An Investigation of the Kinematic and Microphysical Control of Lightning Rate, Extent and NO_X Production using DC3 Observations and the NASA Lightning Nitrogen Oxides Model (LNOM)

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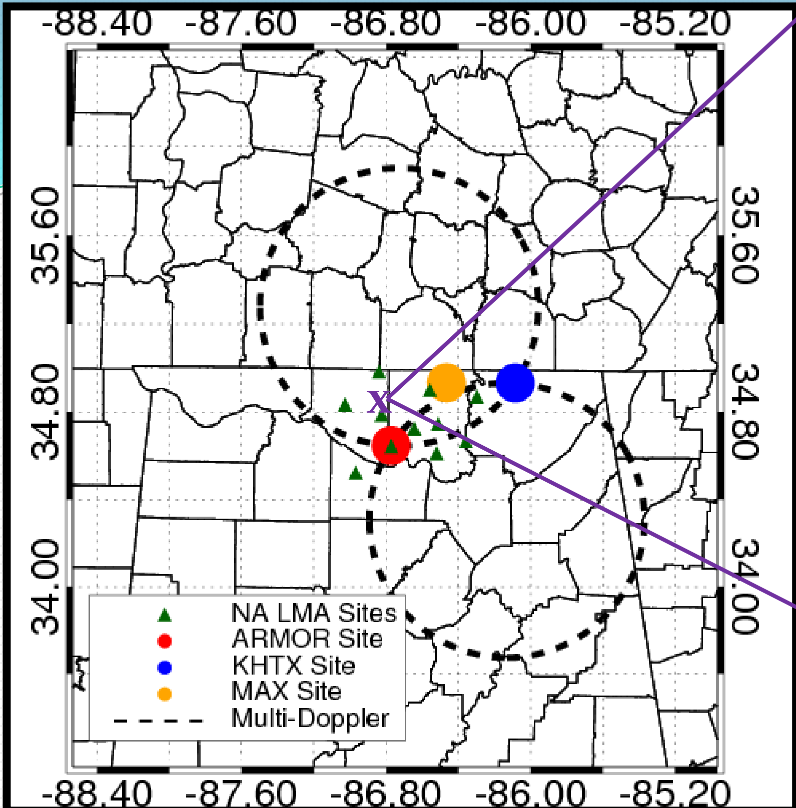
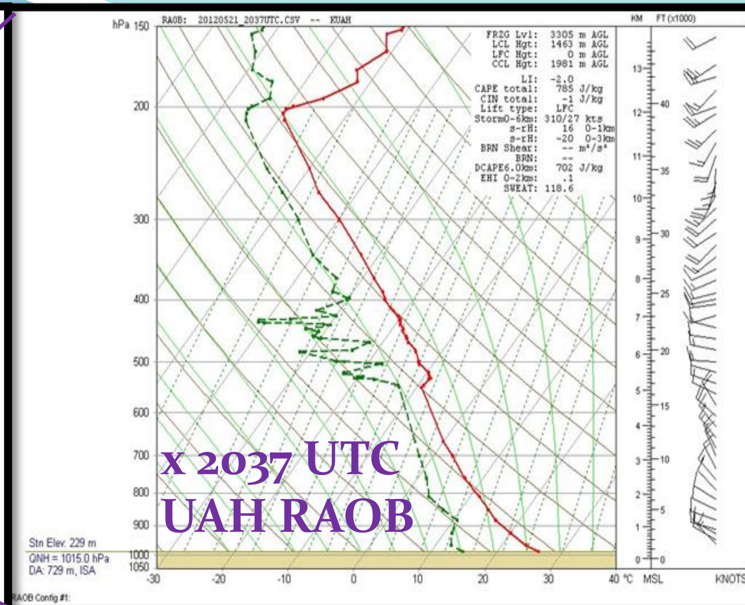
Outline

- Deep Convective Clouds and Chemistry (DC3) Experiment - Alabama (AL) aircraft case on 21 May 2012
  - Environment
  - Dual-Doppler and dual-polarization radar summary during peak lightning period
  - Lightning properties (rate, extent) vs. radar-inferred kinematic and microphysical characteristics
- NASA Lightning Nitrogen Oxides Model (LNOM)
  - Lightning Segment Altitude Distribution (SAD)
  - Lightning NO_x (LNOx) Production
- LNOM SAD and LNOx Production for 21 May 2012 case over AL
  - Comparison to radar



Map of DC3 AL Domain



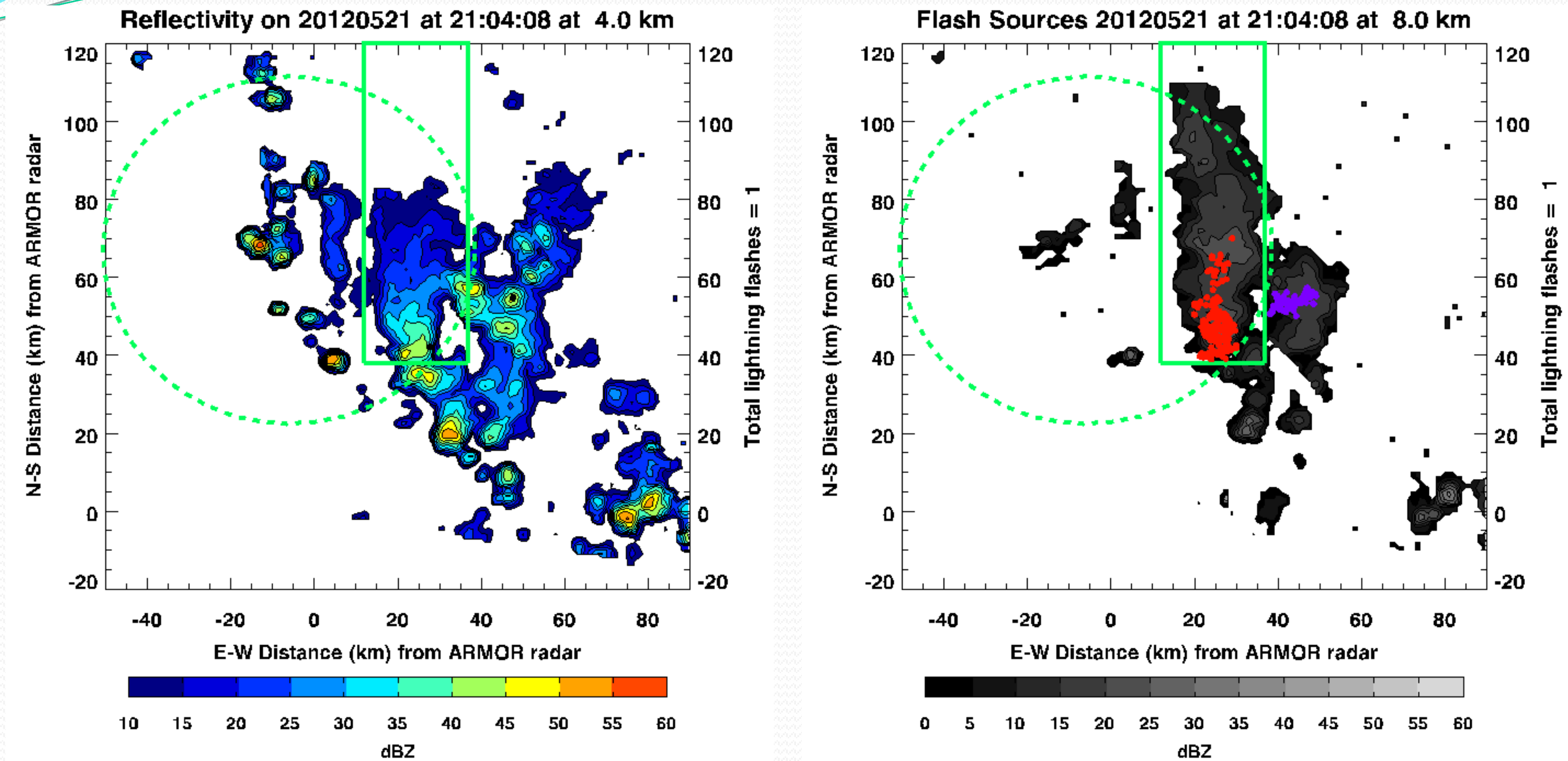
21 May 2012
DC3 AL
Sounding

Convective Parameter	Value
850-700 hPa lapse rate	-3 °C km^{-1}
850-500 hPa lapse rate	-6.2 °C km^{-1}
SFC-3 km lapse rate	-7.3 °C km^{-1}
SBCAPE	**785 J kg^{-1}**
SBCIN	-1 J kg^{-1}
DCAPE	702 J kg^{-1}
Lifted Index	-2 °C
0-6 km shear	**1.2 m s^{-1}**
0 °C level	3.5 km
-10 °C level	5.5 km
-40 °C level	9.5 km

Low-moderate CAPE, low shear → ordinary multicell storms

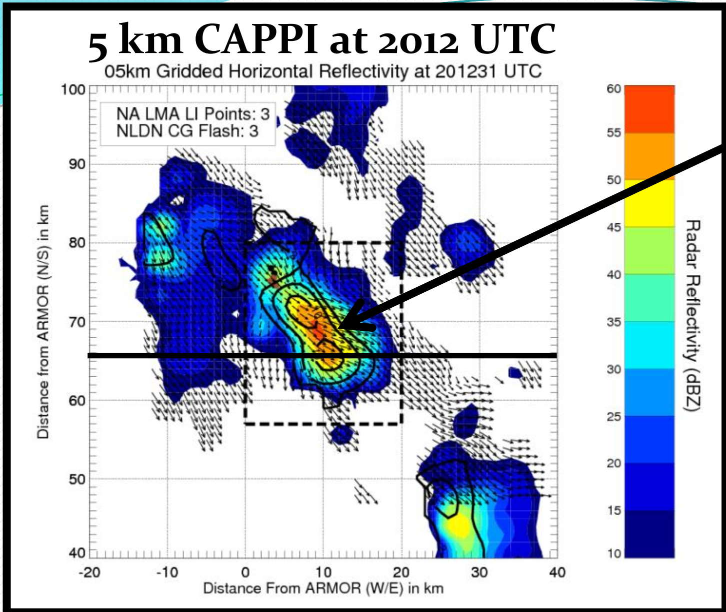
Environmental Conditions
21 May 2012
DC3 AL Aircraft Case
2037 UTC UAH RAOB

LNOM and Radar Analysis Domains



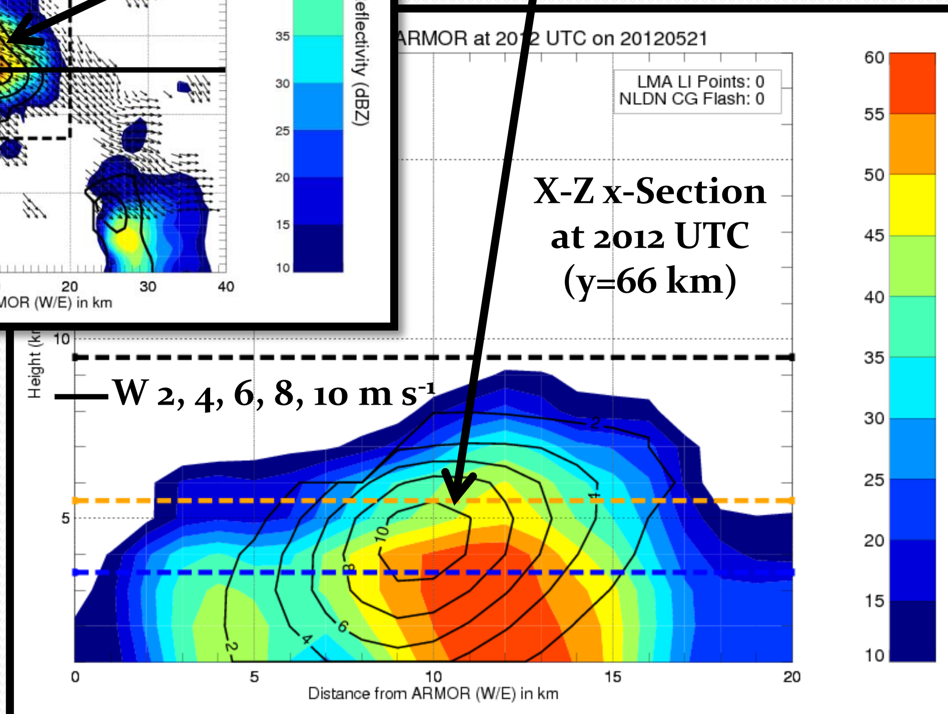
- Initiation approximately around 1940 UTC nearly 80-85 km north of ARMOR
- Multicellular with noticeable cell merger around 2015 UTC
- Peak NA LMA Total Flash Rate ~ 5 flashes min^{-1}
- Peak NLDN CG Flash Rate ~ 1 flash min^{-1}
- Peak Vertical Velocity ~ 20 m s^{-1}

21 May 2012 (Rapid Intensification, Post Merger 2012-2023 UTC)

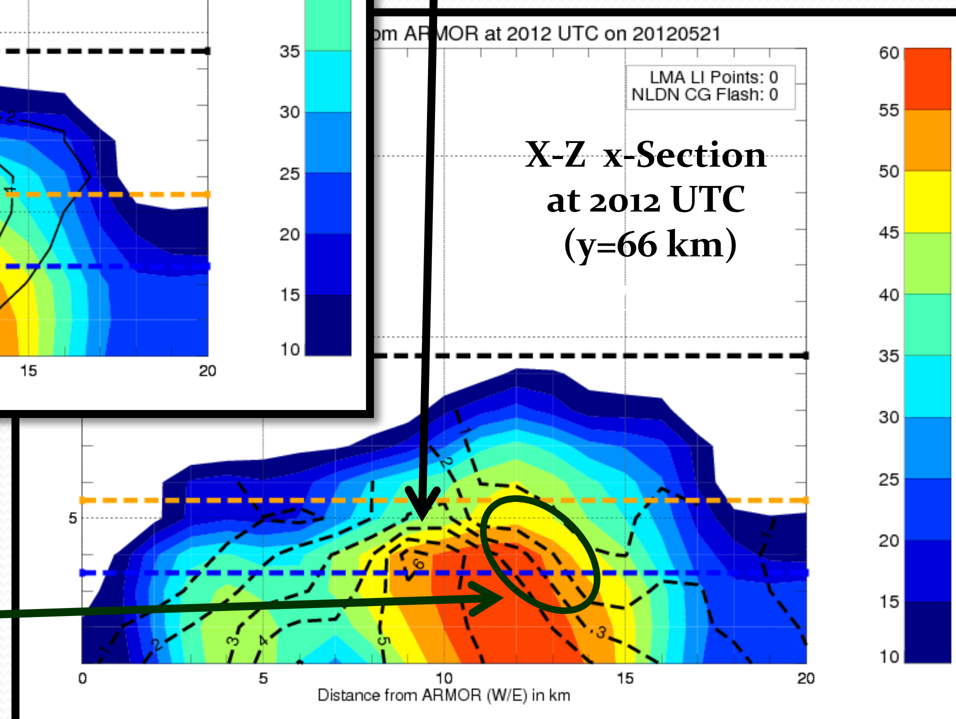


Cell Merger

- Northern updraft congeals with southern updraft
- Continued increase in w_{max} ~ 10 m s^{-1}
- Pronounced Z_{dr} column (5-6 dB)



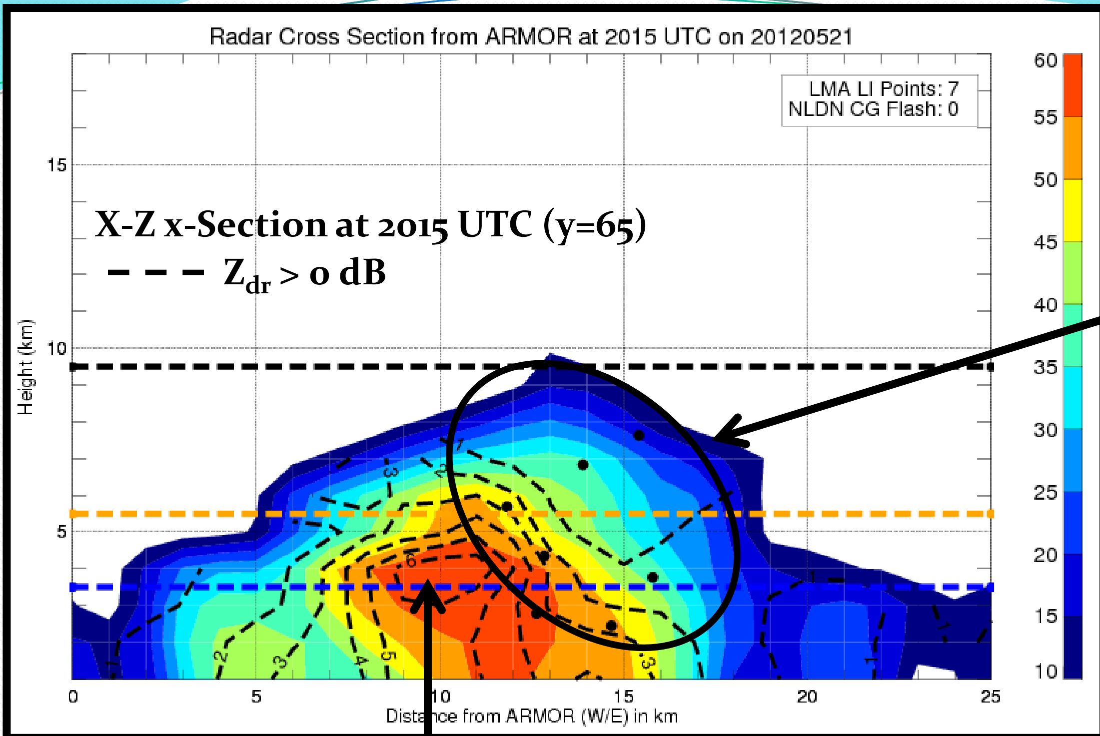
0 °C Level
-10 °C Level
-40 °C Level



Cell Merger

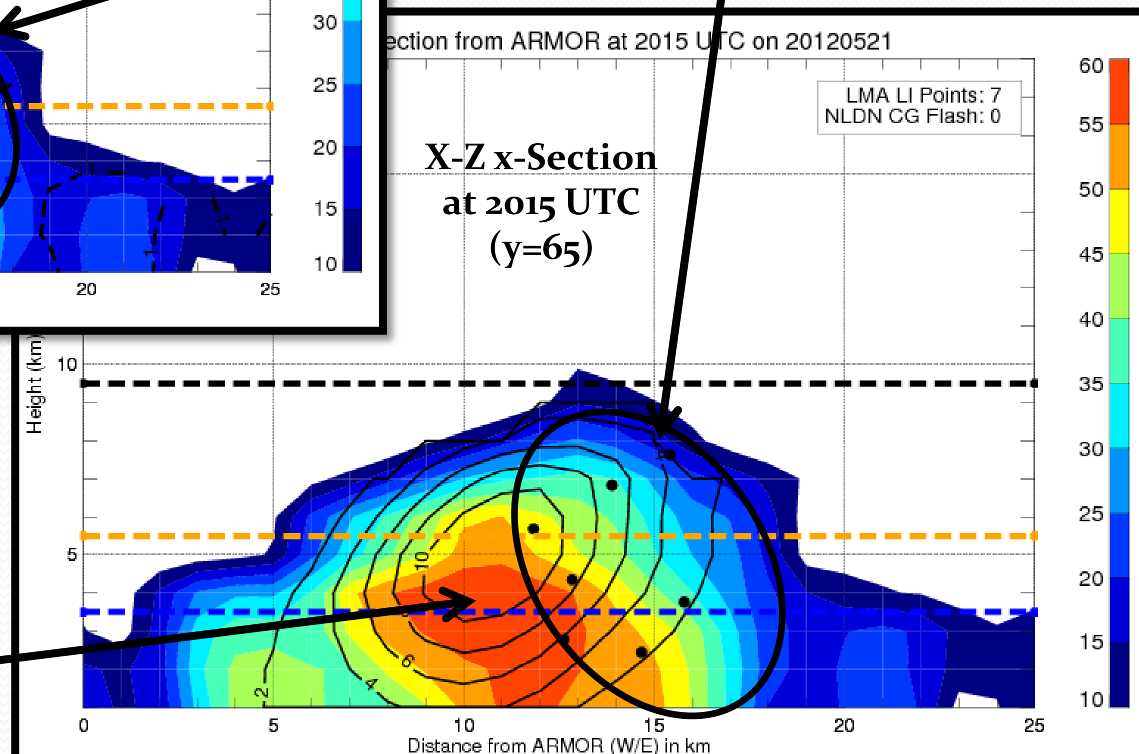
- Strengthening updraft supportive of lofting raindrops upward into MP region for freezing
- Gradient in Z_{dr} (ΔZ_{dr} ~ 4 dB < 2 km depth) suggest transition from liquid to frozen particles

21 May 2012 (Lightning in Southernmost Updraft 2015 UTC)



Initial Lightning in "Merged" Cells

- Along gradient of Z_h and Z_{dr}
- Collocated with w_{max} > 8 m s^{-1}
- Storm Scale particle (and thus charge) separation occurred between rimed graupel and ice
- Resultant electrification and flashes



Z_{dr} Column

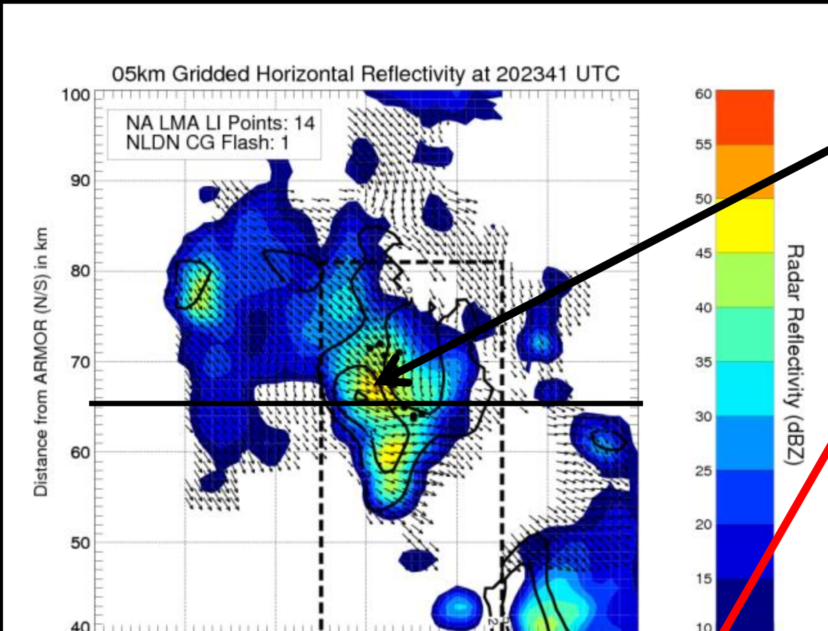
- High Z_h(55-60 dBZ) and Z_{dr} (> 5 dB) into 0 °C to -10 °C layer
- Possible resonance impacts due to high density hail and/or graupel particles
- Persistent Z_{dr} column is coincident with strong updraft

- LMA flash initiation

0 °C Level
-10 °C Level
-40 °C Level

— W 2, 4, 6, 8, 10 m s^{-1}

21 May 2012 (Peak Lightning, Post Merger 2023 UTC)

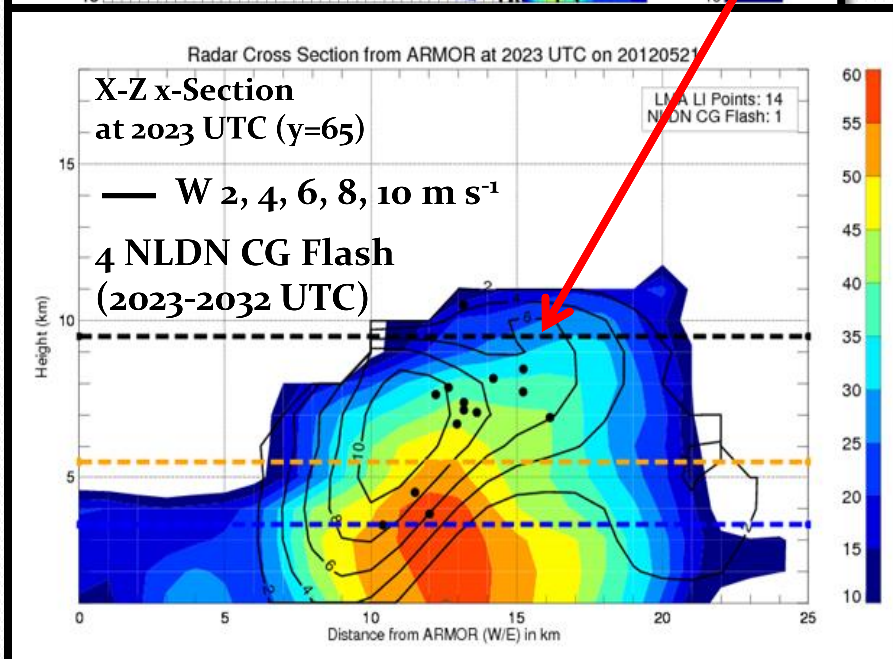


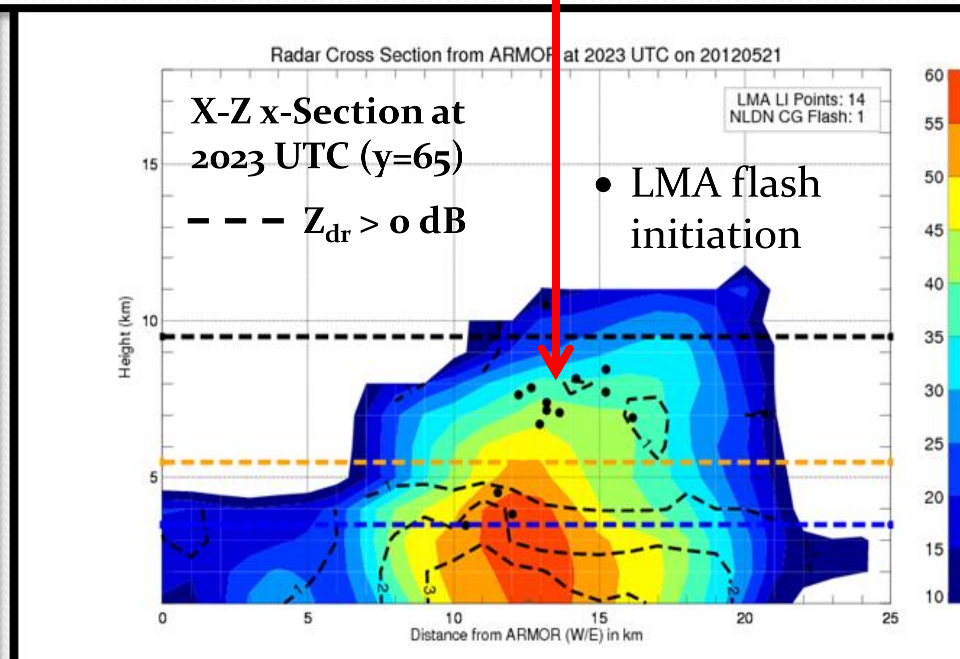
Peak Lightning

- Peak ~ 5 flashes min^{-1}
- Peak likely associated w/ strong 'w' observed at 2015 UTC
- Max 10 dB echo tops above 10 km
- Strong front-to-rear flow (sloped 'w' contours). Efficient at transporting precipitation ice mass aloft for NIC
- Predominately IC flashes aloft with relatively few CG's

0 °C Level
-10 °C Level
40 °C Level

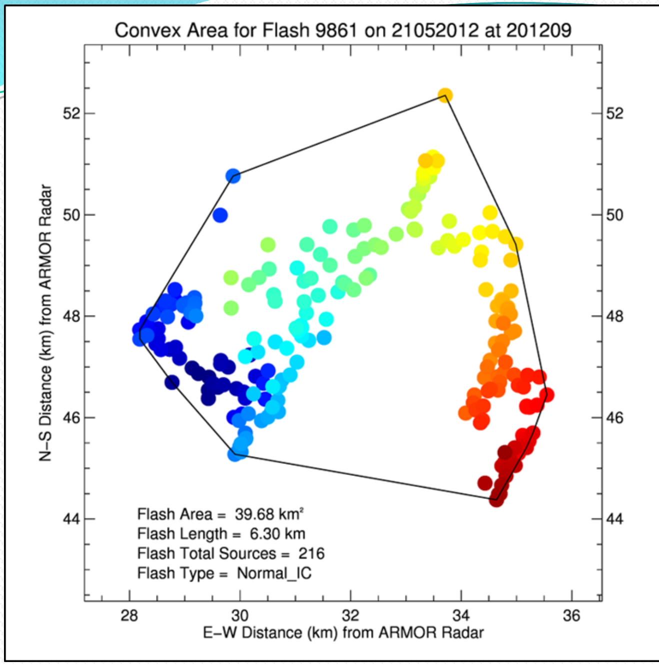
Large quantity of graupel given extension of modest Z_h and low Z_{dr} into -10 °C to -40 °C layer

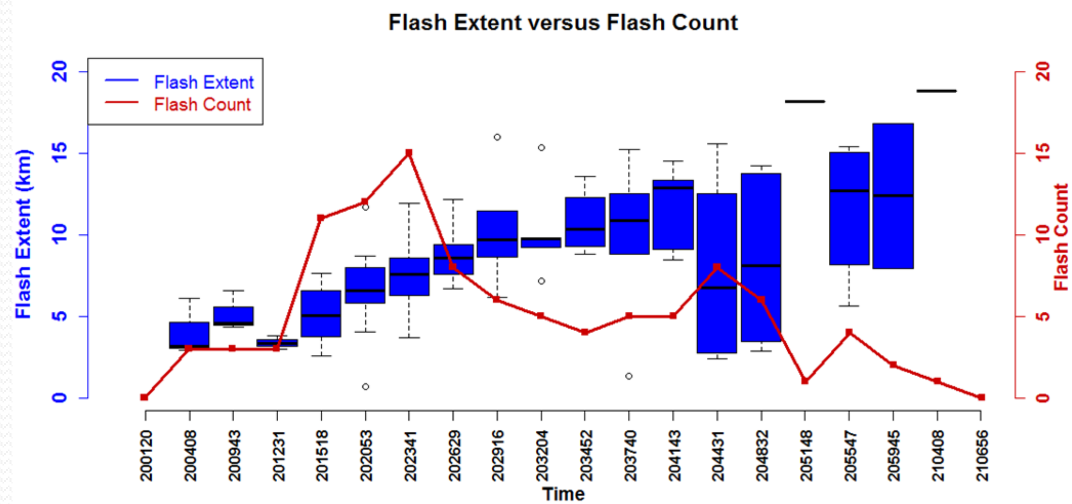




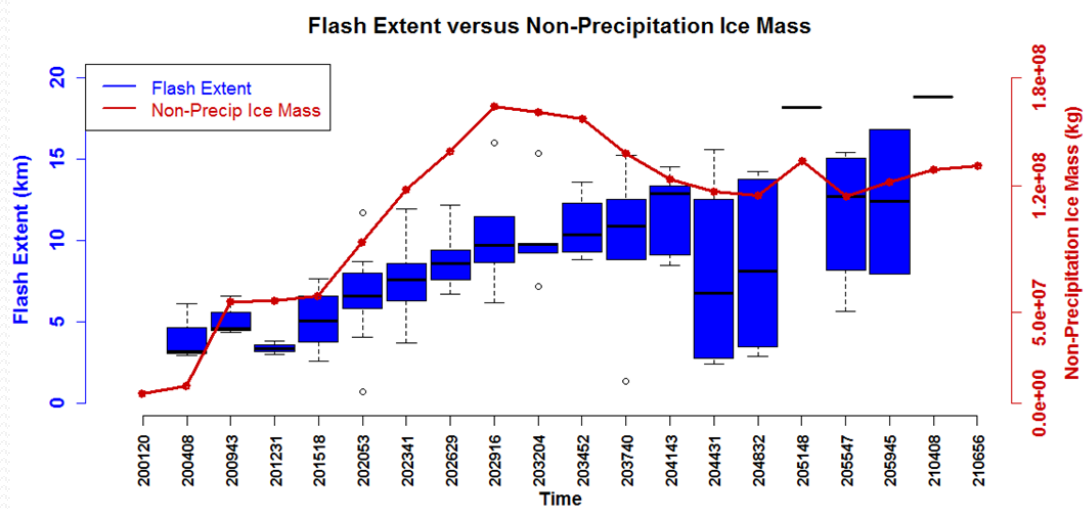
Flash Extent = (Convex Hull Flash Area) $^{1/2}$

Flash Extent (Convex Hull) vs. Flash Count vs. Radar Microphysics/Kinematic



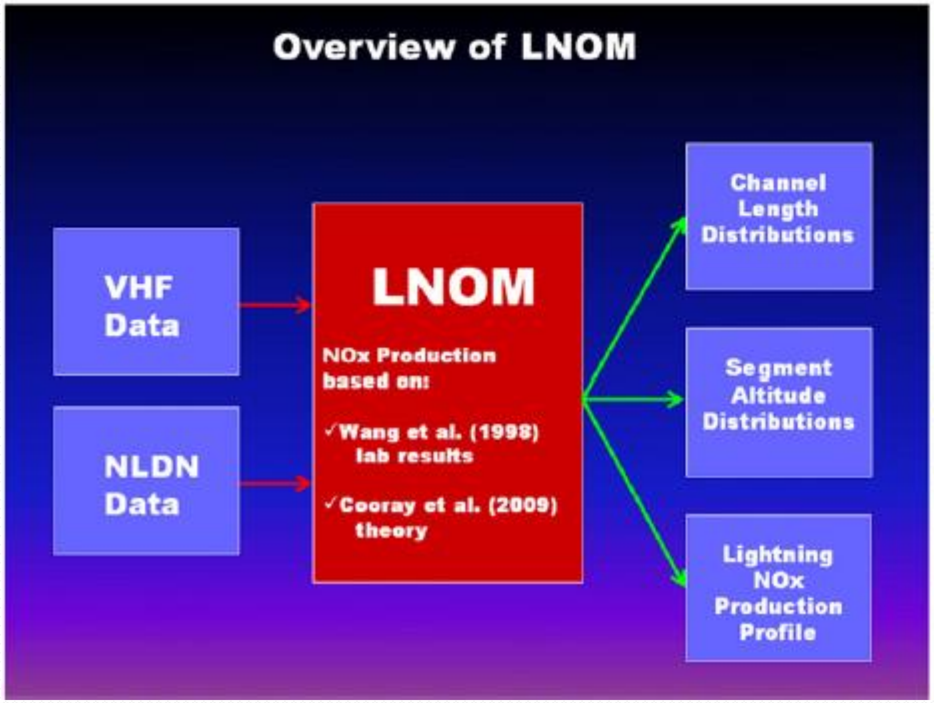


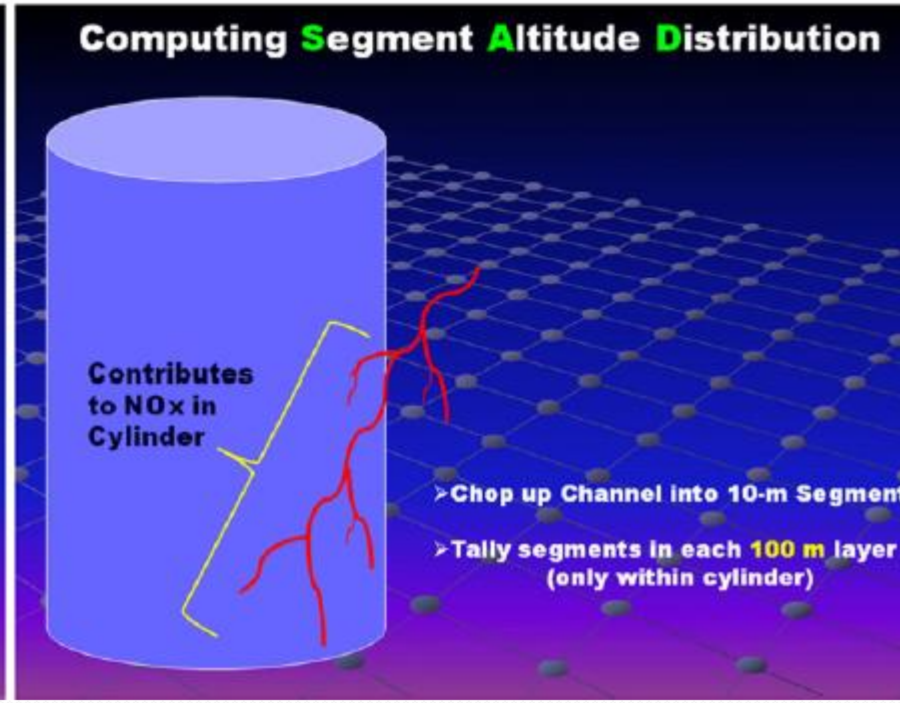
- Flash count correlated with MP precipitation ice and updraft.
- Median flash extent increases as convection pulses
- Largest flashes lag convective pulse but correlated to non-precipitation (anvil) ice
- Flash count and extent opposed; most large flashes when flash rate low (e.g., Bruning and MacGorman 2013)



Poster: Matthee et al. , AE33B-0342 (Today 1:40 PM)

NASA Lightning Nitrogen Oxides Model (LNOM)





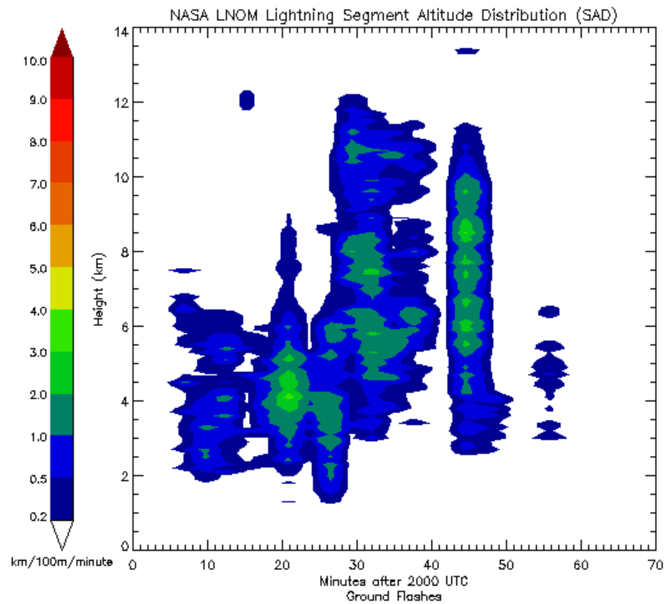
Koshak et al. (2013)

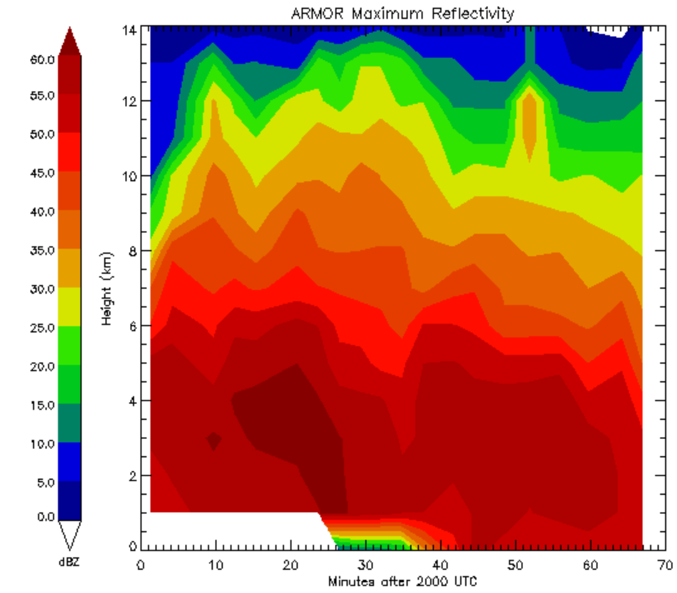
- LNOM run in Lagrangian (i.e., storm following cylinder) mode for multi-cell cluster sampled by DC3 aircraft on 21 May 2012 over AL
- Subjective radar- and LMA-based definition of multicell cluster, shown earlier
- Variable LNOM cylinder radius size and location that change each ARMOR radar volume time

Time-Height Evolution

Max dBZ

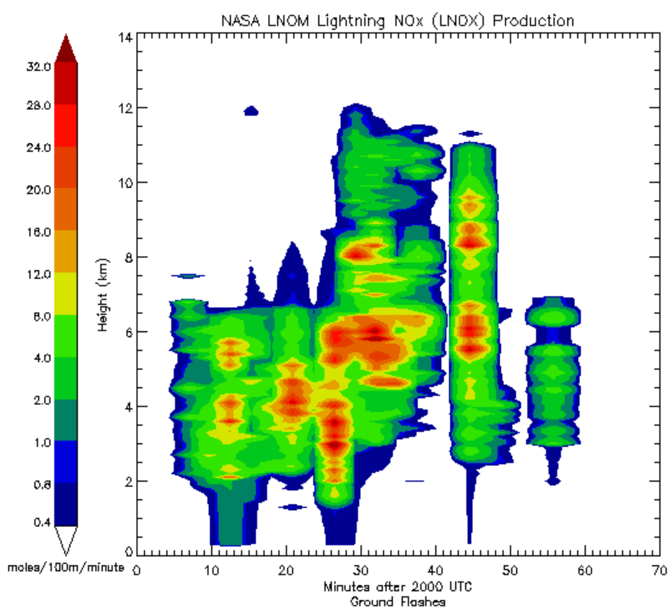
NASA LNOM Lightning Segment Altitude Distribution (SAD)





Ground Flashes

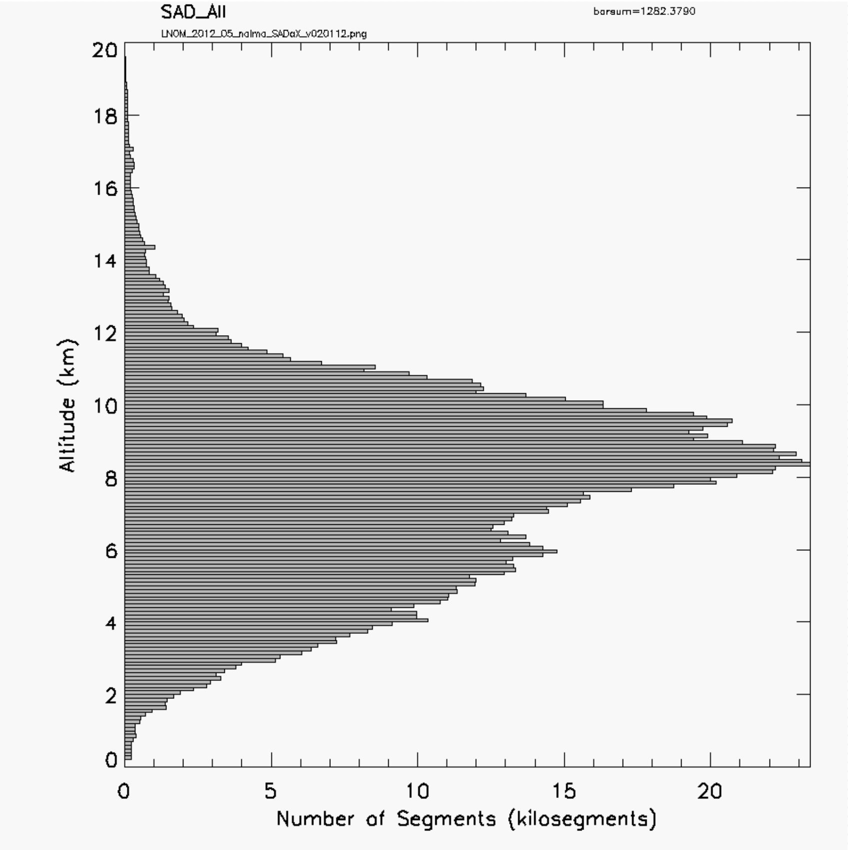
NASA LNOM Lightning NO_x (LNOx) Production



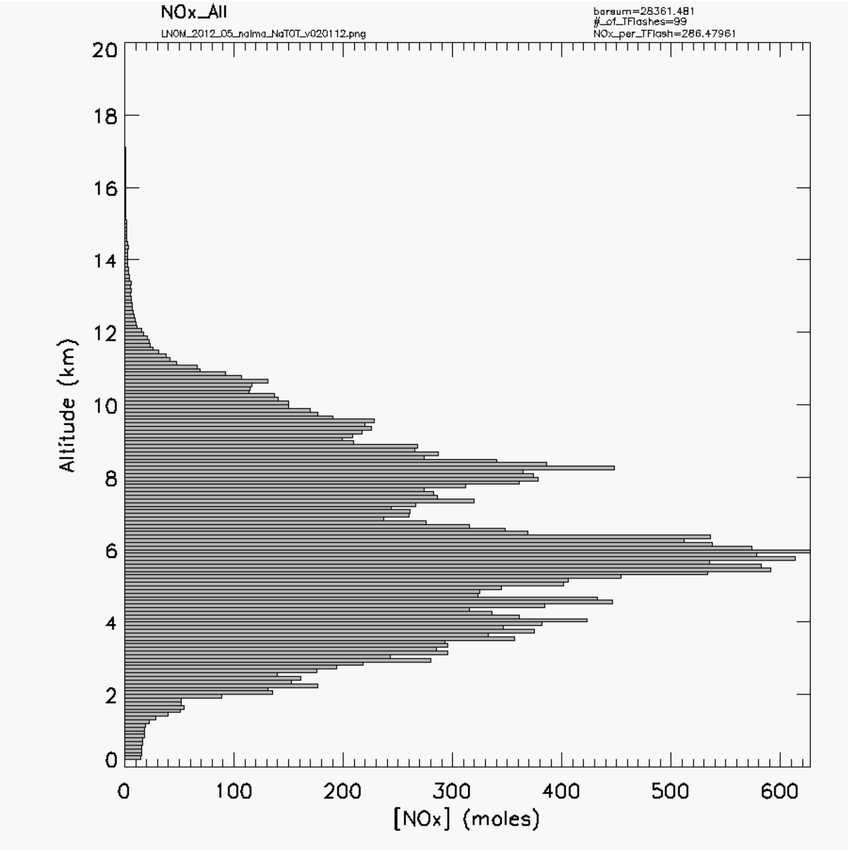
- Cloud flashes dominate SAD
- Ground SAD ≤ Cloud SAD, especially aloft
- Yet, LNOx production from Ground Flash significant fraction of overall LNOx production, especially but not exclusively at low levels

Storm Integrated (≈ 1-hour) LNOM Profiles
21 May 2012 DC3 AL Aircraft Cluster

SAD All Flashes



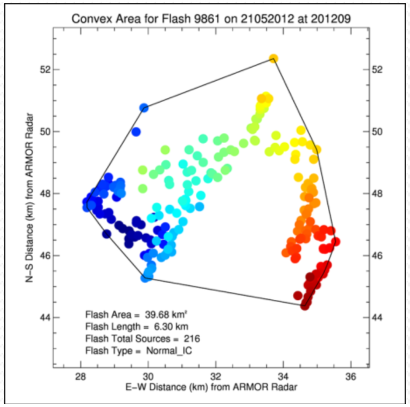
LNOx Production All Flashes

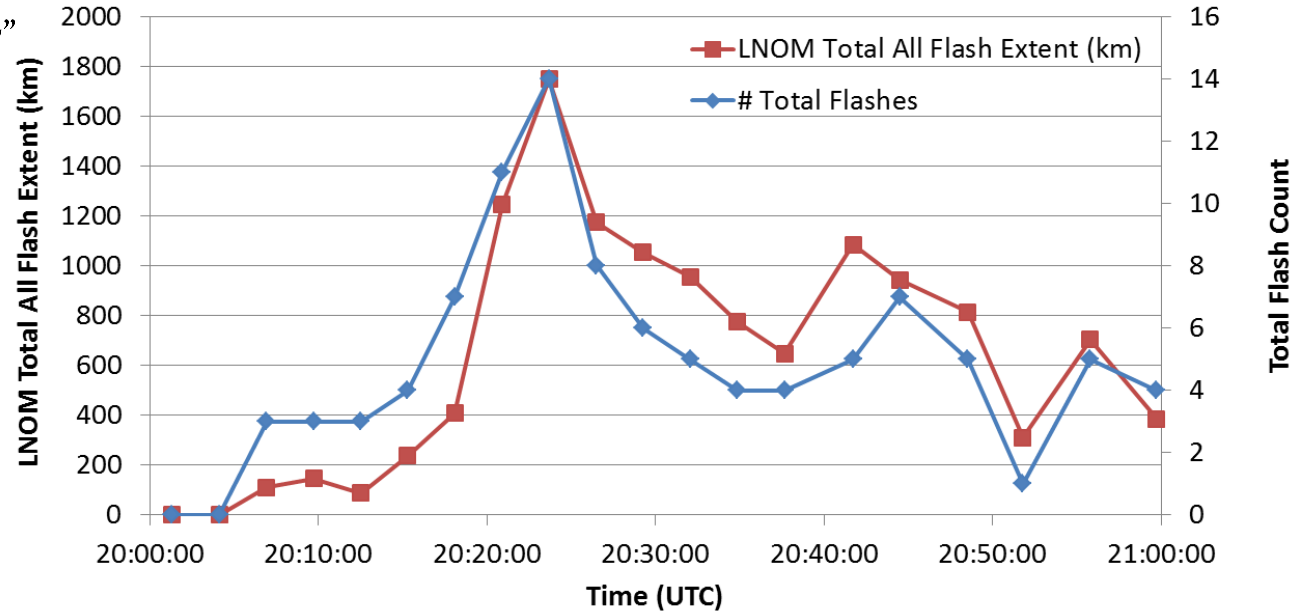


LNOM Flash Extent [Σ(SAD)]vs. Convex Hull Length vs. Radar

SAD: “connect-the-dots”

Convex Hull: “polygon wrapper”





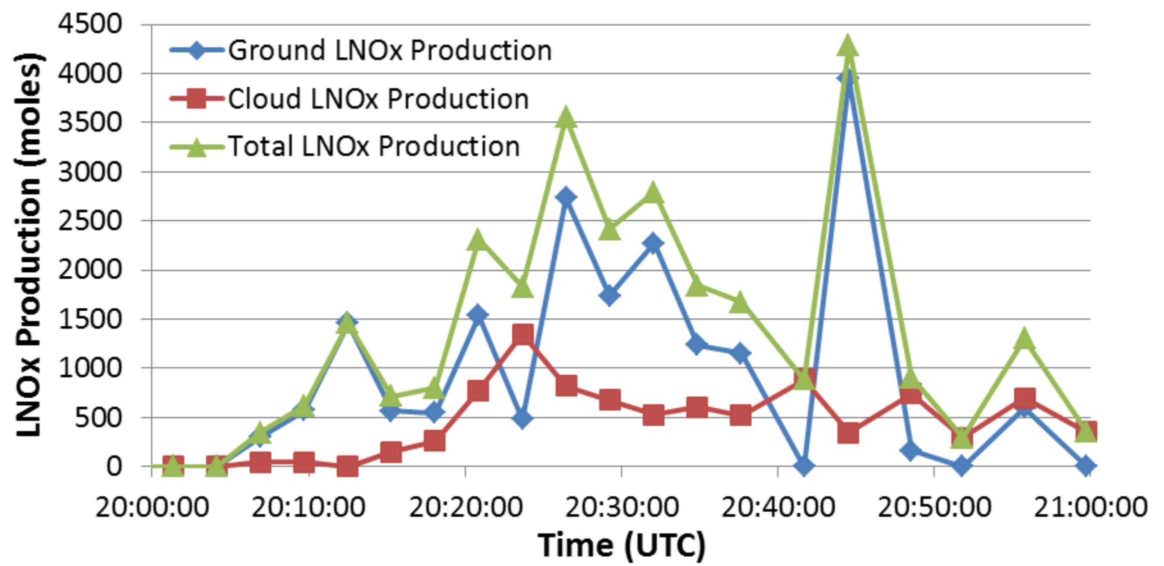
LNOM Flash

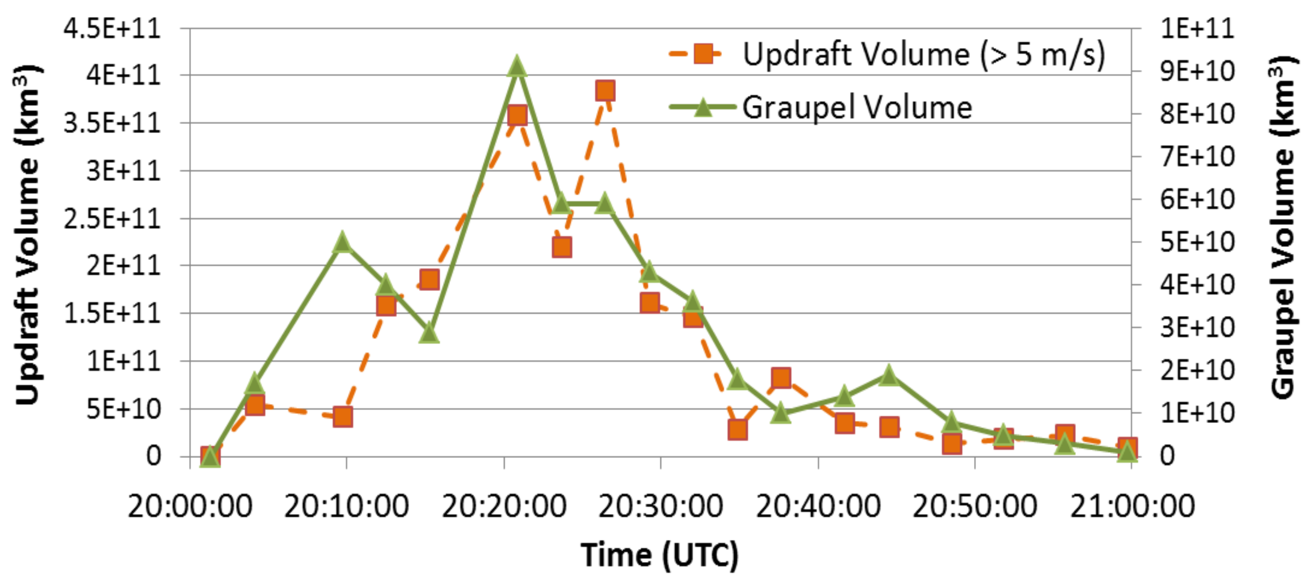
ρ(Rate, Extent) = 0.90

Radar Parameter	Flash Rate (min^{-1})	Flash Extent Rate ($km\ min^{-1}$)
Graupel Echo Volume	ρ = 0.79	ρ = 0.61
Precipitation Ice Mass	ρ = 0.78	ρ = 0.55
Updraft Echo Volume	ρ = 0.76	ρ = 0.61
Maximum Updraft	ρ = 0.60	ρ = 0.41

LNOM LNOx Production

- Cloud LNOx production highly correlated to total cloud flash extent;
- Ground LNOx production also correlated to total ground flash extent
- Ground LNOx governed in part by other CG flash parameters (e.g., peak current) in LNOM
- Radar microphysical parameters (e.g., graupel volume) somewhat correlated (ρ=0.47) to Total LNOx Production
    - LNOx lags graupel (ρ_{lag}=0.64)

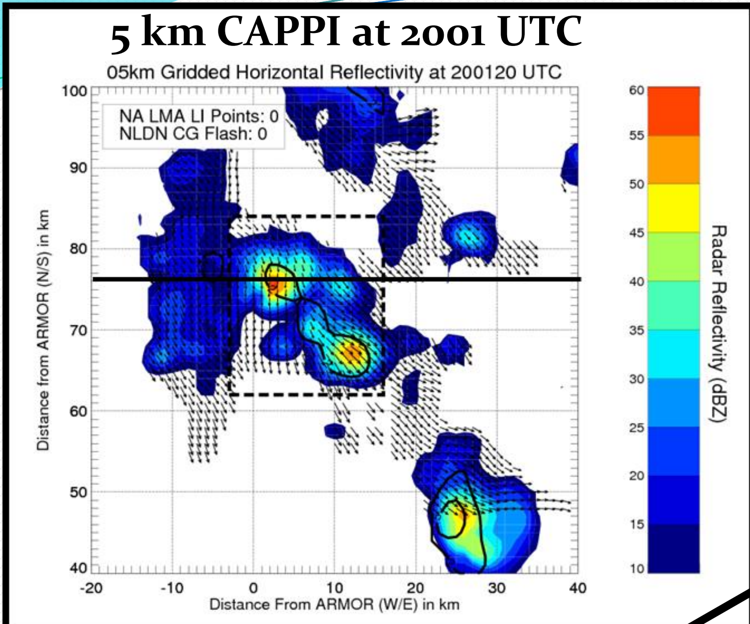


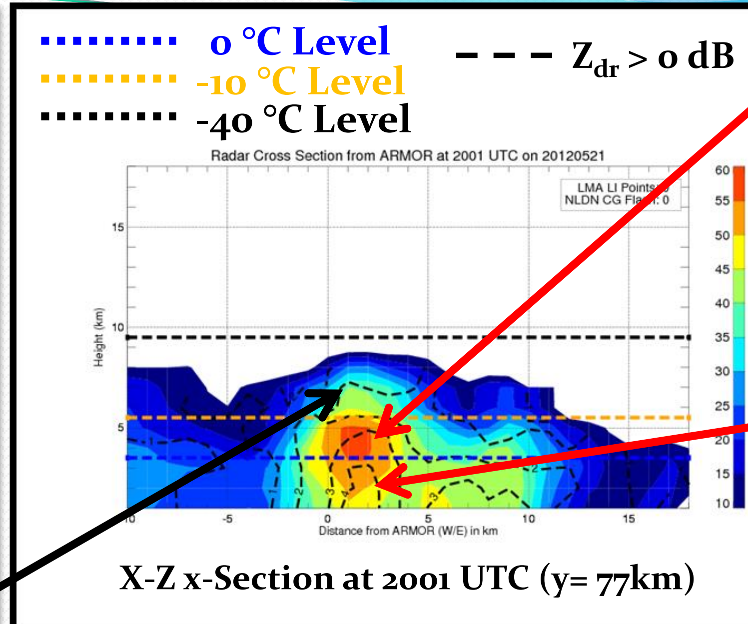


Summary

- Dual-Doppler, dual-polarization radar, LMA and LNOM study of the 21 May 2012 DC3 aircraft case over Alabama
- Coalescence-freezing, modest convective updrafts and subsequent graupel growth drives lightning production
- Total lightning flash rate well correlated to kinematic (e.g., updraft volume) and microphysical properties (e.g., graupel volume) inferred from radar, as in past studies
- To a somewhat lesser extent, LNOM flash extent and LNOx production also correlated to radar properties
- LNOM SAD ("connect the dots") flash extent well correlated to convex hull length scale of flash
- Flash count and extent opposed; largest extent flashes lag the convective generator.

21 May 2012 Development Phase (1945-2001 UTC)





Z_{dr} Column

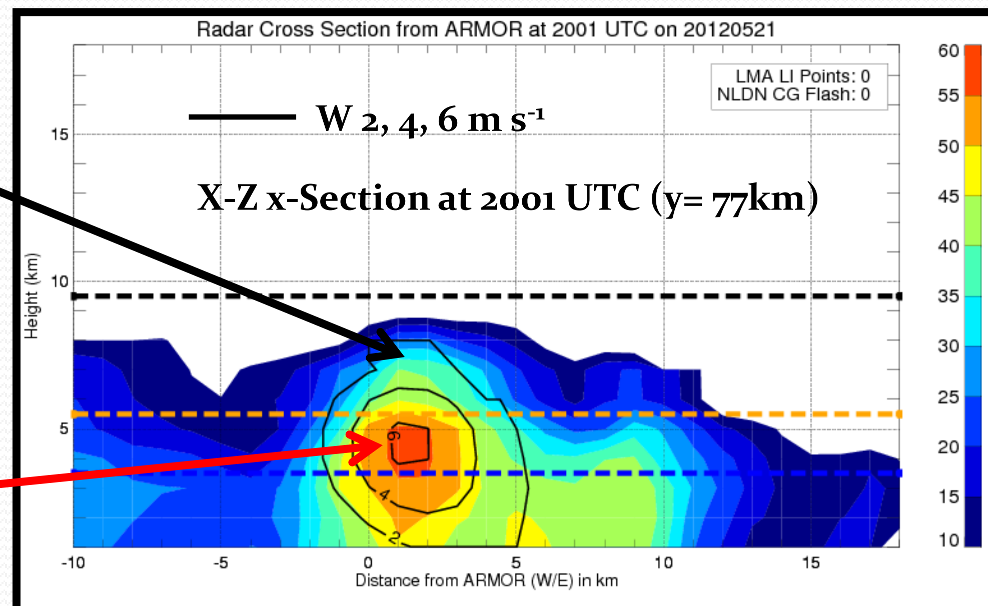
- Z_{dr} ~ 2-3 dB
- Z_h ~ 50-55 dBZ
- raindrops

Warm Rain Coalescence

- Z_{dr} ~ 3-4 dB
- Z_h ~ 40-50 dBZ
- raindrops

MP Hydrometeor Region

- Z_{dr} 0-1 dB
- Z_h ~ 40-45 dBZ
- w_{max} ~ 2-4 m s^{-1}
- Depressed values of ρ_{hv} (not shown) suggest mix of freezing/frozen raindrops, graupel/small hail



6 m s^{-1} Updraft

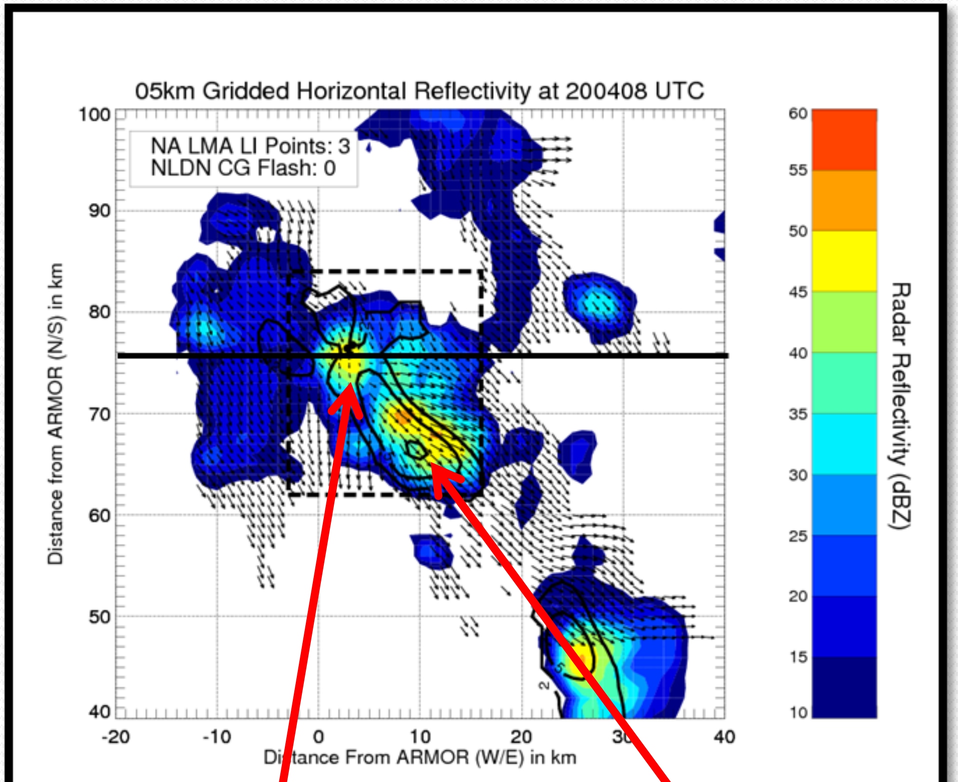
- Peaks into 0 °C to -10 °C layer
- Sufficient to loft liquid drops into MP zone
- Favors freezing of rain drops with time

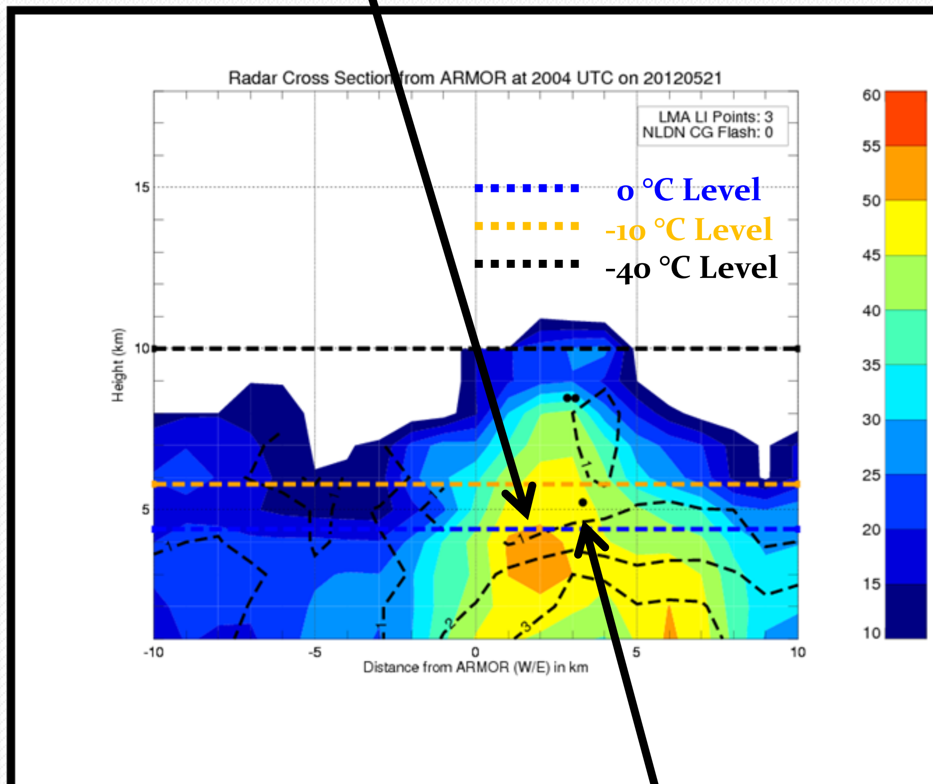
21 May 2012 (Electrification of Northernmost Updraft 2004 UTC)

Sufficiently strong vertical motion to loft rain into mixed phase (MP) where freezing by 2001 UTC, likely resulted in the northernmost updraft producing 3 LMA flashes by 2004 UTC.

Northern Updraft

- $Z_{dr} < 1$ dB
- Z_h ~45-50 dBZ
- Likely Graupel/Small Hail (PID Confirmed)





Northern Updraft

- Short lived & decayed
- Z_h decrease to 50-55 dBZ
- w_{max} ~ 2-4 m s^{-1}

Southern Updraft

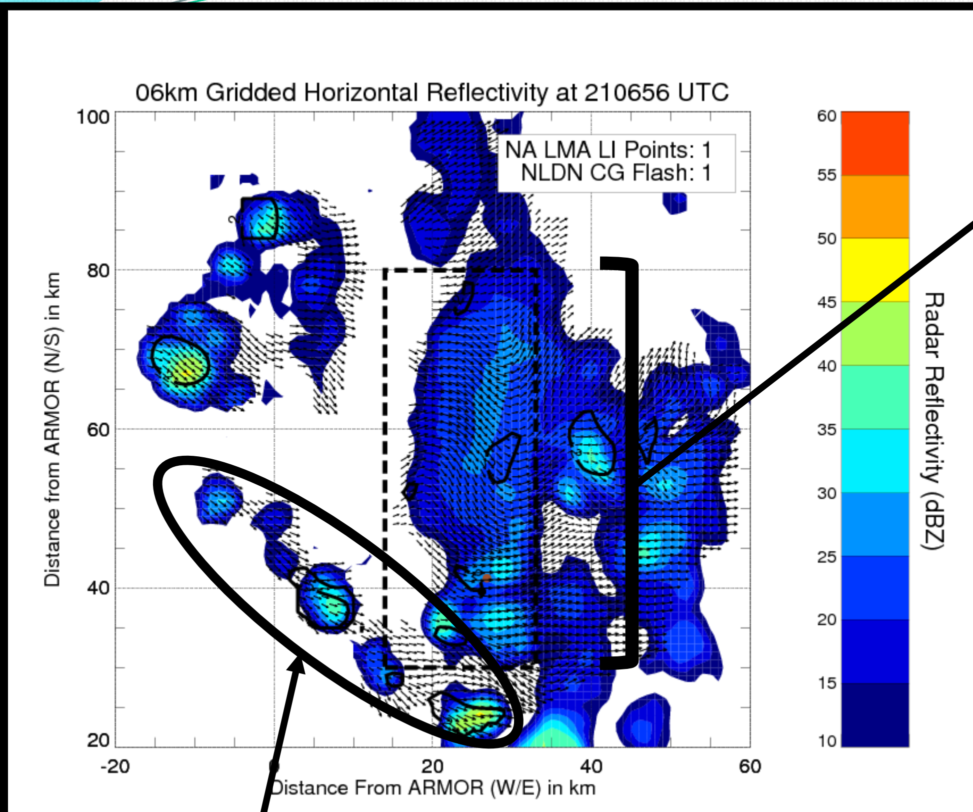
- Strengthens
- Z_h decrease to 55 dBZ
- w_{max} ~ 5-10 m s^{-1}

- LMA flash initiation

First Lightning

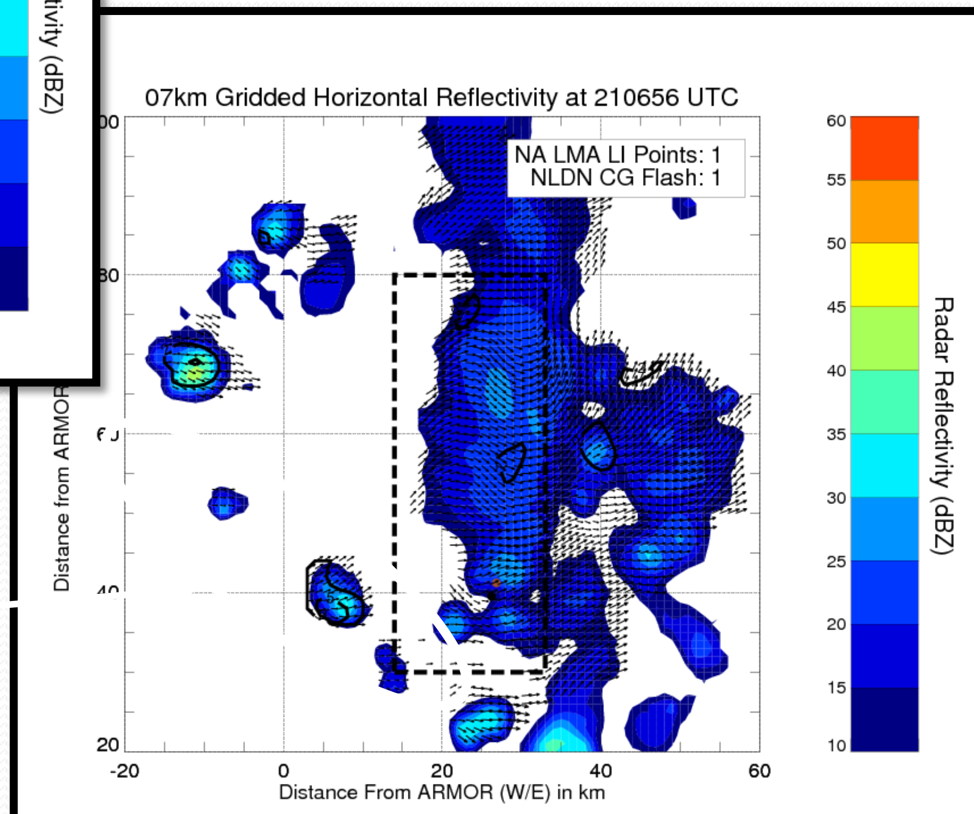
- First flashes are associated with northern updraft

21 May 2012 (Decay and Dissipation Stages 2106 UTC)



Gradual Decay

- Anvil (rich with ice crystals) extends nearly 40-50 km north of previous convection, but little to no graupel
- $W_{max} < 4\ m\ s^{-1}$
- TLFR decreases to ~1 flash min^{-1}
- More extensive flashes in anvil region



New Convection

- Classic multicell evolution with additional cells developing along southwestward moving gust front