storm by roughly a factor of two

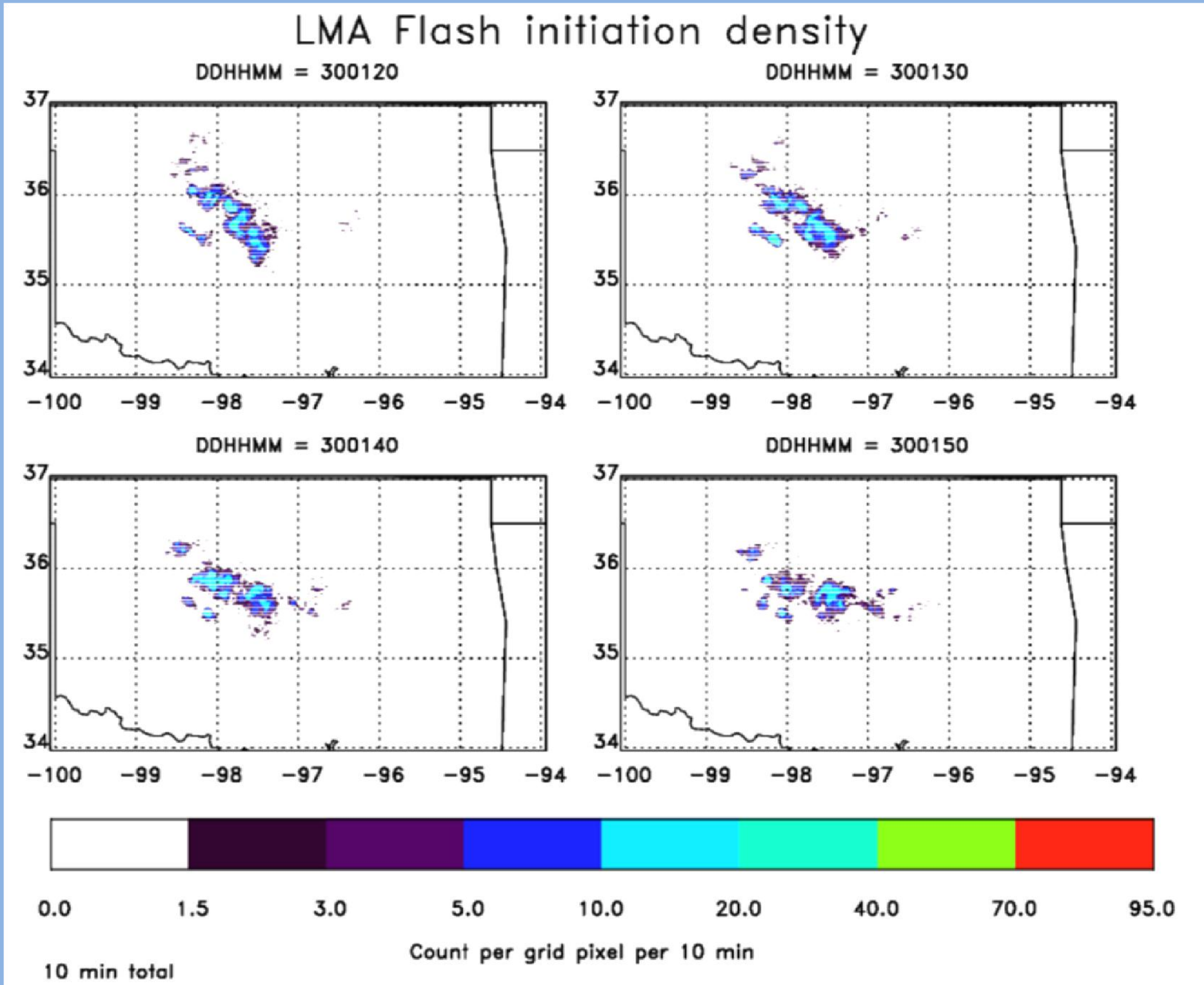
Compared instantaneous flash rates from WRF at 10-min intervals with corresponding 1-min periods from the observed NLDN flash rates

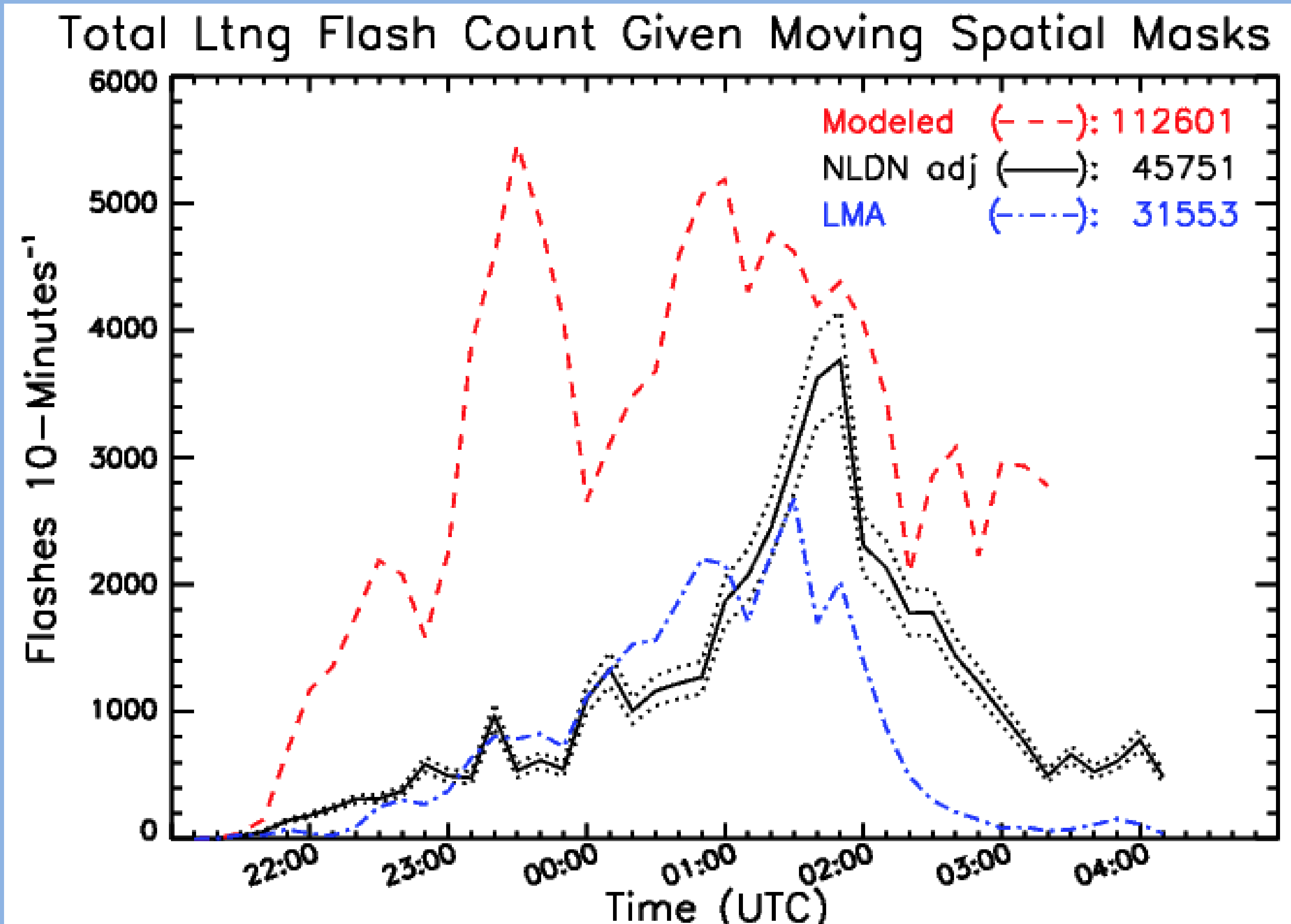
Model-simulated flash rate trends are adjusted 90 minutes later to coincide with observations



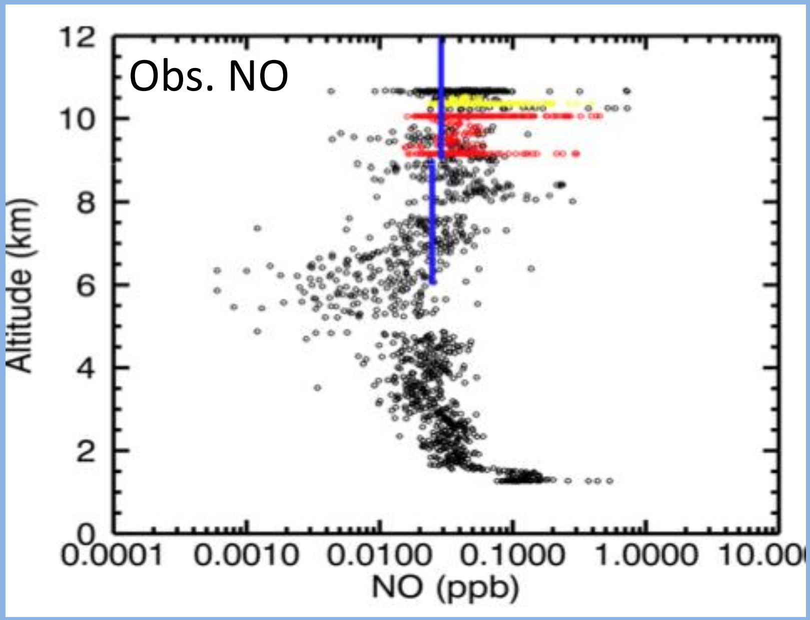
Flash Rate Parameterization Scheme	Total Flashes Prior to Scaling	Scaling Factor
Maximum vertical velocity	**3,951**	**1.1310**
Cloud top height	708	6.3138
Updraft volume	21,118	0.2116
Ice water path	**4,452**	**1.0035**
Ice mass flux product	36,745,336	0.0001
Precipitation ice mass	164,749	0.0271

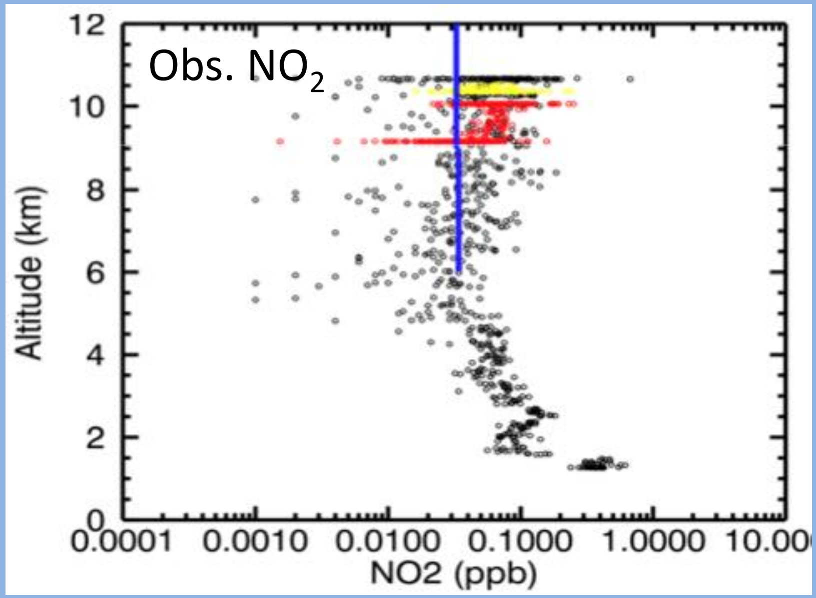
- *Flux product*, *precipitation ice mass*, and *updraft volume* trends are similar to the increasing trend of observations
- Timing of W_{max} and *ice water path* peaks is similar to observations (140, 200, & 310 min)
- Magnitude of observed primary peak greater than those in FRPSs
- W_{max} and *ice water path* schemes need the least adjustment to match observed total flashes at each 10-min interval (4,468 flashes)


LMA Flash initiation density
DDHHMM = 300120
DDHHMM = 300130
DDHHMM = 300140
DDHHMM = 300150
37
36
35
34
−100
−99
−98
−97
−96
−95
−94
0.0
1.5
3.0
5.0
10.0
20.0
40.0
70.0
95.0
Count per grid pixel per 10 min
10 min total



W_{max} FRPS <u>*overestimates*</u> the total flashes of both the NLDN (~2.5) and LMA (~3.5)





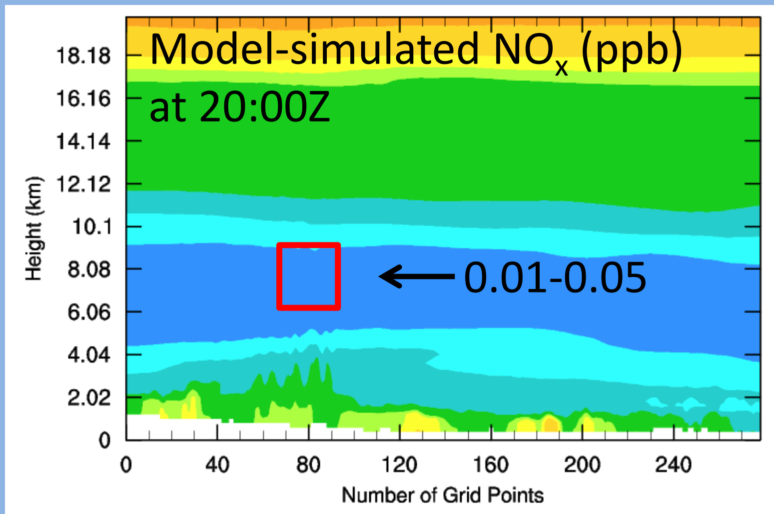
Observations taken in cloud-free air to the south of the storm system

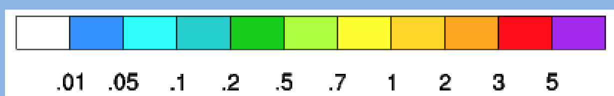
To define the real background air at 9-12 km, the 10th percentile is used to remove any influence from old convective outflow

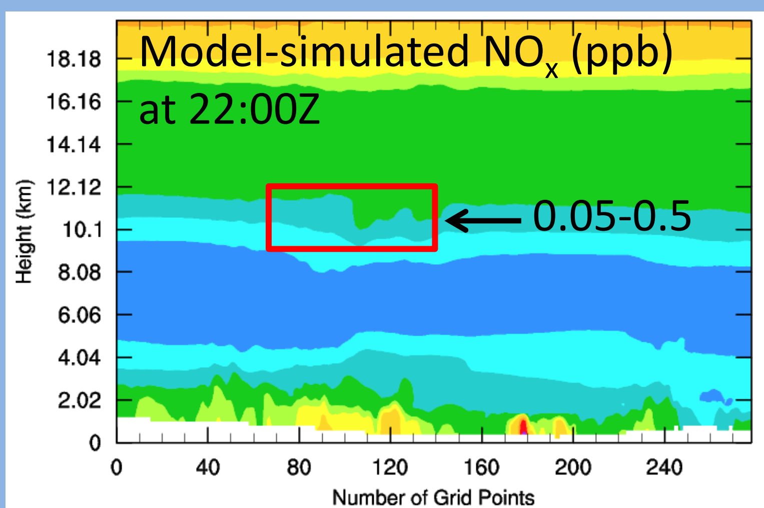
Aircraft	Time of UT Background Sampling (Z)
DC-8	20:40-21:10 (black)
GV	22:15-22:30 (red); 22:58-23:05 (yellow)

Obs. Species	6-9 km (*DC-8*)	9-12 km (*DC-8, GV*)
	Median (ppb)	10th percentile (ppb)
NO	0.025	0.029
NO_2	0.034	0.033
NO_x	0.059	0.062

**Plots courtesy of M. Bela*







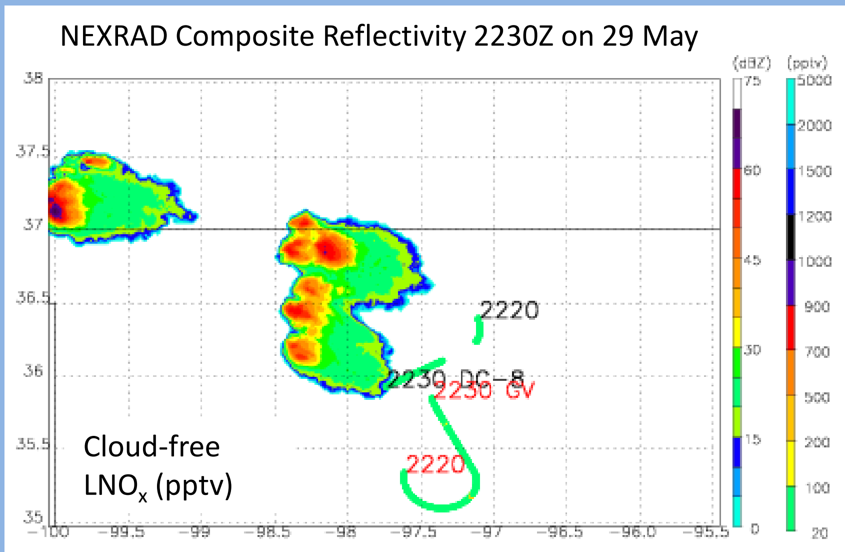
Model-simulated vertical cross-section taken in <u>cloud-free air</u> to the south of the storm system

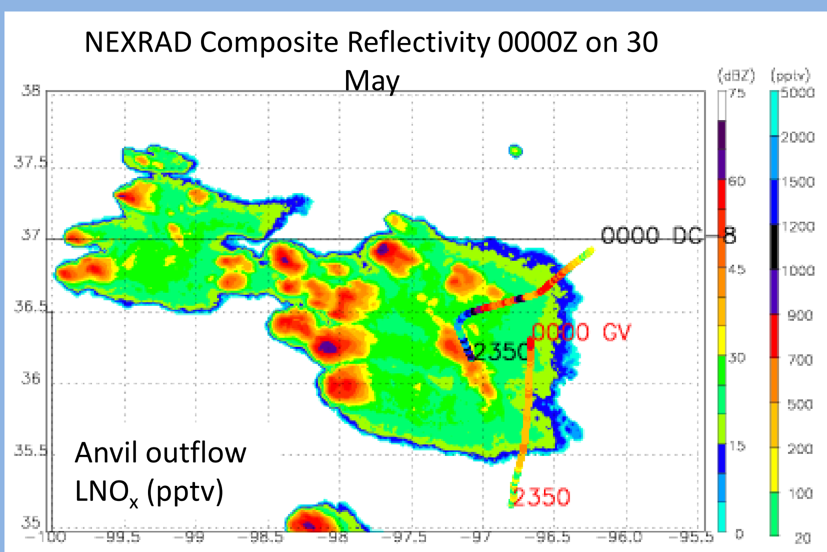
Aircraft	Time of UT Background Sampling (Z)	Model Time (Z)
DC-8	20:40-21:10	20:00
GV	22:15-22:30; 22:58-23:05	21:00; 22:00

Altitude		NO (ppb)	NO_2 (ppb)	NO_x (ppb)
6-9 km (*Median*)	Obs.	0.025	0.034	0.059
	Model	0.020	0.017	*0.01-0.05*
9-12 km (*10th percentile*)	Obs.	0.029	0.033	0.062
	Model	0.041	0.023	*0.05-0.5*

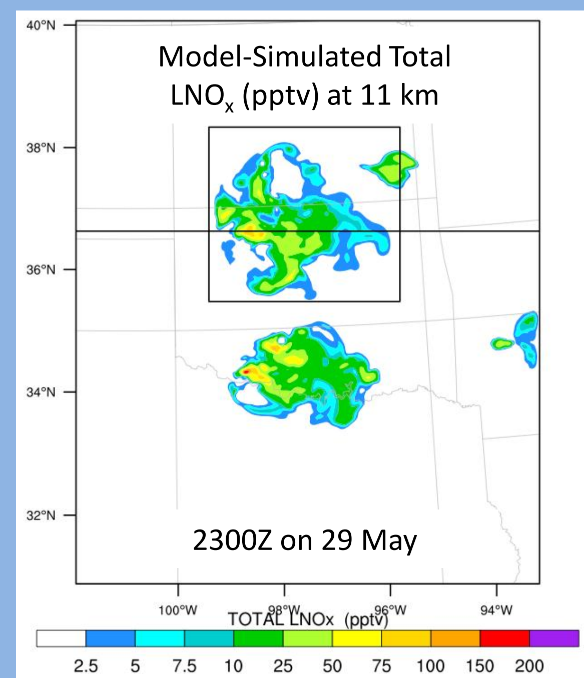
Model-simulated NO_x at 9-12 km is given as a range. Although the observed NO_x is found at the lower end of this range, it should be kept in mind that the observed value represents the 10th percentile.

Initial LNO_x Analysis from Aircraft





- Radar observations overlaid with 10-min intervals of aircraft NO_x measurements
- NO_x measurements increase from sampling in cloud-free upper tropospheric air (0.02-0.1 ppbv; *upper left*) to making transects through anvil outflow (peaks to ~2 ppbv; *bottom left*)
- Model-simulated total LNO_x a magnitude lower in anvil outflow than observations (*bottom right*)



New Model Simulation

- Changes include:
  - One domain (1 km) vs. two-way nested domain (15/3 km)
  - NAM 18Z vs. DART/GFS 12Z initialization
  - CLM vs. NOAH land surface scheme
- Model-simulated storm now begins about an hour after observed storm
- Area of observed and model-simulated storm is roughly similar
- Comparison of offline WRF flash rate calculations against observations indicates an overestimation of a factor of ~10

Conclusions

- Based on offline calculations, W_{max} FRPS was selected for use in model:
  - Needs little adjustment to match the observed total flashes
  - Coincides with several of the observed flash rate peaks
- Scale up model-simulated flash rates in offline calculations and scale down online:
  - May partly be due to how offline calculations are computed
- Model overestimate of observed flashes may be due to:
  - Area of model-simulated storm ~2x larger than observed
  - Observed storm passes over northern edge of LMA
- Initial look at NO_x chemistry in UT air undisturbed by storm:
  - At 6-9 km, NO values similar between aircraft and model, and model-simulated NO2 underestimates observations by ~0.02 ppbv
  - At 9-12 km, the 10^{th} percentile NO_x values are similar (~0.06 ppbv) between the aircraft and model
- New simulation at finer resolution produces model-simulated storm of roughly same size as observed
- WRF-Chem model estimates of P(NO_x) in works
  - Model-simulated LNO_x underestimates aircraft observations in anvil outflow by roughly a magnitude
  - LNO_x calculations are being evaluated in the model and in offline calculations for verification

Future Work

- Perform a trace gas simulation and analysis of NO_x, CO, and O_3 using WRF-Chem
- Compare model-simulated LNO_x against aircraft measured NO_x
- Determine NO production scenario per IC and CG flash that best matches aircraft observed NO_x mixing ratios
- Investigate O_3 changes downwind of flight

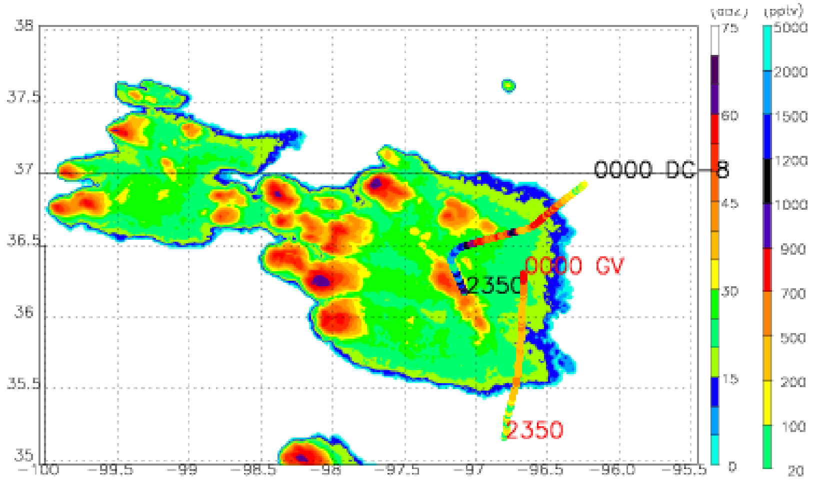
Acknowledgements

- Regional NEXRAD level II data provided by Cameron Homeyer (NCAR)
- NLDN data collected by Vaisala, Inc. and archived by NASA MSFC

QUESTIONS?

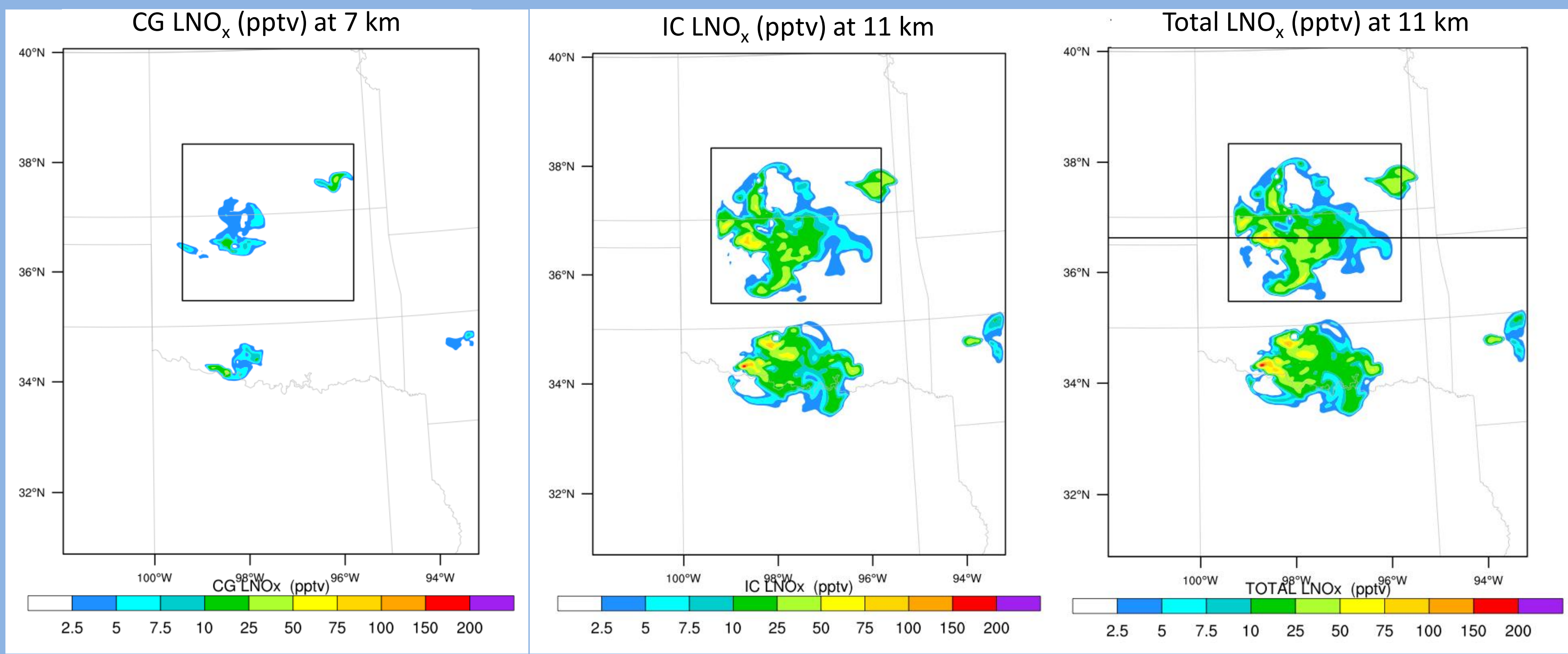
Photo by C. Cantrell

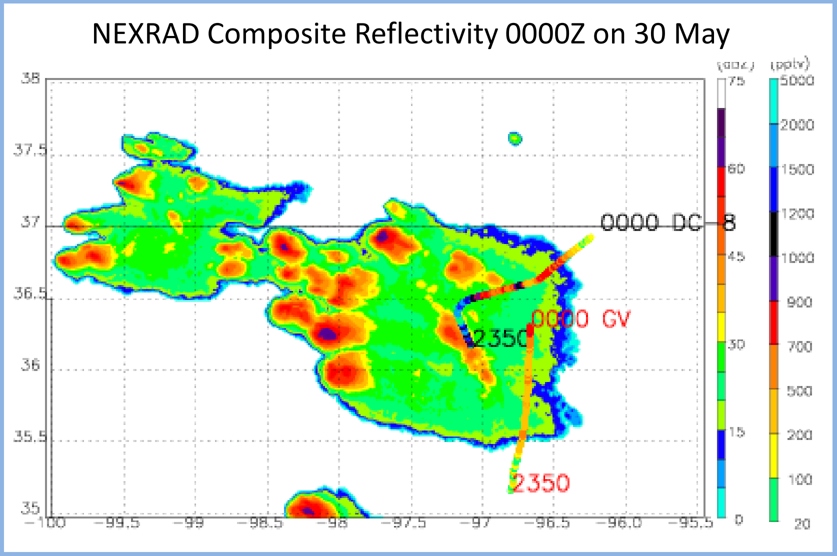
NEXRAD Composite Reflectivity 0000Z on 30 May



Model-simulated total LNO_x about a magnitude lower in anvil outflow than aircraft observations

Model-Simulated LNOx Composite Reflectivity 2300Z on 29 May





Model-simulated total LNO_x about a magnitude lower in anvil outflow than aircraft observations

Model-Simulated LNOx Composite Reflectivity 2300Z on 29 May