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Thunderstorm lifecycle and morphological influences on lightning channel distributions

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DC3 Science plan: Figure 3
Uncertainty in NOx production

- 3 orders of magnitude variation in mol NO per flash, per channel length.

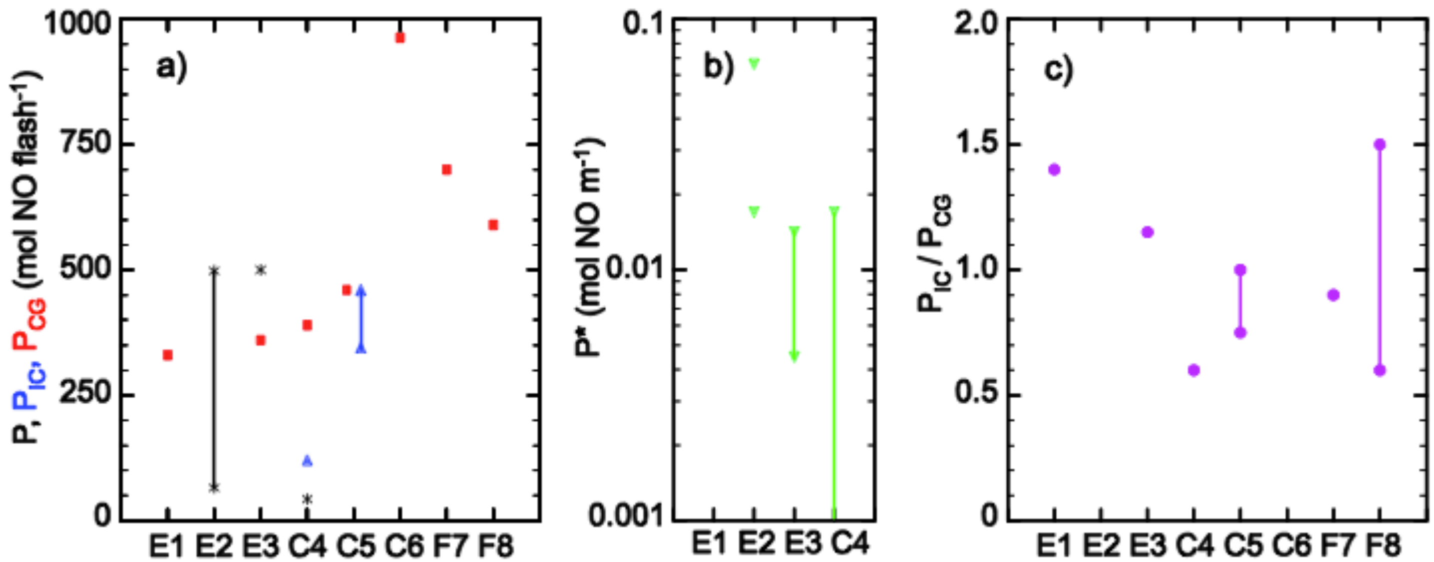


Figure 3. Production of NO from lightning, literature review. a) Estimate of total (black), intracloud (blue), and cloud-to-ground NO production per lightning flash as a function of storm studied; b) estimate of NO production per lightning flash length as a function of storm studied; and c) estimated ratio of NO production from IC flashes to CG flashes as a function of storm studied. E1 is the 21 July 1998 EULINOX storm (Fehr et al., 2004); E2 a LINOX storm in S. Germany and Switzerland (Huntrieser et al., 1998; Höller et al., 1999); E3 the 21 July 1998 EULINOX storm (Huntrieser et al., 2002; Thery et al., 2000; Ott et al., 2007). C4 is the 10 July 1996 STERAO storm (Stith et al., 1999; Skamarock et al., 2003; Ott, 2006; Barthe and Barth, 2008); C5 the 12 July 1996 STERAO storm (DeCaria et al., 2000, 2005); C6 the 12 September 2002 Colorado storm (Langford et al., 2004). F7 is the 16 July 2002 CRYSTAL-FACE storm (Ott et al., 2005); F8 the 29 July 2002 CRYSTAL-FACE storm (Ott et al., 2005).

Convection to NO_X production: energy conversion

- Thermodynamic potential energy to kinematic energy
  - *Convection transports hydrometeors that bear charge*
- Kinematic energy to electrical potential energy
- Electrical energy is used to develop a lightning channel
  - *Some energy used in NO_x production*

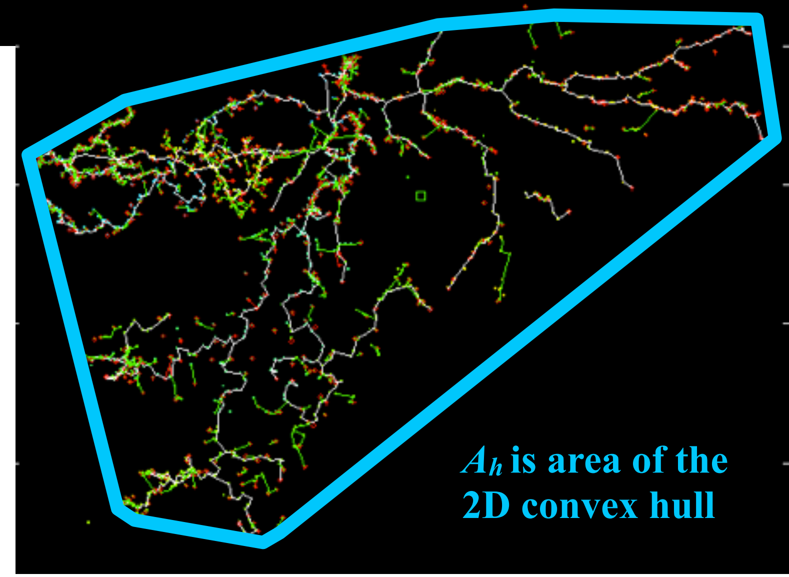
A SIMPLE MODEL OF FLASH ENERGY

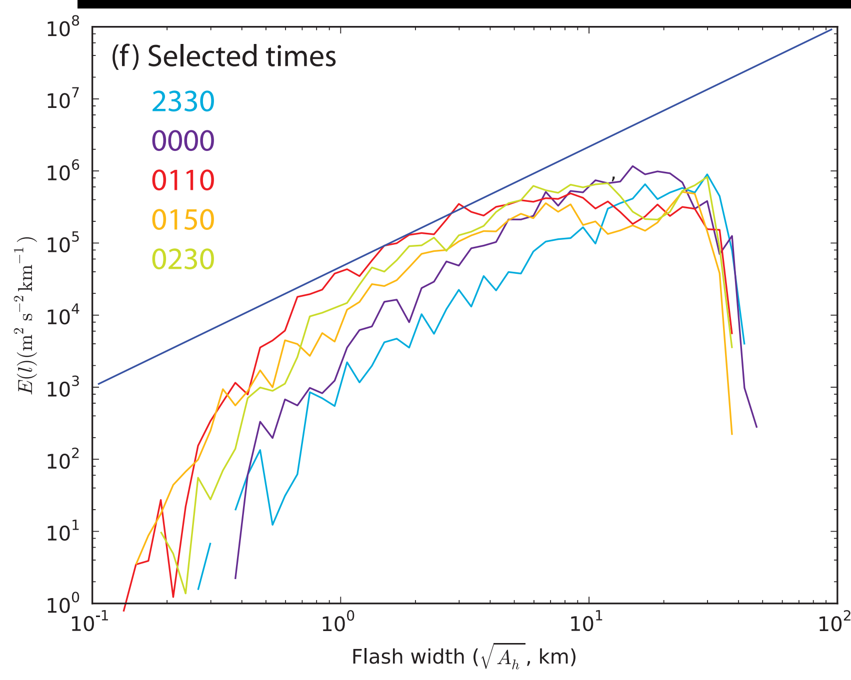
Bruning and MacGorman (2013, JAS)

- Predictable shape to energetically-scaled flash size spectrum.
  - ***Size scale*** $l = \sqrt{A_h}$
- Choice of energetic scaling relationship naturally arises from capacitor model of a lightning flash
- Treat charge density and plate spacing as unknown, and focus on variation in energy with *l*.

$$E(l) = \frac{\rho^2 l^2 d^3}{2\epsilon_0} = K l^2$$

Do we get a different picture of total lightning activity by considering even one more parameter in addition to flash rate?





Energy distribution from the flash size distribution

- The flash count $N(l)$ at size l depends on the probability $P(l)$ of size l and total flash count N_T

$$N(l) = N_T \int_0^\infty P(l) dl$$

- The total energy is therefore given by

$$\begin{aligned} E_T &= \int_0^\infty E(l) N(l) dl \\ &= K N_T \int_0^\infty l^2 P(l) dl \end{aligned}$$

- The total energy is proportional to the second raw moment of the flash size distribution.
- Energy scales linearly with flash rate, but also varies as flash size probabilities change

Total energy for different distribution shapes

- Normal $$E_T = \frac{\rho^2 d^3}{2\epsilon_0} N_T (\mu^2 + \sigma^2)$$

- Log-normal $$N(l) = \frac{N_T}{S\sqrt{2\pi}l} \exp\left(-\frac{(\ln(l) - M)^2}{2S^2}\right)$$
$$E_T = \frac{\rho^2 d^3}{2\epsilon_0} N_T \exp\left(2(M + S^2)\right)$$
$$l_M = e^M \qquad = \frac{\rho^2 d^3}{2\epsilon_0} N_T l_M^2 \exp\left(2S^2\right).$$

- Gamma $$N(l) = N_T \frac{l^{\alpha-1} e^{-l/\theta}}{\Gamma(\alpha)\theta^\alpha}$$
$$E_T = \frac{\rho^2 d^3}{2\epsilon_0} N_T \theta^2 \frac{\Gamma(\alpha+2)}{\Gamma(\alpha)}$$

Each depends on flash rate and the square of a characteristic length scale (“mean”) and another variance-like parameter

Channel length distribution as a moment

Likewise, the total flash length is given as the *D*th fractional moment of the size distribution by

$$L_T = \frac{N_T}{b_s^{D-1}} \int_0^\infty l^D P(l) dl$$

which uses Bruning et al. (2012, AGU) for the dependence of flash length on step length b_s and fractal dimension *D:*

$$L(l) = \frac{l^D}{b_s^{D-1}}$$

DEEP CONVECTIVE CLOUDS AND CHEMISTRY EXPERIMENT

Parameterization of NOx production on flash rate cannot account for diversity in flash size

- IC/CG classification probably (implicitly) takes into account some of the variability in flash size

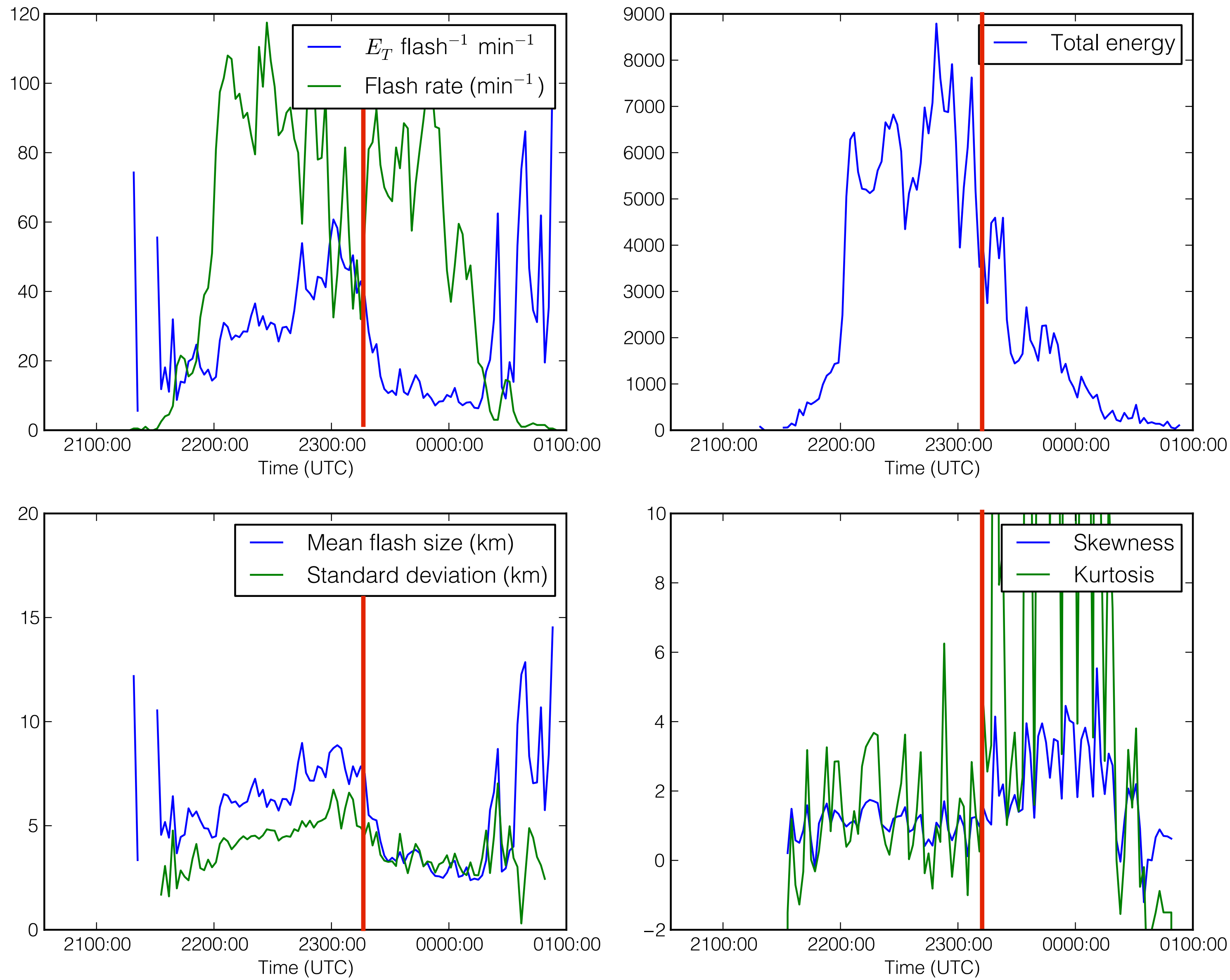
Still, this is not a terrible problem if…

- Flash size distribution is not skewed
- There is a typical, universal flash size

LMA observations show these are both problems

- Cases from TELEX (2004), DC3 (2012)

26 May 2004: Oklahoma low-precipitation supercell (Bruning et al. 2010, MWR)

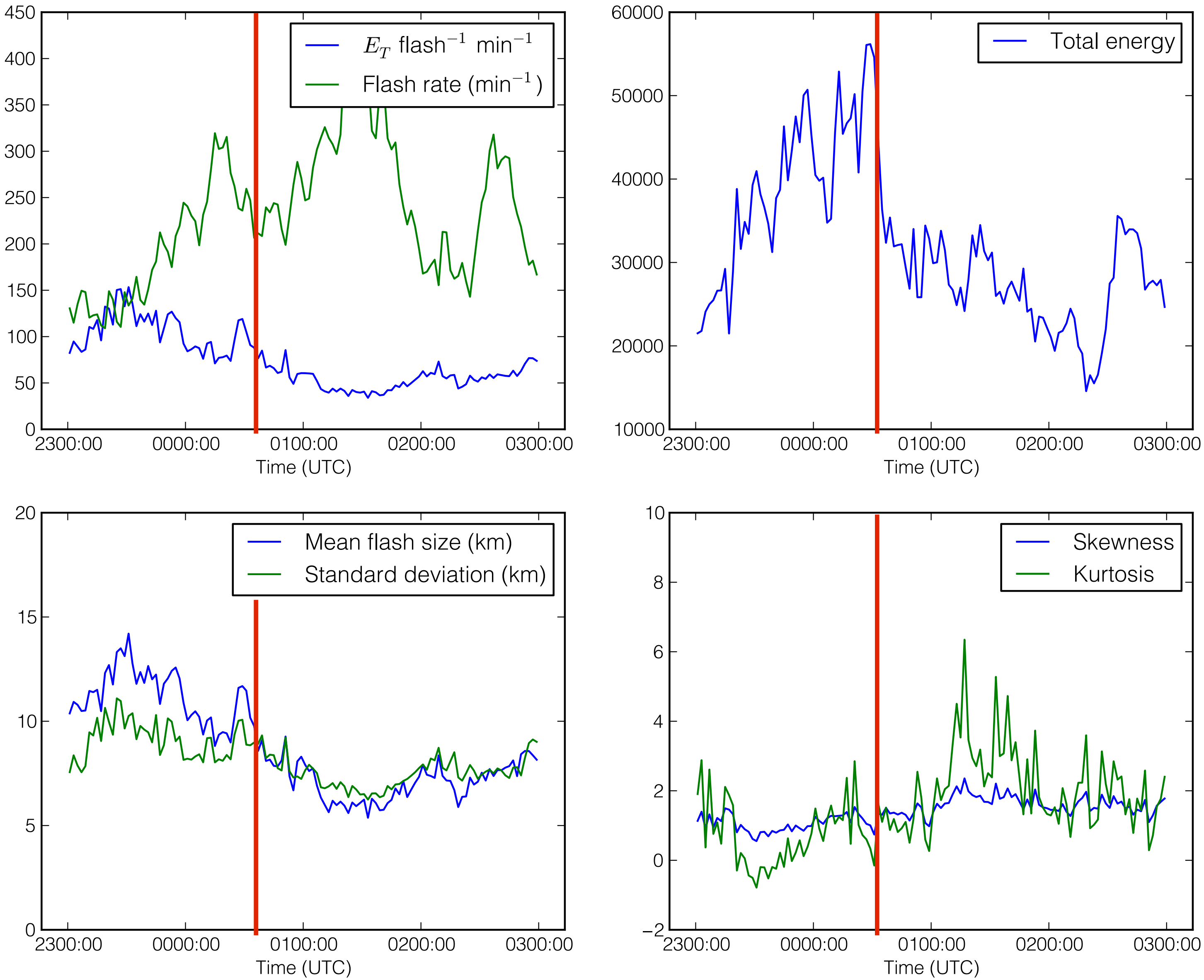


2250 UTC: transition from negative to positive CGs

2310 onward: minimum in flash size until storm death and largest flashes, more skew to distribution

Flash rate remains elevated 2300–0000 UTC, but energy decays

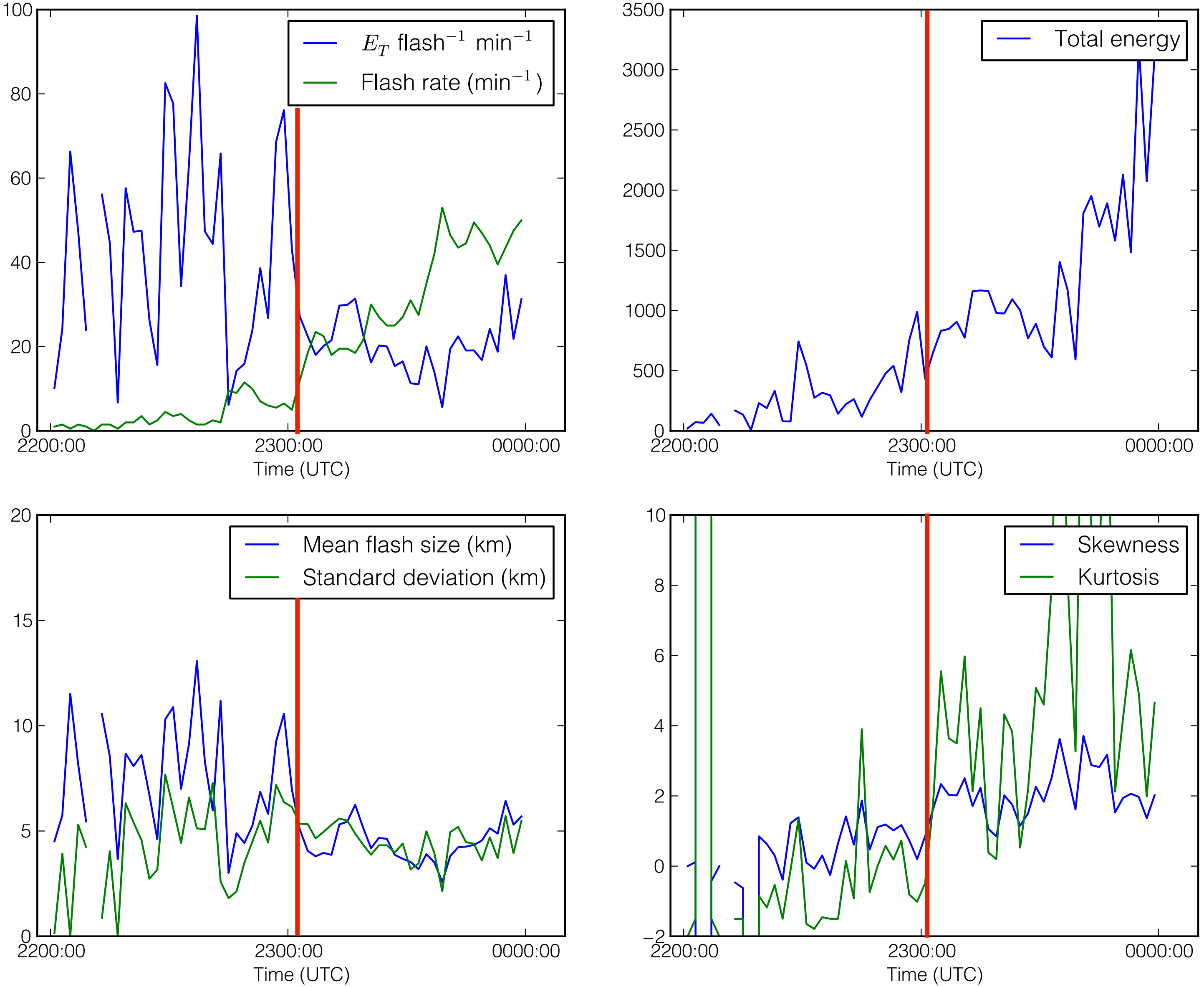
29 May 2004: Oklahoma high-precipitation supercell (Calhoun et al. 2013, MWR)



Sudden change in total energy at 0040 UTC, as there is a shift to small flash sizes.

Completely different picture from flash energy, flash rate.

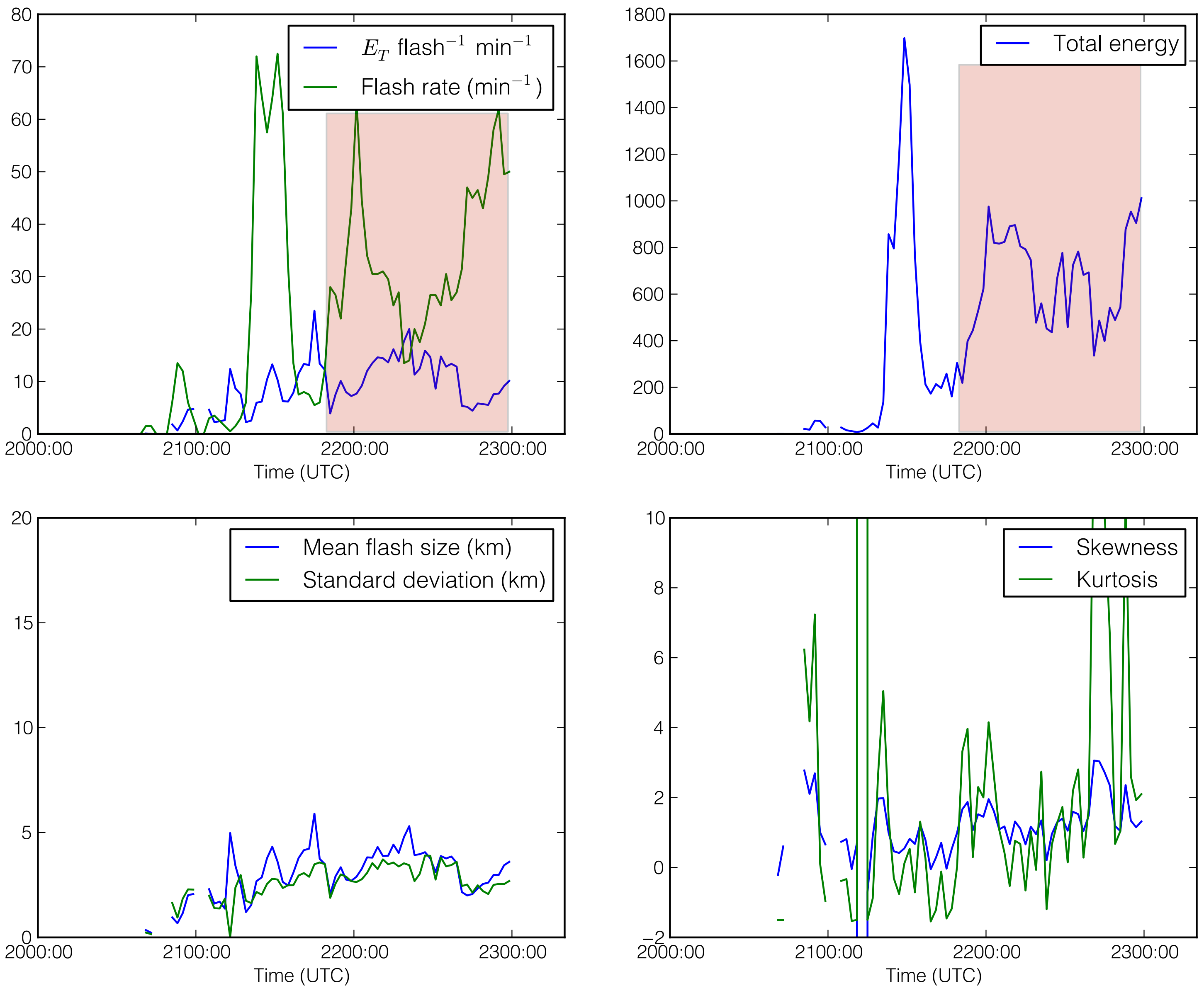
29 May 2012: Oklahoma cell observed by ground teams



5 – 10 km mean flash size prior to 2300 UTC.

Size drops to 3 – 5 km as supercell structure develops from 2300 – 0000 UTC (Biggerstaff et al., this conf.)

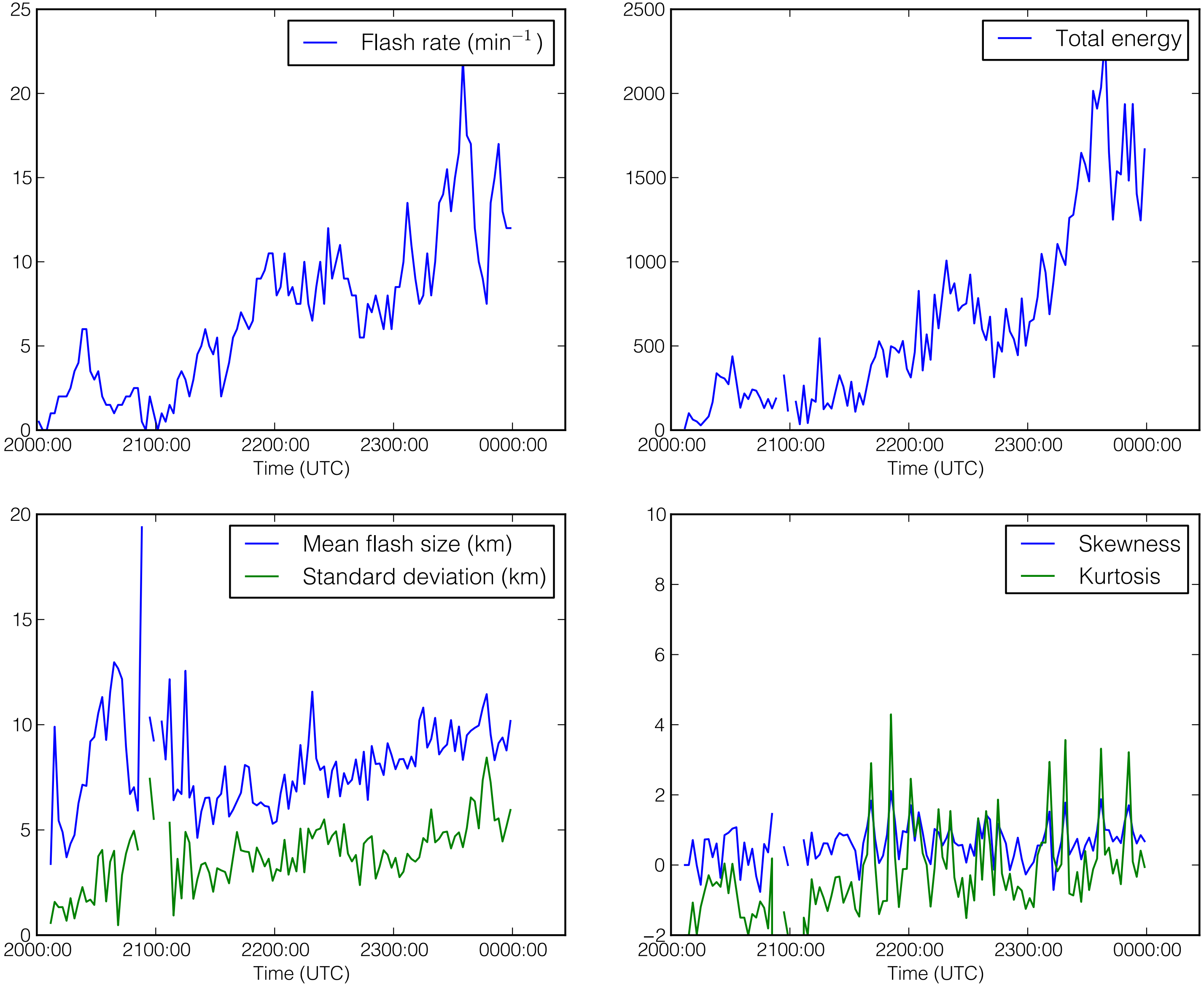
6 June 2012: Colorado, first target cell (~2130 UTC)



Later peaks in flash rate correspond to smaller flashes, and so less total energy than first peak.

Flash sizes < 5 km throughout, similar to late stage of LP supercell.

21 May 2012: Alabama, all cells in 100 km box



Flash sizes in 5 – 10 km size range, nearly zero skew to distribution

Energy and flash rate trend similarly (though not exactly)

SUMMARY

- Total flash energy shows dependence on typical flash size
- Typical flash size can shift, and is not normally distributed
- Flash rate and total energy are substantially different
- Shifts in storm character and polarity due to organization by shear and differences in environment may be correlated to these shifts in flash size

- Prediction: NOx vs. flash energy should have less scatter than NOx vs. flash rate, and will be comparable to estimates using channel length, because both can account for shifts in flash size as thunderstorms develop.