# Impact of lightning and anthropogenic NOx sources on tropospheric $O_3$ and radiative forcing over the U.S. and the western North Atlantic

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- Radiative forcing sensitivity of upper tropospheric $O_3$ is significantly larger than that of lower tropospheric $O_3$ [e.g., Lacis et al., 1990].
- In this study, we apply CTM simulation results to quantify the relative contribution of lightning NOx and anthropogenic NOx to chemical components (tropospheric $NO_2$ and $O_3$) and radiative components (OLR, radiative forcing, and total radiative rates).

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# CTM and radiative transfer scheme

## Regional chEmical trAnsport Model (REAM)

- Horizontal resolution of 70 km with 23 vertical layers reaching to 10 hPa
- Reduction in 50% industrial and power plant NOx emissions in the eastern U.S. from 1999 EPA NEI [Hudman et al., 2007]
- GEOS-Chem (v7.2) simulation results are used for chemical boundary condition.
- Archive meteorological variables every 2.5 min for cloud convection and lightning NOx production.
- REAM model details and evaluations are in our previous studies [Choi et al., 2005, 2008a, 2008b].

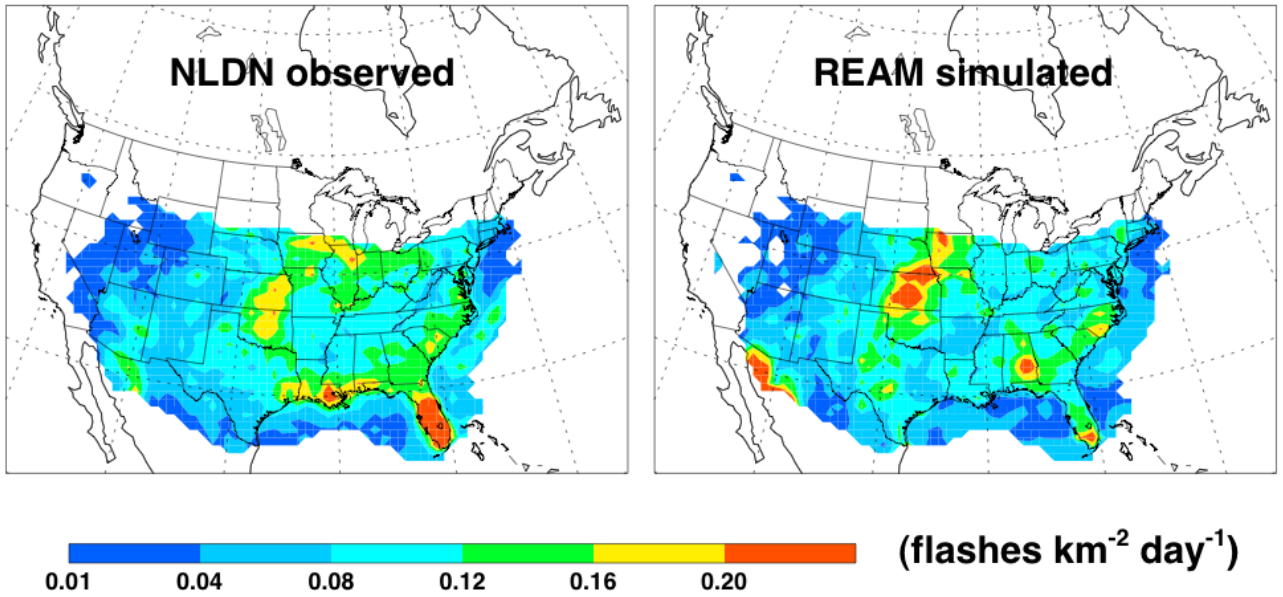
## Fu-Liou radiative transfer scheme

- Fu-Liou radiative transfer scheme [Gu et al., 2003] is used to calculate the radiative estimates.
- For the calculation of radiative estimates, the vertical profile of dynamic variables (temperature, pressure, air density and cloud) and chemical variables (gas and aerosol concentrations) are from MM5 and CTMs, respectively.

# Satellite Measurements

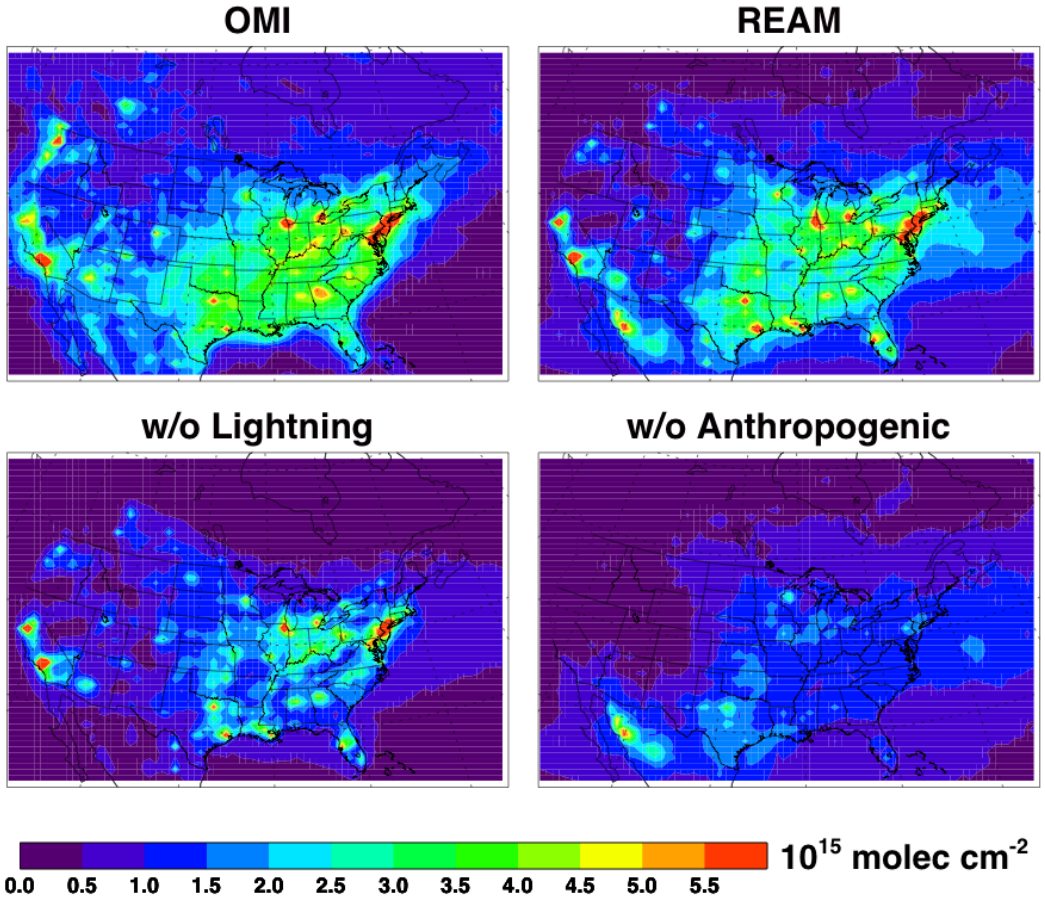
- Tropospheric $NO_2$ column: OMI
- Tropospheric $O_3$ column: OMI/MLS residual method
- Tropospheric $O_3$ vertical profile: TES
- Outgoing Longwave Radiation: NOAA-16

# Lightning flash rates for 2005 summer



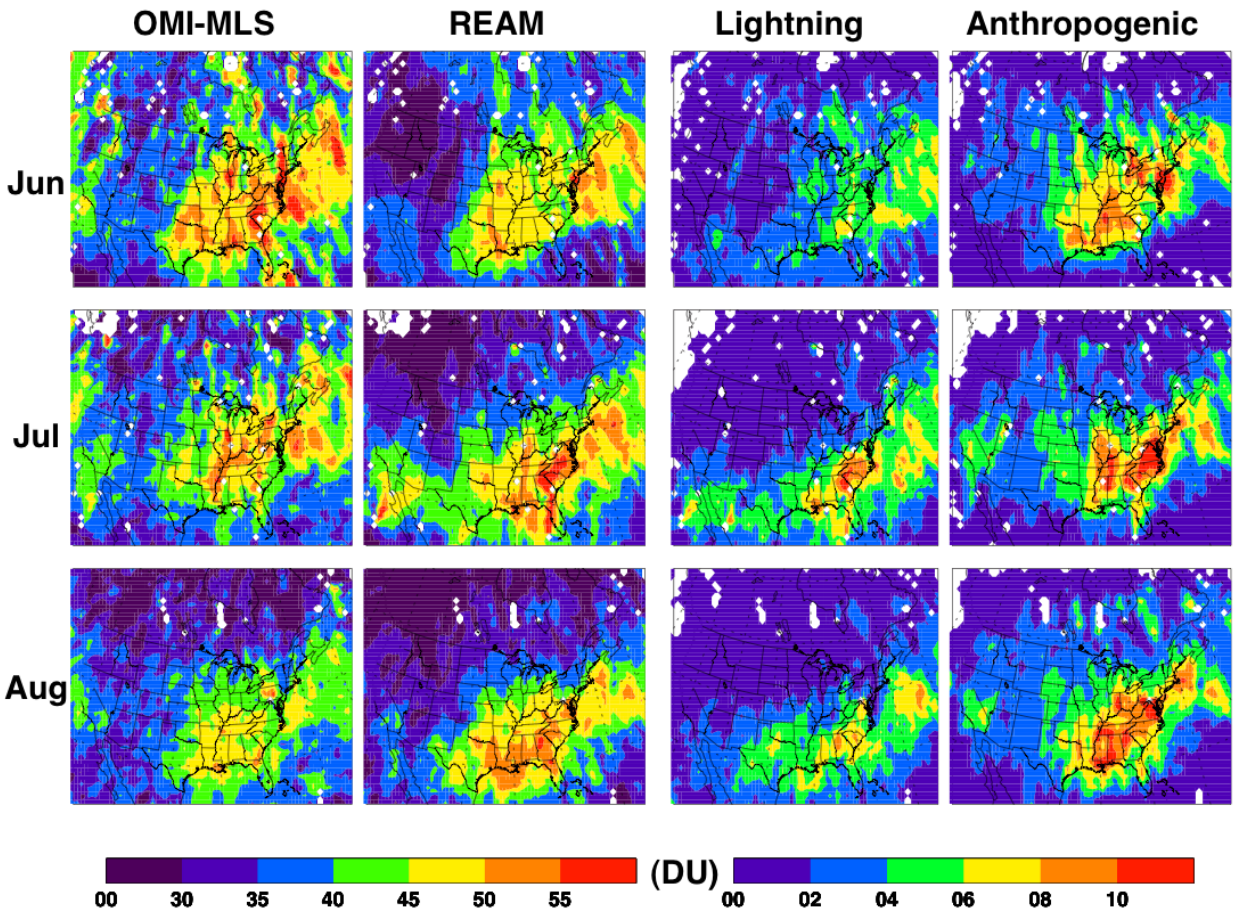

- Dependence of lightning occurrence on CAPE and cloud mass flux is used for estimating lightning flash rates in the model [Choi et al., 2005].
- Reasonable agreement between NLDN observed- and REAM simulated- lightning flash rates (R=0.65)
- High flash rates over the midwestern U.S. in June
- High flash rates over Mexico, Texas, and the southern U.S. in July

# Tropospheric $NO_2$ for 2005 summer



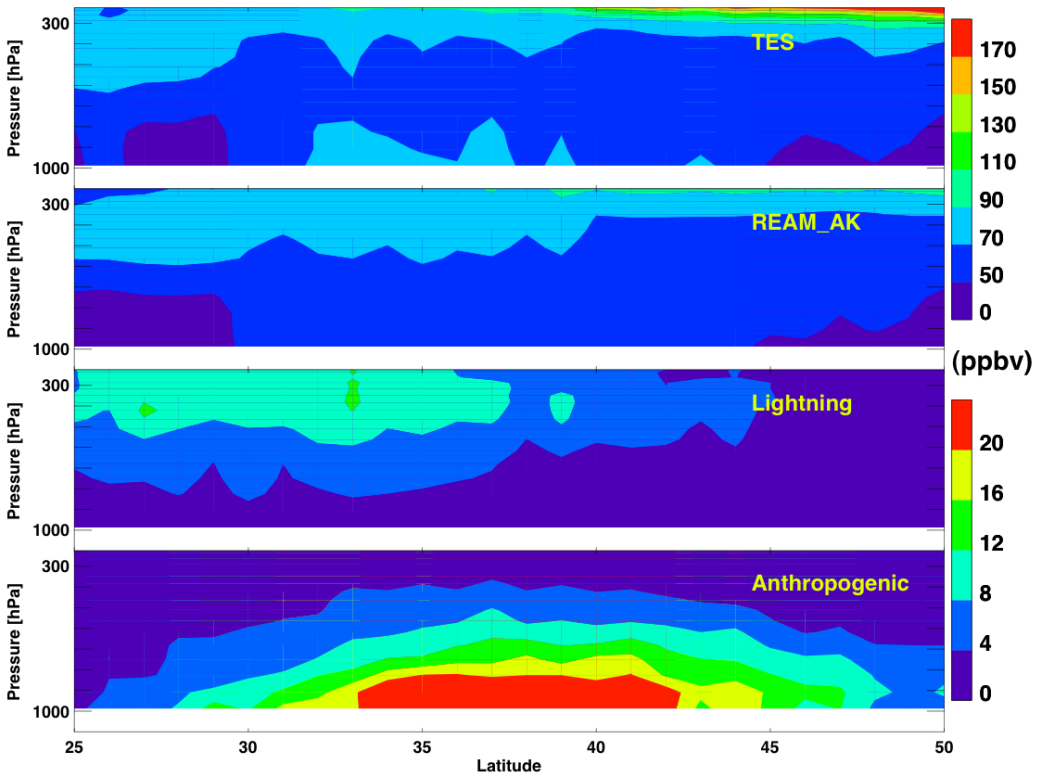

- Good agreement between OMI observed- and REAM simulated- tropospheric $NO_2$ column (R=0.85)
- Even with the large reduction in anthropogenic NOx emissions, it is still the dominant term in constraining tropospheric $NO_2$.

# Tropospheric $O_3$ for 2005 summer



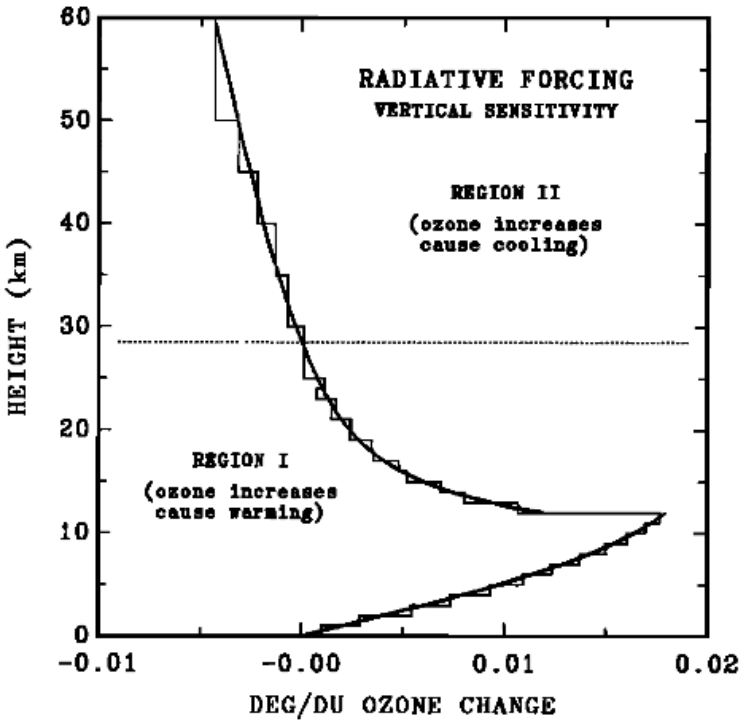

- Reasonable agreement between OMI-MLS derived- and model simulated- tropospheric $O_3$ column (R=0.61-0.77)
- Impact of lightning NOx on tropospheric $O_3$ is comparable to that of anthropogenic NOx.

# TES vertical $O_3$ profile for July



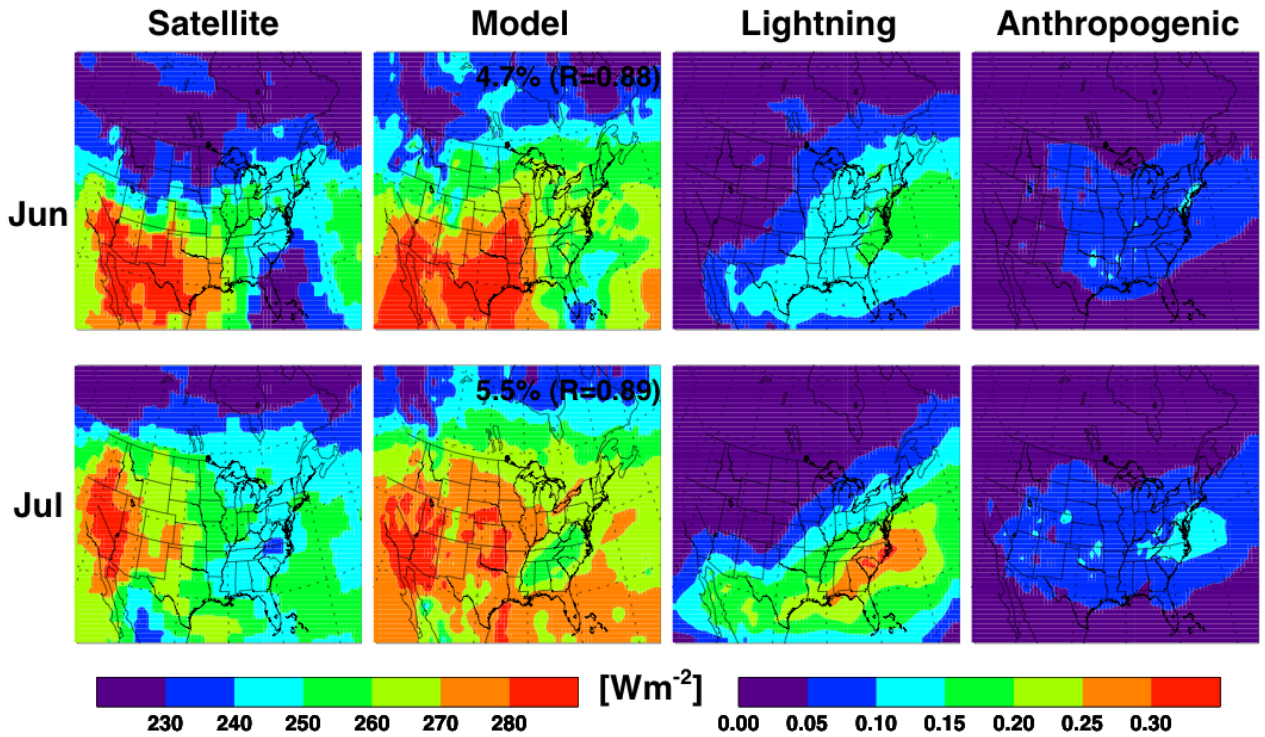

- Lightning NOx derived- $O_3$ enhancements are significantly smaller than anthropogenic NOx derived enhancements.
- Anthropogenic NOx derived $O_3$ enhancements are in the lower troposphere, but lightning activity enhances upper tropospheric $O_3$.

# Radiative forcing sensitivity



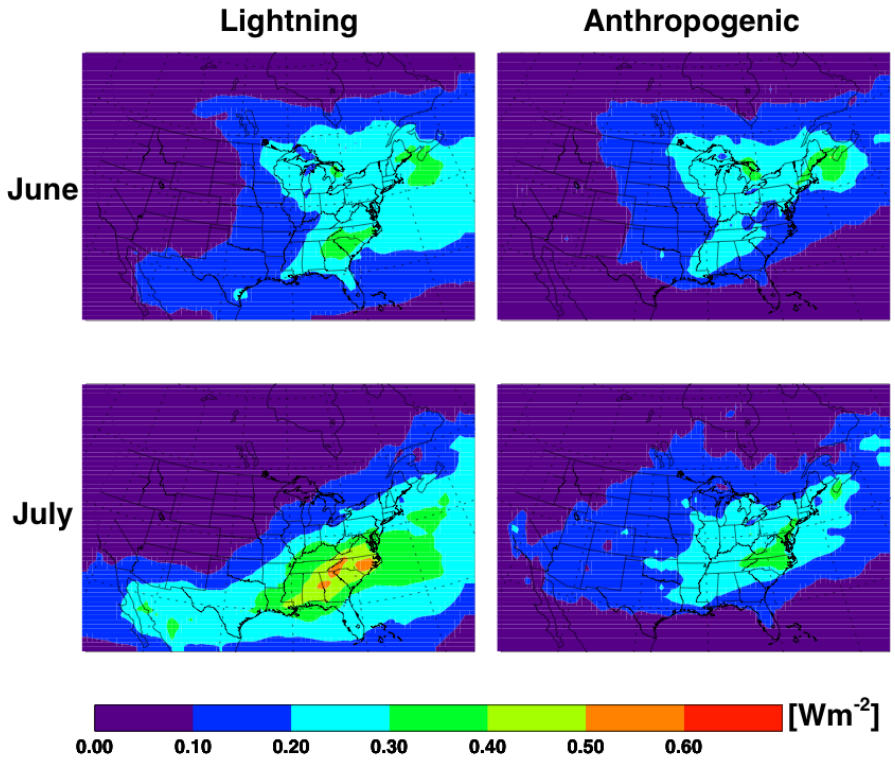

- Adopted from Lacis et al., 1990
- Strong sensitivity of radiative forcing to changes in $O_3$ in the upper troposphere where lightning plays a key role in the creation of $O_3$

# OLR from NOAA satellite and CTM



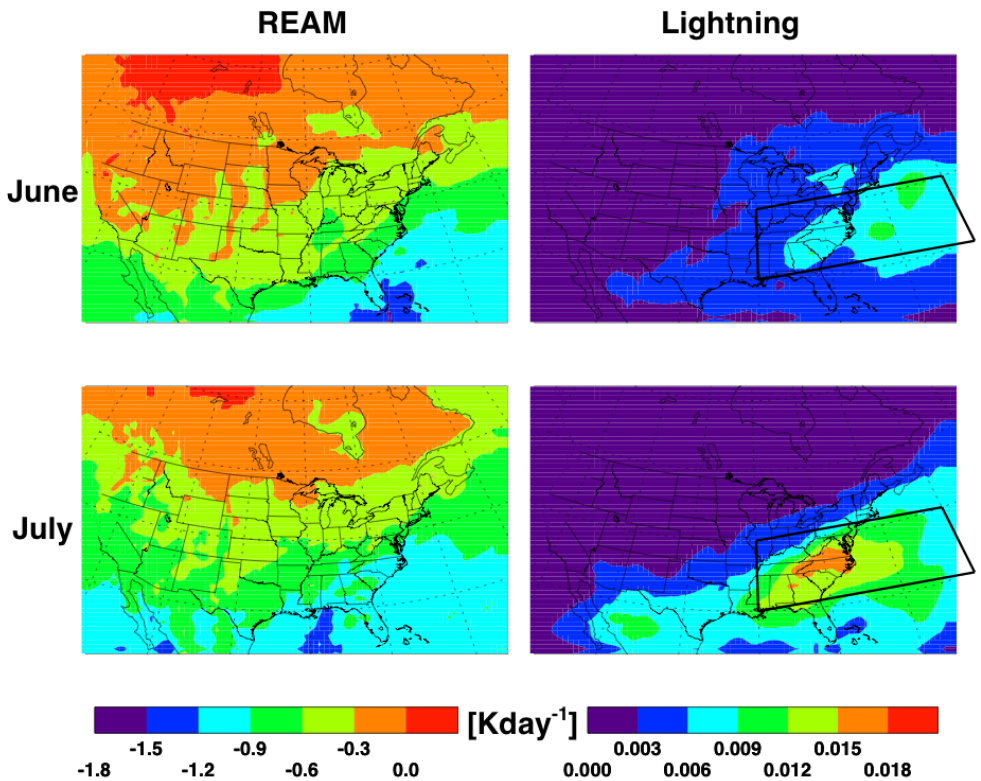

- Reasonable agreements between satellite measured- and REAM simulated- OLR with high correlation coefficients (R>0.88) and mean differences (<5.5%).
- Impact of lightning NOx on OLR via its $O_3$ production is larger by up to a factor of 3 than that of anthropogenic NOx in the convective outflow regions.

# Radiative forcing




- Radiative forcing is a change of net LW and SW fluxes at the top of the atmosphere.
- Impact of lightning NOx on radiative forcing via its $O_3$ production is significantly larger than that of anthropogenic NOx.
- Highly impacted regions in June are different from those in July due to change in the monsoon impacted regions.

# Total radiative rate at 300 hPa




- Total radiative rate = SW heating rates + LW cooling/heating rates
- Impact of lightning NOx on total radiative rate at 300 hPa via its $O_3$ production in the outflow regions in July is larger by a factor of 2 than that in June.

# Conclusions

- REAM captures the spatial distribution of lightning flash rates, OMI $NO_2$ column, OMI-MLS $O_3$ column and NOAA OLR with high correlation coefficients (0.6-0.9).
- For tropospheric $NO_2$, anthropogenic NOx emissions are major sources.
- For tropospheric $O_3$, the contribution of anthropogenic NOx is significantly larger than that of lightning NOx.
- For radiative estimates, the contribution of lightning NOx via its $O_3$ production is larger by up to a factor of 3 than that of anthropogenic NOx.
- For total radiative heating rate at 300 hPa, the contribution of lightning NOx in the convective outflow in July is larger by a factor of 2 than than in June.
- Relative importance of lightning NOx on chemical and radiative components has increased as anthropogenic NOx has decreased in recent years.