A WRF-Chem Analysis of Flash Rates, Lightning-NO_x Production & Subsequent Trace Gas Chemistry of the 29-30 May 2012 Convective Event in Oklahoma during DC3

Kristin A. Cummings

Department of Atmospheric & Oceanic Science, University of Maryland (UMd)/NASA-KSC

Presented by Kenneth E. Pickering

NASA-GSFC/Department of Atmospheric & Oceanic Science, UMd

M. Barth & A. Weinheimer (NCAR), M. Bela (Univ. of CO), Y. Li & D. Allen (UMd), E. Bruning (Texas Tech Univ.), D. MacGorman (NOAA/NSSL), S. Rutledge, B. Basarab & B. Fuchs (CSU), I. Pollack & T. Ryerson (NOAA CSD), H. Huntrieser (Inst. of Atmos. Physics, Germany), & M. Biggerstaff (Univ. of OK)

Photo by C. Cantrell

Key Objectives

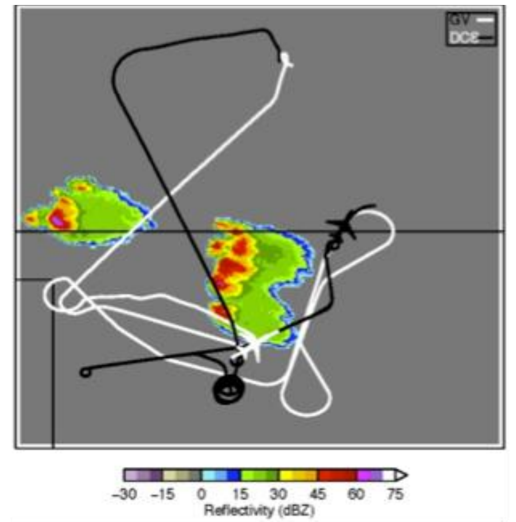
- Continuation of previous work, which compared flashes generated by various flash rate parameterization schemes (FRPSs) from the literature in a WRF-Chem model simulation with lightning observations:
  - Oklahoma Lightning Mapping Array (OK LMA)
  - National Lightning Detection Network (NLDN)

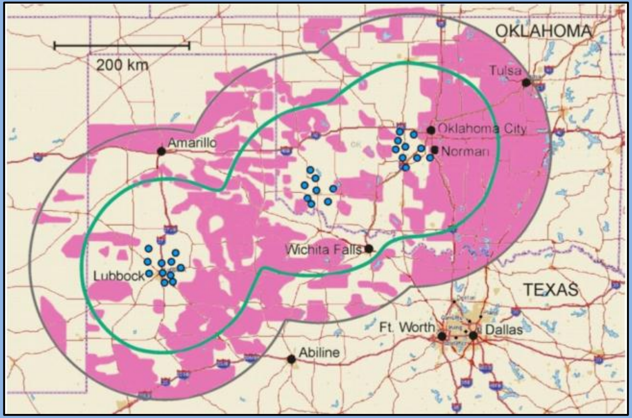
- Current work objectives:
  - Analyze distribution of observed and model-simulated trace gas species in storm inflow and outflow
  - Determine NO production scenario for IC and CG lightning-generated NO_x (LNO_x) scheme
  - Investigate additional FRPSs recently developed from DC3 radar and LMA data

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 & outflow
  - GV & Falcon concentrated on outflow
- Ground-based instrumentation 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

NEXRAD Composite Reflectivity 2240Z on 29 May





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

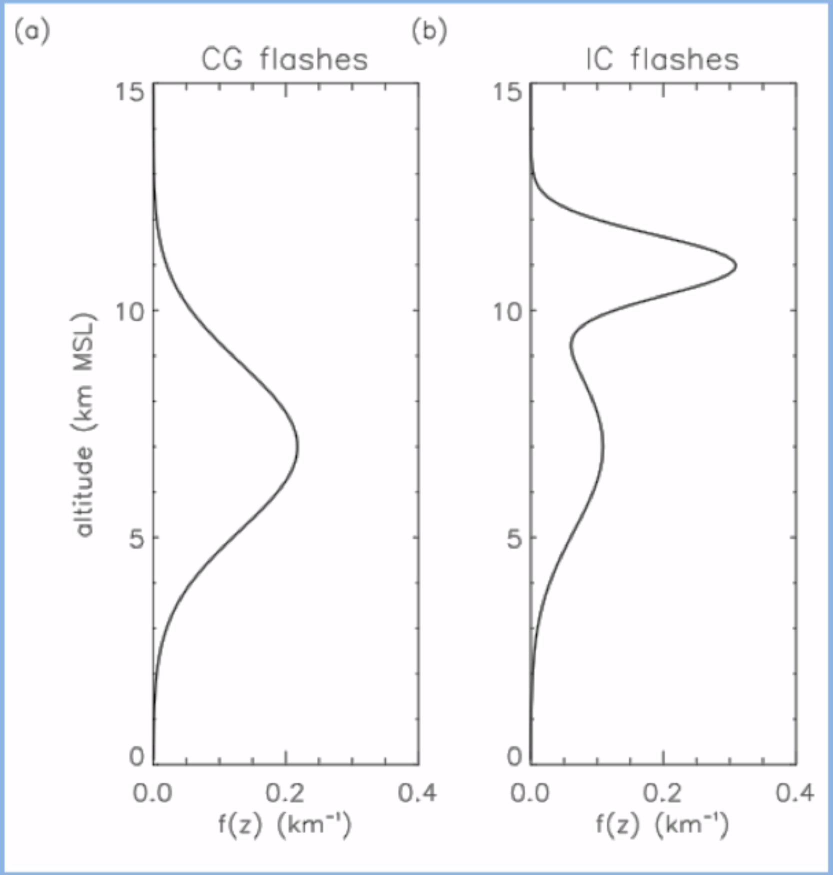
WRF-Chem Model V3.6.1

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

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	➢ Maximum vertical velocity (W_{max}; *Price & Rind, 1992*) ➢ Coarsely prescribed IC:CG ratios (*Boccippio et al., 2001*)
LNO_x	DeCaria et al. (*2000, 2005*)

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)
- NO production can be specified
  - Mean value of 500 moles $flash^{-1}$ found in previous mid-latitude simulations (*Ott et al., 2010*)
- Horizontal placement of NO based on reflectivity ≥ 20 dBZ in each grid cell



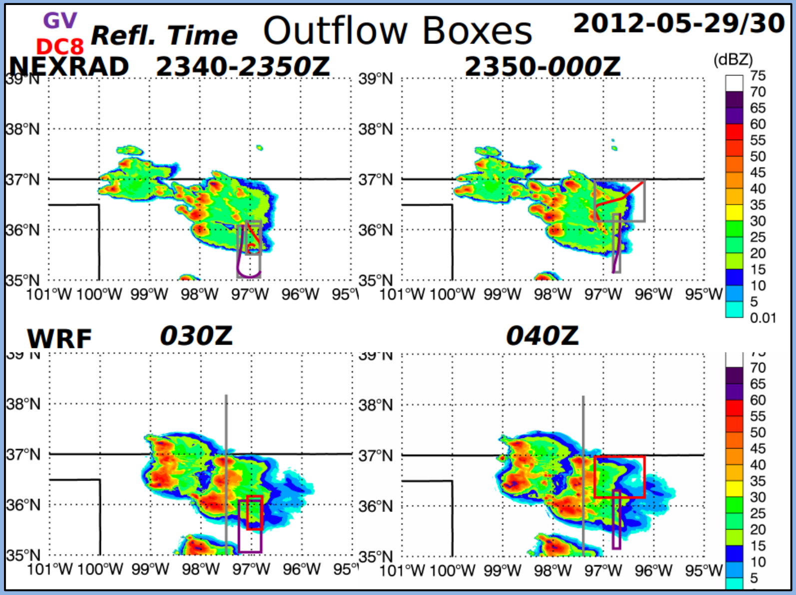
Methodology

- Used W_{max} FRPS in model, since scaling factors provided reasonable results and we were interested in how aircraft observations compared with model-simulated trace gases:
  - Find W_{max} per processor (17 km x 19 km) and apply to FRPS equation:

$$5.0 \times 10^{-6} \times W_{max}^{4.5}$$

- Compared flash rate trends over the observed and model-simulated storm's lifetime

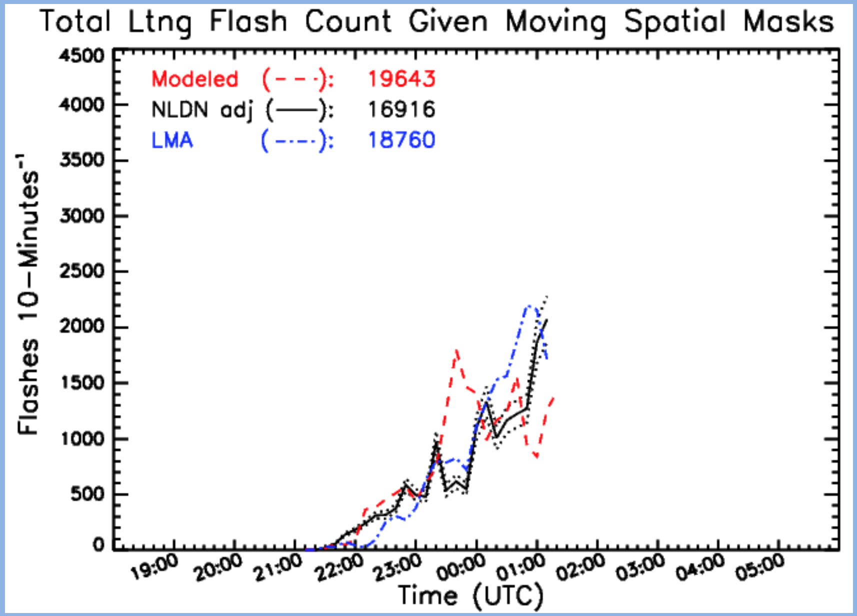
- Analyzed trace gas species (i.e., CO, NO_x, O_3) using model-simulated values and aircraft (DC-8 & GV) observations to:
  - Investigate NO production scenario
  - Compare inflow and outflow statistics
  - Create probability distribution function (PDF) plots in storm outflow



*Plots courtesy of M. Bela

Model Flash Rates vs. Observations

- Model-simulated storm onset occurs 40 min (21:50-05:00 UTC) <u>after</u> observed storm (21:10-04:10 UTC)
- Model severely <u>*overestimated*</u> the simulated flash rates compared with observations
- Scaling the W_{max} FRPS equation generates similar flash rates as observations
- Initial peak in model-simulated flashes (23:40 UTC) occurs earlier than observations (~01:30 UTC)



Note: Model-simulated flash rates shifted 40 min earlier to start with observed flashes (21:10). The model-simulated flash rates plotted above are scaled.

NO Production Scenario

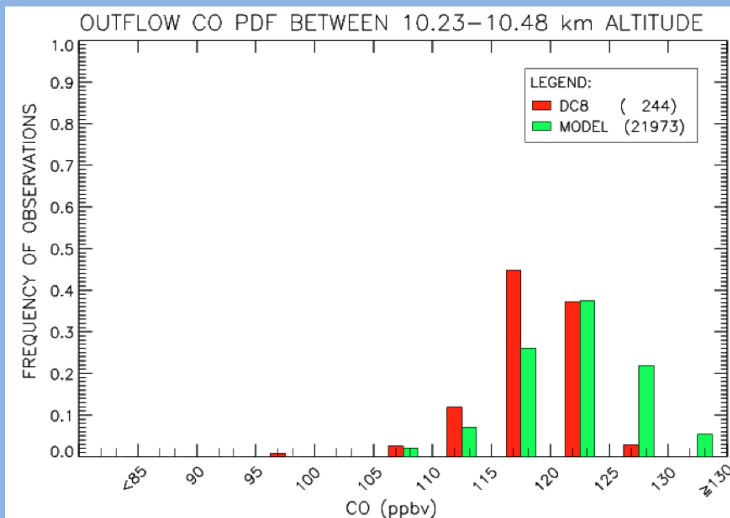
- LNO_x production of 500 moles flash^{-1} produced NO_x mixing ratios in anvil outflow a factor of four greater than observed by aircraft

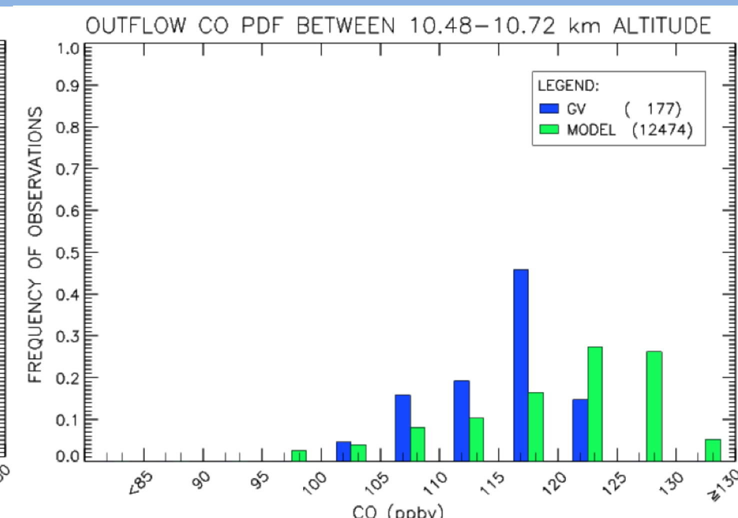
- Reduced LNO_x production to 125 moles flash^{-1} (*see table*):
  - Inflow NO_x larger in model possibly due to emissions
  - Outflow NO_x larger in model possibly due to strong vertical velocity

		CO (ppb)	O_3 (ppb)	NO_x (ppb)
Outflow	Obs	115.2	85.1	0.798
	WRF-Chem	115.9	85.9	0.895
Inflow	Obs	132.8	54.8	0.399
	WRF-Chem	143.1	60.6	0.547

**Statistics represent mean values from 23:00-00:20 UTC (courtesy of M. Bela).*

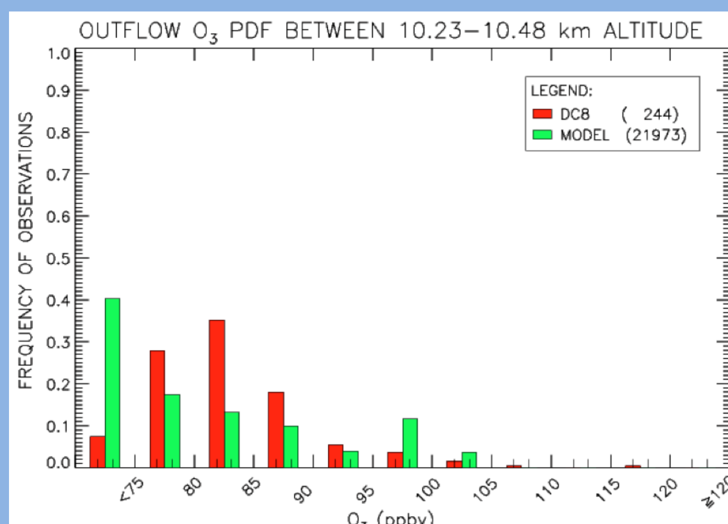
Trace Gas PDFs in Storm Outflow

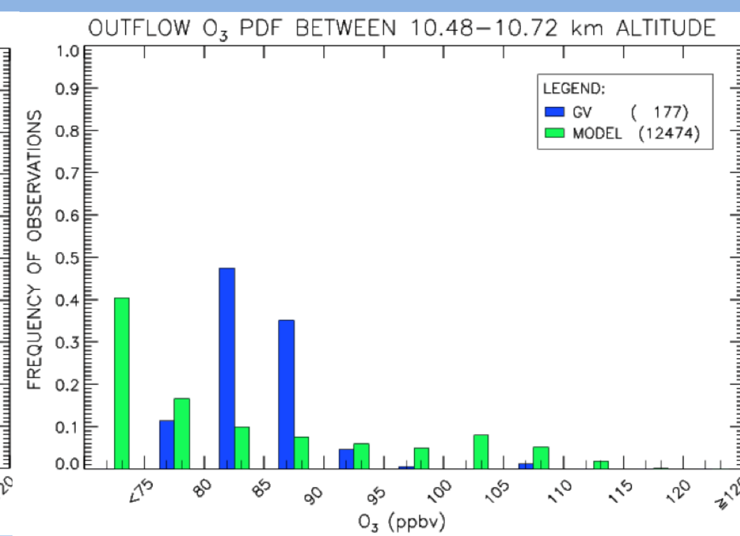




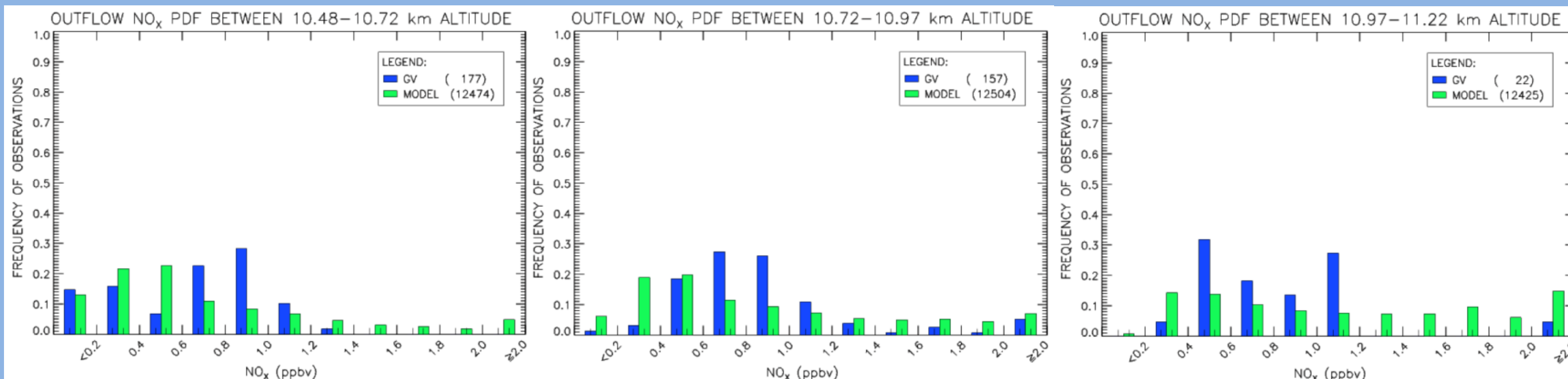
Model-simulated CO (*green*) peaks at higher values than observations

Model-simulated O_3 (*green*) peaks at lower values than observations



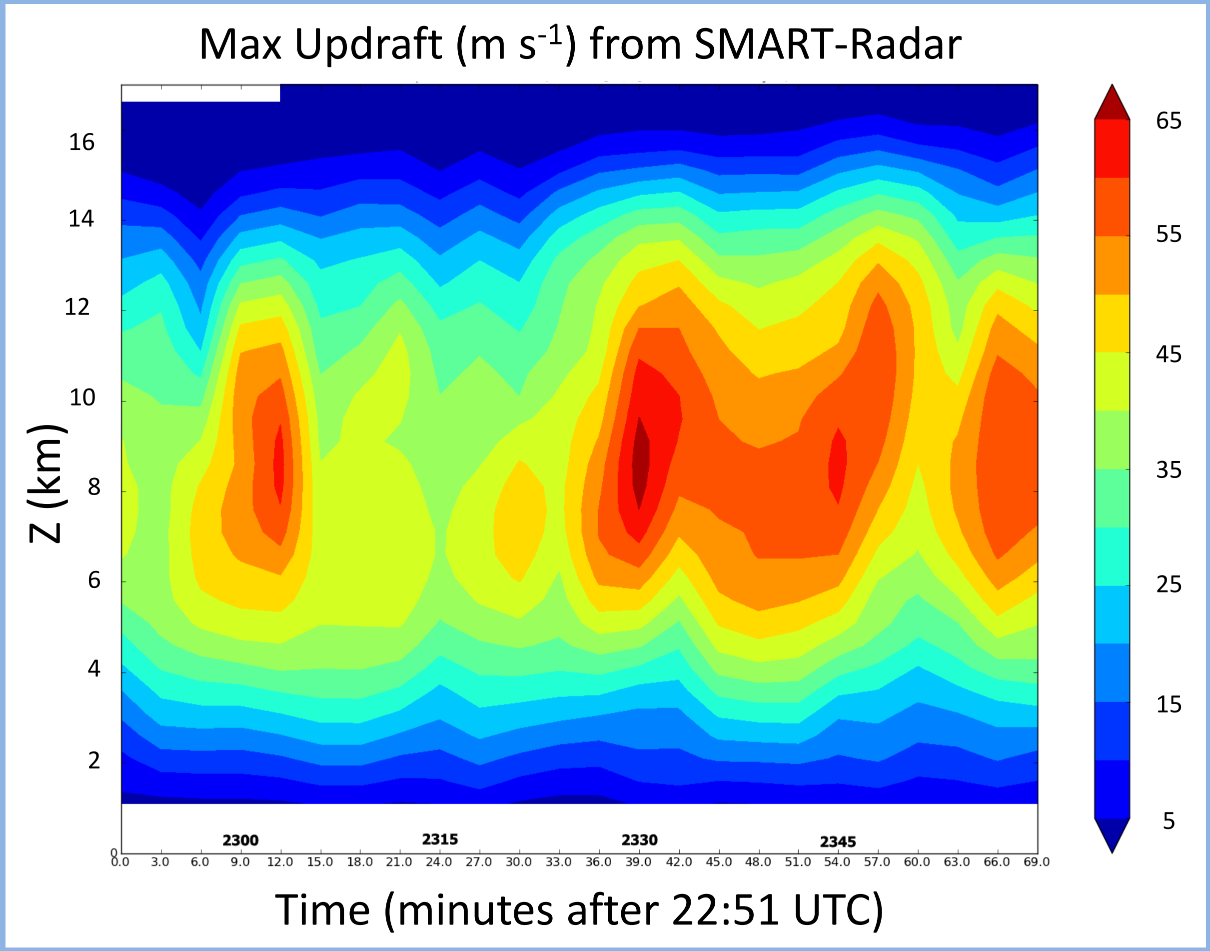


Trace Gas PDFs in Storm Outflow



- Aircraft measurements (*blue*) indicate the number of higher NO_x values start to slightly increase from 10.48-11.22 km
  - Influence from upper lightning channel peak at -45°C (10.5 km)
- Model-simulated NO_x (*green*) peaks at lower values than observations
  - Is model-simulated vertical velocity slightly stronger?
- Higher NO_x values observed by model (*green*) due to influence from upper lightning channel

Comparison of Storm Vertical Velocity

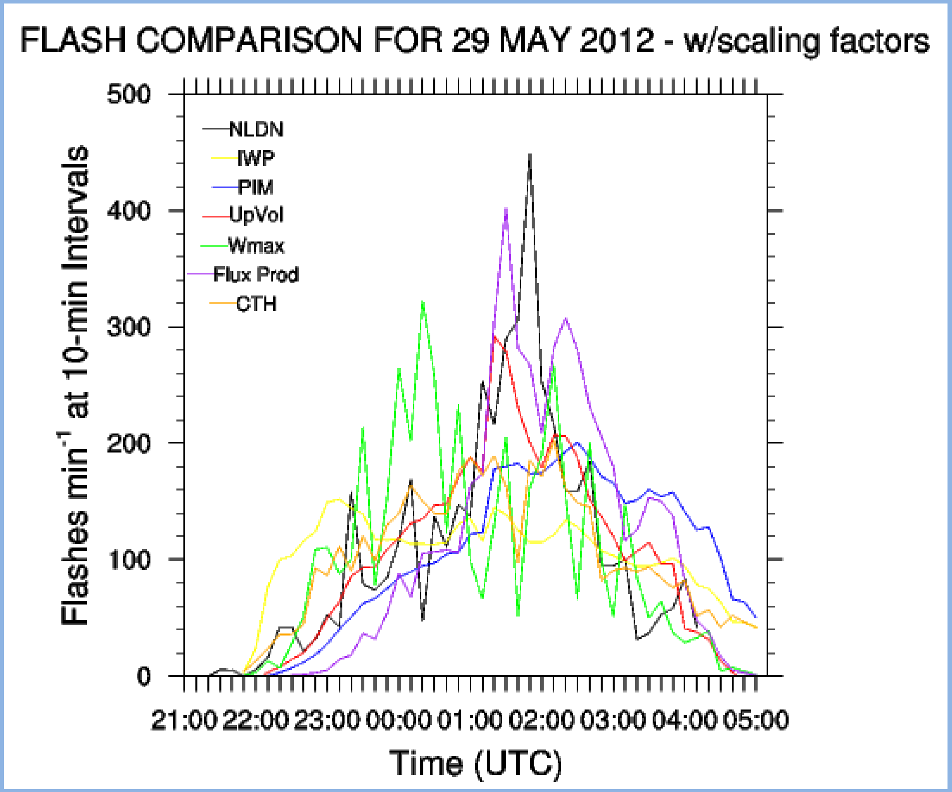


**Plot courtesy of M. Biggerstaff*

- SMART-Radar data:
  - Complete record of 3 mobile radars between 22:51-00:00 UTC
  - Average W_{max} ~49 m s^{-1}
- WRF output data (*not shown*):
  - Storm onset delayed 40 min (23:30-00:40 UTC)
  - Average model-simulated W_{max} ~59 m s^{-1}

Conclusions

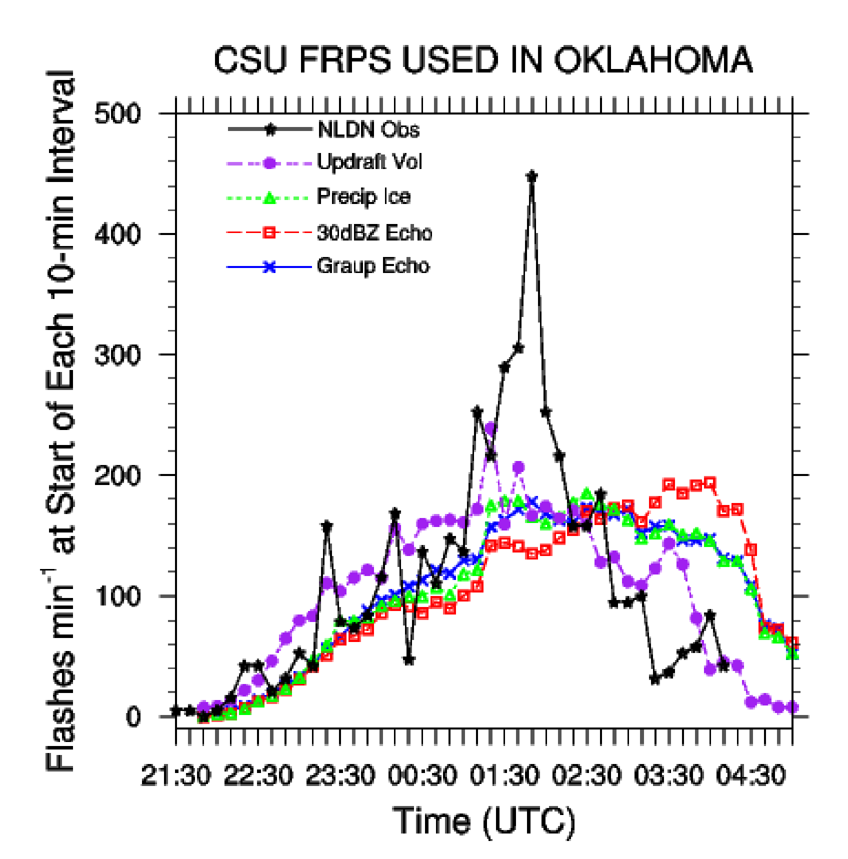
- A single model domain at fine resolution (1-km) produces a storm of roughly the same size as observed, however, the model-simulated:
  - Flashes must be scaled
  - W_{max} is 1.2X stronger
- W_{max} FRPS is not appropriate for the 29-30 May storm:
  - Flashes overestimated despite applying a scaling factor to the vertical velocities
- Slightly stronger model-simulated W_{max} leads to the over prediction of trace gas transport shown in CO, NO_x, and O_3 PDFs
- Tentatively conclude LNO_x production is around 125 moles $flash^{-1}$
- Other FRPSs should be pursued, which:
  - Don't require significant scaling
  - Better follow observed flash rate trend
  - Examples include updraft volume and ice mass flux product



Note: The FRPS flash rate trends in the above plot are based on offline calculations and are adjusted with scaling factors.

Future Work

- Six FRPSs from CSU will be tested in the online model:
  - Updraft volume > 15 m s^{-1}
  - Precipitating ice mass
  - 30-dBZ echo volume
  - Graupel echo volume
  - Area-height schemes based on graupel or dBZ
- Compare results of FRPSs with 1-min/1-km LMA data
- Investigate O_3 changes within the cloud and downwind of the storm



Note: The FRPS flash rate trends in the above plot are based on offline calculations and are adjusted with scaling factors.

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

Mean Values

	ppb		CO	O3	NOx	NO2
Outflow	**Obs**	**Mean**	**115.2**	**85.1**	**0.79808**	**0.29233**
		Std Dev	9.7	9.3	0.70721	0.36244
	WRF-Chem	**Mean**	**115.9**	**85.9**	**0.89537**	**0.29245**
		Std Dev	16.1	12.7	0.79960	0.23671
Inflow	**Obs**	**Mean**	**132.8**	**54.8**	**0.39930**	**0.39574**
		Std Dev	2.7	3.8	0.06889	0.06554
	WRF-Chem	**Mean**	**143.1**	**60.6**	**0.54680**	**0.46221**
		Std Dev	1.5	1.3	0.26098	0.21547
	ppb/ppb		**CO**	**O3**	**NOx**	**NO2**
Outflow	**Obs**	**Mean**	---	**0.746**	**0.00665**	**0.00242**
		Std Dev	---	0.127	0.00558	0.00294
	WRF-Chem	**Mean**	---	**0.758**	**0.00723**	**0.00240**
		Std Dev	---	0.160	0.00601	0.00183
Inflow	**Obs**	**Mean**	---	**0.406**	**0.00298**	**0.00296**
		Std Dev	---	0.022	0.00052	0.00050
	WRF-Chem	**Mean**	---	**0.424**	**0.00381**	**0.00322**
		Std Dev	---	0.009	0.00171	0.00142
Outflow	**Obs**		**0.867**	**1.839**	**2.235**	**0.817**
/Inflow	**WRF-Chem**		**0.810**	**1.789**	**1.900**	**0.745**

**Expanded table from slide 8, where statistics represent mean values from 23:00-00:20 UTC (courtesy of M. Bela). Top half of table represents mixing ratios. Bottom half represents CO ratios.*