Lightning NO Production in the GMI Model

Kenneth E. Pickering
Dale J. Allen

Department of Atmospheric and Oceanic Science
University of Maryland
College Park, MD
Outline

• Current procedure in GMI model
• Necessity of co-locating lightning NO with convective transport
• Parameterization development for GMI
• Implementation and Results
Current Procedure

• Climatological monthly spatial distributions of total (CG+IC) lightning flashes (Price et al., 1997) based on ISCCP deep convective cloud top heights (Price and Rind, 1992).
• CG fraction based on cold cloud depth (Price and Rind, 1993)

\[ P_{CG} = 10 P_{IC} \quad P_{CG} = 6.7 \times 10^{26} \text{ molec/flash or } \sim 1100 \text{ moles/flash} \]  (Price et al., 1997)

• Grid cell NO production values scaled such that global production equals a specified value (e.g., 5 TgN/yr)
• Vertically distributed according to C-shape profiles derived from cloud-resolving model simulations of Pickering et al. (1998)
Lightning NO and Convective Transport

• Use of climatological lightning NO production results in lightning NO not being injected into the model at same times and locations as at which the model convective transport occurs

• Therefore, lightning NO and convectively-transported species (HO\textsubscript{x} precursors, NO\textsubscript{x}, CO, NMHC) are introduced to the upper troposphere in different locations

• Results in “fuzzy” middle and upper tropospheric chemistry

• Lightning and convection need to be co-located!
Available Parameterizations

LIGHTNING FLASH RATES MUST BE PARAMETERIZED IN TERMS OF VARIABLES FROM THE MODEL CONVECTIVE SCHEME

• Cloud-height-based approach
  Price and Rind (1992)
• Cloud-mass flux based approach ← BEST
  Allen and Pickering (2002)
• Convective precipitation based approach
  Allen and Pickering (2002)
Evidence is mounting that refutes the assumption that $P_{CG} = 10 P_{IC}$. We are now assuming $P_{CG} \sim P_{IC}$.
Lightning NO Production Scenarios

$P_{cc}$ (moles NO/flash)

$P_{ic}/P_{cc}$

Median $\sim 0.9$

DATA POINTS:
- PRICE et al. 97
- CF-7/16
- CF-7/29
- NALDN Median
- DECARIA-7/12
- ST-7/10
- FEHR-7/21
- EU-7/21
- CRYSTAL-FACE
- STERAO-A
- EULINOX
Estimates of IC/CG flash ratio not necessary.

Boccippio et al. (2002) analysis of IC/CG ratio over U.S. based on OTD and NLDN indicates that storm intensity, morphology, and level of organization have much more impact on IC/CG ratios than environmental variables that can be extracted from GCM output.

CG flashes estimated from cloud mass fluxes will be scaled up to total flashes based on OTD/LIS climatology.
Step 1: Polynomial construction

- **Data**: NLDN/LRF 6-hr avg 4° x 5° CG flash rates for 1997

- **Model output**: Convective mass flux (CLDMAS) at 0, 6, 12, 18 UT
  - i=1: GMAO analyzed fields at ~353 hPa for Mar-Dec ‘97, Jan-Feb ‘98
  - i=2: FVGCM-fields at ~434 hPa for model year
  - i=3: GISS GCM-fields at ~374 hPa for model year

- **Geographic Region**: 10°-60°N; 120°-60°W
Polynomial fit to normalized CLDMAS

1. For 10°-60°N, 120°-60°W, extract 00, 06, 12, and 18 UT time-averaged CLDMAS at model-specific pressure levels.

2. Normalize CLDMAS by dividing by model-dependent mean(CLDMAS)+2*sigma(CLDMAS).
   \[ x_i = \frac{CLDMAS_i}{[\text{mean}(CLDMAS_i)+2\sigma(\text{CLDMAS}_i)]} \]
   \[ y = \text{NLDN/LRF CG flash rates} \]

3. For i=1,3 do sort \( x_i \) and \( y \) independently by magnitude.

4. For i=1,3 do fit polynomial \( (y_{\text{fit}} = ax_i + b[x_i]^2 + c[x_i]^3) \)

5. Adjust \( y_{\text{fit}} \) for area of grid box; Constrain to be \( \geq 0 \)
GMI flash rates before regional adjustments

OTD/LIS climate

DAO 97–98

G4AGCM "1994"

GISS "1977"

Flash rate (flashes min⁻¹)
Step 2: Adjust flash rates to best match OTD/LIS climatology

Marine-continental contrast not captured especially in the tropics.

For i=1,3 do
1. Adjust global CG flash rates so that the annual average total global flash rate matches observed total flash rate from v1.0 OTD/LIS climatology (46.6 flashes s\(^{-1}\)) [see previous plot]
2. Reduce tropical marine flash rates to best match climatology
3. Increase tropical continental flash rates to best match climatology
4. Adjust midlatitude continental flash rates to best match climatology
5. Constrain flash rates to be < 100 flashes/min based on obs.
6. Adjust global flash rates to match climatology
GMI flash rates before regional adjustments

OTD/LIS climate

DAO 97–98

G4AGCM "1994"

GISS "1977"

Flash rate (flashes min⁻¹)
January – December

OTD/LIS climate: RMS_c = 0.00

DAO 97-98: RMS_c = 0.46

G4AGCM "1994": RMS_c = 0.49

GISS "1977": RMS_c = 0.55

Flash rate (flashes min⁻¹)
DAO model: July 400 hPa

NO\textsubscript{x}(base) vs NO\textsubscript{x}(new lightning)

O\textsubscript{3}(base) vs O\textsubscript{3}(new lightning)

Legend: 0 2 10 20 35 50 65 80 100 125 200 250 300 350 400 600 900

NO\textsubscript{x}(ppt) or O\textsubscript{3}(ppb)
DAO model: July 250 hPa

NOx(base) vs NOx(new lightning)

O3(base) vs O3(new lightning)

NOx(ppt) or O3(ppb)
DAO model: July

HNO3(base) 400 hPa

HNO3(new) 400 hPa

HNO3(base) 250 hPa

HNO3(new) 250 hPa

HNO3 (pptv)
GISS model: July 400 hPa

NOx(base) vs NOx(new lightning)

O3(base) vs O3(new lightning)

NOx (ppt) or O3 (ppb)
GISS model: July 250 hPa

NOx(base) vs NOx(new lightning)

O3(base) vs O3(new lightning)

Color bar: NOx(ppt) or O3(ppb)
GISS model: July

HNO3(base) 400 hPa

HNO3(new) 400 hPa

HNO3(base) 250 hPa

HNO3(new) 250 hPa

HNO3 (pptv)
Summary

• Relationship between NLDN/LRF and normalized CLDMAS was used to derive lightning parameterizations for each of the three met. fields used by GMI.

• Flash rates at tropical marine locations were too high (normalized so that tropical marine/tropical continental flash rate ratio matches observations).

• Resulting flash rate data sets were normalized to match v1.0 LIS/OTD annual average climatological flash rate.

• Test run of GMI model with DAO and GISS met. fields for one year with 5 TgN/yr from lightning.
Summary

PRELIMINARY FINDINGS - JULY

• DAO: Greatest impact of new lightning scheme is greater NOx, O3 and HNO3 in the UT over the North Atlantic

• GISS: More ozone downwind of North America and Asia
Figure 12
Lightning NOx Profiles for Use in Regional and Global Chemical Transport Models

Pickering et al. (1998)