Storm Physics and Lightning Properties over Northern Alabama during DC3

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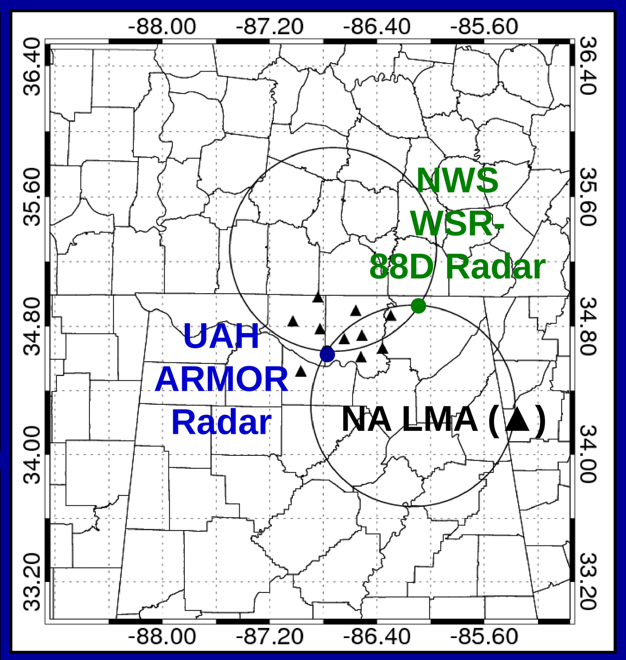
Motivation & Project Goals

- The Deep Convective Clouds and Chemistry (DC3) experiment seeks to examine the relationship between deep moist convection (DMC) and the production of nitrogen oxides (NO_x) via lightning (LNO_x).
- The focus of this study will be to examine integrated storm microphysics and lightning properties of DMC across northern Alabama (NA) during the DC3 campaign through use of polarimetric radar and lightning mapping array platforms.
- We explore the ability of radar inferred microphysical (e.g., ice mass, updraft volume) measurements to parameterize flash rates (F) and flash extent for estimation of LNO_X production in cloud resolving models.

Data and Methodology

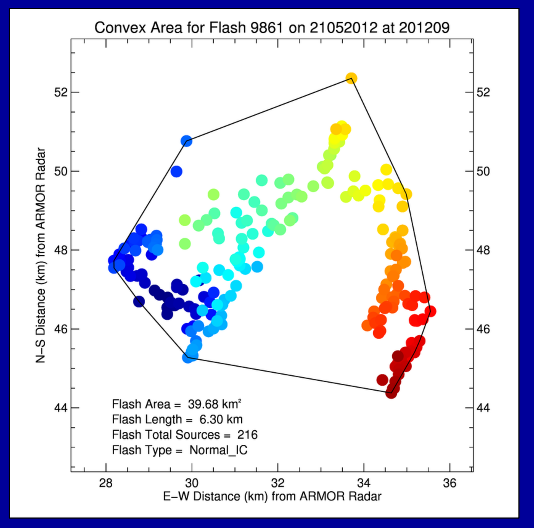
Radars:

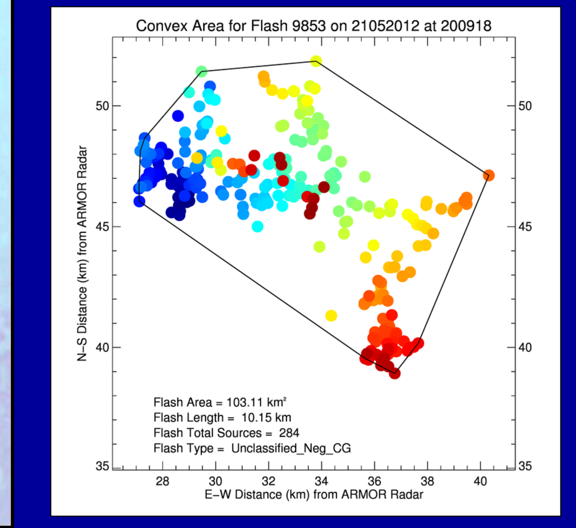
- Advanced Radar for Meteorological Operational and Research (ARMOR)
  - C-Band Polarimetric Radar
  - 100 km range
- Weather Surveillance Radar 1988D at Hytop, AL (KHTX)
  - S-Band Polarimetric Radar
  - 100 km range



Lightning:

- North Alabama Lightning Mapping Array (NA LMA)
  - 11 Sensors (NA)
  - Electrical breakdown in VHF range
- Vaisala National Lightning Detection Network^{TM} (NLDN)
  - Over 100 sensors across U.S.A.
  - Detects return strokes





Ice Mass Calculations:

- Using the methods from Heymsfield and Palmer (1986); Carey and Rutledge (1996, 2000), Cifelli et al. (2002), Deierling et al. (2008) we calculated:
  - Precipitation ice mass using the "rain line" equation (Carey and Rutledge (1996, 2000), Cifelli et al. (2002))
  - $Z_H \geq 35$ dBZ and −40 °c ≤ T ≤ − 10 °C

$$Z_{DP} = 10\log_{10}(Z_H - Z_V)$$

$$M_i = 1000\pi\rho_i N_0^{\frac{3}{7}}\left(5.28x10^{-18}\frac{Z_{HI}}{720}\right)^{(4/7)} (gm^{-3})$$

  - Non-precipitation ice mass using Heymsfield and Palmer's (1986) Z−M relationship (and Deierling et al. (2008))
  - ZH ≥ 0 dBZ and T ≤ − 40 °C

$$M = 0.08976(Z_H)^{0.529}$$

Updraft Calculations:

- Multi-Doppler wind retrievals were obtained via the Custom Editing and Display of Reduced Cartesian Space (CEDRIC) (Miller and Frederick 1998).
- Storm motion was derived from radar-derived storm motion, an input used in CEDRIC in the advection correction scheme.
- U and V components of the air are computed using the terminal fall velocity. Upon the re-computation of U and V, the anelastic form of the mass continuity equation is integrated using a variational scheme.

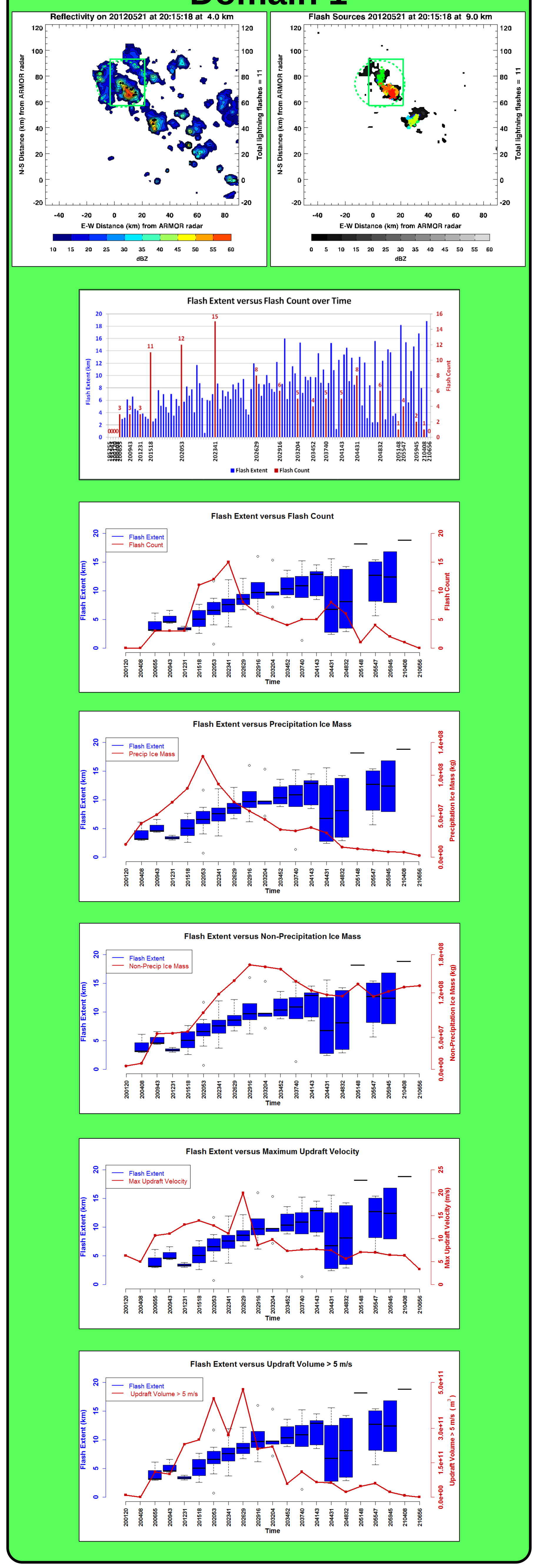
Flash Extent Calculations:

- Using the "convex hull" area of Bruning and MacGorman (2013):
  - This method essentially draws a polygon around all the sources that comprise a flash. From this polygon, the convex hull area that describes the minimum polygon that circumscribes the horizontal flash extent is calculated

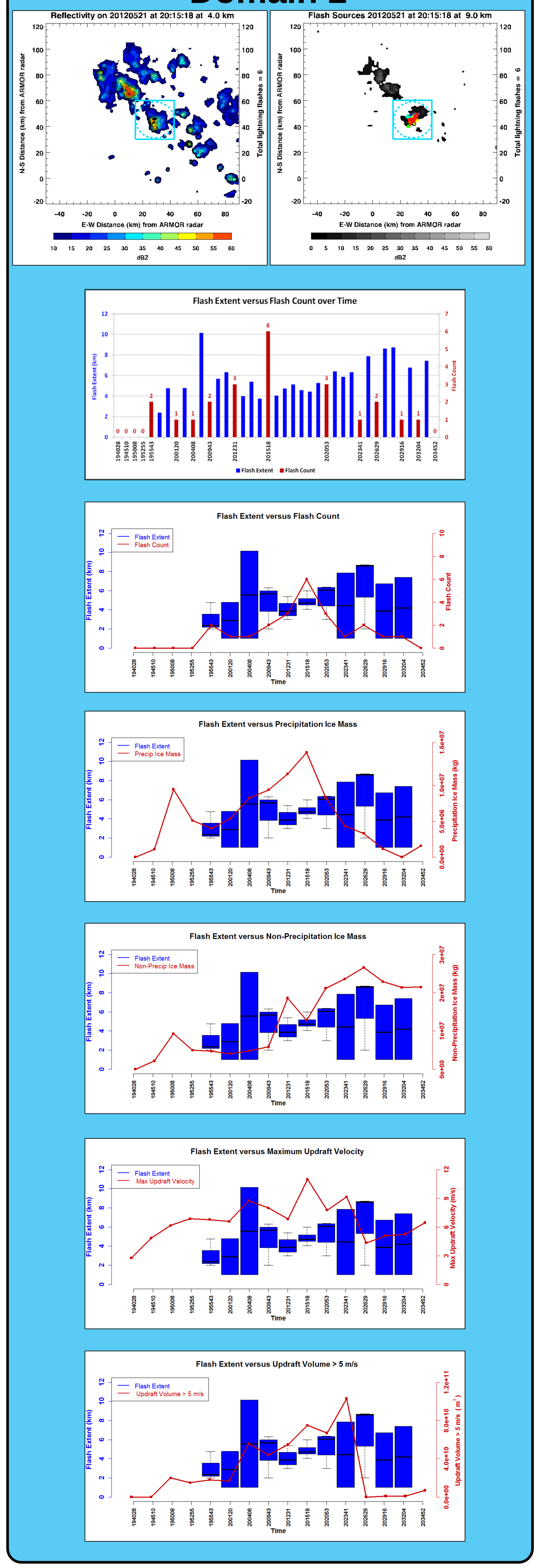
$L = \sqrt{A}$ Where L is the Flash Length or Flash "Extent" and does NOT account for the tortuous propagation of a flash's branches.

Research Results

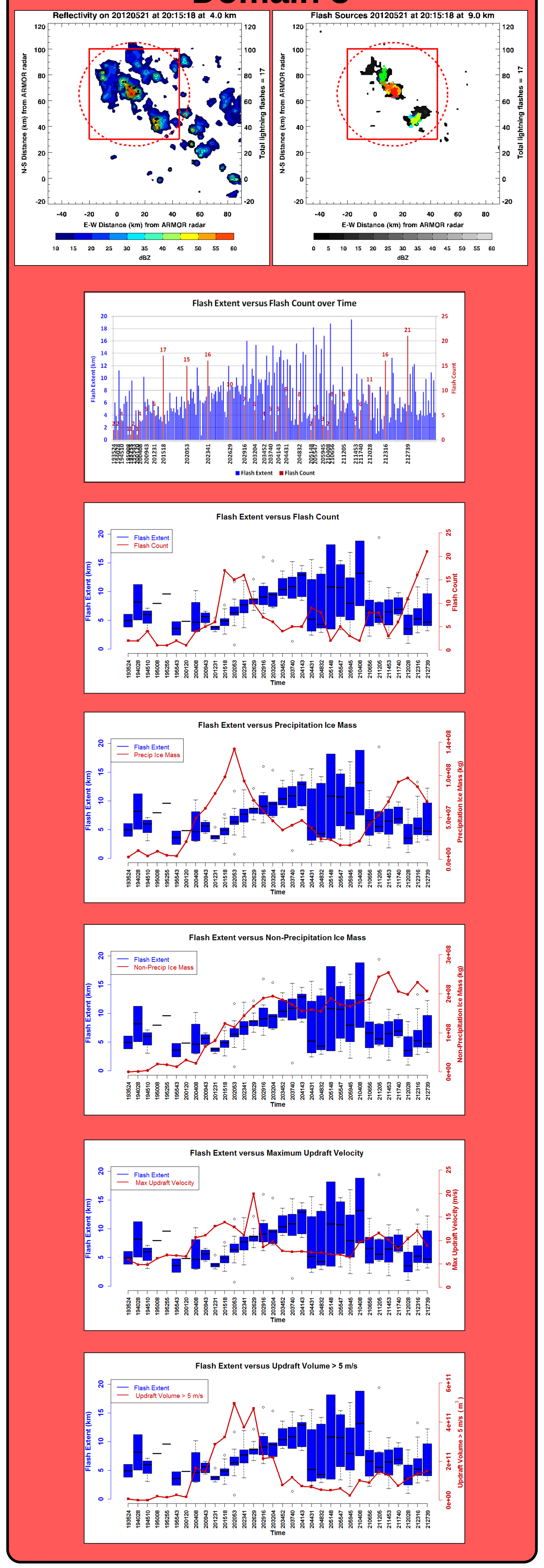
Domain 1



Domain 2



Domain 3



Discussion

- Many studies have shown that higher "mixed–phase" precipitation ice masses are strongly correlated to higher flash rates (Goodman et al., 1988; Carey & Rutledge, 1996; Carey & Rutledge, 2000; Petersen & Rutledge, 2001; Deierling et al., 2005; Deierling et al., 2008 and Barthe et al., 2010).
- In addition, increased updraft strength inferred from radar variables directly results in more ice mass aloft, and thus more lightning (Carey & Rutledge, 2000).
- These same results were found in our analysis of the 21 May 2012 DC3 case day; stronger updrafts are correlated to larger amounts of precipitation and non-precipitation ice masses and therefore higher flash rates.
- However, for all three domains shown here, as the flash rates increase, the flash extents decrease and therefore the average flash extent opposes local breakdown (i.e. the more precipitation ice mass, the more breakdown, the higher the flash rate, the smaller the flash). This was also observed by Bruning and MacGorman, 2013.
- In particular, and overall, the breadth of the flash extent is initially small, but as the maximum updraft strength, volume of updraft > 5 m/s, precipitation and non-precipitation ice masses increase, the breadth in flash extent increases
- More specifically, the increase in flash extent breadth lags the peak increase in maximum updraft strength, volume of updraft > 5 m/s and precipitation ice mass production.
- Therefore, the flashes with the largest extents do not occur at the same time as the peak in the maximum updraft strength, volume of updraft > 5 m/s, precipitation and non-precipitation ice masses.
- Therefore our results compare well with what was found by Bruning and MacGorman (2013), even though their results focused on supercell storms.
- We show here that these results are consistent whether one focuses on a "single storm complex" or on a larger domain that includes many convective complexes.

Conclusions and Future Work

- As the maximum updraft speed and updraft volume > 5 m/s increase, precipitation ice mass increases, flash rates increase and flash extents decrease. Therefore stronger updrafts → more ice → more charged particles → more "blobs" of charge regions → more breakdown → higher flash rates → smaller flash extents.
- The breadth of the flash extent distribution seem to increase after a peak in the precipitation ice (i.e. maximum flash extent lags maximum precipitation ice).
- Flash extent is initially small (small breadth), but once non-precipitation ice "levels out" the breadth of the flash extents increase.
- Future work includes applying these same methods to more case days during DC3 (such as 11 June 2012, which was also aircraft penetrated) as well as verifying whether these same principles hold for various flash types, i.e. inter-cloud (IC), cloud-to-ground (CG) and IC-CG hybrid flashes.

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