Lightning NO_x from TEMPO: Plans for a Green Paper Experiment

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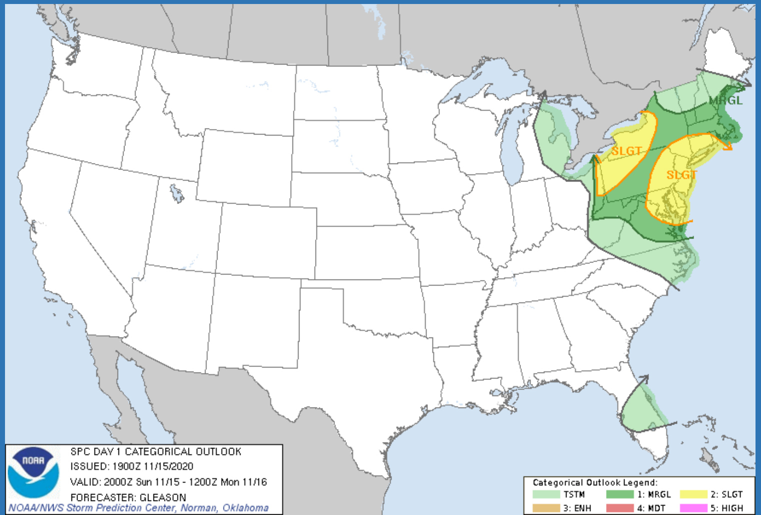
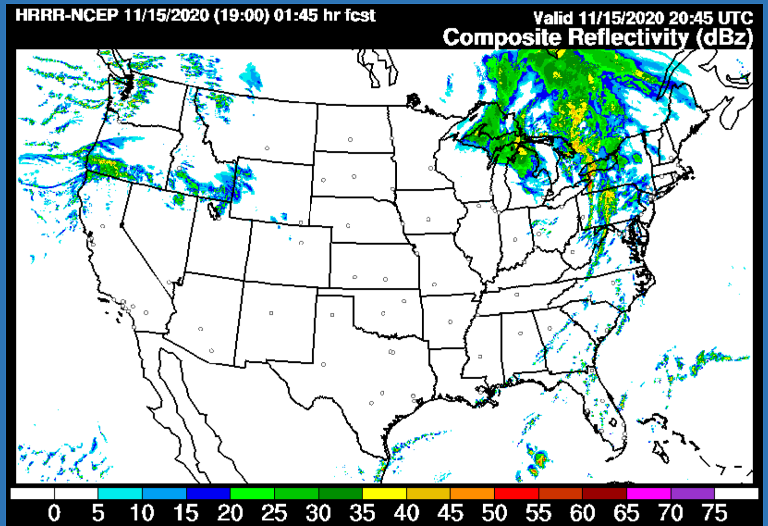
TEMPO High-Resolution Lightning NO_x (LNO_x) Experiment

Study selected thunderstorm systems over Greater North America:

- **TEMPO special operations NO_2 retrievals at 10-min time resolution over a selected ~800 km-wide swath on Summer 2023 days with high probability of thunderstorms**
- **Sample a variety of storm types (individual air mass cells, multi-cellular storms, squall lines, supercells) and a wide range of lightning flash rates**
- **Region and time periods selected based on NOAA/NCEP/Storm Prediction Center Convective Outlooks -- some skill at 3 days ahead; much better at 2 days and 1 day**
- **If 24-hr notice is adequate – use NCEP/High Resolution Rapid Refresh (HRRR) forecasts run hourly with output at 15-minute intervals; 3-km horizontal resolution; cloud resolving model; includes radar data assimilation**





General Algorithm for Lightning NOx Retrieval and Production Efficiency (PE) Estimation

- **LNO_x PE is estimated by dividing the moles of NO_x due to recent lightning by the number of flashes contributing to the tropospheric columns over/within storms**
- **These columns are determined by dividing the tropospheric slant column of NO_2 over deep convective pixels (large cloud radiative fraction (CRF); low cloud top pressure (CTP)) by a specially derived AMF appropriate for a thunderstorm.**

OMI/TROPOMI/GCAS Lightning NO_x Results

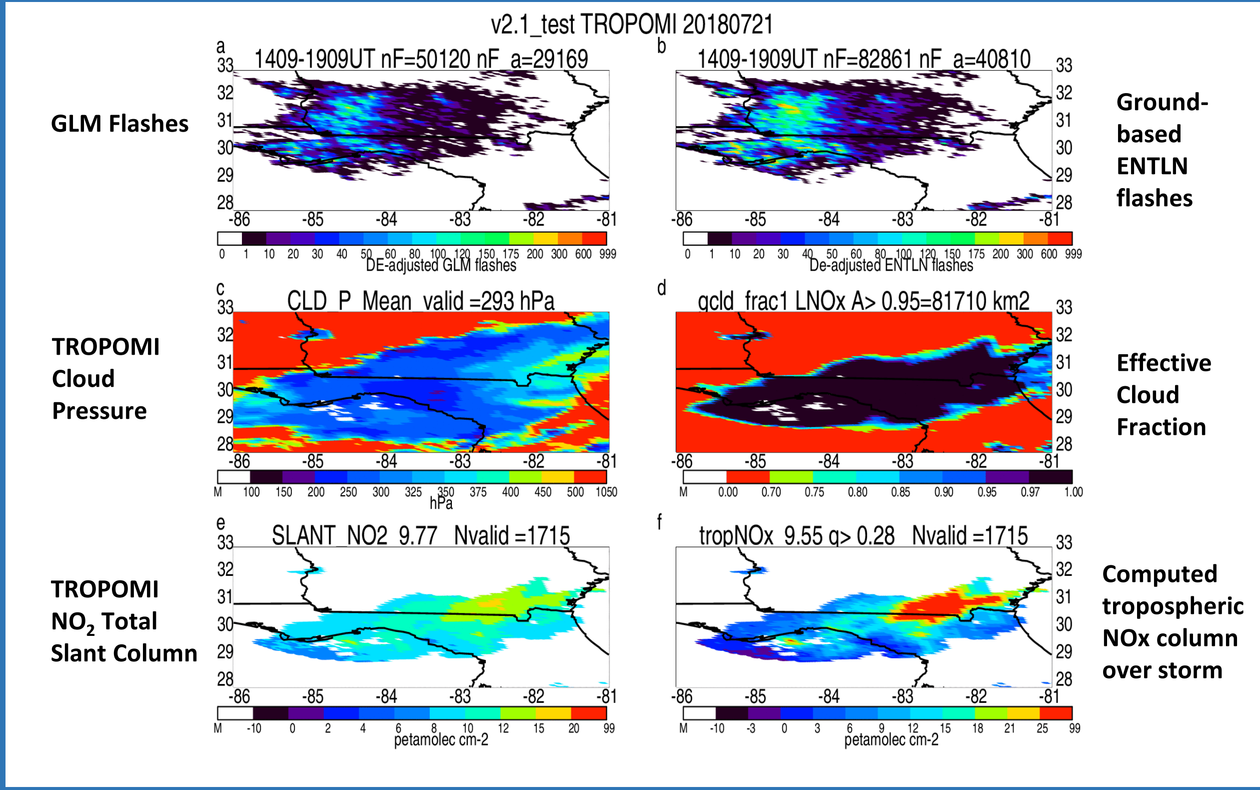
Pickering et al. (2016, *JGR*): OMI for 5 summers over Gulf of Mexico & WWLLN flashes

Bucsela et al. (2019, *JGR*): Mid-latitude continental OMI analysis with WWLLN

Allen et al. (2019, *JGR*): Regional tropical OMI analysis with WWLLN

Allen et al. (2021a, *JGR*): GCAS instrument on ER-2 aircraft overflew 12 storms over CONUS and Western Atlantic in GOES-R Geostationary Lightning Mapper (GLM) validation mission → allowed demonstration of future synergy between TEMPO and GLM; ENTLN also used

Allen et al. (2021b, *JGR*): TROPOMI with GLM and ENTLN analyses for 29 storms over CONUS



After background subtraction & bias/uncertainty analysis:
LNO_x PE with GLM flashes = 175 ± 100 moles/flash
LNO_x PE with ENTLN flashes = 120 ± 65 moles/flash

What is needed for TEMPO LNO_x Analysis ?

- **Stroke and flash data from GOES-16 and GOES-18 GLM instruments**
- **Initially – use tropospheric NO_2 columns from standard TEMPO retrievals (available a few hours after observation); convert to estimated NO_x columns using GEOS-Composition Forecast (GEOS-CF) NO_x/NO_2 ratios in deep convection near the time and location of TEMPO-observed storms, along with NO_2 profiles typical of electrified storms.**
- **Post-experiment -- TEMPO total slant column NO_2, stratospheric vertical column NO_2, stratospheric AMF, optical cloud pressure, cloud radiative fraction will be used in a specialized algorithm appropriate for deep convective clouds containing LNO_x. AMF_{LNOx} for use in this algorithm will be based on TEMPO-observed clouds and typical NO_2 and NO_x profiles for electrified storms**
- **LNO_x production analysis will be conducted for individual case-study storms observed by TEMPO.**
- **In addition to individual storm studies, similar analysis will be applied to NO_2 and lightning data from multiple storm systems over 2 - 3 months. Data can be aggregated to obtain regression-based statistical relationships between LNO_x and lightning flashes.**

Bias and Uncertainty Analysis

Need to perform bias and uncertainty analyses:

- **The three largest uncertainties in OMI and TROPOMI LNO_x analyses were:**
  - **Chemical lifetime of NO_x in near field of storm**
  - **NO_x background – from upwind storms and convective transport of PBL NO_x**
  - **NO_x/NO_2 ratio within and near storm - affects AMF_{LNOx}**
- **TEMPO 10-min resolution data will enable better quantification of these uncertainties:**
  - **Lagrangian data will allow analysis of decay of NO_x as it moves downwind for determing estimates of chemical lifetime**
  - **Examine time evolution of NO_x in cells with no lightning to aid background estimate**
  - **Diurnal variation of NO_2 will be better constrained**
- **Simultaneous aircraft data would aid in better quantifying NO_x/NO_2 ratio**

Extra Slide

Calculation Details

$PE = [V_{tropLNOx} \times A] / [N_A \times F]$; PE=moles NOx/flash; A=area of storm or grid cell; F= number of contributing flashes

$F = \Sigma_N F_i \exp(-(t_s - t_i) / \tau)$; F_i is an observed flash; t_i = time of flash; t_s = overpass time; $\tau = NO_x$ chemical lifetime ~ 3 hrs

$V_{tropNOx} = [S_{NO2} - Avg(V_{stratNO2} \times AMF_{strat})] / AMF_{LNOx}$; S = slant column; V = vertical column

$V_{tropLNOx} = Average(V_{tropNOx}) - V_{tropbkgn}$ ('Average' is computed over regions with lightning)

Methodology for tropospheric background calculation has evolved:

Pickering et al. (2016) OMI: fixed 18% background used in combination with a minimum flash threshold

Bucsela et al. (2019) OMI: $V_{tropNOx}$ over non-flashing grid cells meeting deep convective CRF and cloud pressure criteria

Allen et al. (2019) OMI: y-intercept of LNO_x vs flashes regression

Allen et al. (2020) TROPOMI: 10th and 30th percentile $V_{tropNOx}$ nonflashing deep convective pixel values over storms

Uncertainties (from largest to smallest):

LNO_x chemical lifetime, AMF_{LNOx} (as affected by NO_x/NO_2 ratio), NO_x background, flash detection efficiency, total slant columns, stratospheric columns, LNO_x below effective cloud top pressure