

Assessment of the Impact of Lightning NO_x on Air Quality over the Northern Hemisphere

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Motivation

- Global production of lightning NO_x (LNO_x) is estimated to be 2-8 Tg N per year (10-15% total NO_x budget)¹.
- The importance of natural emissions will increase as anthropogenic emissions decrease over parts of the world.
- Where do uncertainties exist?
 - –Influence of lightning on air quality at the surface (particularly ozone, O_3).
 - –Production and distribution of LNO_x on hemispheric/global scales.
- Four annual hemispheric Community Multiscale Air Quality^{2,3} (CMAQ) simulations are performed with varying LNO_x emission configurations.
 - -Results for July are presented.
 - -Performance analyses are featured.





What are these LNO_x emission configurations?

LNO _x Configurations	Details
"BASE"	LNO_x is turned off (a control simulation.)
"WWLLN"	Hourly Lightning Flash Data from the World Wide Lightning Location Network (WWLLN) ¹
"WWLLNId"	An adjusted version* of the WWLLN run using monthly mean ratios from WWLLN and the National Lightning Detection Network (NLDN) ^{2,3}
"GEIA"	Climatological LNO _x Emissions from the Global Emissions InitiAtive (GEIA) ^{4,5}

*Please see the Kang et al. poster during the same session for additional details.

³ ¹Rodger, C.J., et al. (2006), ²Cummins, K.L., et al. (1998), ³Nag, A., et al. (2014), ⁴Graedel, T.E., et al. (1993), ⁵Vukovich and Eyth (2019) – (U.S. EPA TSD)



Model Configurations

Feature	Setting
Domain	Northern Hemisphere (horizontal)
Horizontal Resolution	108km
Vertical Levels	44 Levels; Surface-50hPa
Simulation Period	2016
Initial Conditions	Results from a previous hemispheric model simulation.
Boundary Conditions	Default conditions of the hemispheric model.
Anthropogenic Emissions	HTAPv2 (Hemispheric Transport of Air Pollution)*
Biogenic Emissions	Biogenic Emissions Inventory System (BEIS) for the United States; Model of Emissions of Gases and Aerosols from Nature (MEGAN) for remaining areas. Updated halogen emissions are used for marine environment.

⁴ *Except for the United States, China, and Canada, where country-specific emissions inventories are used.



Spatial Distributions for July





Boxplot Diagrams for July

Boxplot diagrams of monthly mean O_3 for various regions.

Boxplot Definitions:

Top Line: Maximum Top of Box: 75th Percentile Middle Line: Median Bottom of Box: 25th Percentile Bottom Line: Minimum





Overall Model Performance for the U.S.

Performance analyses for July Using Air Quality System (AQS) Sites Across the U.S.

	Metric	BASE	WWLLN	WWLLNId	GEIA
Daily Maximum 8-hr	Mean Bias	0.23	1.99	3.67	5.55
Surface O ₃	RMSE	14.56	14.16	14.1	14.21
(1293 sites)	Corr.	0.46	0.49	0.52	0.55

	Metric	BASE	WWLLN	WWLLNId	GEIA
Daily Surface NO_2	Mean Bias	-2.68	-2.69	-2.69	-2.69
	RMSE	5.53	5.53	5.54	5.54
(440 51185)	Corr.	0.47	0.47	0.47	0.47



Timeseries Comparison for July

Timeseries comparison of daily-max 8-hour O_3 (DM8HR) for July between simulations and AQS data.



While statistics indicate the overall overprediction of O_3 over the U.S. from the LNO_x simulations (for July), the LNO_x simulations perform better for areas that typically have underestimations of O_3 (but perform worse for areas with overestimations of O_3)...



Performance Statistics at the Surface

Daily Maximum 8-hr	Metric	BASE	WWLLN	WWLLNId	GEIA
Surface O ₃	Mean Bias	0.23	1.99	3.67	5.55
(1293 sites – entire	RMSE	14.56	14.16	14.1	14.21
United States)	Corr.	0.46	0.49	0.52	0.55

Same, but for the Southeast US .	Metric	BASE	WWLLN	WWLLNId	GEIA
	Mean Bias	4.25	6.17	7.82	8.85
	RMSE	10.3	10.97	11.83	12.45
(104 5105)	Corr.	0.62	0.63	0.65	0.66
Same, but for the US Northeast . (190 sites)	Metric	BASE	WWLLN	WWLLNId	GEIA
	Mean Bias	4.89	5.78	6.81	9.05
	RMSE	18.86	18.98	19.2	19.57
9	Corr.	0.49	0.5	0.5	0.5

Southeast states: VA, NC, SC, GA, AL, FL

Northeast states: NY, MD, VT, NH, ME, PA, DC, NJ, DE, MA, RI, CT



Performance Statistics at the Surface

Daily Maximum 8-hr	Metric	BASE	WWLLN	WWLLNId	GEIA
Surface O ₃	Mean Bias	0.23	1.99	3.67	5.55
(1293 sites – entire	RMSE	14.56	14.16	14.1	14.21
United States)	Corr.	0.46	0.49	0.52	0.55

Same, but for the Western US .	Metric	BASE	WWLLN	WWLLNId	GEIA
	Mean Bias	-4.89	-2.91	-0.93	1.68
	RMSE	19.11	18.06	17.33	16.76
(200 3103)	Corr.	0.33	0.38	0.42	0.46
Same but for the US	Metric	BASE	WWLLN	WWLLNId	GEIA
Same, but for the US Northwest.	Metric Mean Bias	BASE -3.27	WWLLN -2.26	WWLLNId -1.17	GEIA 1.75
Same, but for the US Northwest . (28 sites)	Metric Mean Bias RMSE	BASE -3.27 9.2	WWLLN -2.26 8.63	WWLLNId -1.17 8.22	GEIA 1.75 8.07
Same, but for the US Northwest . (28 sites)	MetricMean BiasRMSECorr.	BASE -3.27 9.2 0.58	WWLLN -2.26 8.63 0.61	WWLLNId -1.17 8.22 0.63	GEIA 1.75 8.07 0.66

Western states: California & Nevada

Northwest states: Washington, Oregon, & Idaho



Performance Statistics at the Surface

Daily Maximum 8-hr	Metric	BASE	WWLLN	WWLLNId	GEIA
Surface O ₃	Mean Bias	0.23	1.99	3.67	5.55
(1293 sites – entire	RMSE	14.56	14.16	14.1	14.21
United States)	Corr.	0.46	0.49	0.52	0.55

Same, but for the	Metric	BASE	WWLLN	WWLLNId	GEIA
	Mean Bias	-8.14	-5.8	-3.39	0.35
Rockies and Plains.	RMSE	11.38	9.33	7.78	6.41
(58 sites)	Corr.	0.36	0.47	0.54	0.62
		DACE			
Same but for the US	Metric	BASE	VVVLLN	VVVLLNIC	GEIA
Southwest.	Mean Bias	-14.32	-10.35	-6.58	-4.24
(120 sites)	RMSE	16.28	12.95	10.33	8.92
11	Corr.	0.45	0.43	0.41	0.44

Northern Rockies & Plains states: Montana, North Dakota, South Dakota, & Wyoming

Southwest states: Utah, Colorado, Arizona, & New Mexico



Mean Ozonesonde & CMAQ Profiles for July



Locations in the Western U.S.

Vertical analyses show improvements in the O_3 profile.

The GEIA simulation shows consistently higher magnitudes for most locations and heights.



Mean Ozonesonde & CMAQ Profiles for July



Locations in the Eastern/Southern U.S.

Similar conclusions are made for locations in the Eastern/Southern U.S.

Overall, the addition of LNO_x results in a better representation of O_3 throughout the vertical profile.



ection Monthly Mean NO₂ OMI retrievals VCD



Left:

NO₂ Retrievals from Ozone Monitoring Instrument (OMI)

BASE - OMI

WWLLN - OMI



WWLLNId - OMI

Right: CMAQ NO₂ Difference Plots (CMAQ minus OMI)





"VCD" = "Vertical Column Density"



Summary

• There are clear differences in the magnitude, distribution, and spread of surface O₃ and column LNO_x between simulations.

- –Most simulations underpredict column NO₂ globally, whereas the simulation with GEIA overpredicts column NO₂ for some regions.
- The inclusion of LNO_x in CMAQ results in improvements in simulated surface O_3 in the Western U.S., as well as in the vertical profiles of O_3 . Model performance deteriorates for other locations (e.g., Eastern U.S.).
- Future work will examine...
 - –Additional CMAQ LNO_x emission configurations;
 - -High bias of predicted O_3 in the Eastern U.S.;
 - -Global ozonesonde measurements.



Thank you / References

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