Estimates of Lightning NO_x Production Per Flash from OMI NO_2 and Lightning Observations

Ken Pickering, NASA Goddard Space Flight Center
Allison Ring, Dale Allen, University of Maryland
Eric Bucsela, SRI International
Robert Holzworth, University of Washington

Lightning NO_x

- **Lightning is responsible for approximately 10-15% of NO_x emissions globally. This is roughly 2 – 8 Tg N yr^{-1} [Schumann and Huntrieser, 2007], most likely 5 TgN yr^{-1} (~250 moles/flash on average). Much of uncertainty stems from little knowledge of NO_x production per flash or per unit flash length.**

- **Most of lightning-produced NO_x (LNO_x) is injected into middle and upper troposphere. Lifetime is long (a few days) relative to lower troposphere. NO_x in this region plays a key role in the chemistry of ozone, the importance of which as a greenhouse gas maximizes in the UT.**

- **We have previously used Aura/OMI NO_2 to obtain estimates of LNO_x production per flash in four convective events during NASA's TC4 field program based in Costa Rica (Bucsela et al., 2010, *JGR*) and in five events over the US.**

Previous investigations of lightning NO_x production for individual storms

Method	Moles NO/flash (Notes)	Reference
Theoretical	1100 (CG), 110 (IC)	Price et al., 1997
Laboratory	~103	Wang et al., 1998
Aircraft data, cloud model	345-460 (STERAO-A)	DeCaria, et al., 2005
Aircraft data, cloud model	360 (STERAO-A, EULINOX)	Ott et al., 2007; 2010
Aircraft data, cloud model	590-700 (CRYSTAL-FACE)	Ott et al., 2010
	500 (Mean midlat. from model)	Ott et al., 2010
Satellite (OMI)	440 (Central US, Gulf)	Pickering et al. (2010)
LMA/Theoretical	484 (CG), 34 (IC)	Koshak et al., 2013
Aircraft data	70-210 (TROCCINOX)	Huntrieser et al., 2008
Aircraft data	121-385 (SCOUT-O3 Darwin)	Huntrieser et al., 2009
Aircraft data	70-179 (AMMA)	Huntrieser et al., 2011
Aircraft data, cloud model	500 - 600 (Hector)	Cummings et al., 2013
Satellite (GOME)	32-240 (Sub-Tropical)	Beirle et al., 2006
Satellite (OMI)	87-246 (TC4 – tropical marine)	Bucsela et al., 2010
	174 (TC4 mean from OMI)	Bucsela et al., 2010
Satellite (SCIAMACHY)	33-50 max. (global analysis)	Beirle et al., 2010

Recent aircraft/cloud model studies suggest intracloud (IC) flashes at least as productive as cloud-to-ground (CG) flashes

Mid-latitude storms possibly more productive per flash than tropical storms (Huntrieser et al., 2008)

Lightning NO_x Production per Flash Using Data from the Ozone Monitoring Instrument (OMI) on NASA's Aura Satellite

Need a specialized algorithm to retrieve LNO_x from OMI. Retrievals are done for each OMI pixel and summed over 1 x 1 deg. grid cells

$$\underline{\textbf{Mean}}\ \textbf{LNO}_x\ \textbf{production per flash} = \frac{\textbf{OMI-retrieved LNO}_x}{\textbf{\# of contributing flashes}}$$

Lightning Data

- World-wide Lightning Location Network (WWLLN)
  - Obtained global data set 2005 – 2012 from University of Washington
  - Computed detection efficiency through comparison with OTD/LIS

- Analysis periods:

  <u>August 2008</u>:

  OMI instrument relatively healthy

  WWLLN in the process of adding stations; DE low

  <u>July 2011</u>:

  OMI suffering from "row anomaly"; about half of field of view blocked

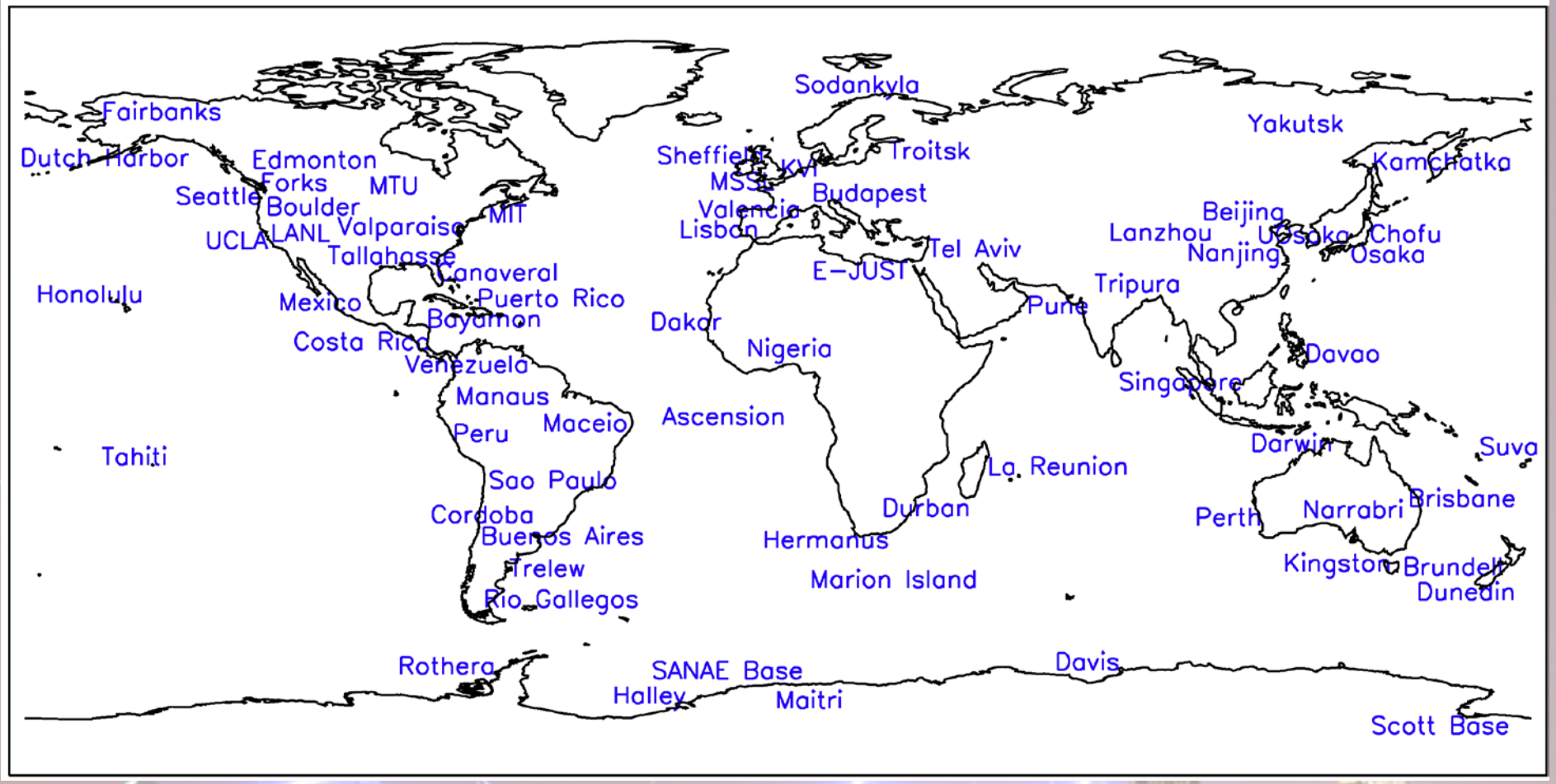
  WWLLN DE much improved

Focus of this talk will be on the Gulf of Mexico region

Considered flashes in the 6 hours prior to OMI overpass

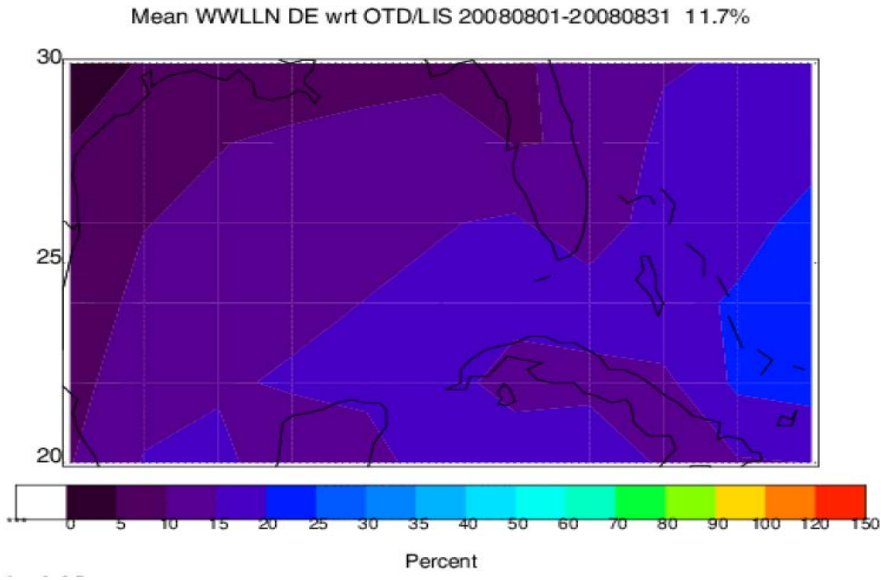
Flash thresholds of 100, 300, 500, and 1000 per 1 x 1 degree grid cell used

World Wide Lightning Location Network (WWLLN)

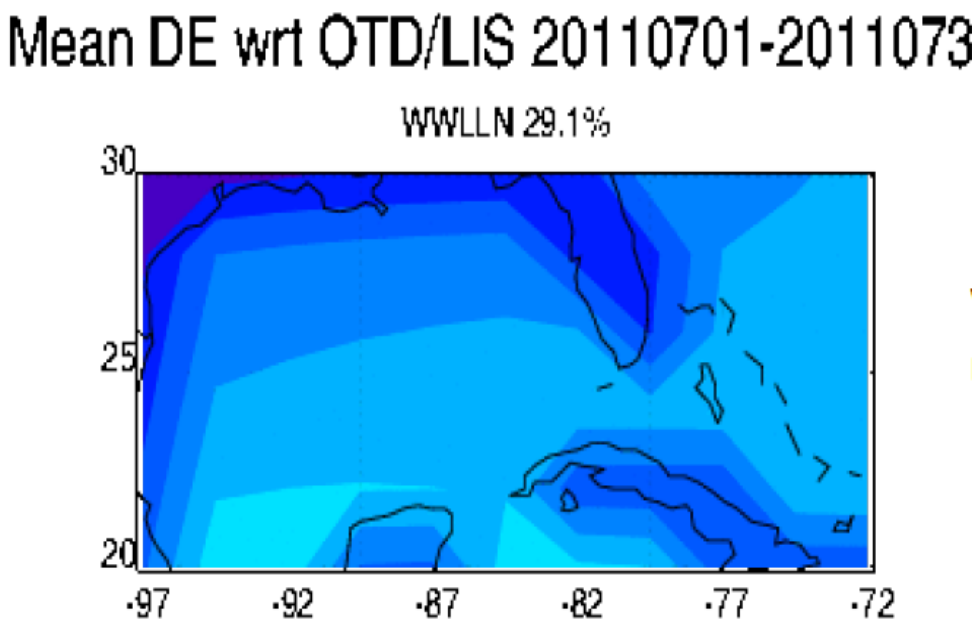


- Composed of about 70 stations world wide
- Detects VLF signals from lightning strokes (3-30 kHz)
- A minimum of 5 WWLLN stations must receive a signal for each detected stroke

WWLLN Detection Efficiency Relative to OTD/LIS



August 2008
11.7%



July 2011
29.1%

Lightning NO_x retrieval algorithms

Two approaches needed:

1) Retrieval of LNO_x over/within active or recently active convection.

Analysis restricted to OMI pixels with Cloud Radiative Fraction > 0.7 or > 0.9

2) Retrieval of LNO_x downwind of storms in relatively clear conditions

Requires trajectories to link OMI NO_2 enhancement with upwind flashes and assumption of NO_x loss rate during transport

$$\Omega_{LNOx} = \frac{\Omega_{total}^{slant} - \Omega_{strat}^{OMI} \times AMF_{strat} - \Omega_{BG}^{OMI} \times AMF_{trop}}{AMF_{LNOx}}$$

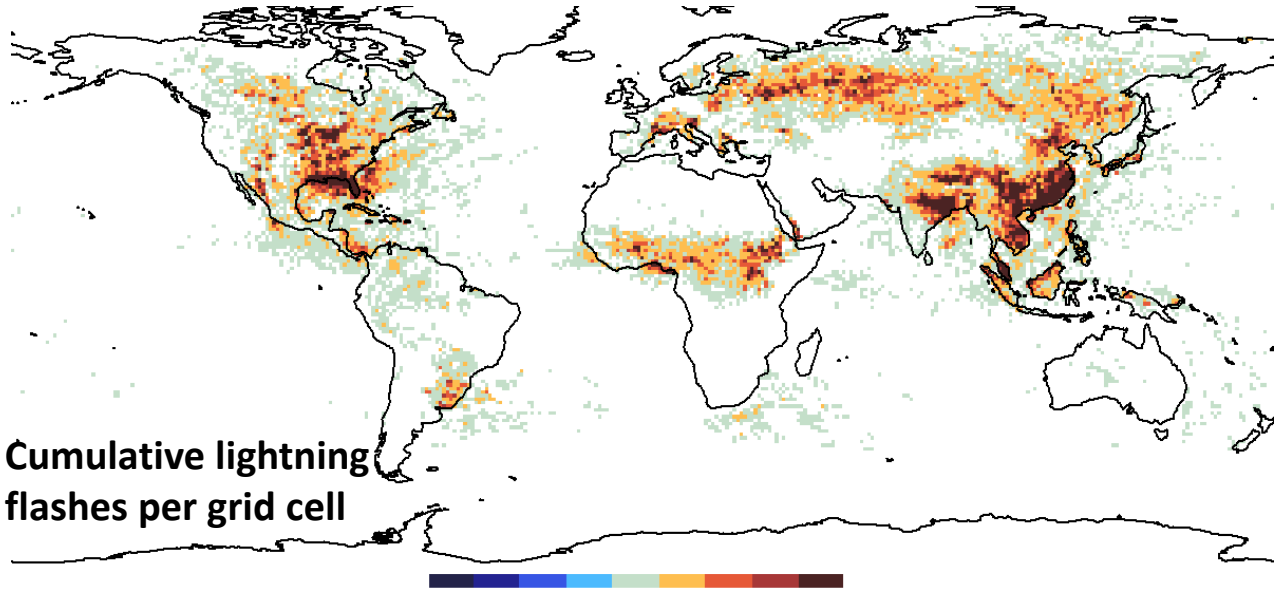
- **Stratospheric column (red) is based on mean OMI stratospheric NO_2 from the standard algorithm for 4 days surrounding day of analysis.**
- **Tropospheric background (BG) column (green) is an estimate of the contributions of sources other than lightning to tropospheric column.**

For approach (1): BG term can be neglected

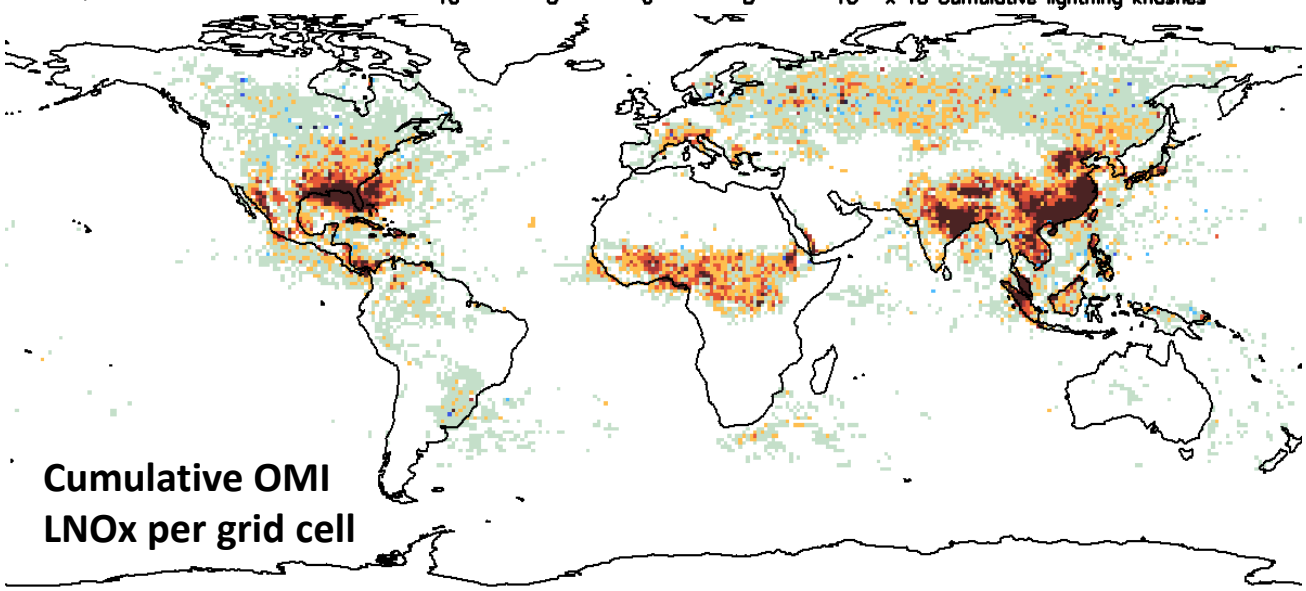
For approach (2): BG approximated by the fraction of the monthly mean tropospheric NO_2 column from the standard algorithm that is not due to lightning. Fraction from GMI CTM

AMF_{strat} - AMF for stratospheric NO_2 from the NASA standard retrieval
AMF_{trop} - AMF for tropospheric NO_2 from the NASA standard retrieval
AMF_{LNOx} - uses LNO_2 and LNO_x profile shapes derived from NASA Global Modeling Initiative (GMI) CTM simulations with and without lightning

2008, 2011 June, July, August
CRF > 70% and > 500 flashes per day per grid cell



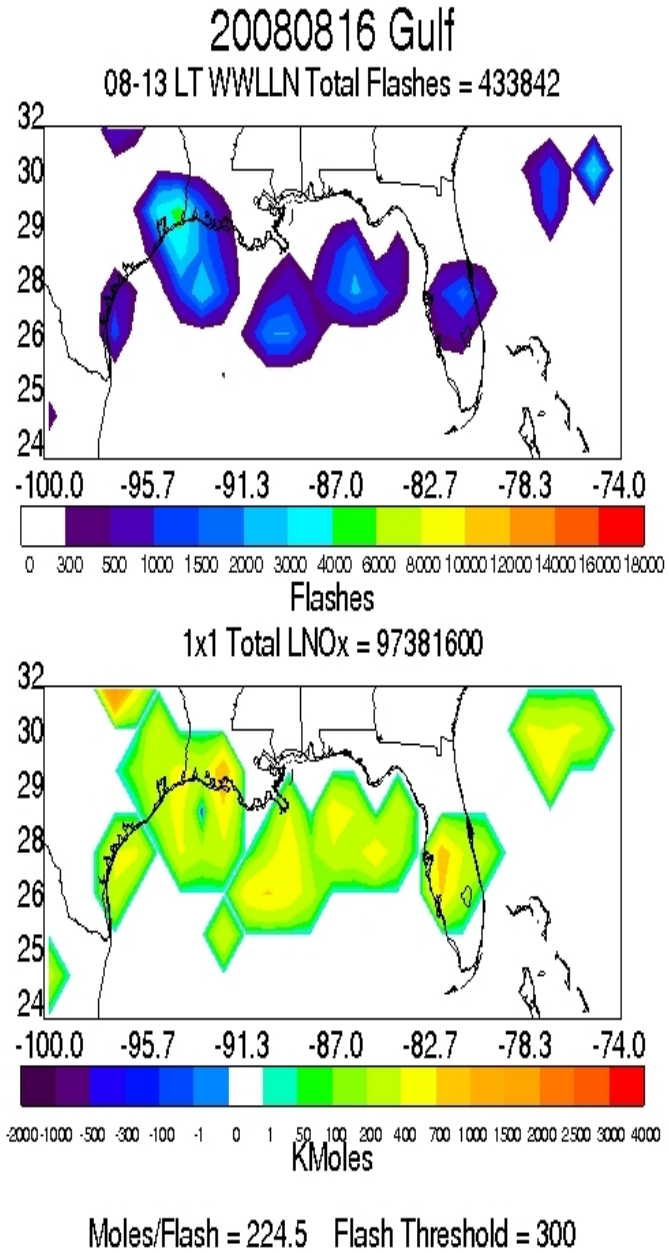
2008,11 06–08 crf>70% & flashes>500 −16 −8 0 8 16 × 10 Cumulative lightning kflashes



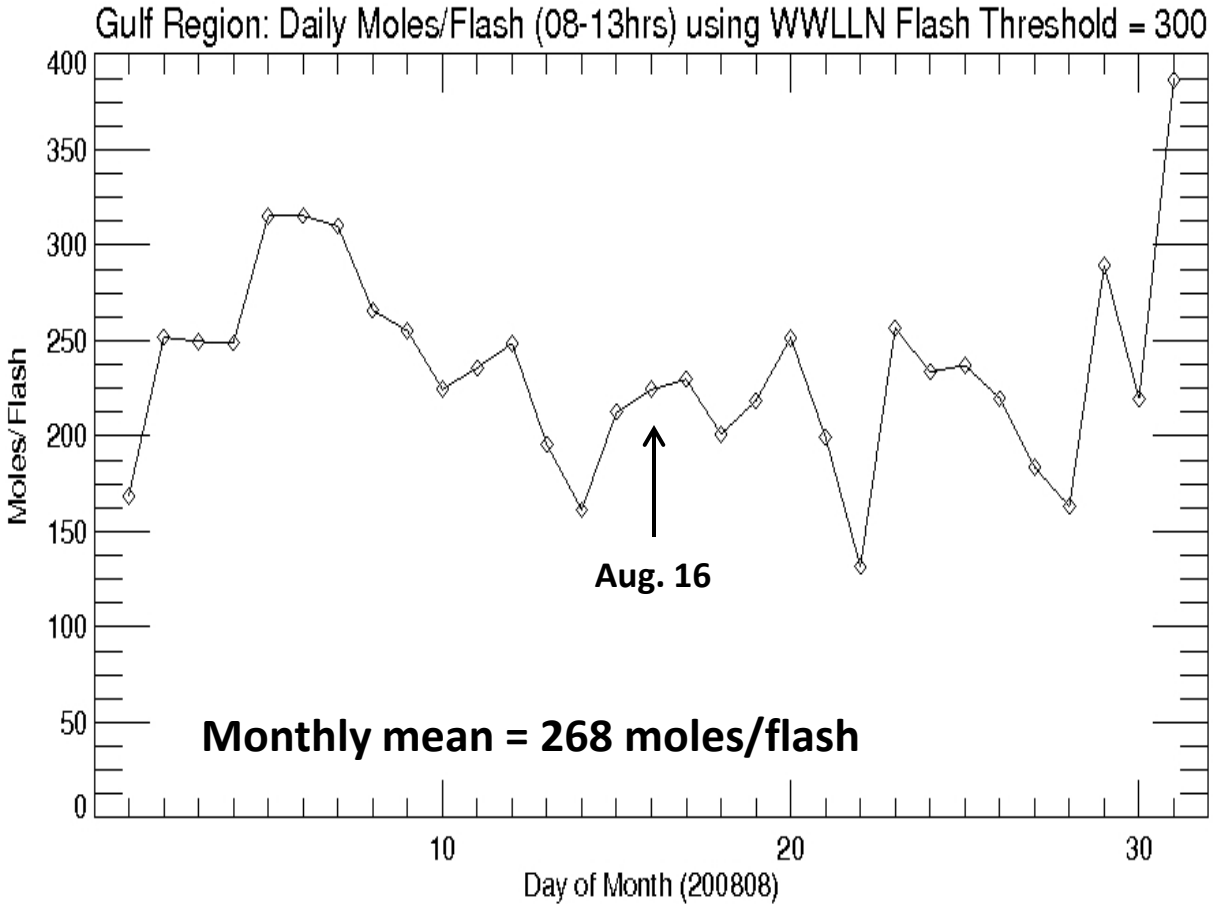
2008,11 06–08 crf>70% & flashes>500 −20 −10 0 10 20 Cumulative Mmoles/(4 × 10^4 km^2)

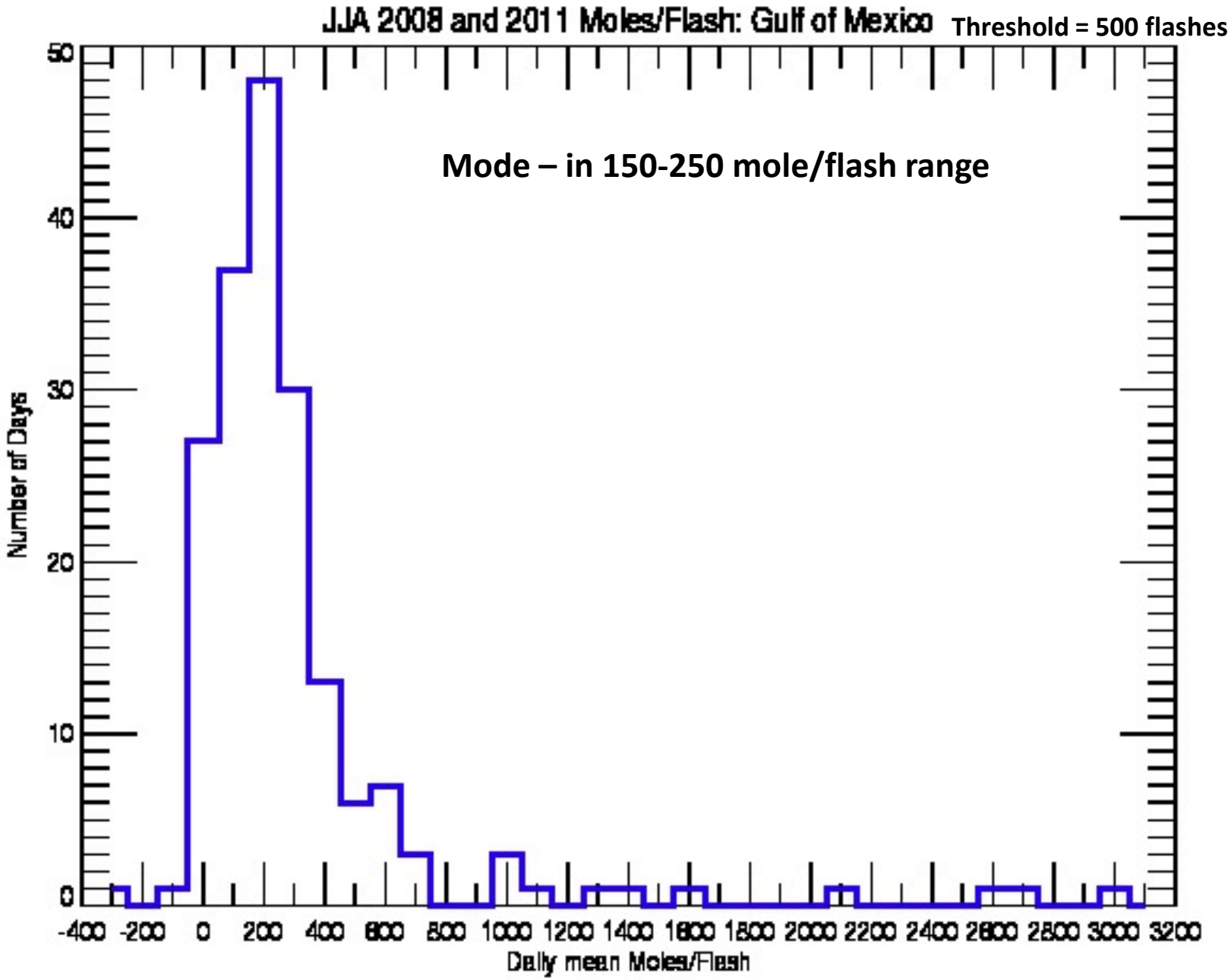
August 16, 2008

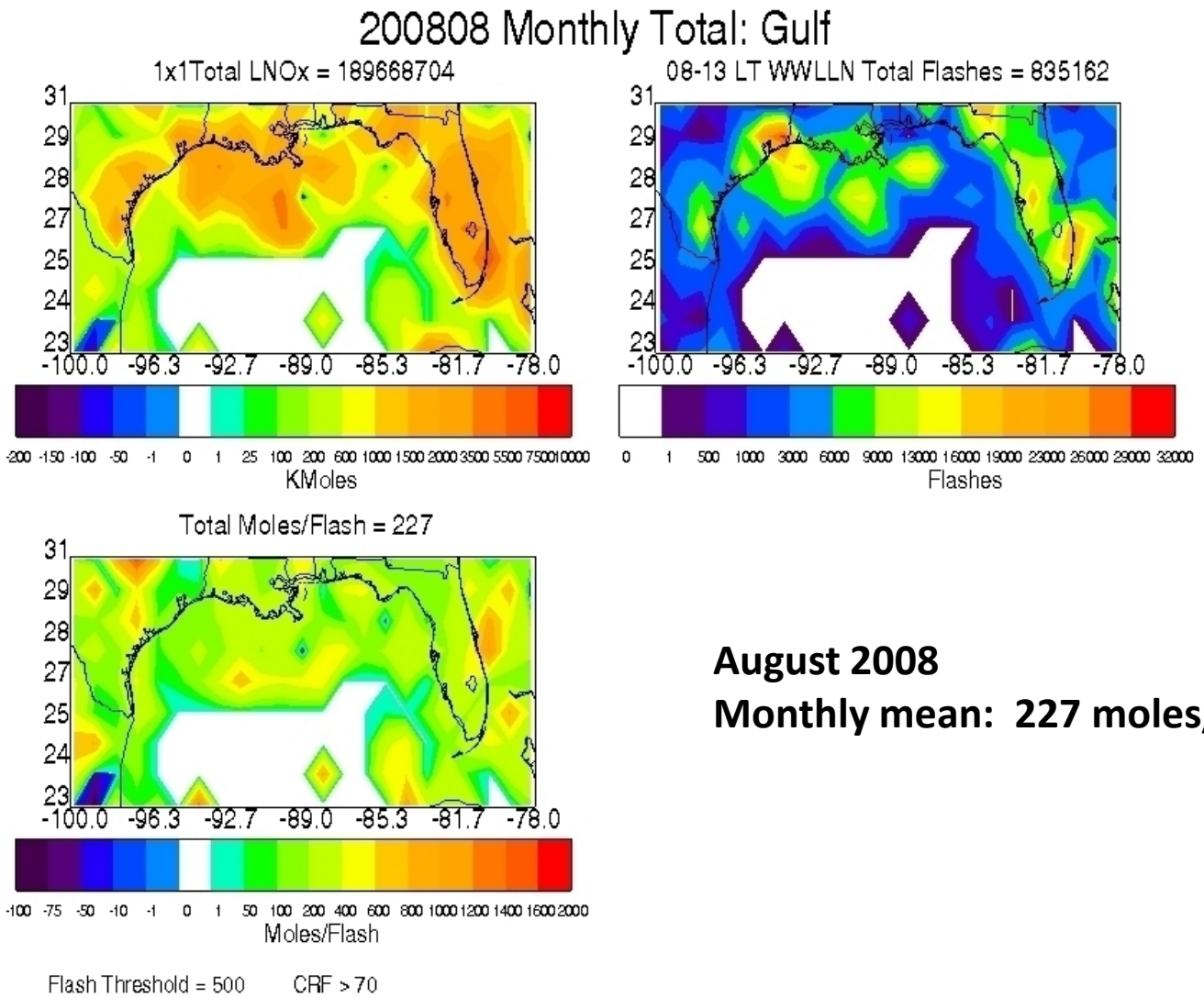
Mean LNO_x production = 224.5 moles/flash



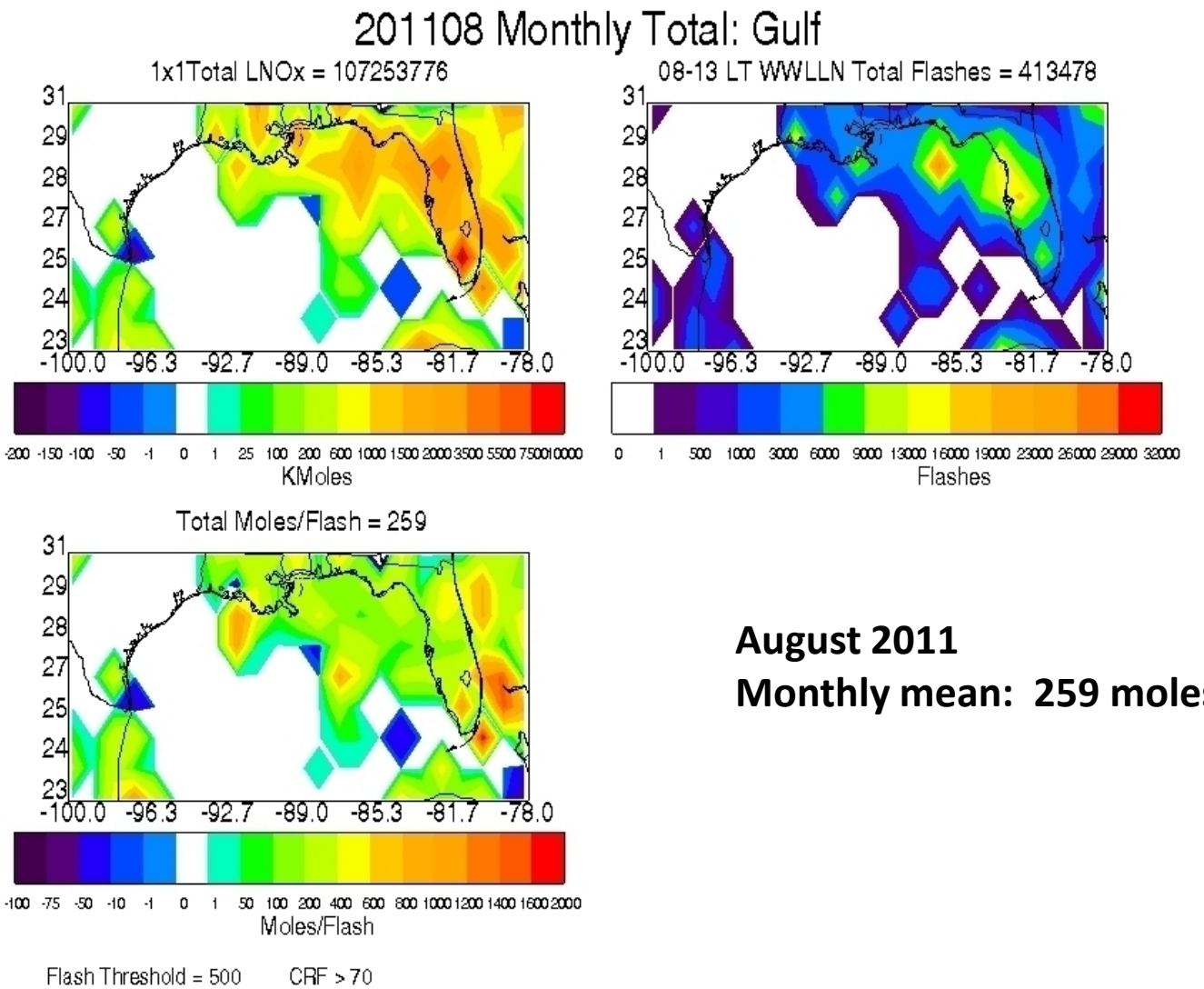
August 2008 Daily Mean LNO_x Production Gulf of Mexico Region




JJA 2008 and 2011 Moles/Flash: Gulf of Mexico
Threshold = 500 flashes
Mode – in 150-250 mole/flash range
Number of Days
Daily mean Moles/Flash
0
10
20
30
40
50
-400
-200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200



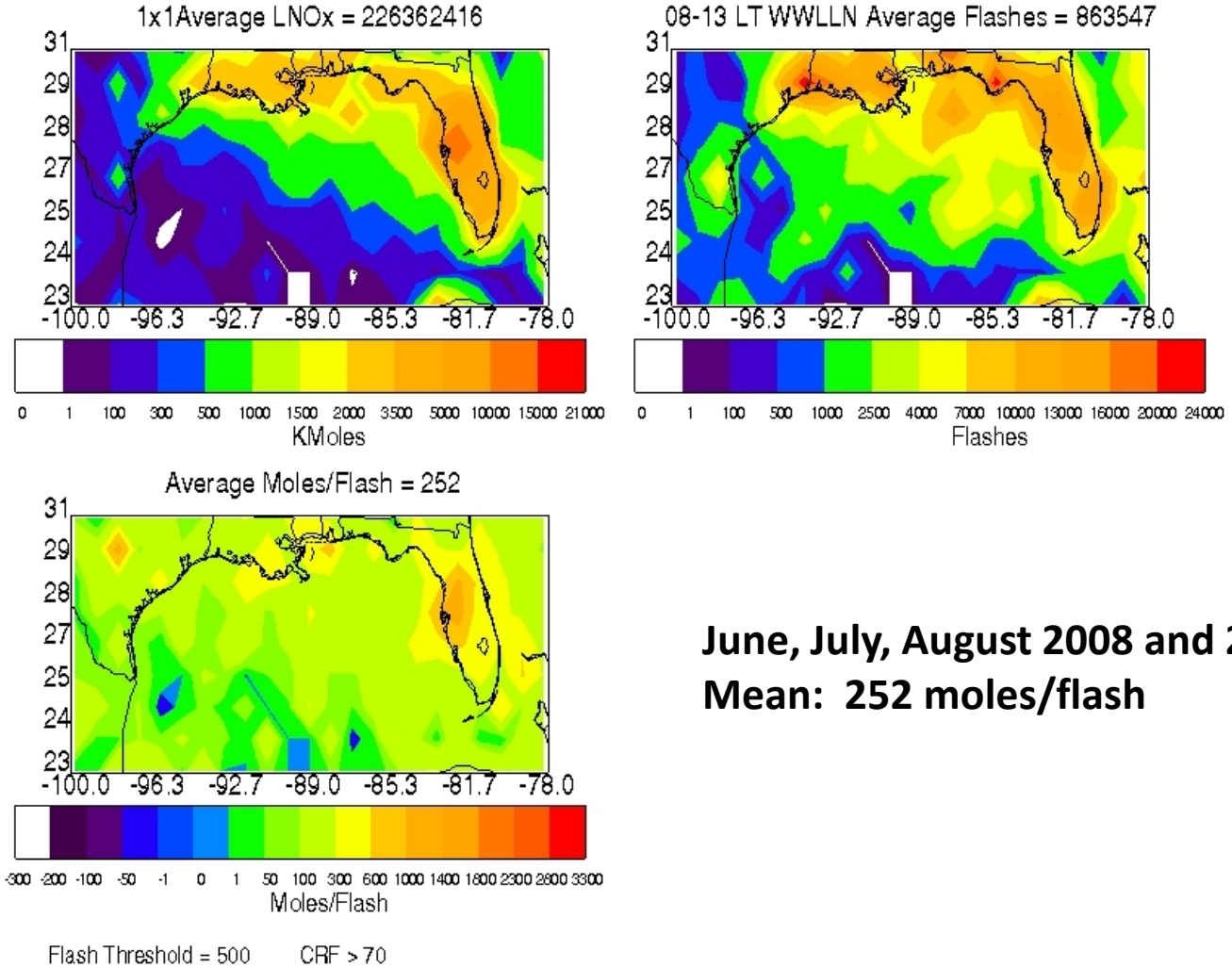
August 2008
Monthly mean: 227 moles/flash



August 2011

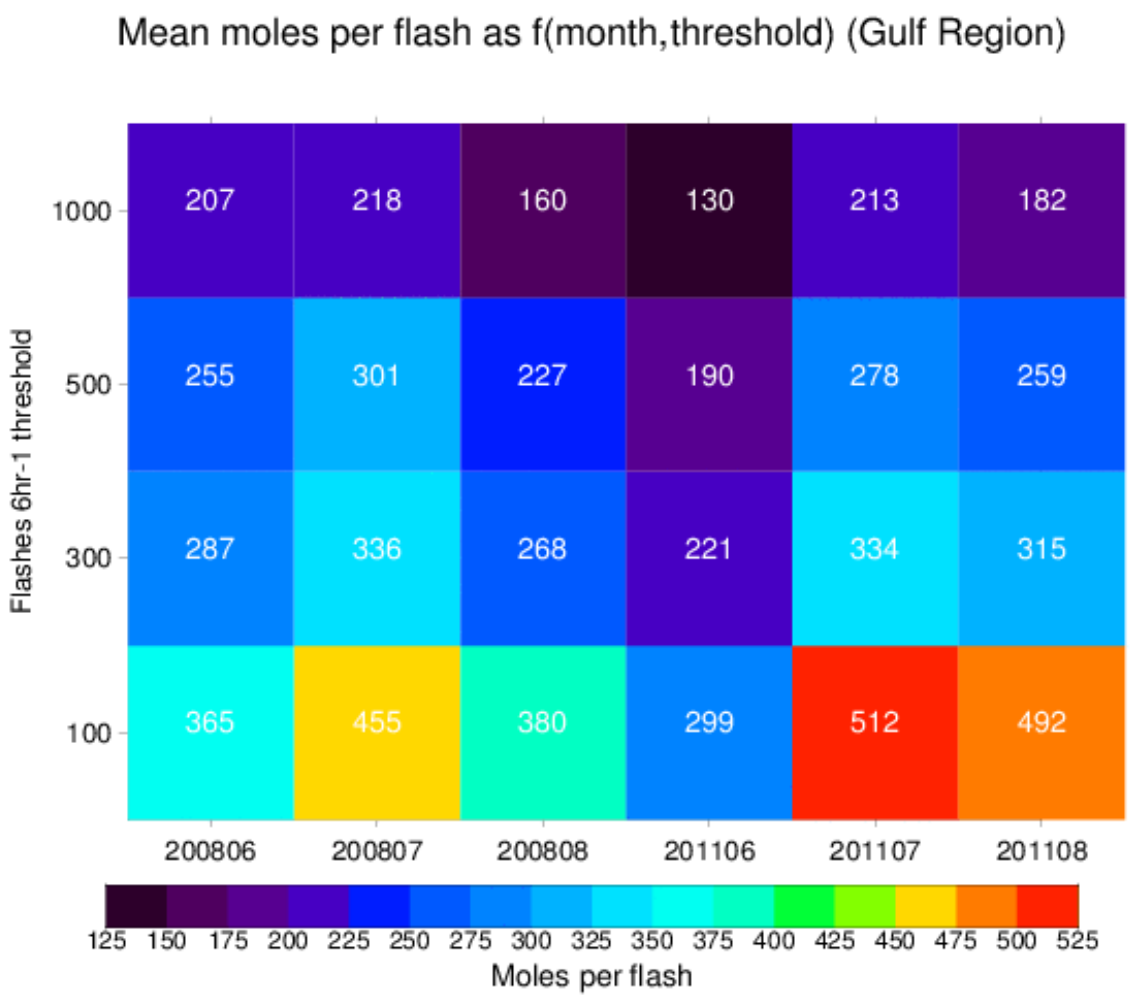
Monthly mean: 259 moles/flash

2008 and 2011 JJA Average: Gulf



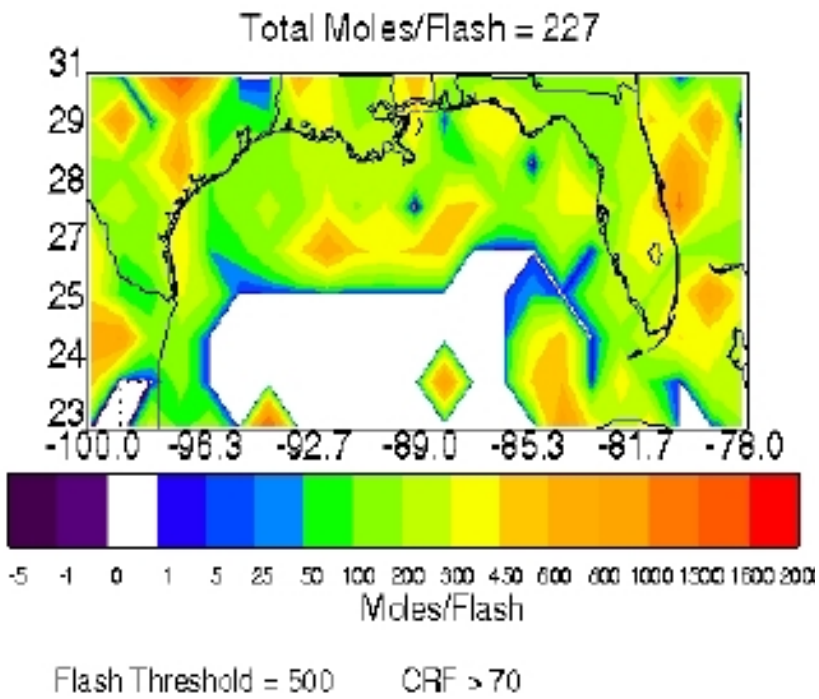
June, July, August 2008 and 2011
Mean: 252 moles/flash

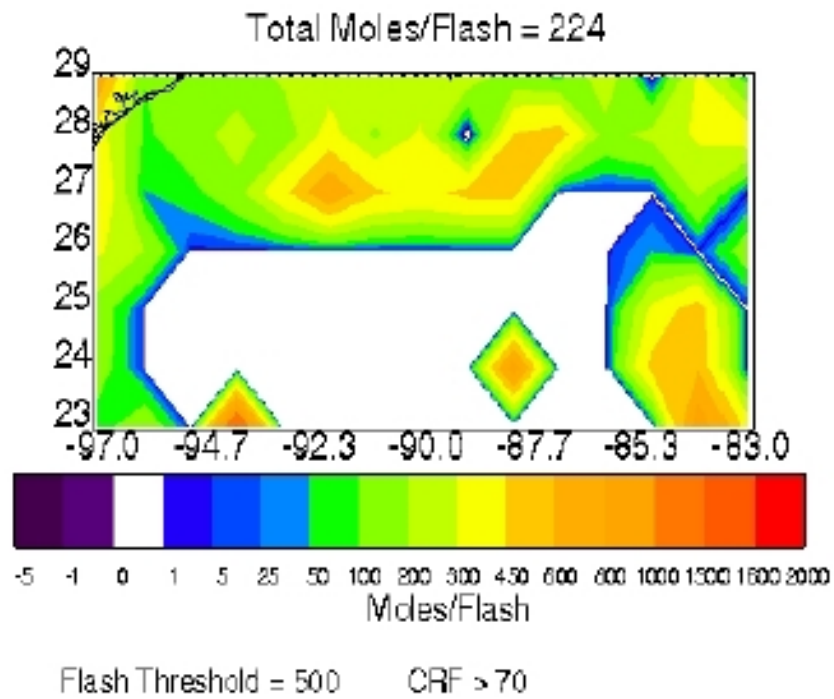
Monthly Mean LNO_x Production Per Flash



Mean over 6 months	# of grid cells
185 moles/fl	1434
252	2222
293	2784
417	4037

Assessment of Continental Pollution Influence

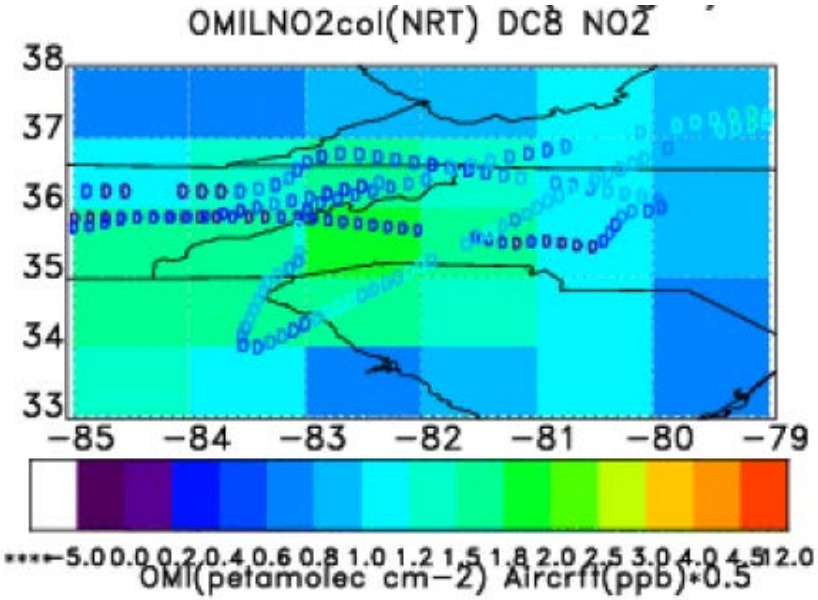




Very little difference in LNO_x retrieval between Gulf-only region and region including surrounding land areas.

Convective transport of boundary layer NO_x pollution has minimal influence on LNO_x production estimates.

May 30, 2012 Deep Convective Clouds and Chemistry (DC3) Downwind Event

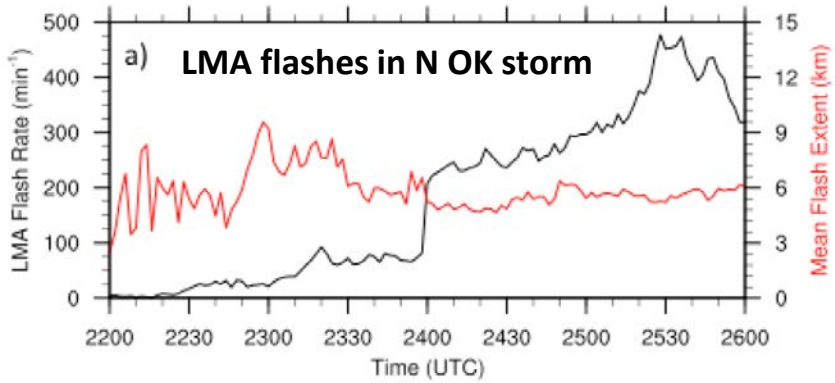


Downwind case with clear sky: used OMI pixels with CRF < 0.3; 50% of OMI monthly mean as trop BG – based on scaled CMAQ estimate

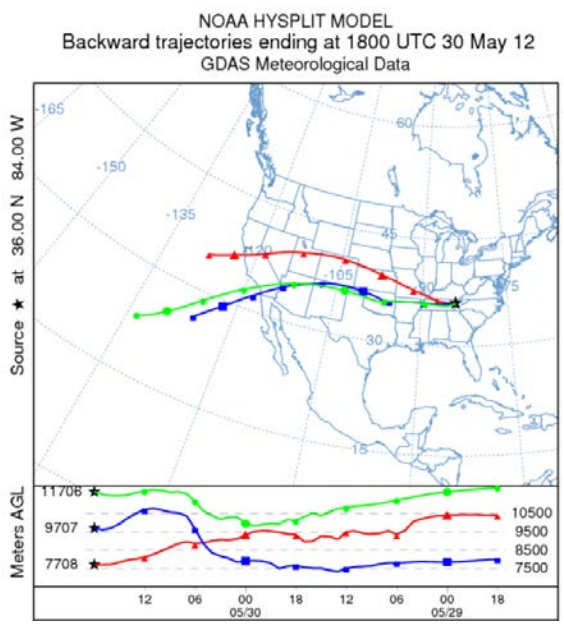
OMI LNO_2 = 1.45 x 10^{15} molec/cm^2

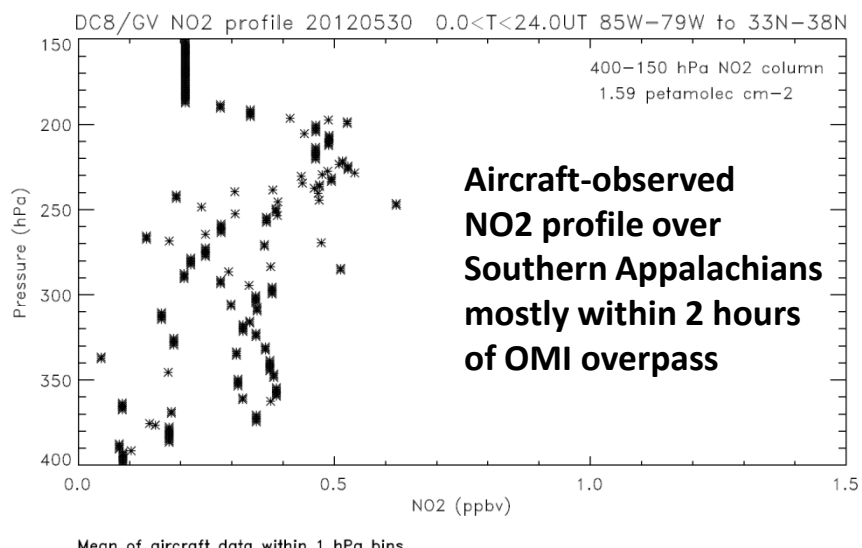
Aircraft NO_2 = 1.59 x 10^{15}

Less than 10% difference!



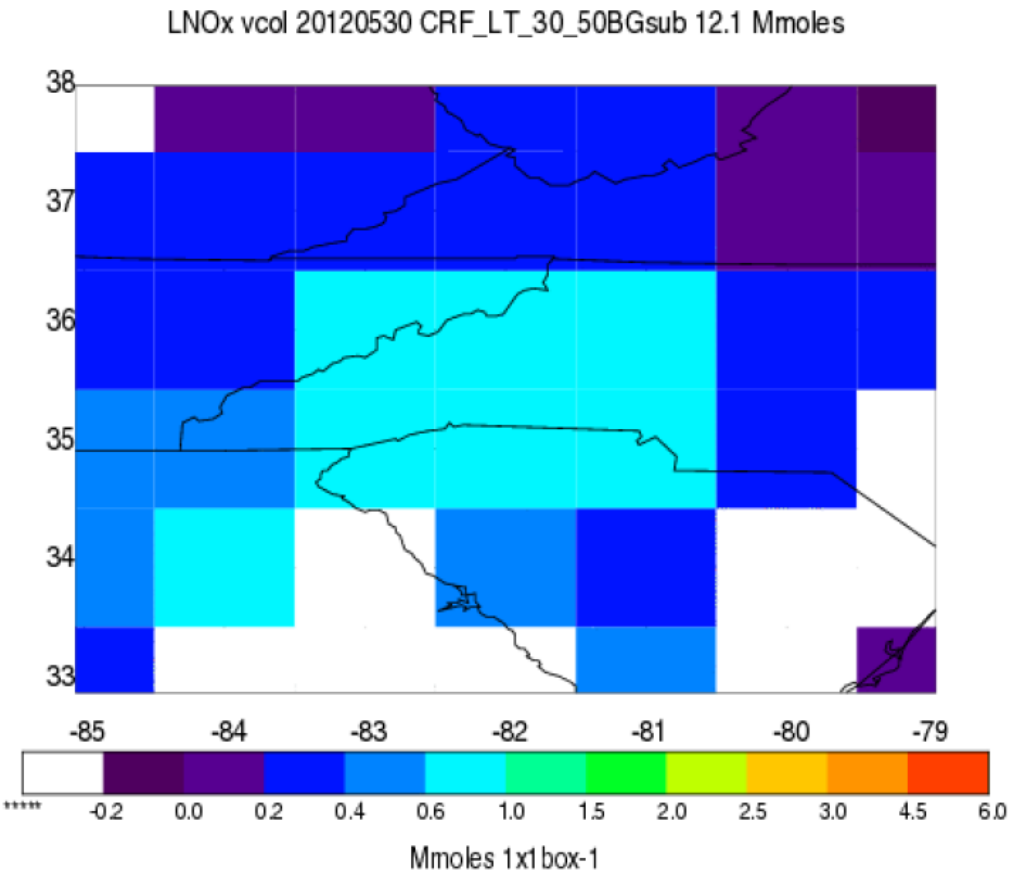
All contributing OK and AL storms: 104,513 flashes





Aircraft-observed NO2 profile over Southern Appalachians mostly within 2 hours of OMI overpass

May 30, 2012 DC3 Downwind Event



12.1 Mmoles x exp(t/τ) = 14.3 Mmoles
Transport time, t = 16.1 hrs
Assume τ = 4 days in UT

14.3 Mmoles/104,513 fl = 137 moles/fl

Summary

- OMI LNO_x retrieval scheme for active/recent convection produces reasonable results for production per flash, using pixels with CRF > 0.7 and no tropospheric background subtraction.

- Minimal influence of convective transport of NO_x pollution found in Gulf of Mexico region.

- Our best estimate of LNO_x production per flash in Summer over the Gulf of Mexico and surrounding land areas is ~250 – 300 moles/flash, which is well within the range of literature estimates (equivalent to 5-6 TgN/yr).

- Major advantage of this analysis is the large number of storms considered: over 2000 1 x 1 degree values

- Analysis of clear sky case of downwind LNO_x plume from DC3 shows promise for method of obtaining valid LNO_x in these conditions requiring background subtraction.

Future Work

- Conduct more regional analyses of LNO_x over active/recent convection for multiple years:
  - Continental US
  - West/Central Africa
  - SE Asia
- Develop automated algorithm (incorporating back trajectories) for processing near clear sky (CRF < 0.3) LNO_x downwind of storms