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

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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 $\text{NO}_x$ ($\text{LNO}_x$) 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
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)

<table>
<thead>
<tr>
<th>Type of Scheme</th>
<th>Selection for Simulation</th>
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<tbody>
<tr>
<td>Microphysics</td>
<td>Morrison</td>
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<tr>
<td>Planetary boundary layer</td>
<td>Yonsei University (YSU)</td>
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<tr>
<td>Land surface</td>
<td>Noah</td>
</tr>
<tr>
<td>Radiation (short &amp; longwave)</td>
<td>Rapid radiative transfer model for GCMs (RRTMG)</td>
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<td>Photolysis</td>
<td>F-TUV</td>
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<tr>
<td>Trace gas chemistry</td>
<td>MOZART</td>
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<tr>
<td>Flash rate</td>
<td>➢ Maximum vertical velocity ($W_{max}$: Price &amp; Rind, 1992)</td>
</tr>
<tr>
<td></td>
<td>➢ Coarsely prescribed IC:CG ratios (Boccioppio et al., 2001)</td>
</tr>
<tr>
<td>LNO$_x$</td>
<td>DeCaria et al. (2000, 2005)</td>
</tr>
</tbody>
</table>
LNO\textsubscript{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\degree\textup{C} (CG and IC) and -45\degree\textup{C} (IC)

- NO production can be specified
  - Mean value of 500 moles flash\textsuperscript{-1} found in previous mid-latitude simulations (Ott et al., 2010)

- Horizontal placement of NO based on reflectivity $\geq$ 20 dBZ in each grid cell
Methodology

• Used $W_{\text{max}}$ FRPS in model, since scaling factors provided reasonable results and we were interested in how aircraft observations compared with model-simulated trace gases:
  – Find $W_{\text{max}}$ per processor (17 km x 19 km) and apply to FRPS equation:
    \[ 5.0 \times 10^{-6} \times W_{\text{max}}^{4.5} \]

• 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) after observed storm (21:10-04:10 UTC)
- Model severely *overestimated* the simulated flash rates compared with observations
- Scaling the $W_{\text{max}}$ 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

<table>
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<tr>
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<th>CO (ppb)</th>
<th>O$_3$ (ppb)</th>
<th>NO$_x$ (ppb)</th>
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<td>60.6</td>
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</table>

*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 O₃ (green) peaks at lower values than observations.
Aircraft measurements (blue) indicate the number of higher NO\textsubscript{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\textsubscript{x} (green) peaks at lower values than observations
- Is model-simulated vertical velocity slightly stronger?

Higher NO\textsubscript{x} values observed by model (green) due to influence from upper lightning channel
Comparison of Storm Vertical Velocity

- **SMART-Radar data:**
  - Complete record of 3 mobile radars between 22:51-00:00 UTC
  - Average $W_{\text{max}} \sim 49 \text{ m s}^{-1}$

- **WRF output data (not shown):**
  - Storm onset delayed 40 min (23:30-00:40 UTC)
  - Average model-simulated $W_{\text{max}} \sim 59 \text{ m s}^{-1}$

*Plot courtesy of M. Biggerstaff*
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
  – $W_{\text{max}}$ is 1.2X stronger

• $W_{\text{max}}$ 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 $W_{\text{max}}$ 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?
## Mean Values

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<th>O3</th>
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*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.