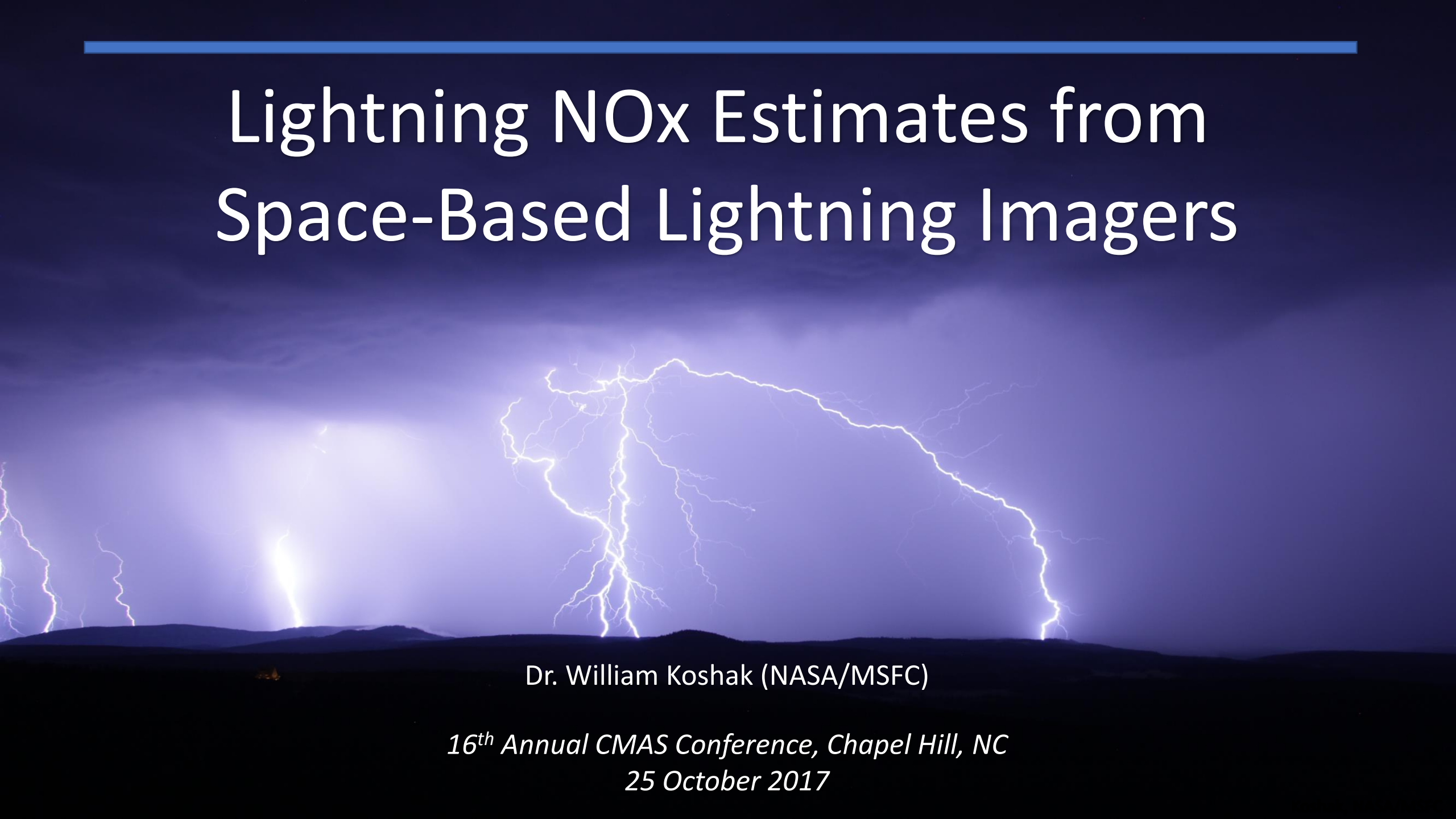
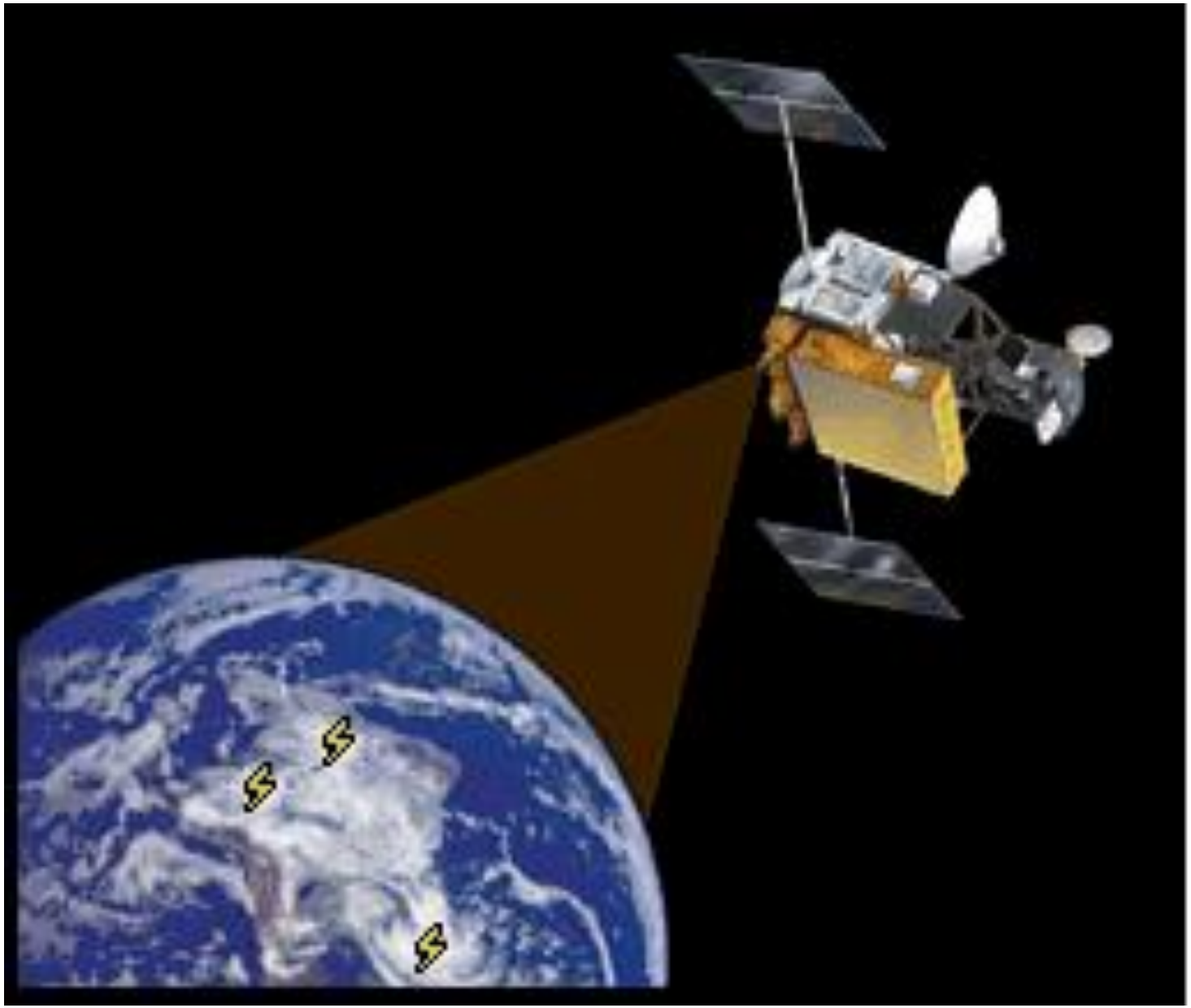
Lightning NOx Estimates from Space-Based Lightning Imagers



Dr. William Koshak (NASA/MSFC)

16th Annual CMAS Conference, Chapel Hill, NC
25 October 2017



Basic idea:

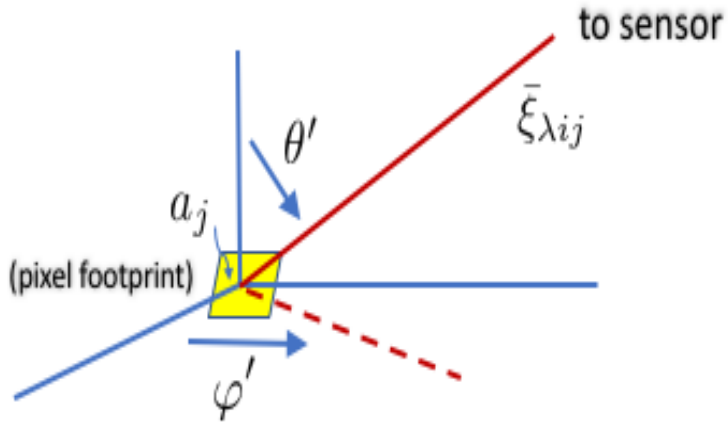
Use observed optical energy to infer <u>total flash energy</u> E … then multiply by thermo-chemical yield to get LNOx.

Koshak, NASA/MSFC

What to use for Flash Optical Energy?

Incident Flash Optical Energy:

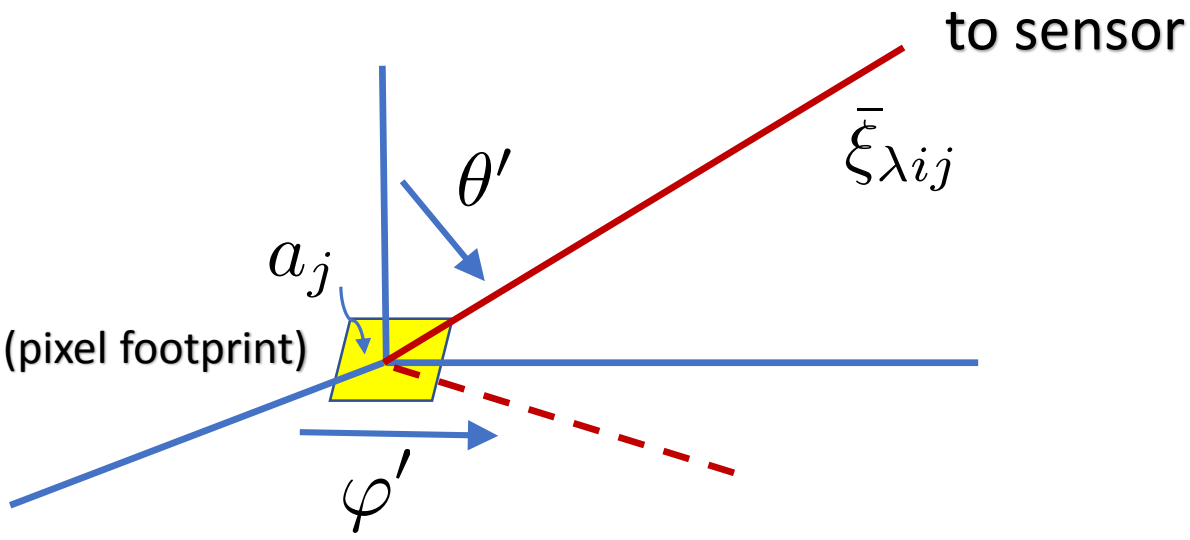
$$Q = \sum_{i=1}^{m}\sum_{j=1}^{n} A_j \Delta\lambda_j \Delta\omega_j \bar{\xi}_{\lambda ij} \qquad (\text{in } \mu J)$$



Sensor - Invariant Upward Spectral Flash Optical Energy:

$$\Gamma_\lambda = \sum_{i=1}^{m}\sum_{j=1}^{n} \pi \bar{\xi}_{\lambda ij} a_j \qquad (\text{in } \mu J\ nm^{-1})$$

isotropy assumed



$$J_{\lambda ij} = \int_{2\pi} \cos\theta' \bar{\xi}_{\lambda ij} d\Omega' = \bar{\xi}_{\lambda ij} \int_0^{2\pi} \int_0^{\pi/2} \cos\theta' \sin\theta' d\theta' d\varphi'$$

$$\Rightarrow \quad J_{\lambda ij} = \pi \bar{\xi}_{\lambda ij} \quad (\mu J\ m^{-2} nm^{-1})$$

Upward flux density from pixel footprint for i^{th} frame

$$\Rightarrow \quad \Gamma_\lambda = \sum_{i=1}^{m} \sum_{j=1}^{n} J_{\lambda ij} a_j = \sum_{i=1}^{m} \sum_{j=1}^{n} \pi \bar{\xi}_{\lambda ij} a_j$$

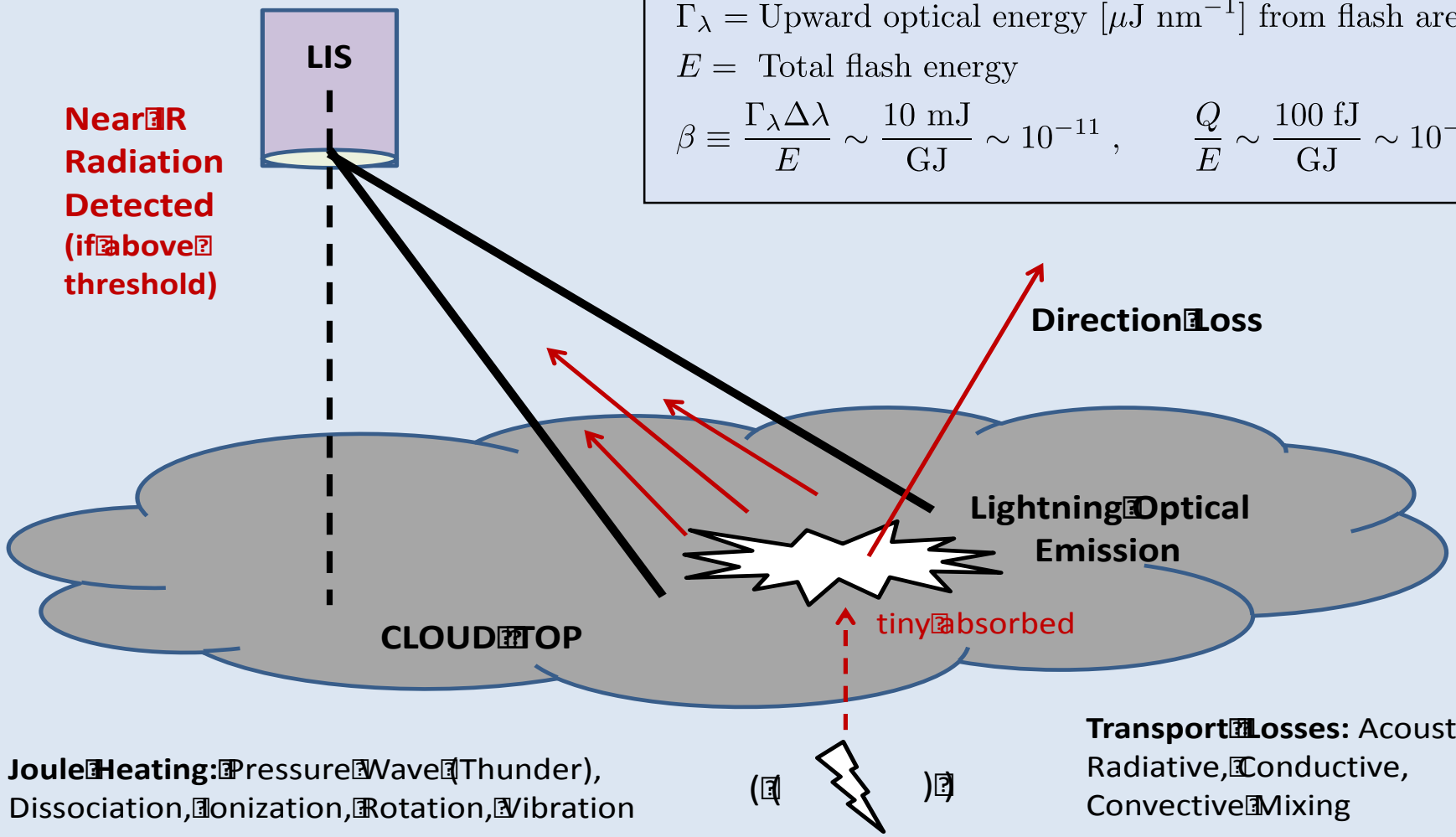
Koshak, NASA/MSFC

Tiny Fraction of E Reaches Sensor

Γ_λ = Upward optical energy [μJ nm^{-1}] from flash area S

E = Total flash energy

$$\beta \equiv \frac{\Gamma_\lambda \Delta\lambda}{E} \sim \frac{10\ \text{mJ}}{\text{GJ}} \sim 10^{-11}\ , \qquad \frac{Q}{E} \sim \frac{100\ \text{fJ}}{\text{GJ}} \sim 10^{-22}$$

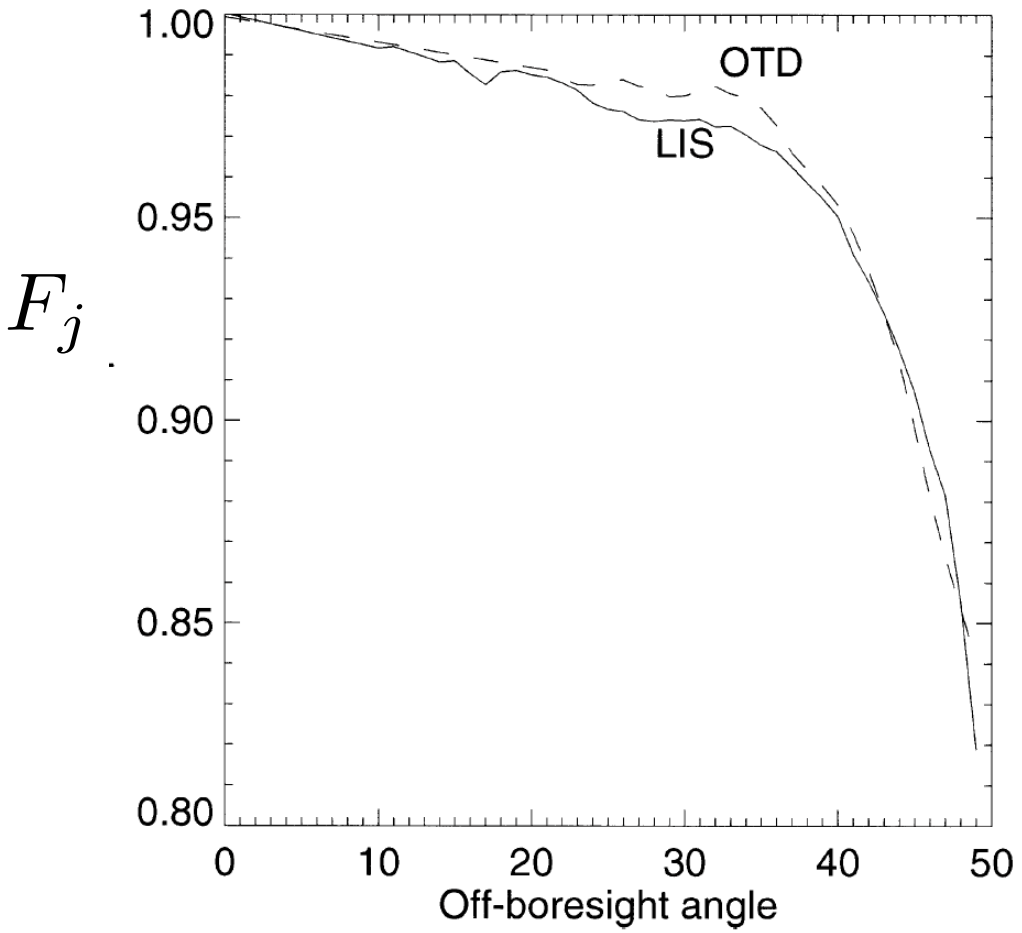


Koshak, NASA/MSFC

Correcting for LIS sensitivity roll-off

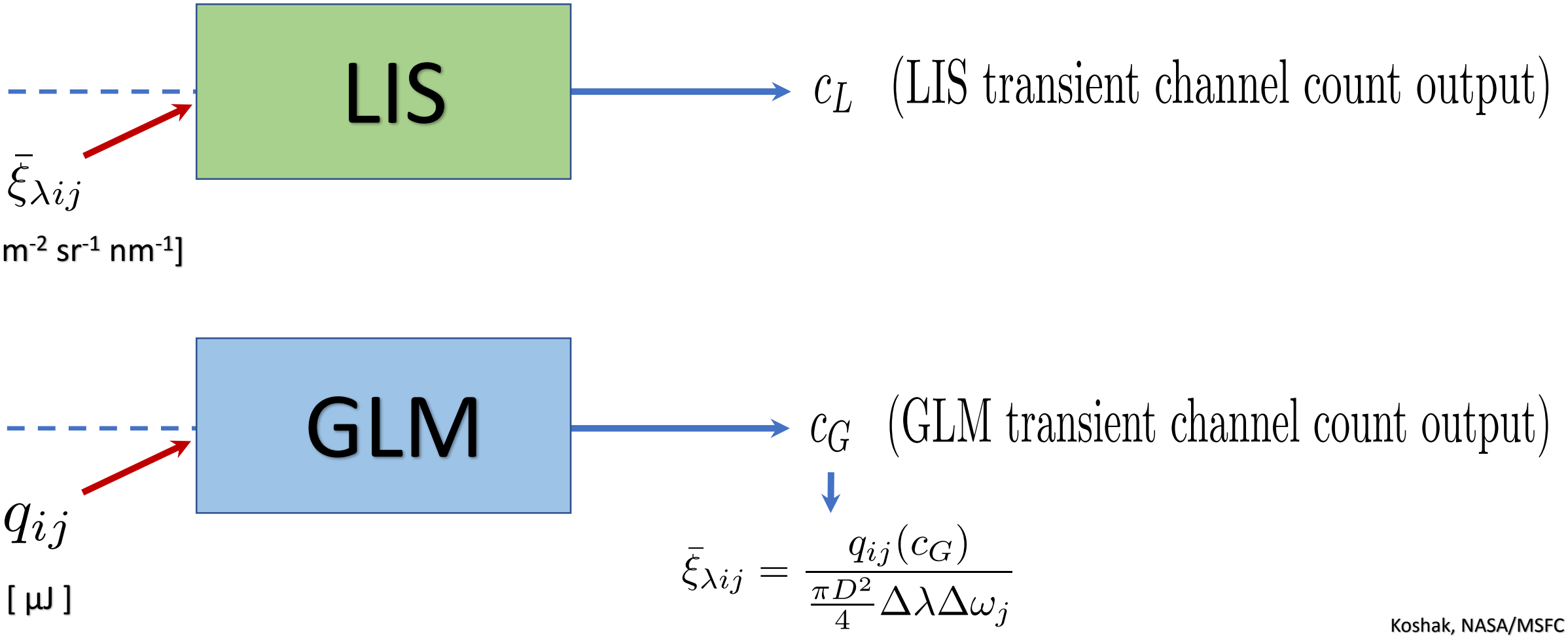
In dataset

$$\bar{\xi}_{\lambda ij} = \frac{0.985\zeta_{\lambda ij}}{F_j}$$



Boccippio, D. J., W. J. Koshak, R. J. Blakeslee, Performance assessment of the Optical Transient Detector and Lightning Imaging Sensor. Part I: predicted diurnal variability, J. Atmos. Oceanic Technol., 19, 1318-1332, 2002.

What do you do for GLM ?



Koshak, NASA/MSFC

LNOx production from kth flash

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\pi\bar{\xi}_{\lambda ijk}a_{jk}$$

$$P_k = \frac{Y}{\beta N_A}\Gamma_{\lambda k}\Delta\lambda$$

$Y \sim 10^{17}$ molecules per Joule ... thermochemical yield

$N_A = 6.022 \times 10^{23}$ molecules per mole ... Avogadro's number

LNOx Production for a region/period

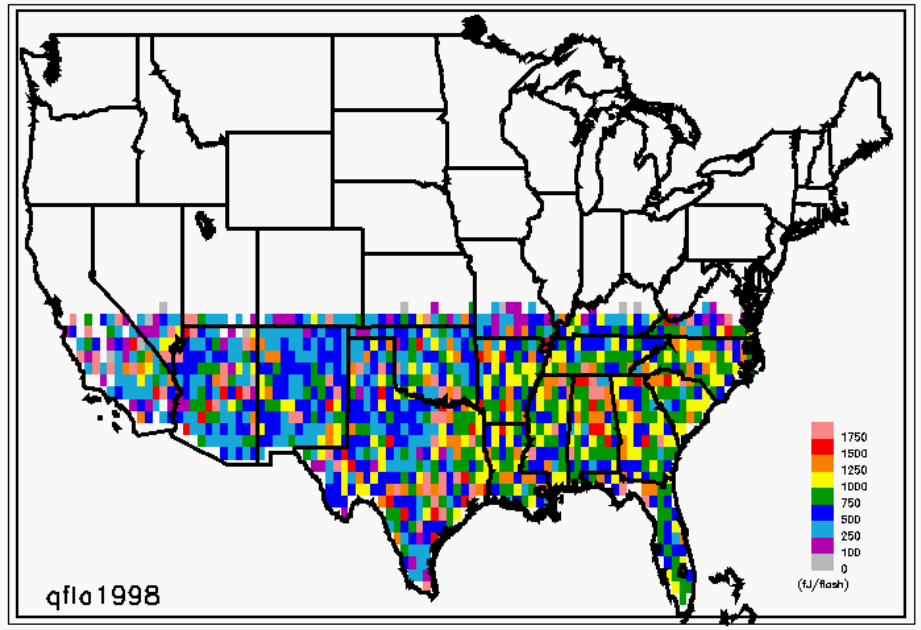
$$P = \sum_{k=1}^{N_o} P_k + N_u \left(\frac{1}{N_o} \sum_{k=1}^{N_o} P_k \right)$$

this estimative term not needed
for GLM since GLM continuously monitors

$$N = N_o + N_u$$ (observed + unobserved)

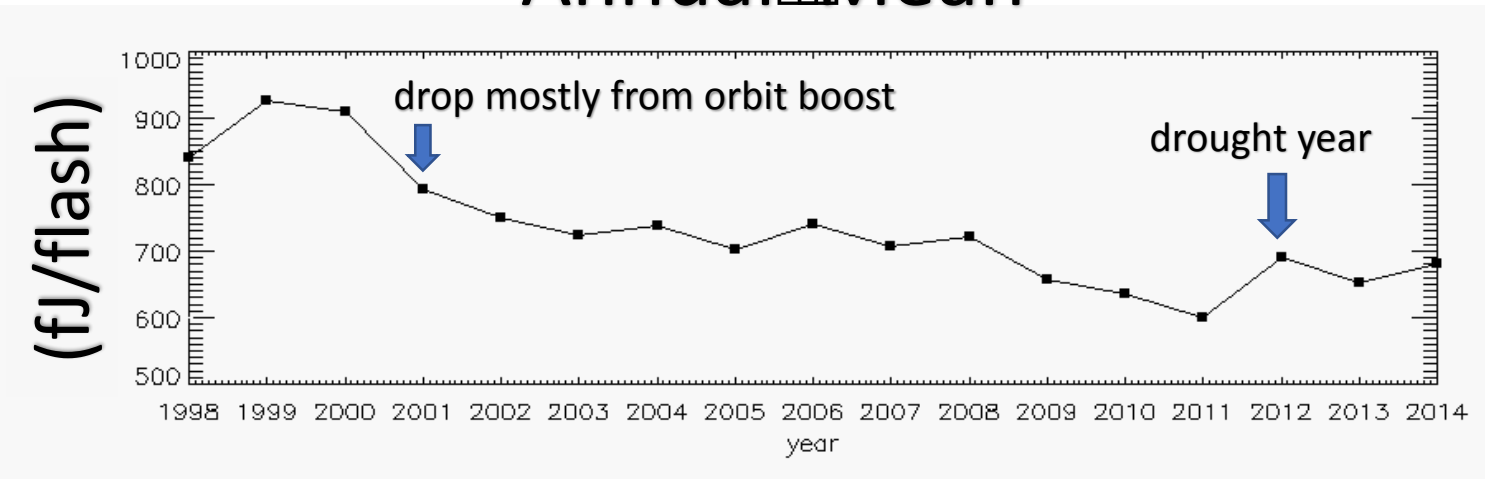
Koshak, NASA/MSFC

TRMM/LIS Mean *Q* per flash (fJ/flash)

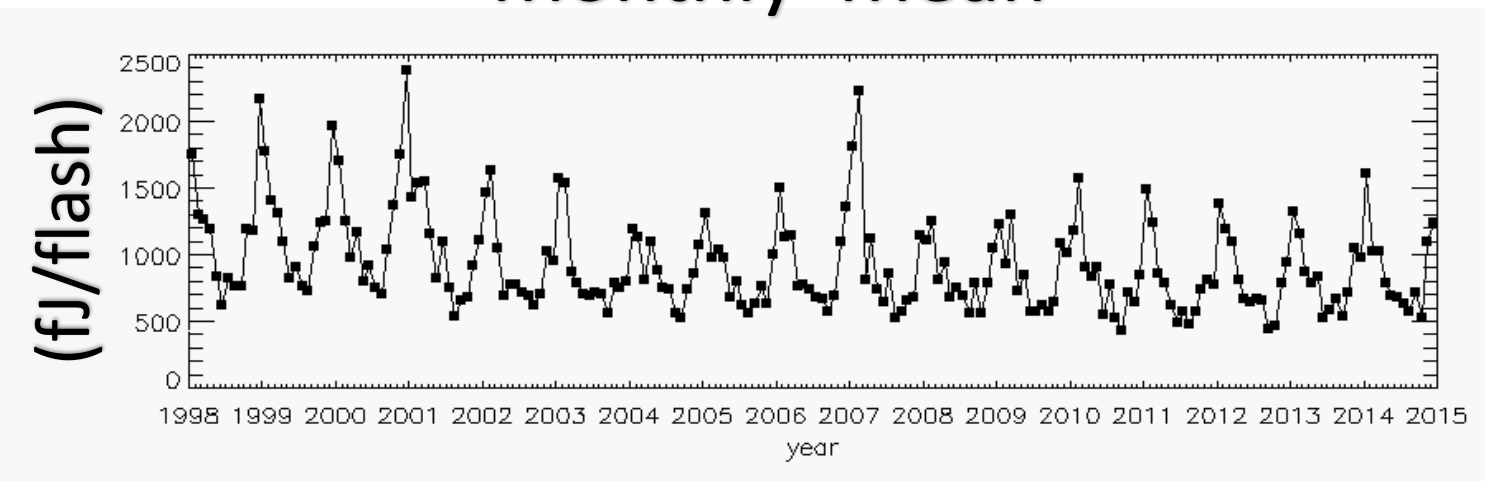


- 2014 added to the record
- 2015 partial year + issues, so not used
- Generally a downward trend (drop in 2001 mostly due to orbit boost)
- Upward trend starting in 2011
- Strong increase in 2012 drought (these are per flash results)

Annual Mean

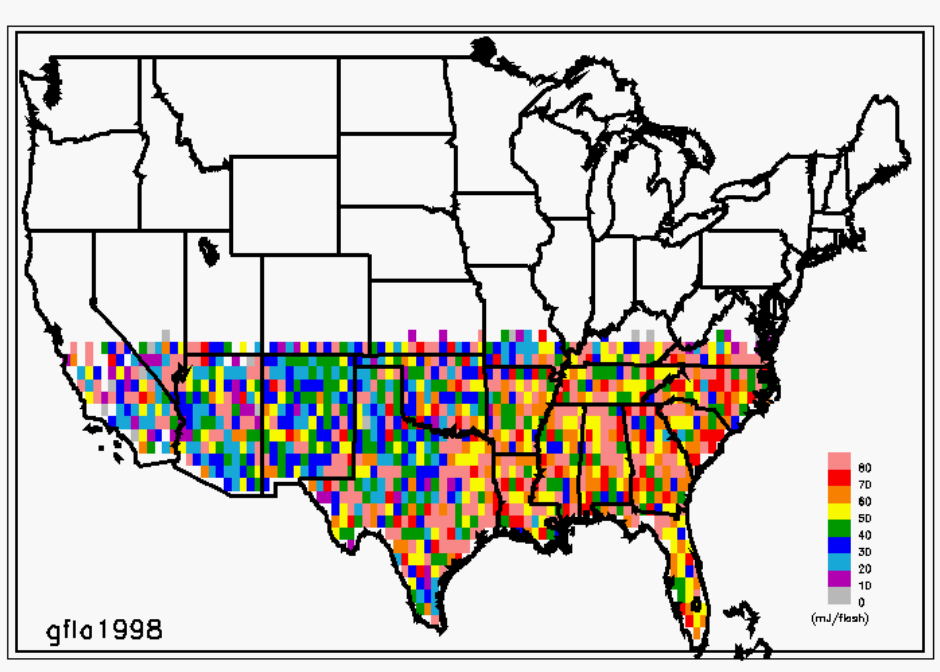


Monthly Mean



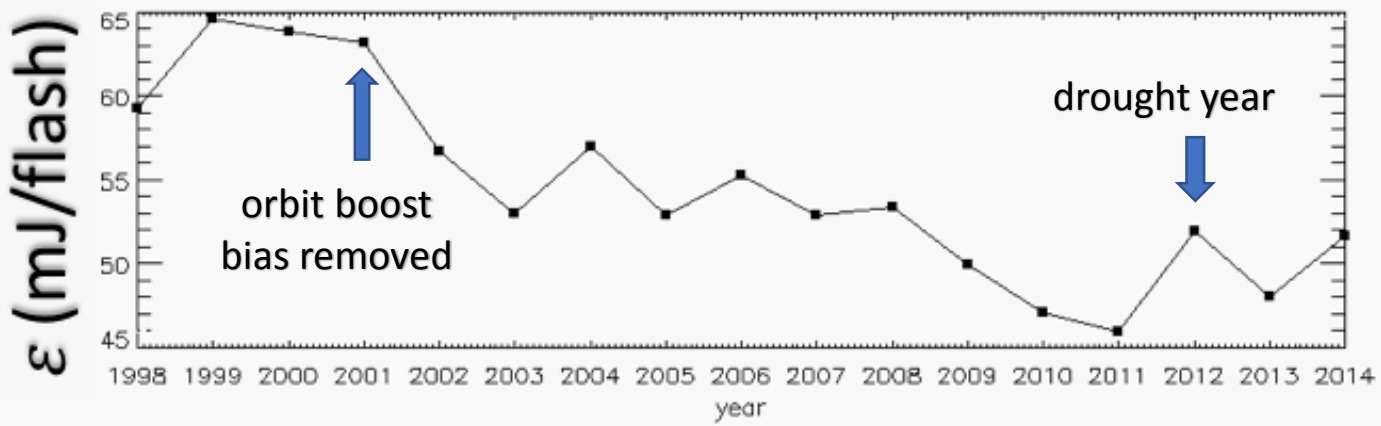
Koshak, NASA/MSFC

TRMM/LIS Mean $\Gamma_\lambda \Delta\lambda$ per flash ≡ $\mathcal{E}$ (mJ/flash)

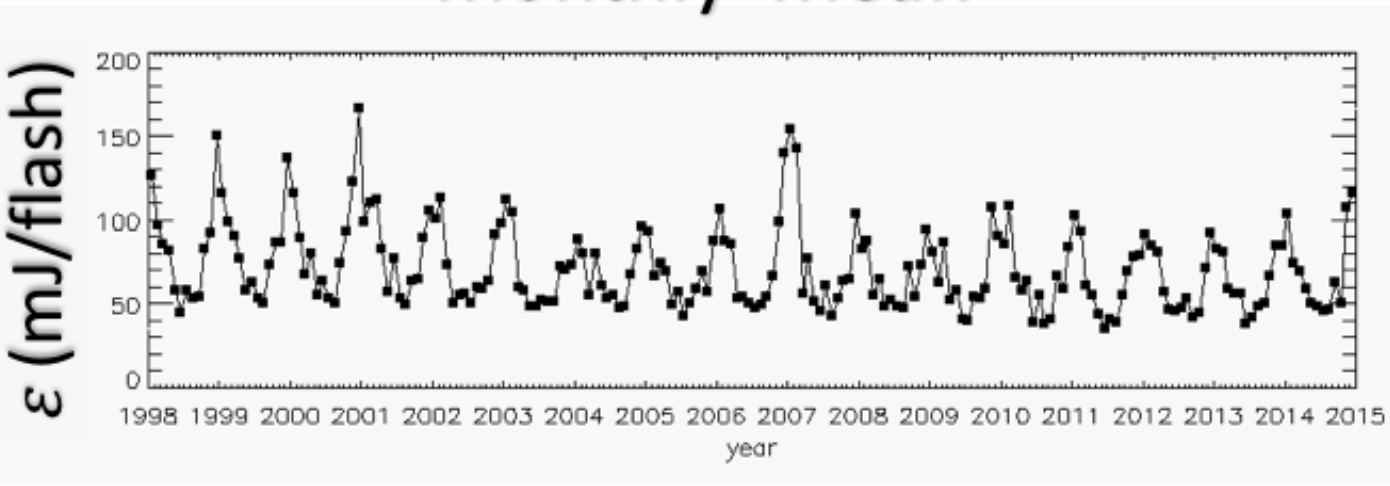


- Monthly Plots: Maxima occurs in January but this is all normalized (i.e. per flash values)
- Jan max possibly indicative of large current +CGs and/or small vertical optical depth, common in winter thunderstorms.

Annual Mean

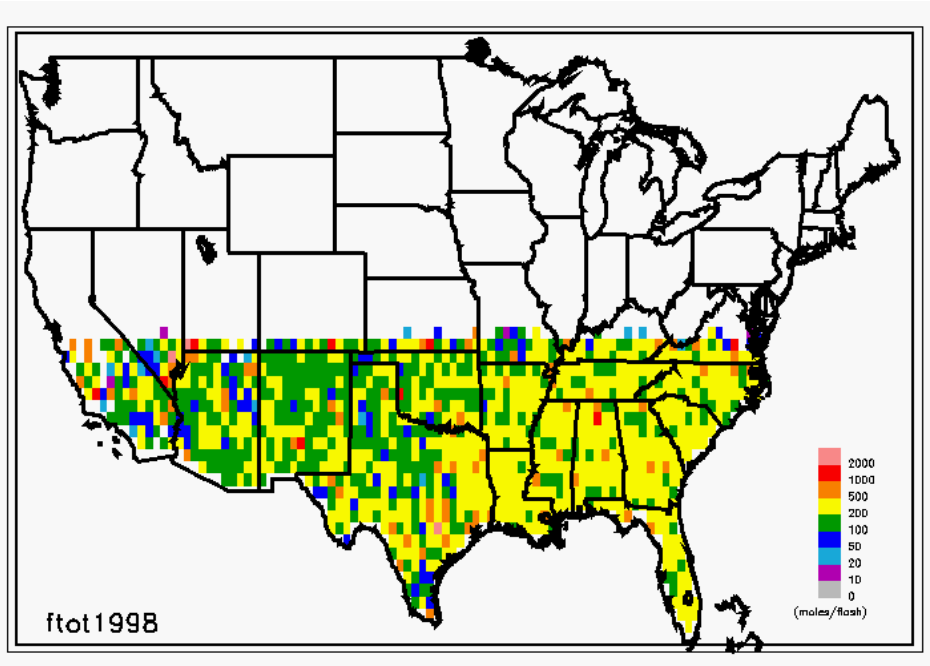


Monthly Mean

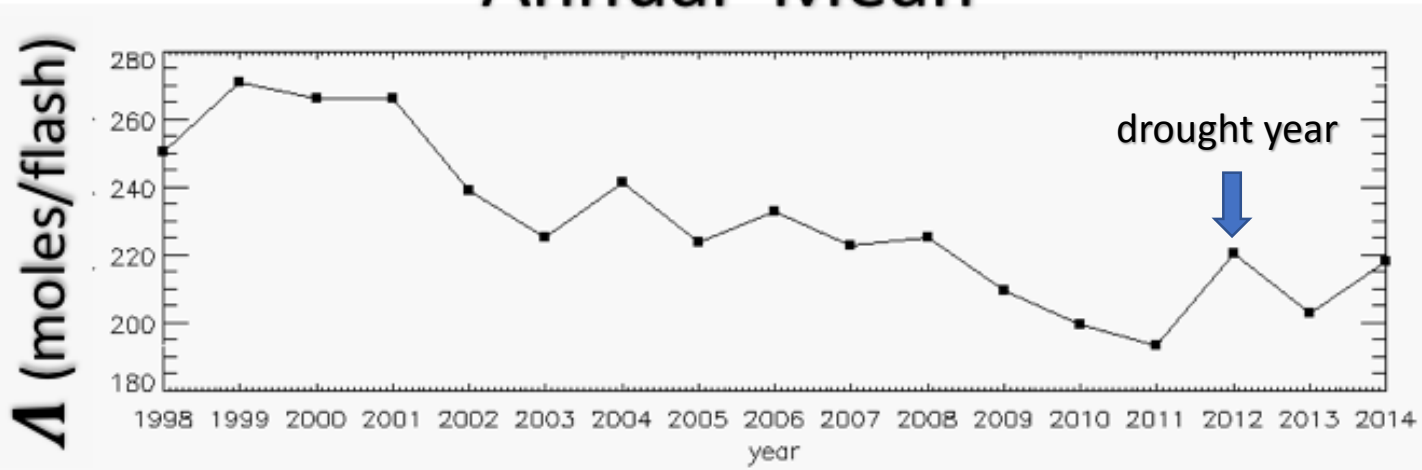


Koshak, NASA/MSFC

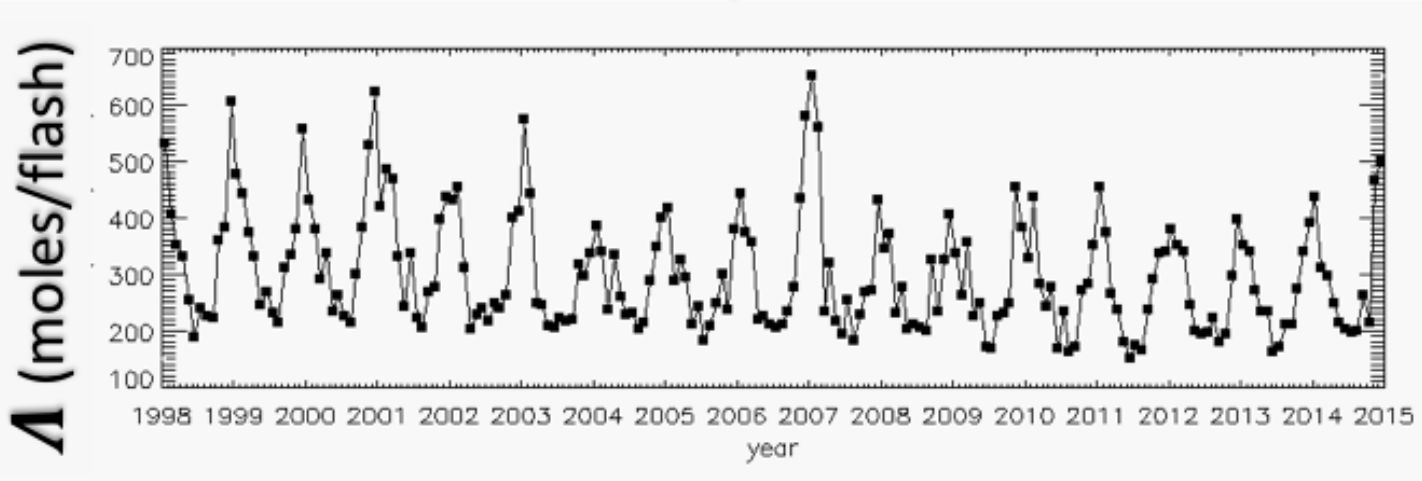
TRMM/LIS Mean LNOx Production per flash ≡ Λ (moles/flash)



Annual Mean

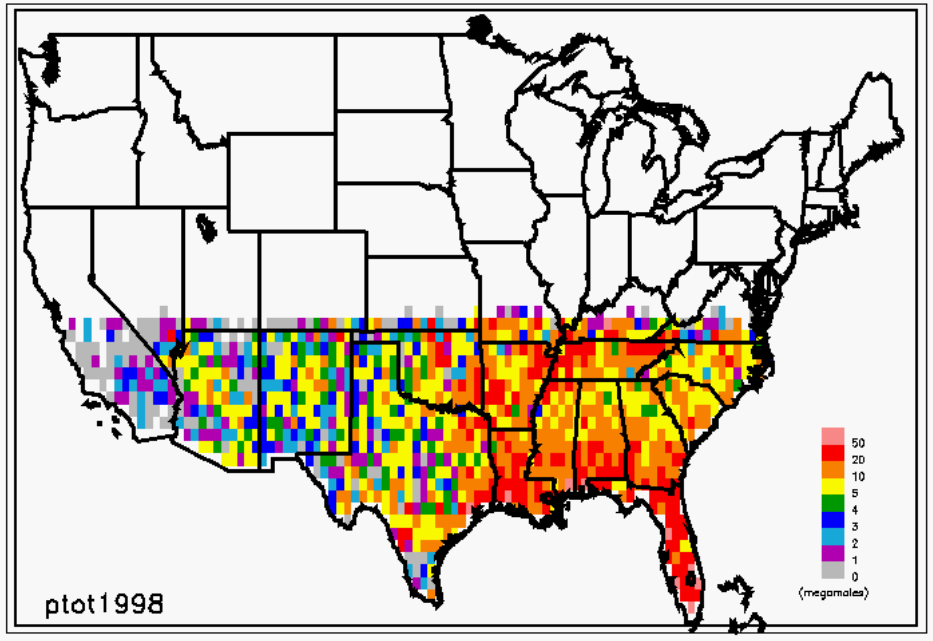


Monthly Mean

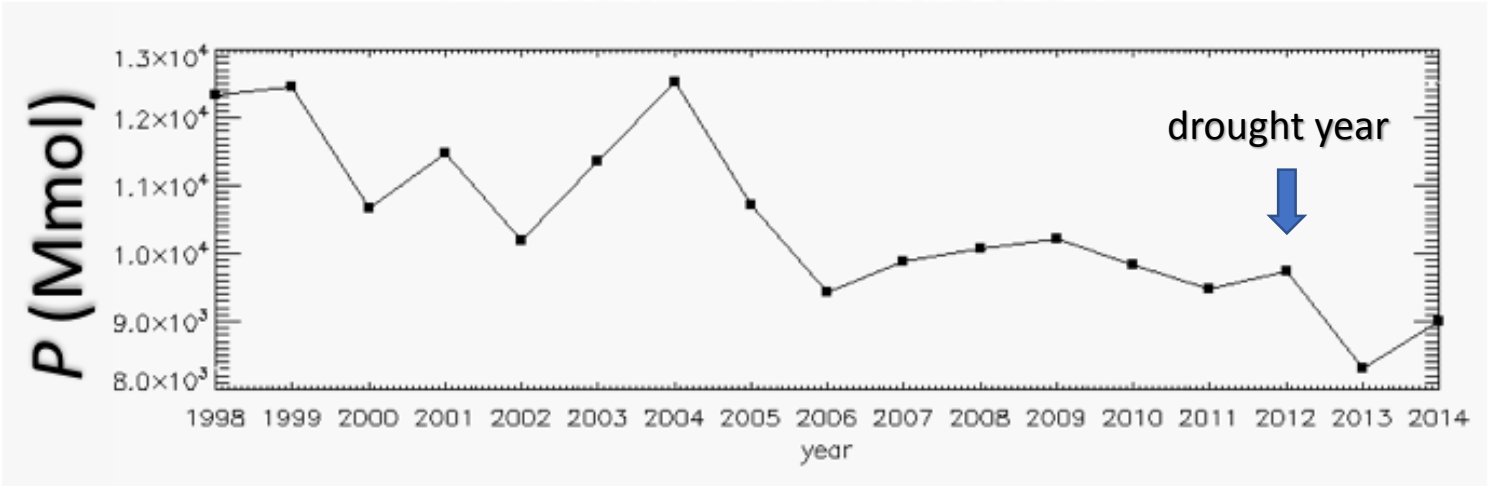


Koshak, NASA/MSFC

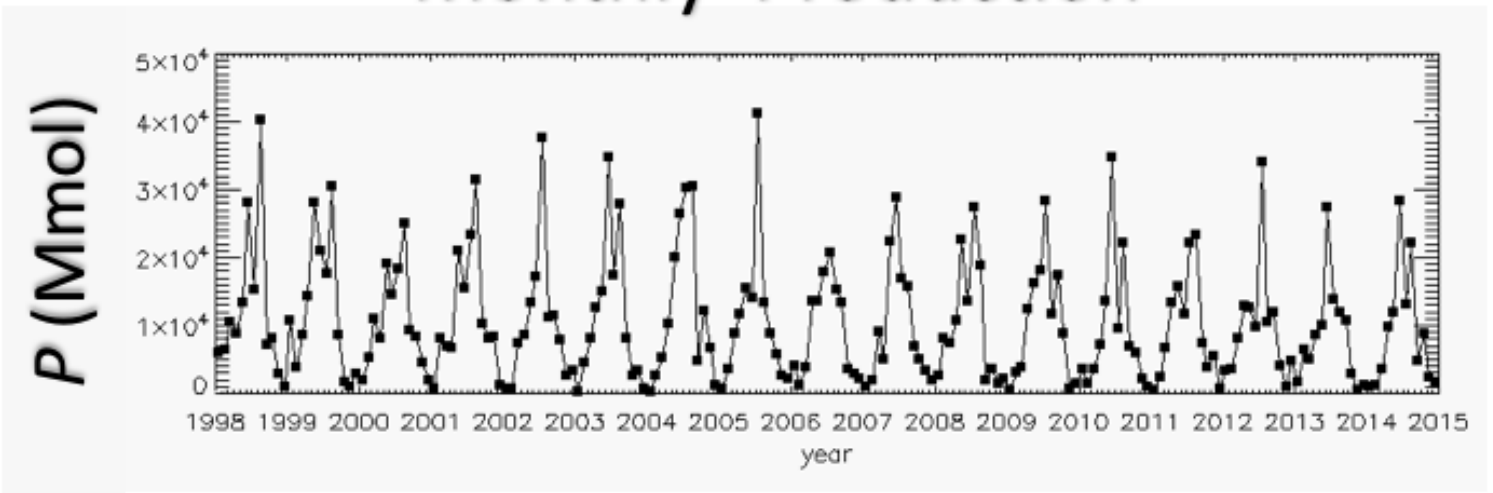
TRMM/LIS LNOx Production *P* (megamoles)



Annual Production



Monthly Production



- Since this is total LNOx production, time-series trends are now modulated by the flash count … so peaks are in the summer months (see monthly plot).
- Previous plots were normalized wrt flash count.

Koshak, NASA/MSFC

Thank You