Changes affecting lightning NO\textsubscript{x} emissions in GEOS-Chem v9-01-01

-- DRAFT VERSION --

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Summary

1. Bug fix for CTH determination
   1.1 Description of error
   1.2 Description of v9-01-01 CTH calculation
   1.3 Backwards-compatibility

2. Updated vertical release profiles

3. Deprecated options in v9-01-01
   3.1 New input.geos interface
   3.2-4 Deprecated options

4. GEOS5 v5.2.1 vs. v5.2.0

5. Description of contents of data directory lightning\_NOx\_201101
1. Bug fix for CTH determination

1.1 Description of error and who is effected

When reading in the 3-D met fields from disk, GEOS-Chem determines the model level of the cloud top height (CTH). Since at least GEOS-3, this was accomplished by running a counter from the surface to the model top, increasing the counter by one when a grid box was discovered to contain a positive convective mass flux across its top interface. The counter value was applied as the cloud top level.

\[ K = 1 \]

\[ \text{DO } L = 1, \text{ LPAR } \]
\[ \text{IF ( CMFMC(I,J,L) > 0d0 ) THEN} \]
\[ K = K + 1 \]
\[ \text{ENDIF} \]
\[ \text{ENDDO} \]
\[ \text{CLDTOPS(I,J) = K} \]

This algorithm neglects the possibility of levels containing no upward mass flux existing beneath a vertical region of convection, which is a common occurrence with the fine tropospheric resolution of GEOS-5 (and MERRA) that contains \( \sim 20 \) levels under 4km. GEOS-5 miscalculates the CTH 84% of the time, versus 1% for GEOS-4.

**Probability of CTH being off by at least one level in GEOS-4 and GEOS-5 for 2005**

Since there are on average 3-4 levels at the surface of no upward convective activity in GEOS-5, the inferred cloud top levels are on average 3-4 levels too low.
The problem is then amplified by the fact the surface levels are very thin, but the subsequently neglected UT levels are thick. Unfortunately, it wasn't originally caught, as lower cloud top heights were expected after the transition to GEOS-5, which is known to have weaker convection than GEOS-4. (Note: With the fix, despite weaker convective mass fluxes, cloud top heights are slightly higher in GEOS-5 than GEOS-4).

Because spatial and seasonal constraints are applied from LIS/OTD on the distribution, the location and timing of lightning in the model is correct with the CTH error. However, the vertical injection of the calculated column NO\textsubscript{x} emissions is from probability distribution functions scaled from the surface to the CTH, and therefore the NO\textsubscript{x} is emitted too low in altitude.

Subsequent UT ozone photochemistry is sensitive to the vertical level of NO\textsubscript{x} injection. INSERT SENTENCES / FIGURES LEARNED FROM BENCHMARK SIMS ABOUT EFFECTS ON BACKGROUND OZONE HERE
We recommend that anyone performing photochemically-sensitive GEOS-5 simulations re-run after implementing the fix. We do not feel it is necessary for GEOS-4 users to re-run their simulations.

1.2 Description of new cloud top height calculation

GEOS-Chem now determines the cloud top height by looping down from the model top until it discovers the first level with a convective mass flux across its top. It exits the loop, and because the flux is across the top of the box, the level containing the cloud top is taken to be one above.

\[
\text{CLDTOPS}(I,J) = 1 \\
\text{DO } L = \text{LLPAR}, 1, -1 \\
\text{IF } ( \text{CMFMC}(I,J,L) > 0 ) \text{ THEN} \\
\text{CLDTOPS}(I,J) = L + 1 \\
\text{EXIT} \\
\text{ENDIF} \\
\text{ENDDO}
\]

This correction is also computationally more expedient. Note the caveat that because our convective mass fluxes are defined as across the top of a grid box, a column with no non-zero values of CMFMC (or ZMMU for GEOS-4) may either be thought of as having a cloud top level of 0 (no convection at all) or 1 (convection started, but stopped before it reached the top of the first level). We apply the latter interpretation, to avoid the creation of many parameterized flash rates of zero, which the LIS/OTD redistribution scaling factors cannot adjust.

Note: All users will need to obtain the new lightning data directory lightning_NOx_201101/

1.3 Backwards compatibility

The fix is backwards compatible for users who do not wish to upgrade to v9-01-01. Users in this category simply need to replace the v9-01-01 versions of the following files into their code directories:

- GeosCore/lightning_nox_mod.f
- GeosCore/a6_read_mod.f

or apply the following git patch, if using a version of the model with git control.

INSERT GIT PATCH CODE

Users using the fix in versions prior to v9-01-01 will continue to use their model’s version of input.geos, but should be aware that the following flags highlighted in red are now depreciated and do nothing. (See Section 3).
Recommended input.geos options for users applying fix to earlier versions of the model

- Use lightning NOx? : T
- Scale glb flrate?: T
  *Always applied in new code*
- OTD reg redist? : F
  *Deprecated option*
- OTD loc redist? : T
- Use CTH param? : T
  *Always applied in new code*
- Use MFLUX param? : F
  *Deprecated option*
- Use PRECON param?: F
  *Deprecated option*
2. Updated vertical release profiles

GEOS-Chem has since its origins used the vertical probability distribution functions of Pickering et al. [1998] for determining how the calculated LNO\textsubscript{x} emissions in a column should be vertically partitioned for tropical marine, tropical continental, and extratropical storms. The Pickering et al. work was updated recently by Ott et al. [2010] using a 3-D cloud resolving model and additional field campaign constraints. The new profiles emit less LNO\textsubscript{x} at the surface than their predecessors, and an additional subtropical profile was determined (applied in regions previously treated as midlatitude).

The updated profiles are contained in the file

lightning_NOx_201101/light_dist.ott2010.dat

In addition to the new profile, we have adjusted the manner in which the type of profile (e.g., subtropical vs. midlatitude) is used to be consistent with that of the NASA GMI model (see [Allen et al., 2010]).

References


Ott L.E., K.E. Pickering, G.L. Stenchikov, D.J. Allen, A.J. DeCaria, B. Ridley, R.-F. Lin, S. Lang, W.-K. Tao, Production of lightning NO\textsubscript{x} and its vertical distribution calculated from three-dimensional cloud-scale chemical transport model simulations, J Geophys Res, 115, D04301, 2010
3. Depreciation of unsupported options in v9-01-01

3.1 New input.geos interface

=> Use lightning NOx? : T
  => Spat-seas constr: T

Emit lightning NOx?
Use LIS/OTD local redistribution?

The LIS/OTD local redistribution constrains the spatial and seasonal variability of the global lightning distribution. It is recommended for all non-GCAP simulations.

3.2 No more alternate parameterizations

The GEOS-Chem standard code no longer supports the MFLUX or PRECON lightning parameterizations [Allen and Pickering, 2002]. The algorithms themselves remain in the lightning module, but are no longer selectable from input.geos, and would require hardwiring and additional work by any end user to make them compatible with their specific model framework.

The GEOS-Chem standard code now uses only the CTH method [Price and Rind, 1992; 1993; 1994], which yields the most accurate a priori global lightning distribution within GEOS-Chem against observations [Murray et al., in prep.].

3.3 No more regional redistribution

GEOS-Chem now only supports the local redistribution technique to constrain the flash rates to the spatial and seasonal distribution of satellite climatological observations. See early description of local redistribution by Sauvage et al. [2007] and current implementation by Murray et al. [in prep.].

3.4 Automatic scaling of global flash rate to match observations

The climatological satellite lightning observations from LIS/OTD indicate an average annual global lightning flash rate of 46 flashes s⁻¹. GEOS-Chem applies a single unitless constant scaling parameter (differs for model version and resolution) to guarantee that the global annual average flash rate matches observations—see β in Murray et al. [in prep.]. (Note: A given year’s annual average flash rate will vary about the mean).

This was originally an option in input.geos (Scale glb flrate?), but it should always be applied. As the magnitude of the global flash rate is constrained, we are able to appropriately apply from the literature (or infer) NOx-per-flash yields.

References


4. GEOS-5 v5.1.0 vs. v5.2.0

Users of GEOS-5 may notice additional LIS/OTD redistribution files in their data directory. This is because the model version of GEOS-5 used for the data assimilation for our input files has changed over time. In GEOS-Chem, all met fields prior to Sept. 2008 were run with GEOS 5.1.0, and after with GEOS 5.2.0.

As convection changed between the two model versions (see the following NASA GMAO technical report for a full description), the lightning parameterization is affected, and requires different treatment for each model version used.

Therefore, v5 of the LIS/OTD redistribution files are constrained using the following months of data for comparison against the LIS/OTD HRMC v2.2 gridded product:

GEOS 5.1.0: Jan. 2004—Aug. 2008
GEOS 5.2.0: Sept. 2008—May 2010

After more months of data become available for GEOS 5.2.0, the redistribution files will be appropriately updated. For now, simulations of months since Sept. 2008 will be close to climatological flash rates. Users whose results are sensitive to lightning in simulations containing months after Sept. 2008 are encouraged to contact Lee Murray (ltmurray@post.harvard.edu) for more information.

References

5. Contents of data directory lightning_NOx_201101

The contents of the new lightning data directory include the Ott et al. [2010] vertical distributions (see Section 2).

./light_dist.ott2010.dat

and updated versions (v5) of the LIS/OTD local redistribution files

./OTD-LIS-Local-Redist.CTH.v5.*

These files contain the scaling factors used to constrain to the LIS/OTD High Resolution Monthly Climatology (HRMC) v2.2 product, which contains the 12 monthly mean flash rates using observations from May 1995-Dec 2005 from the Lightning Imaging Sensor (LIS) and Optical Transient Detector (OTD).

The files are determined by generating dummy HRMC products using the same observation time window if possible, or as many months of present day meteorology as available at Harvard. See third column of the table below for a description of the months used for each specific file (also for determining $\beta$, see Section 3.4), and Murray et al. [in prep.] for a more complete description of the method.

<table>
<thead>
<tr>
<th>GCM</th>
<th>Resolution</th>
<th>Months used to constrain to LIS/OTD HRMC</th>
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<tbody>
<tr>
<td>GEOS 3</td>
<td></td>
<td>None</td>
</tr>
<tr>
<td>GEOS 4</td>
<td>$4^\circ \times 5^\circ$</td>
<td>May 1995—Dec 2005</td>
</tr>
<tr>
<td>GEOS 4</td>
<td>$2^\circ \times 2.5^\circ$</td>
<td>May 1995—Dec 2005</td>
</tr>
<tr>
<td>GEOS 5.1.0</td>
<td>$4^\circ \times 5^\circ$</td>
<td>Jan 2004—Aug 2008</td>
</tr>
<tr>
<td>GEOS 5.1.0</td>
<td>$2^\circ \times 2.5^\circ$</td>
<td>Jan 2004—Aug 2008</td>
</tr>
<tr>
<td>GEOS 5.1.0</td>
<td>$0.5^\circ \times 0.667^\circ$ North America</td>
<td>July 2004 and Jan 2006—Aug 2008</td>
</tr>
<tr>
<td>GEOS 5.1.0</td>
<td>$0.5^\circ \times 0.667^\circ$ China</td>
<td>Jan 2004—Aug 2008</td>
</tr>
<tr>
<td>GEOS 5.2.0</td>
<td>$4^\circ \times 5^\circ$</td>
<td>Sept 2008—May 2010</td>
</tr>
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</tr>
<tr>
<td>MERRA</td>
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<td>May 1995—Dec 2005</td>
</tr>
<tr>
<td>GISS Model 3 (GCAP)</td>
<td>$4^\circ \times 5^\circ$</td>
<td>10 years of present day simulations</td>
</tr>
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</table>

Note: GCAP does not have a redistribution file, as it would be inappropriate to use such a file for future or past climate scenarios. However, those are the years used for determining $\beta$ for GCAP.