Comparison of default and convection-based lightning in the GMI model

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Motivation/Preview

- Production of NO by lightning is an important component of the NO_x budget ; NO_x is the rate-limiting factor in O_3 production in much of the free troposphere.

- The default version of the Global Modeling Initiative (GMI) CTM uses climatological lightning NO emissions. The distribution of these emissions does not match in space or time with the location of model convection.

- In this study, we evaluate the effect of this mismatch on upper tropospheric photochemistry through analysis of fields from GMI simulations with climatological- and convection-based lightning NO.

Comparison of lightning algorithms

Default Run

- Horizontal distribution: Climatological based on ISCCP monthly average deep convective cloud top heights
- Vertical distribution: C-shaped (Pickering et al., 1998) using climatological CLDHT
- Flashrate = f(CLDHT, marine/continental; P+R, 1992)
- $P_{CG} = 10\ P_{IC}$ (Price et al., 1997)
- CG fraction based on cold cloud depth (P+R, 1993)
- Scaled to: 5 Tg N/yr

New Run

- Horizontal distribution: Co-located with model-calculated deep convection
- Vertical distribution: C-shaped as before using model-calculated CLDHT
- Flashrate = f(CLDMAS, region) [Allen+Pickering,2002]
- $P_{CG} = P_{IC}$ (DeCaria et al., Ott et al., Fehr et al.; STERAO, EULINOX, CRYSTAL-FACE)
- CG fraction not needed
- Scaled to ≈5 Tg N / yr

Implications of the different lightning NO treatments

Default Run

- Convectively-transported precursors (HO_x precursors, NO_x, CO, NMHC) introduced to upper troposphere at different locations than lightning NO
- Lightning NO spigot always open on lowest setting (fuzzy NO_x chemistry)
- Biases in spatial distribution and vertical extent of model convection DO NOT contribute to biases in lightning NO

New Run

- Convectively-transported precursors introduced to upper troposphere at same locations as lightning NO
- Lightning NO spigot opens when convection occurs; setting determined by CLDMAS and region
- Biases in spatial distribution, vertical extent, and magnitude of model convection contribute to biases in location of lightning NO

Flash rate parameterization in new run

Step 1: Fit polynomial,

- $y_{fit} = ax_i + b[x_i]^2 + c[x_i]^3$ to relationship between convective mass flux (CLDMAS) and observed CG flash rates [Allen and Pickering, 2002]

- **y** = NLDN/LRF 6-hr avg CG flash rates for 1997 (10º-60ºN; 120º-60ºW) [sorted by magnitude]
- $\mathbf{x_i}$ = Upper tropospheric CLDMAS from the GEOS DAS (Mar 1997-Feb 1998), NCAR CCM3, or GISS GCM [sorted by magnitude]
- Apply polynomial globally (see "bef regional" plot)

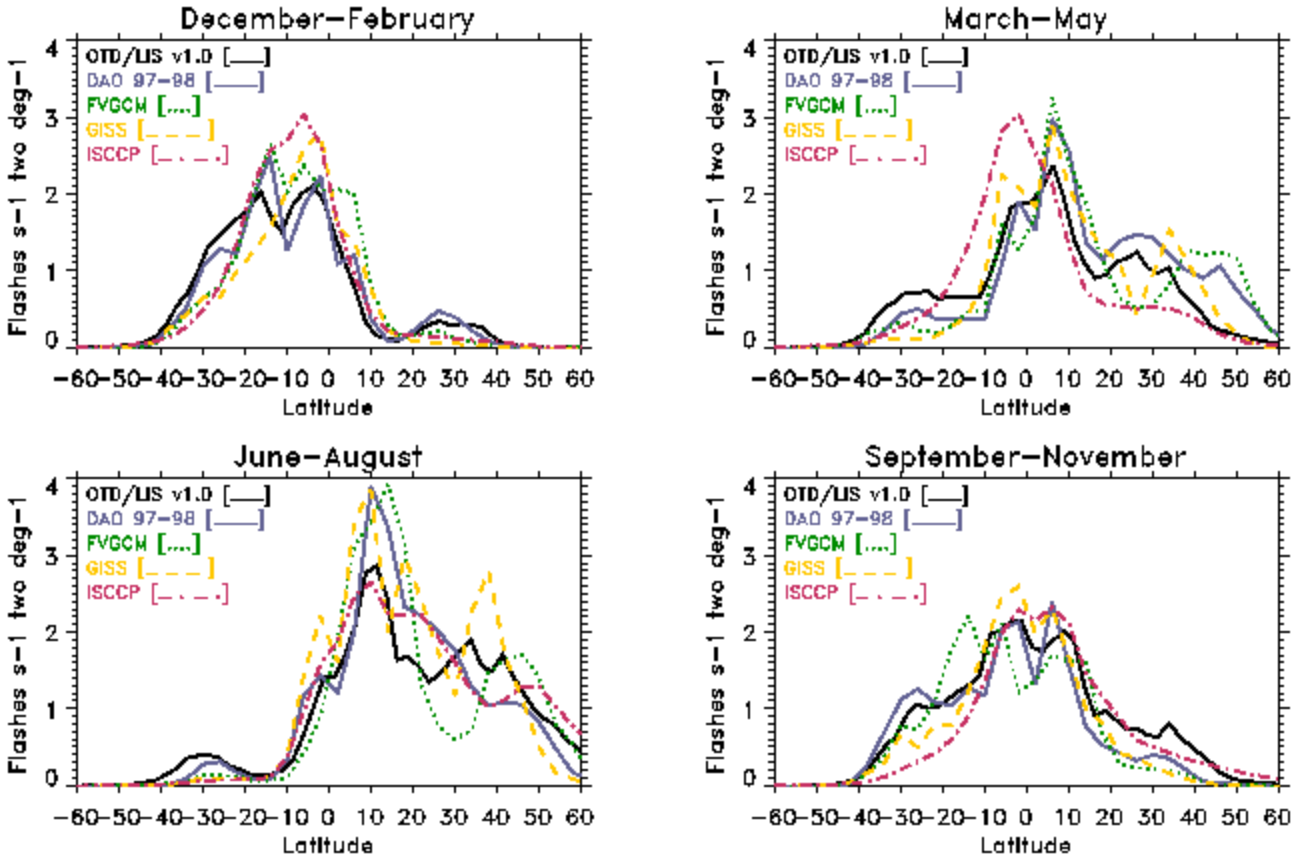
Step 2: Regional adjustments

- Scale polynomial-calculated CG flash rates to match total flash rate from v1.0 OTD/LIS climatology (46.6 flashes s^{-1})

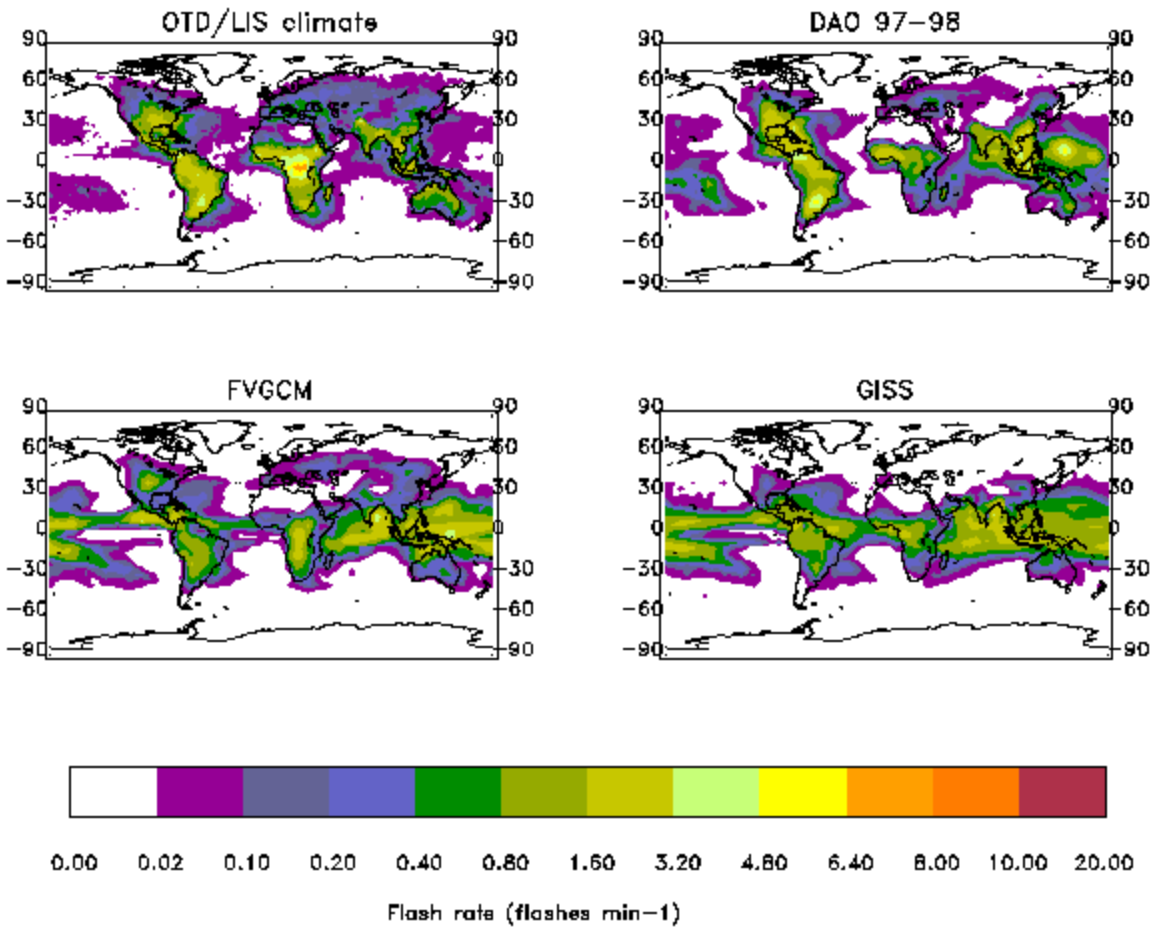
- Adjust tropical-marine (reduce), tropical-continental (increase), and midlatitude-continental (increase) flash rates to best match OTD/LIS climatology.

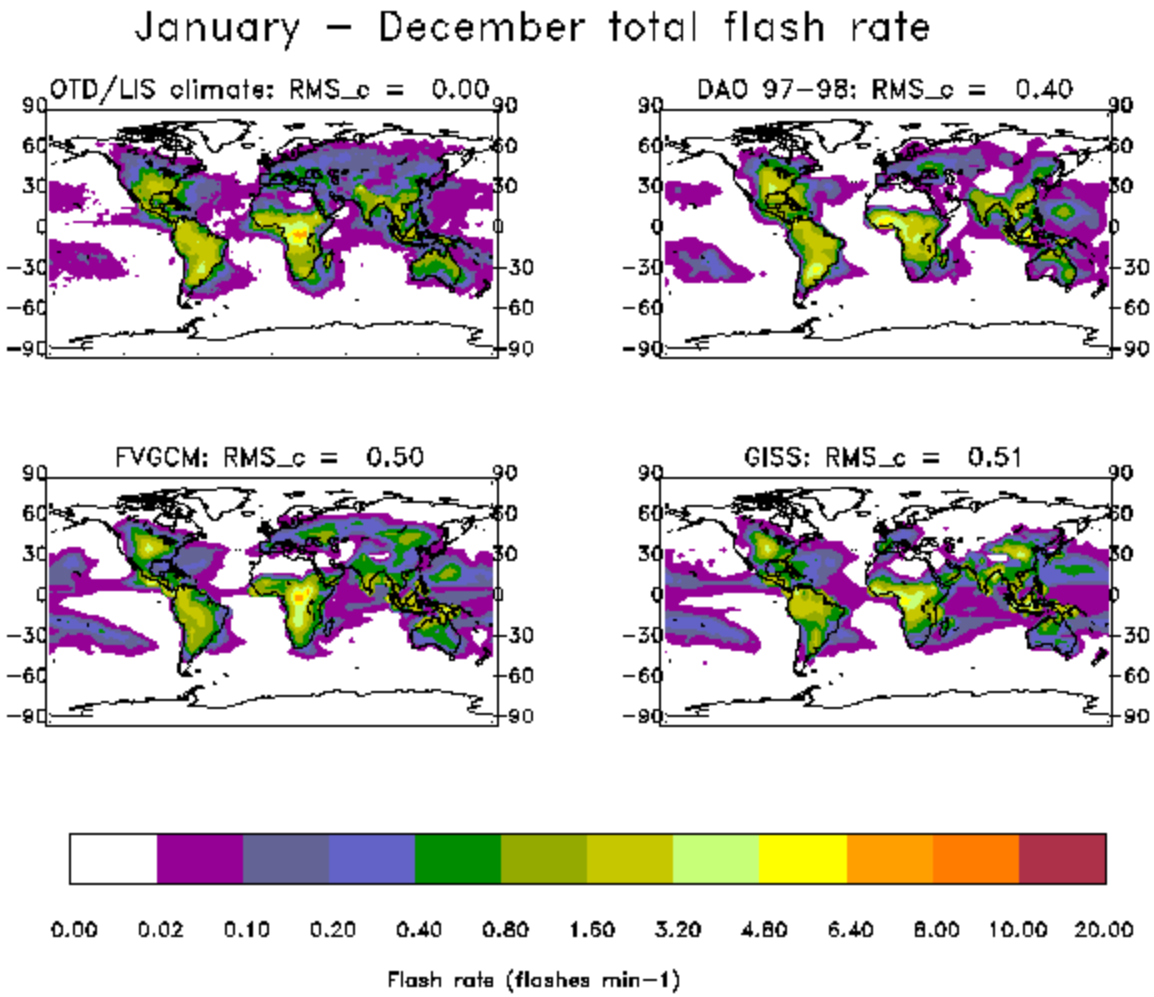
  Also, adjust S.America:Africa ratio to OTD/LIS.

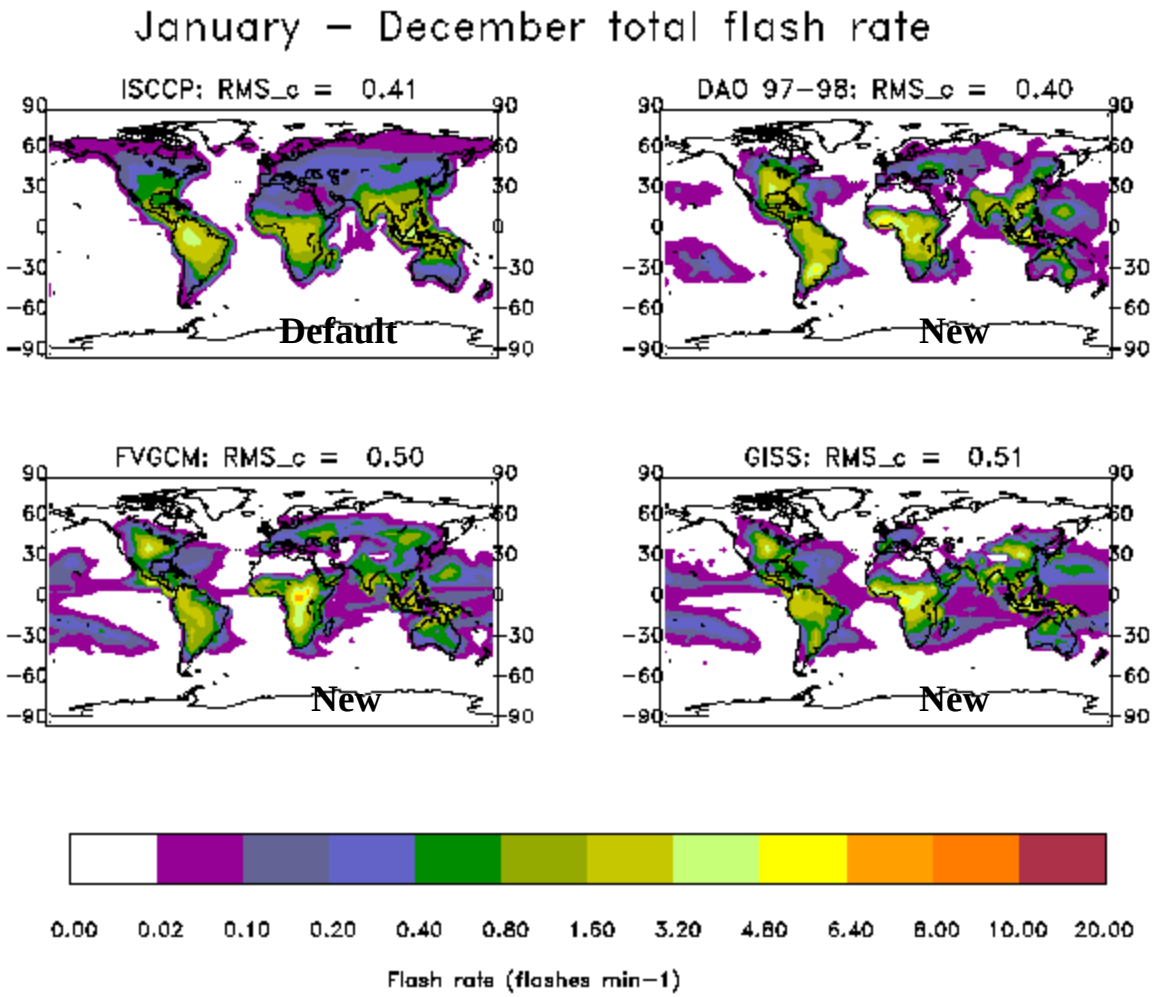
Zonally averaged flash rate as a function of season

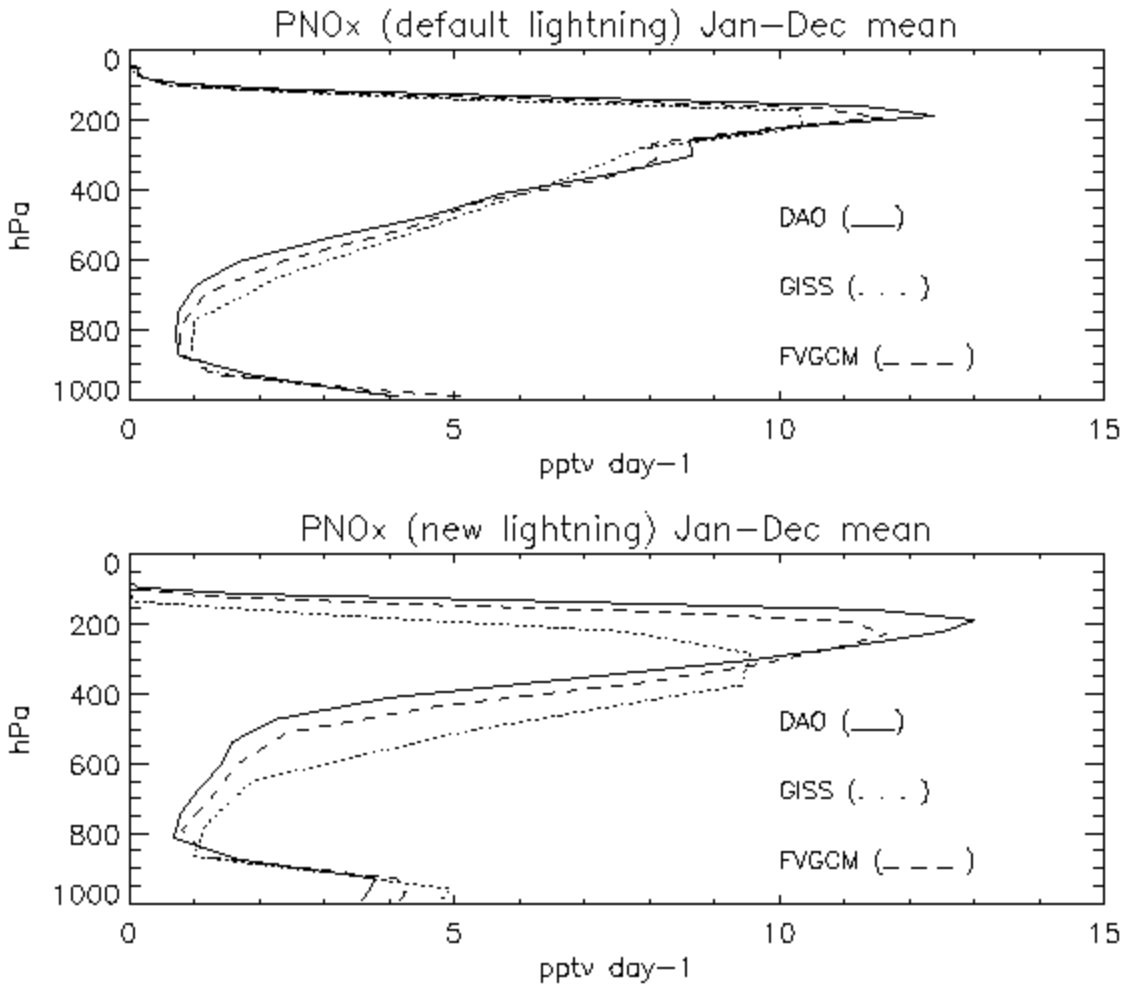


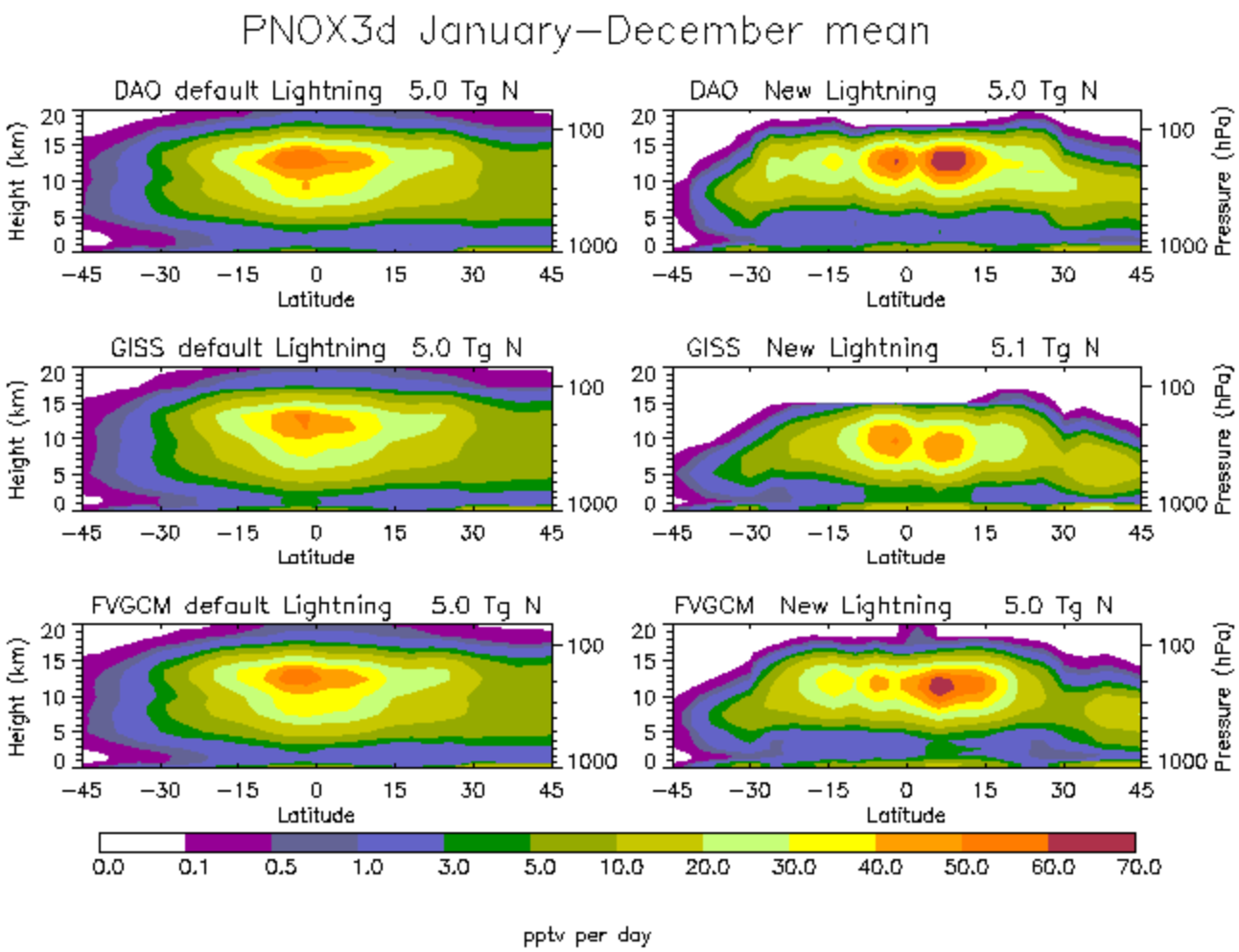
GMI flash rates before regional adjustments

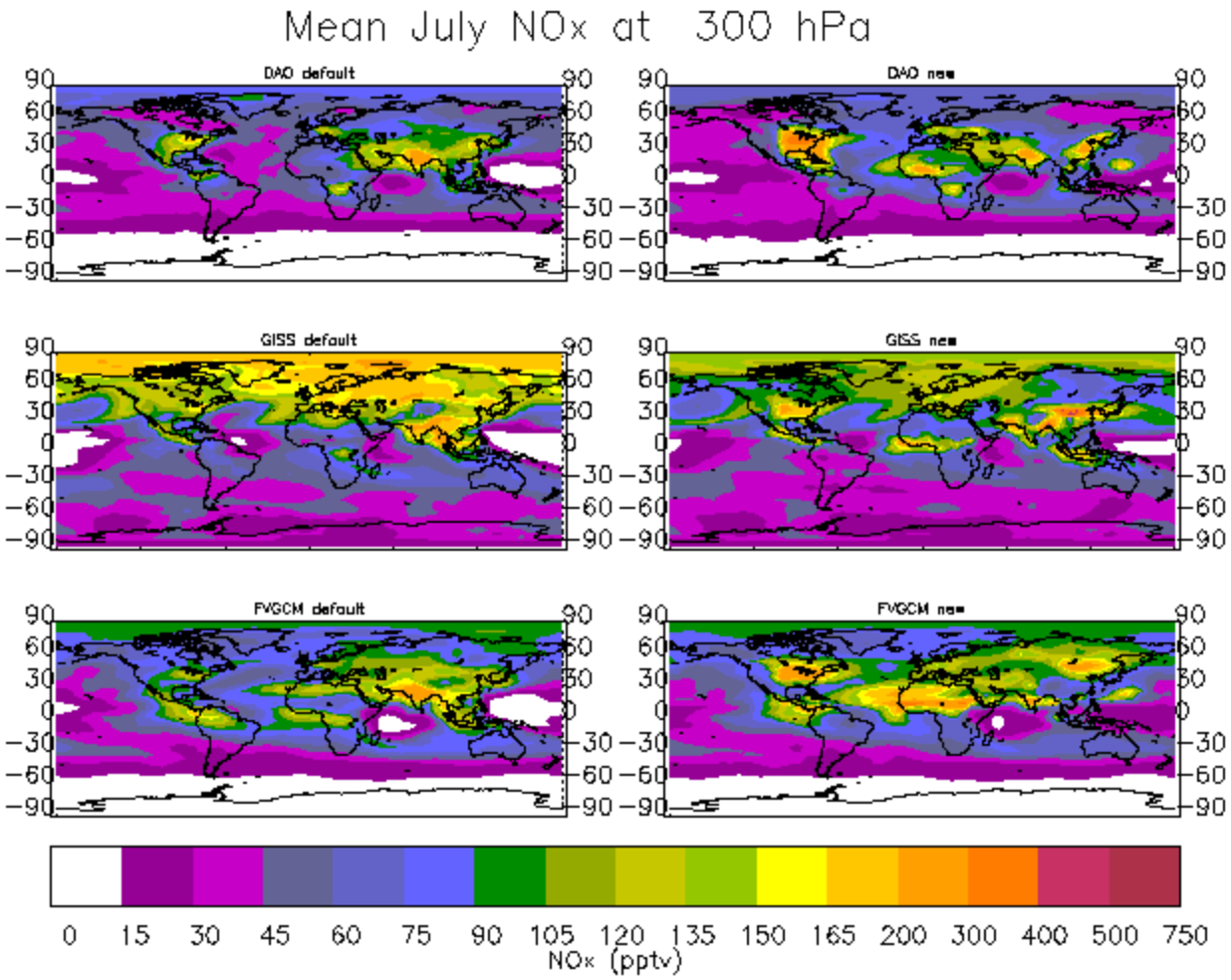


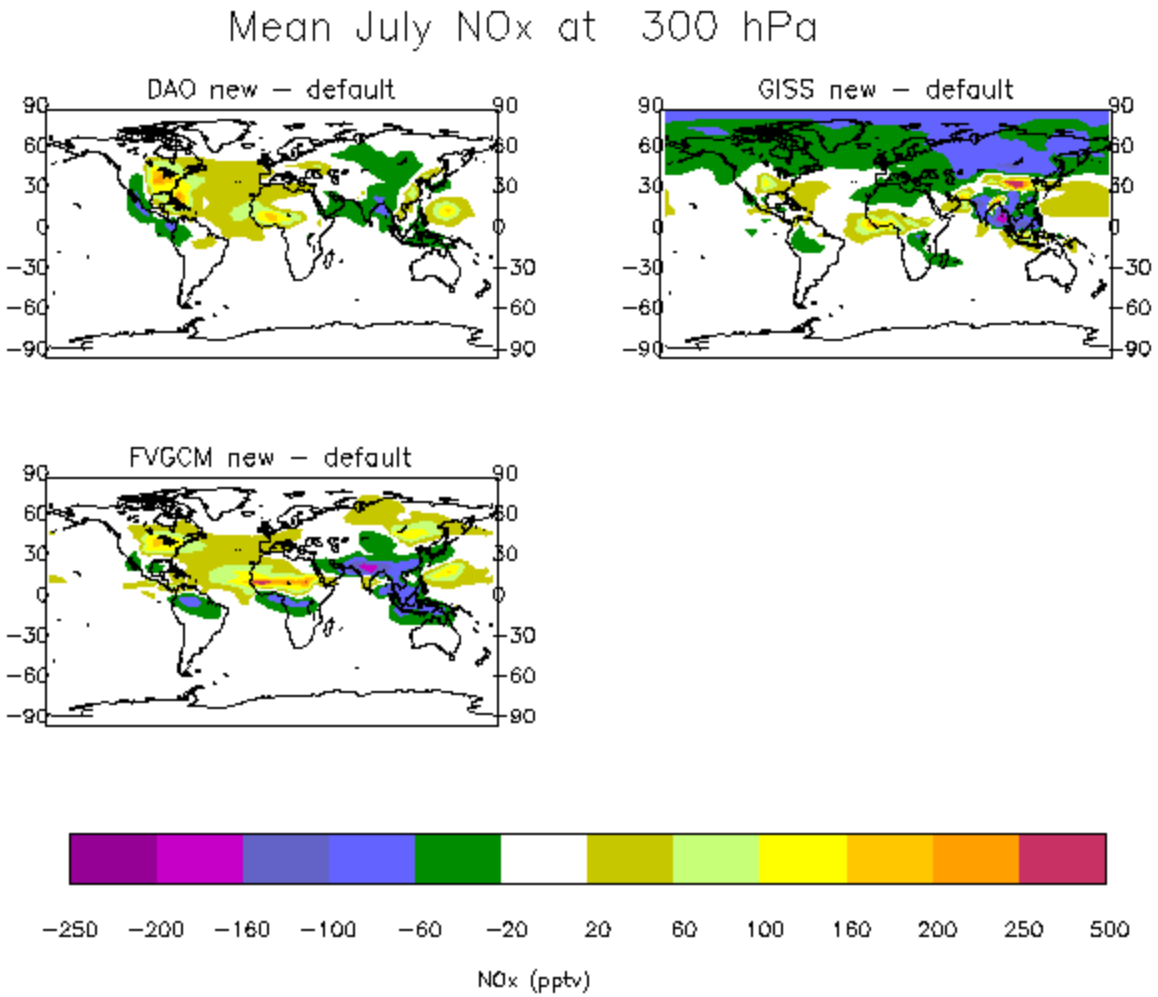

January – December total flash rate
OTD/LIS climate: RMS_c = 0.00
DAO 97–98: RMS_c = 0.40
FVGCM: RMS_c = 0.50
GISS: RMS_c = 0.51
90
60
30
0
-30
-60
-90
0.00 0.02 0.10 0.20 0.40 0.80 1.60 3.20 4.80 6.40 8.00 10.00 20.00
Flash rate (flashes min-1)

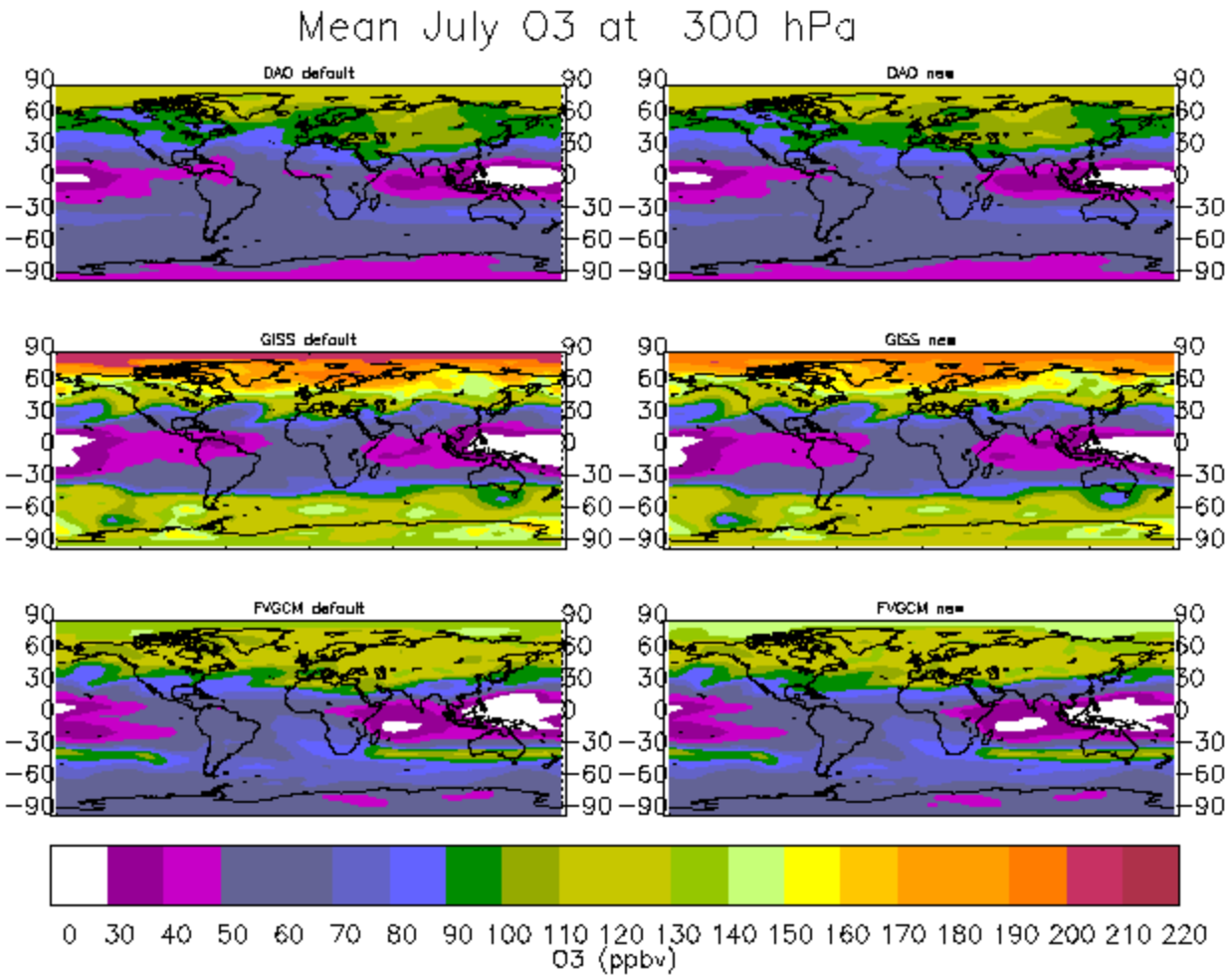

January – December total flash rate
ISCCP: RMS_c = 0.41
Default
DAO 97–98: RMS_c = 0.40
New
FVGCM: RMS_c = 0.50
New
GISS: RMS_c = 0.51
New
0.00 0.02 0.10 0.20 0.40 0.80 1.60 3.20 4.80 6.40 8.00 10.00 20.00
Flash rate (flashes min−1)

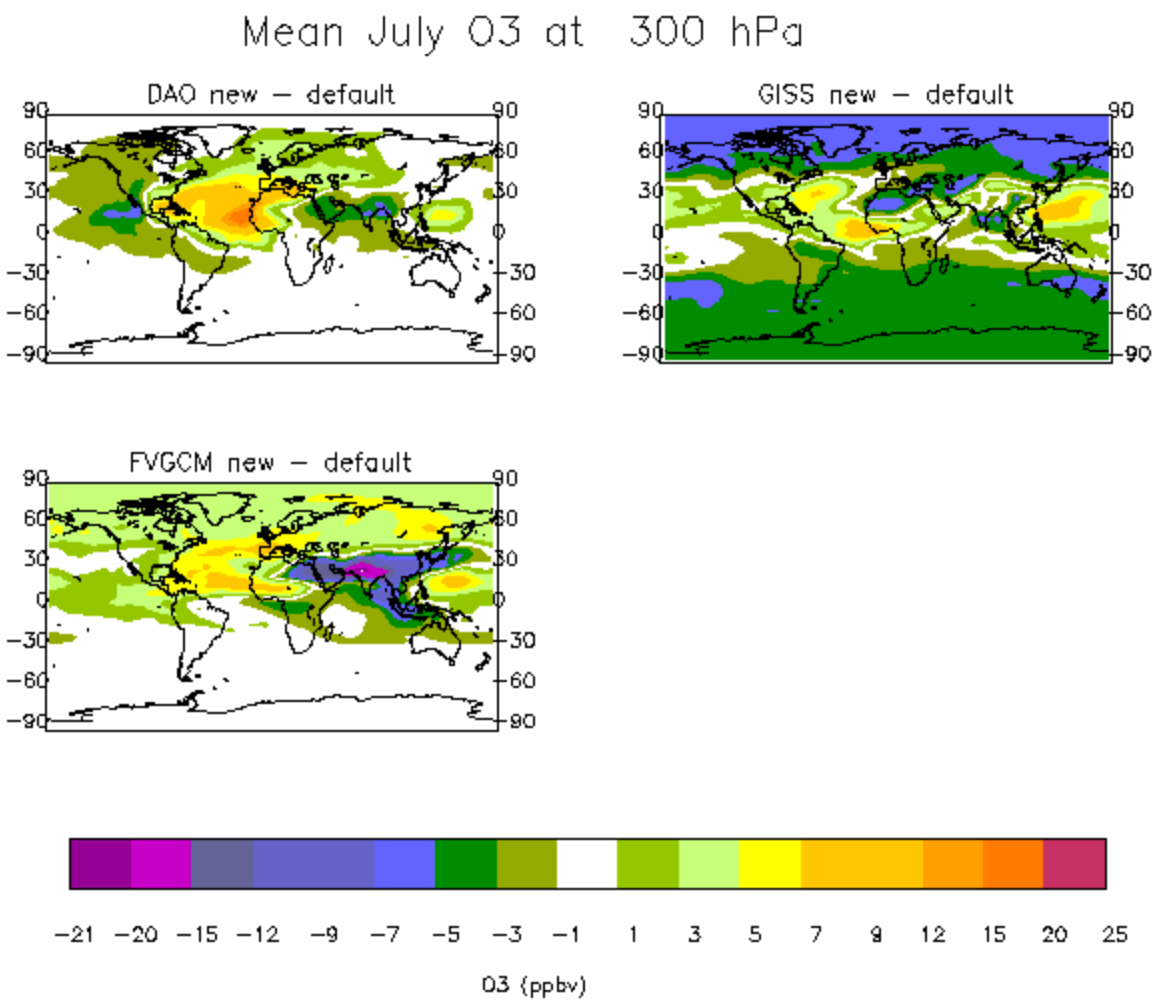

PNOx (default lightning) Jan–Dec mean
hPa
0
200
400
600
800
1000
0
5
10
15
pptv day–1
DAO (___)
GISS (. . .)
FVGCM (_ _ _)
PNOx (new lightning) Jan–Dec mean
hPa
0
200
400
600
800
1000
0
5
10
15
pptv day–1
DAO (___)
GISS (. . .)
FVGCM (_ _ _)


PNOX3d January–December mean
DAO default Lightning 5.0 Tg N
DAO New Lightning 5.0 Tg N
GISS default Lightning 5.0 Tg N
GISS New Lightning 5.1 Tg N
FVGCM default Lightning 5.0 Tg N
FVGCM New Lightning 5.0 Tg N
Height (km)
Pressure (hPa)
Latitude
0 5 10 15 20
100 1000
−45 −30 −15 0 15 30 45
0.0 0.1 0.5 1.0 3.0 5.0 10.0 20.0 30.0 40.0 50.0 60.0 70.0
pptv per day

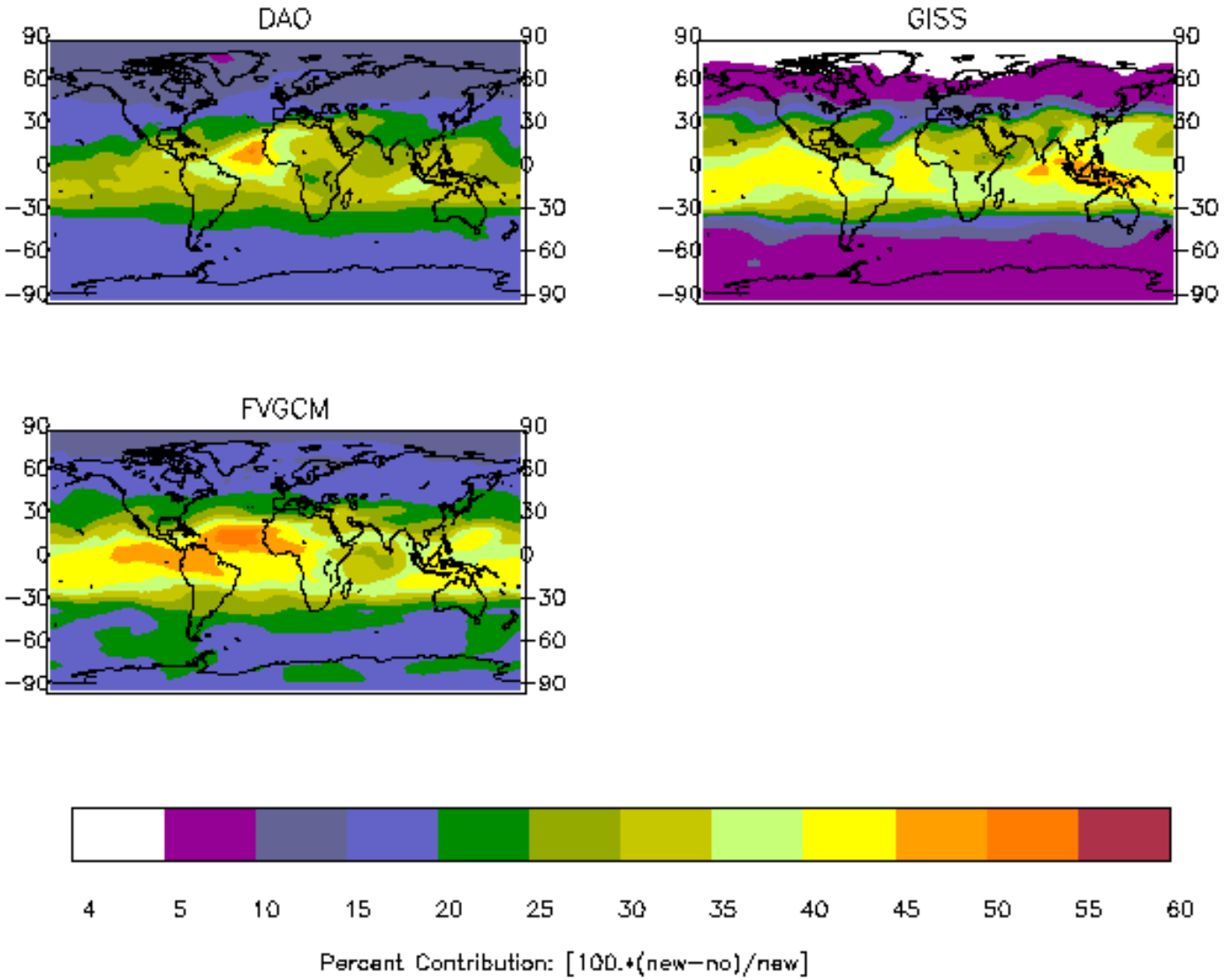

Mean July NOx at 300 hPa
DAO default
DAO new
GISS default
GISS new
FVGCM default
FVGCM new
90
60
30
0
−30
−60
−90
0 15 30 45 60 75 90 105 120 135 150 165 200 300 400 500 750
NOx (pptv)


Mean July NOx at 300 hPa
DAO new – default
GISS new – default
FVGCM new – default
90
60
30
0
−30
−60
−90
−250 −200 −160 −100 −60 −20 20 60 100 160 200 250 500
NOx (pptv)


Mean July O3 at 300 hPa
DAO default
DAO new
GISS default
GISS new
FVGCM default
FVGCM new
90
60
30
0
−30
−60
−90
0 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220
O3 (ppbv)


Mean July O3 at 300 hPa
DAO new – default
GISS new – default
FVGCM new – default
90
60
30
0
−30
−60
−90
−21 −20 −15 −12 −9 −7 −5 −3 −1 1 3 5 7 9 12 15 20 25
O3 (ppbv)

Lightning contribution to O3 at 300 hPa: July



Summary

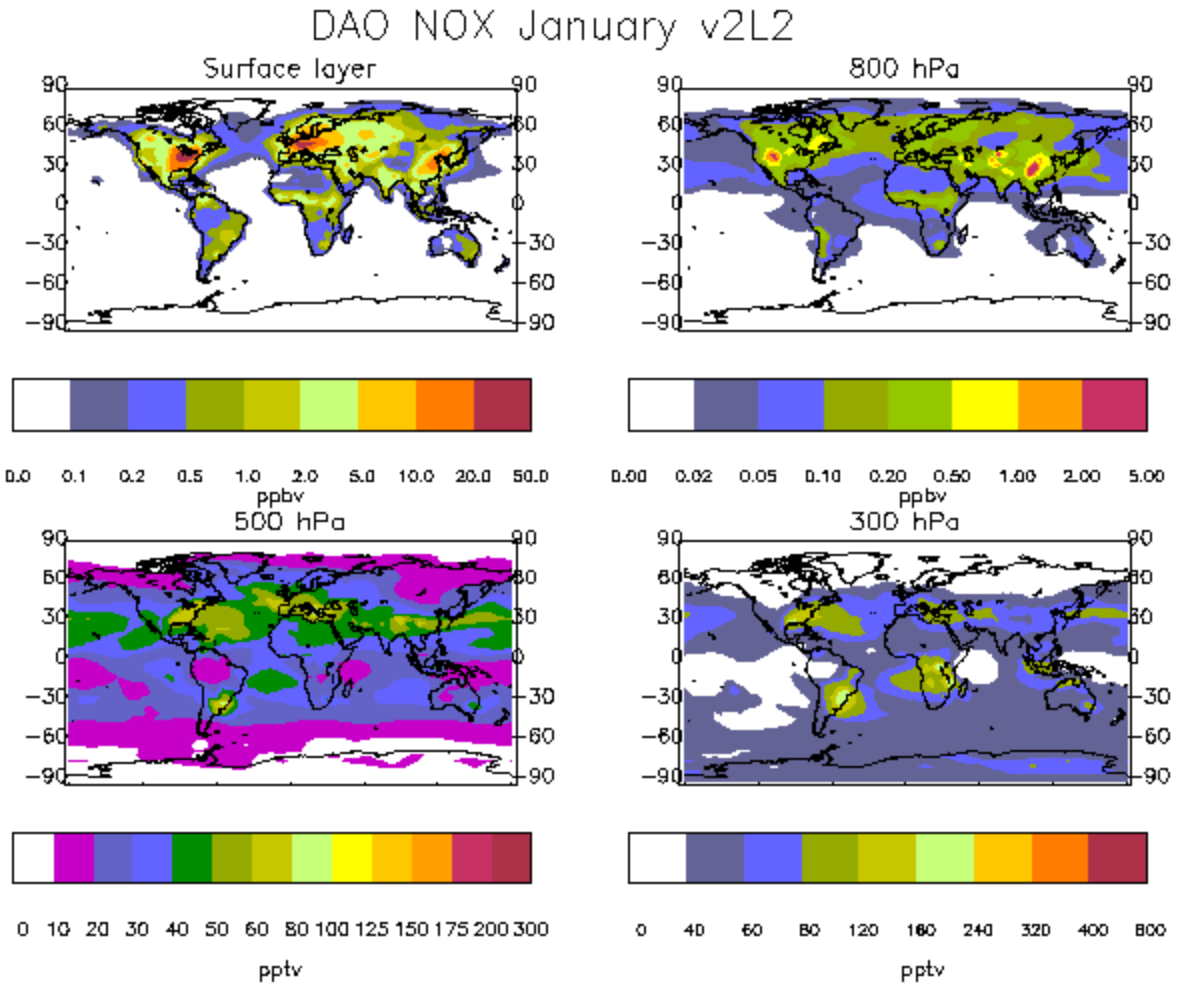
- Relationship between CLDMAS and observed CG flash rates utilized to derive lightning parameterizations for 3 GMI meteorological fields.
- Marine-continental, tropical-midlatitude, midlatitude continental, and regional adjustments made to parameterized flash rates in order to best match annual average OTD/LIS climatology.
- At 300 hPa in July NO_x increases over North America by up to ~140 pptv with all three met. fields using the new lightning scheme. Increases up to 250 pptv over China are noted with GISS.
- At 300 hPa in July O_3 increases over the North Atlantic by 7 to 15 ppbv with all three met. fields. Increases of 7 to 11 ppbv are found off the coast of China.
- Decreases in NO_x in July of –20 to –100 pptv seen regionally, leading to O_3 decreases of –4 to –16 ppbv.
- Lightning contribution to 300 hPa O_3 in July: DAO: 30-50% in tropics; 15-20% in midlatitudes. A bit less with GISS and a bit more with FVGCM.

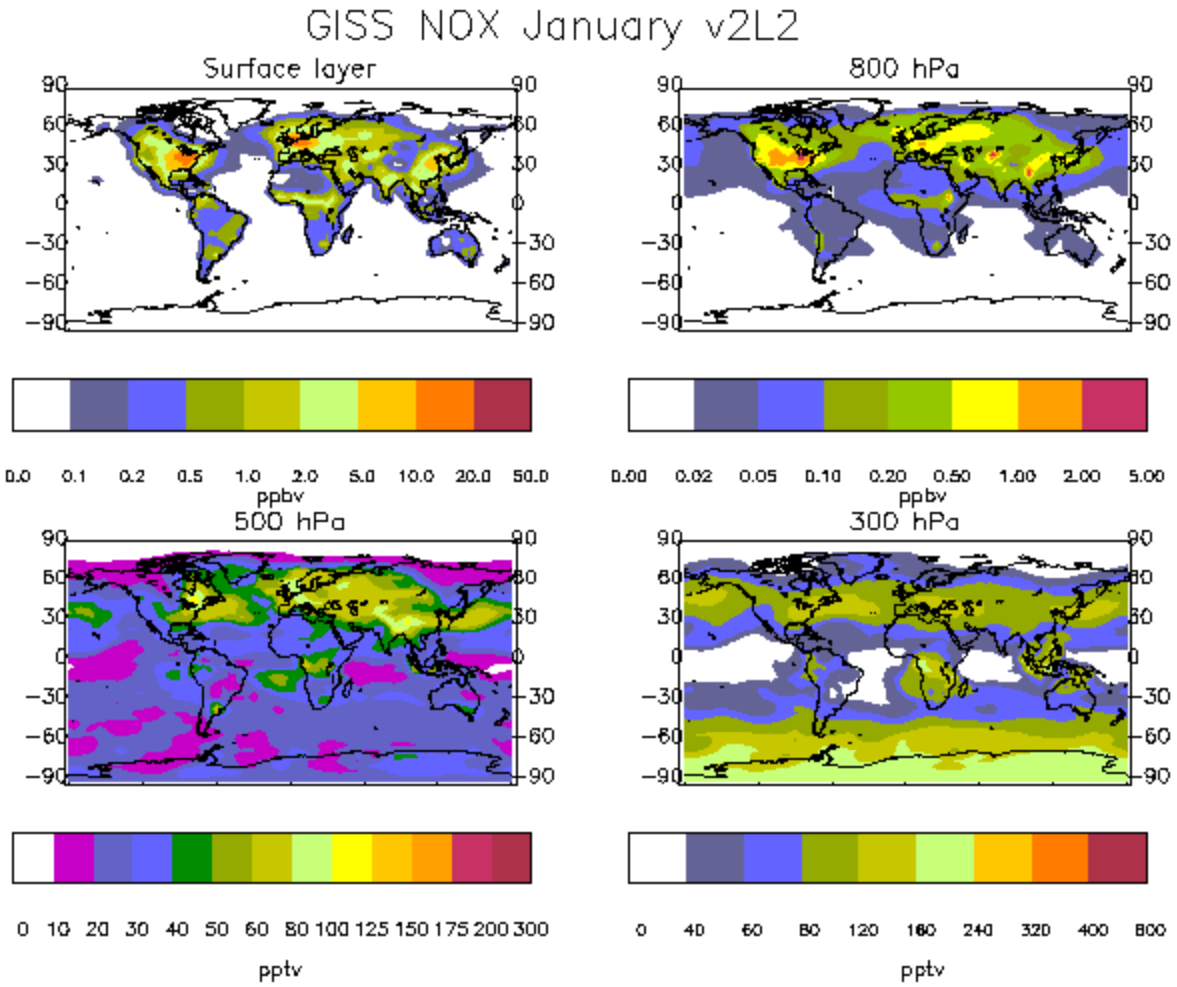
Effects of Clouds, Convection and Lightning on Tropospheric Chemistry in the GMI Model

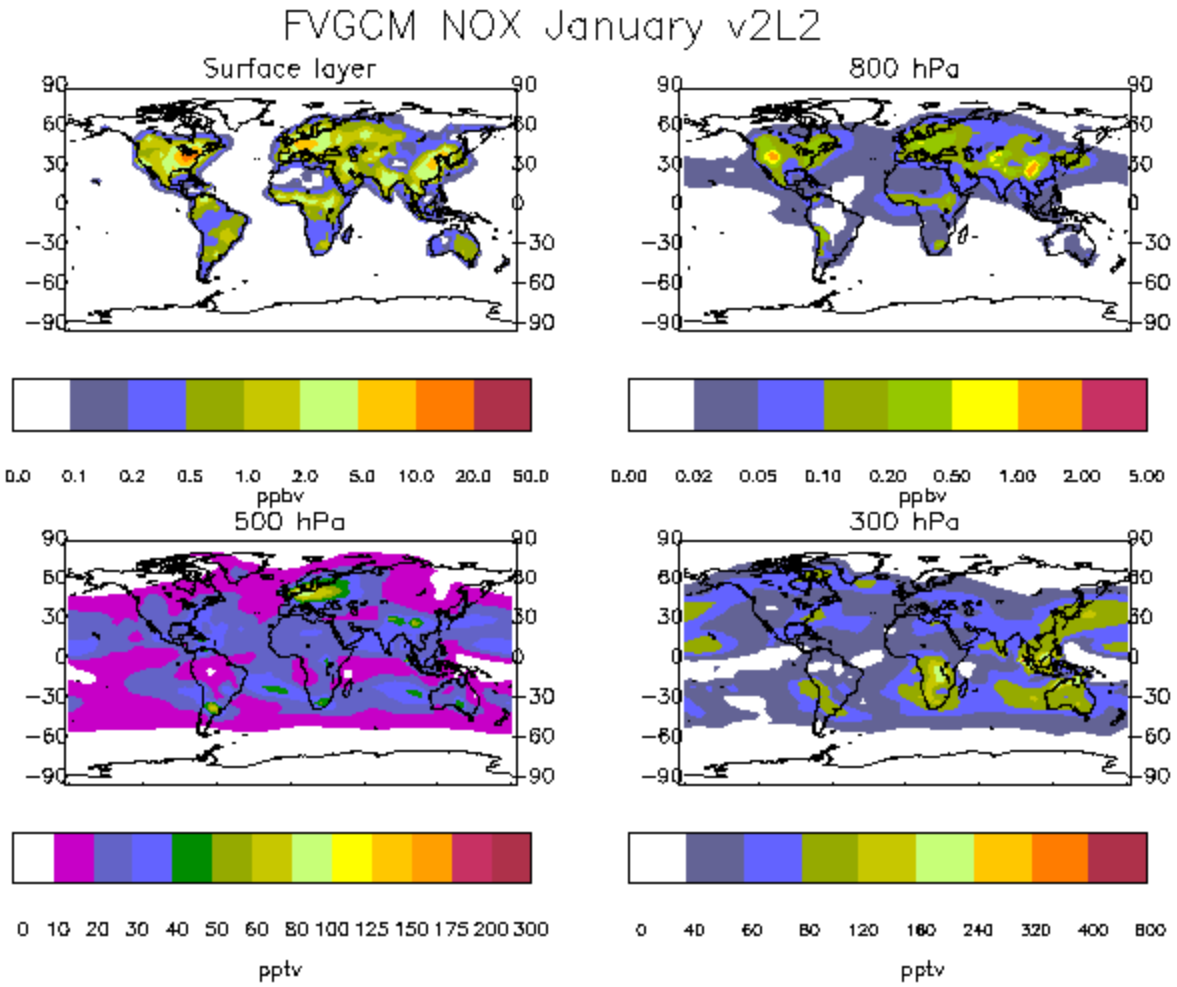
- 1: **Improve representation of lightning NO production in the GMI model through close work with the GMI core team**
- --Implement cloud-mass based approach for additional data sets
- --Develop multivariate (physically based) approach using GMI fields and OTD/LIS, NLDN, and WWLLN lightning data (neural networks?)
- --Develop default approach for quick use with new data sets
- --Evaluate by comparing with chemistry data sets (Logan, Emmons, MOZAIC, etc.)

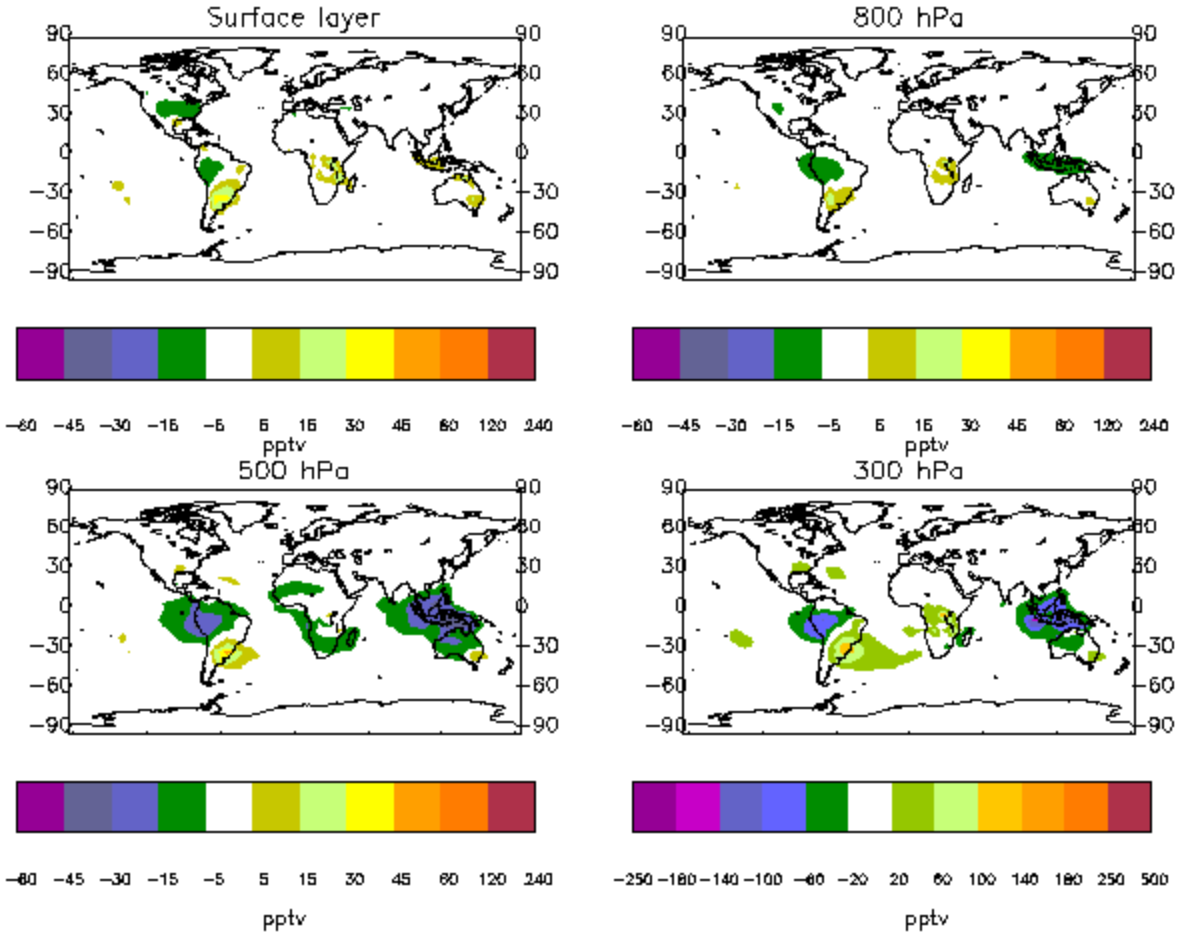
- 2. **Evaluate distribution and structure of clouds in new GMI data sets through comparison with satellite (ISCCP, MODIS, etc.) data sets.**
- --Focus on timing, location, and altitude of deep convection
- --Estimate effect of biases in cloud distribution on tropospheric photochemistry

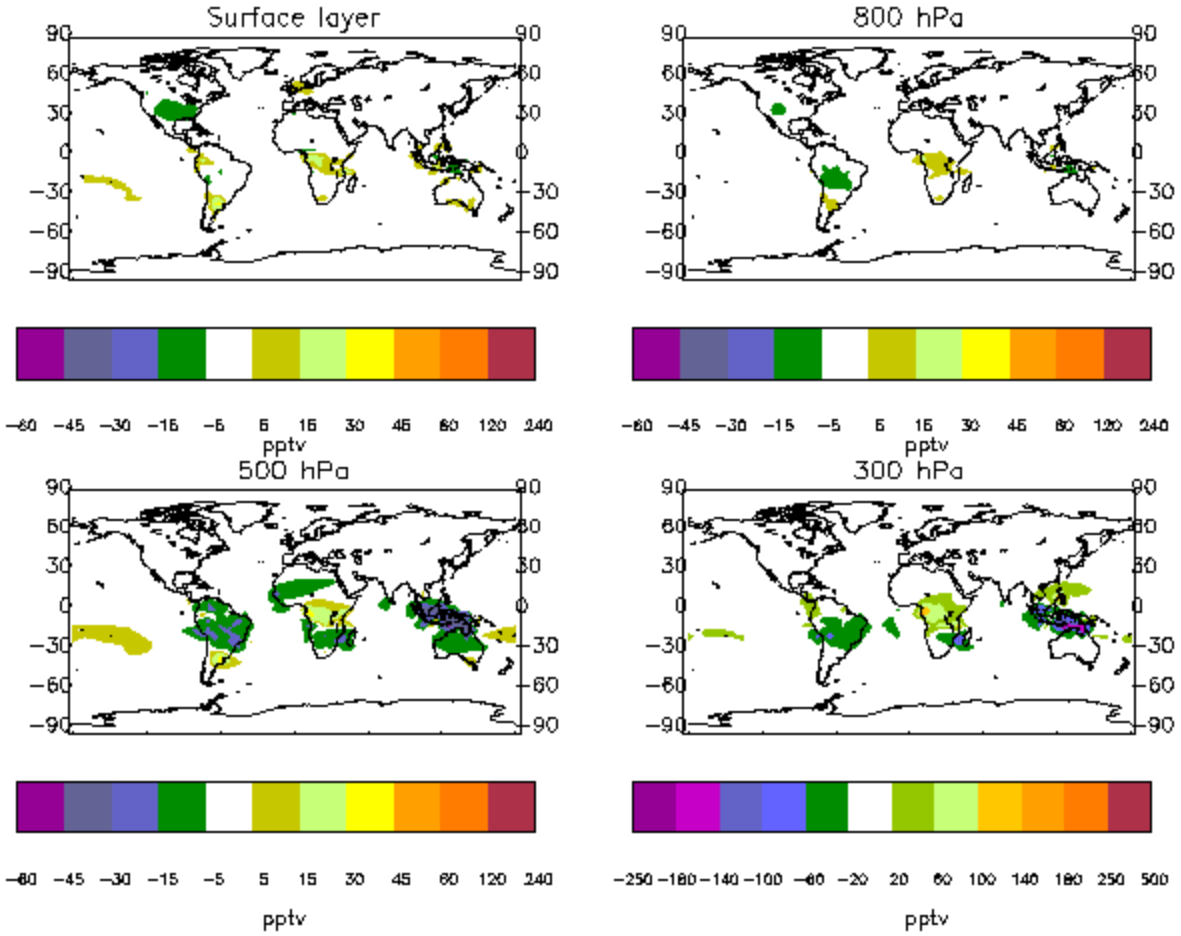
- 3: **Analyze GMI photochemistry in regions dominated by convection and lightning (SONEX period?)**
- --Compare model output with satellite data
- --Determine radiative forcing due to ozone in convective outflow
- --Assess impact of lightning- vs. anthropogenic-NOx emissions on UT chemical budgets

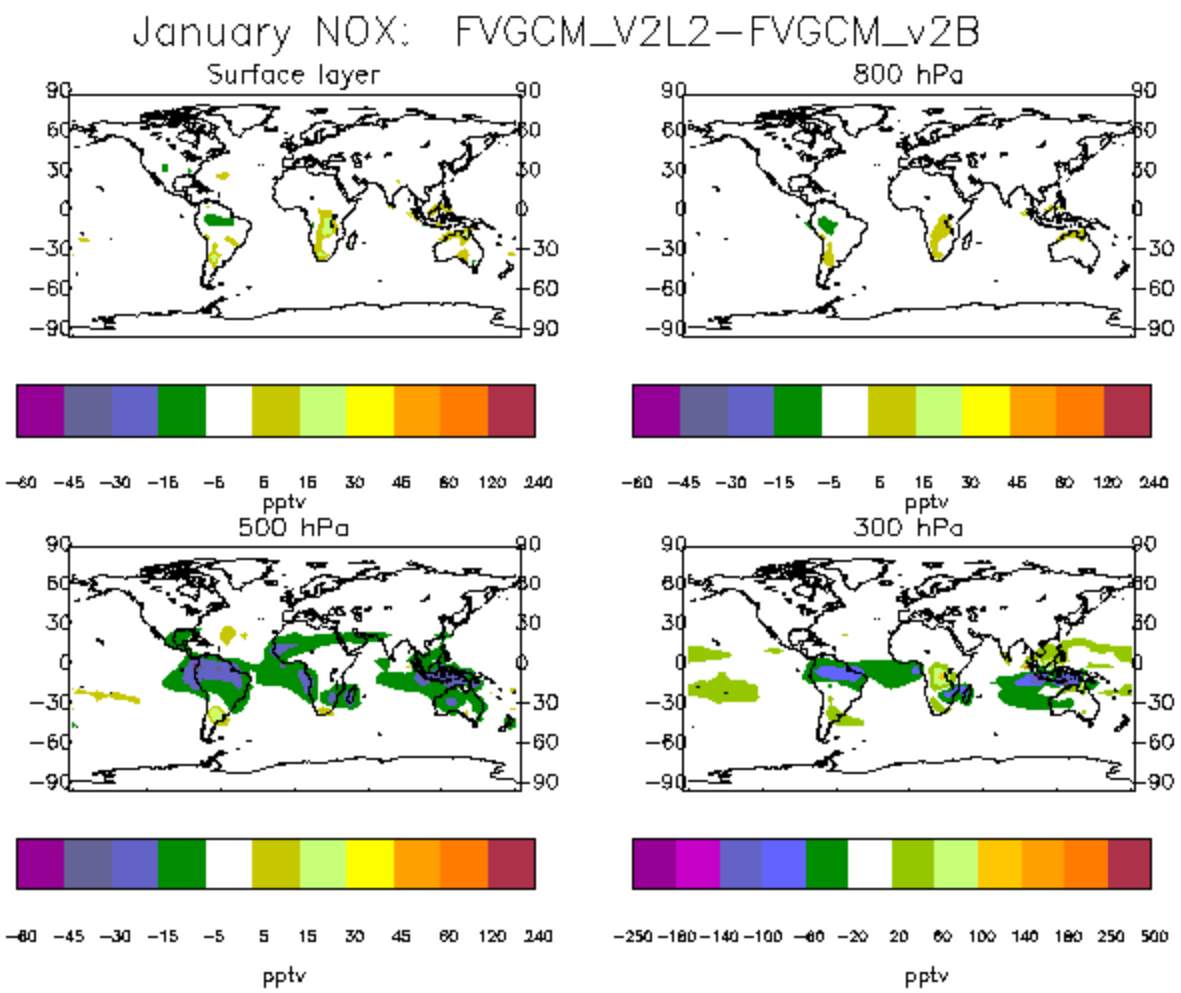

DAO NOX January v2L2
Surface layer
800 hPa
500 hPa
300 hPa
90
60
30
0
-30
-60
-90
0.0 0.1 0.2 0.5 1.0 2.0 5.0 10.0 20.0 50.0
ppbv
0.00 0.02 0.05 0.10 0.20 0.50 1.00 2.00 5.00
ppbv
0 10 20 30 40 50 60 80 100 125 150 175 200 300
pptv
0 40 60 80 120 160 240 320 400 800
pptv

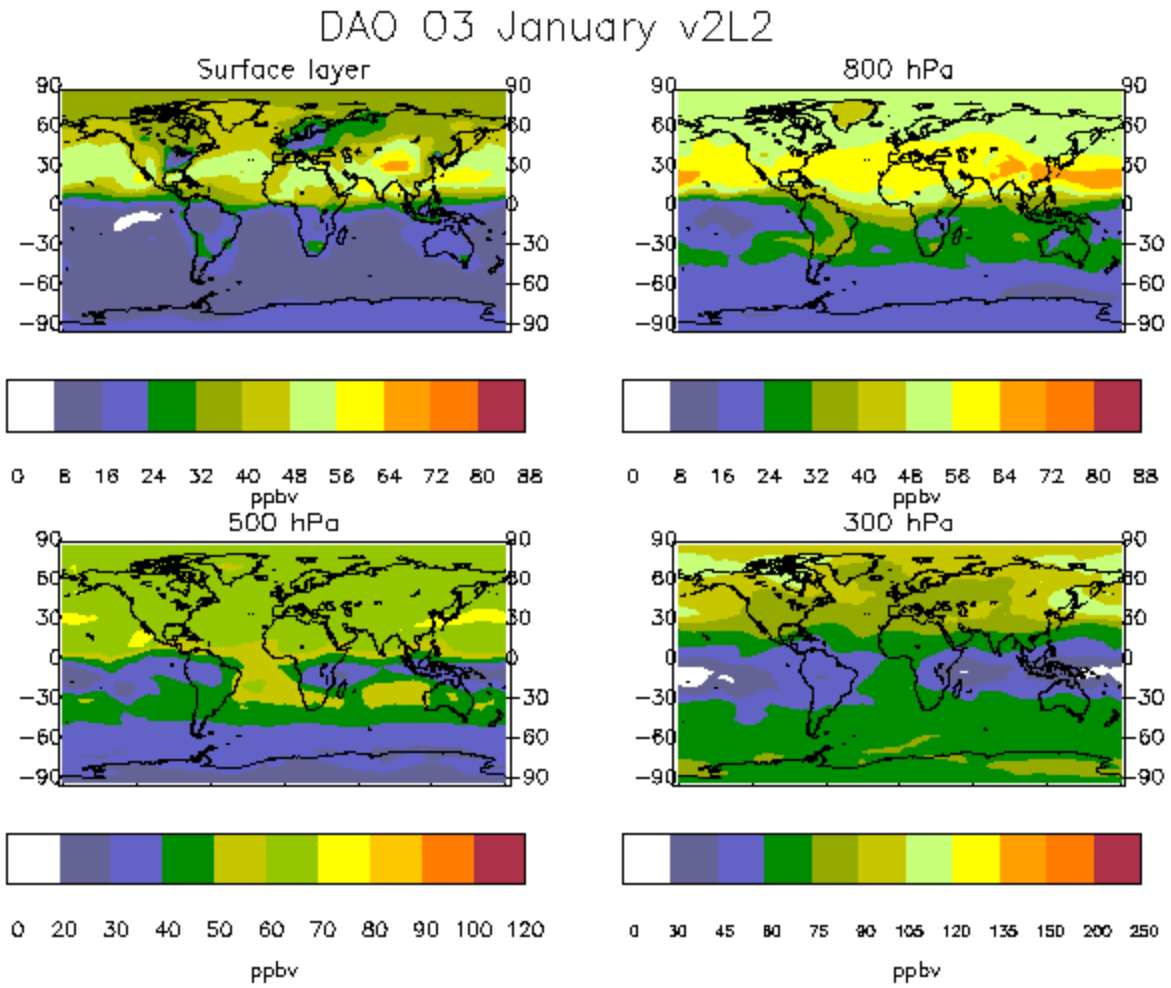

GISS NOX January v2L2
Surface layer
800 hPa
500 hPa
300 hPa
90
60
30
0
-30
-60
-90
0.0 0.1 0.2 0.5 1.0 2.0 5.0 10.0 20.0 50.0
ppbv
0.00 0.02 0.05 0.10 0.20 0.50 1.00 2.00 5.00
ppbv
0 10 20 30 40 50 60 80 100 125 150 175 200 300
pptv
0 40 60 80 120 160 240 320 400 800
pptv

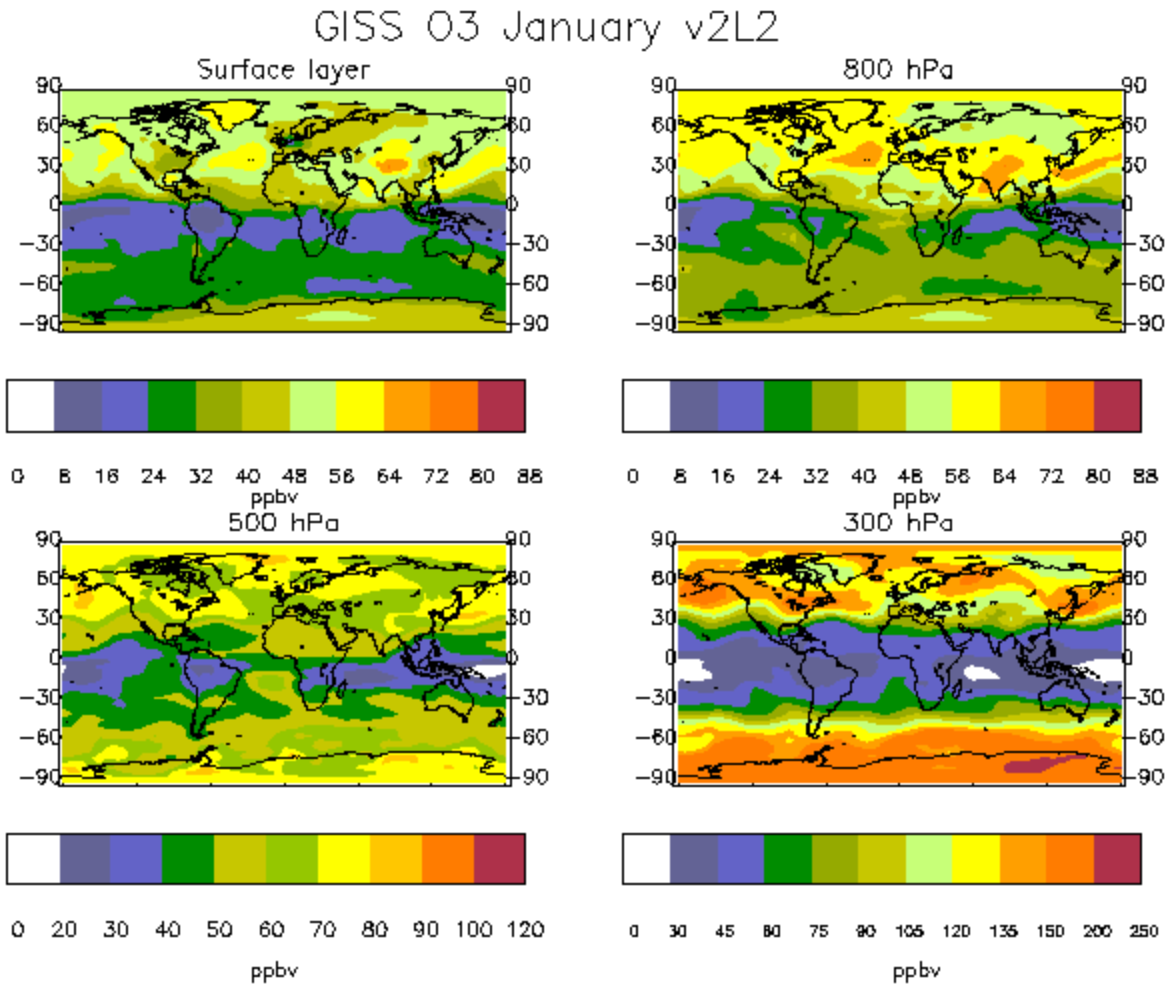

FVGCM NOX January v2L2
Surface layer
90
60
30
0
-30
-60
-90
0.0 0.1 0.2 0.5 1.0 2.0 5.0 10.0 20.0 50.0
ppbv
800 hPa
0.00 0.02 0.05 0.10 0.20 0.50 1.00 2.00 5.00
ppbv
500 hPa
0 10 20 30 40 50 60 80 100 125 150 175 200 300
pptv
300 hPa
0 40 60 80 120 160 240 320 400 800
pptv

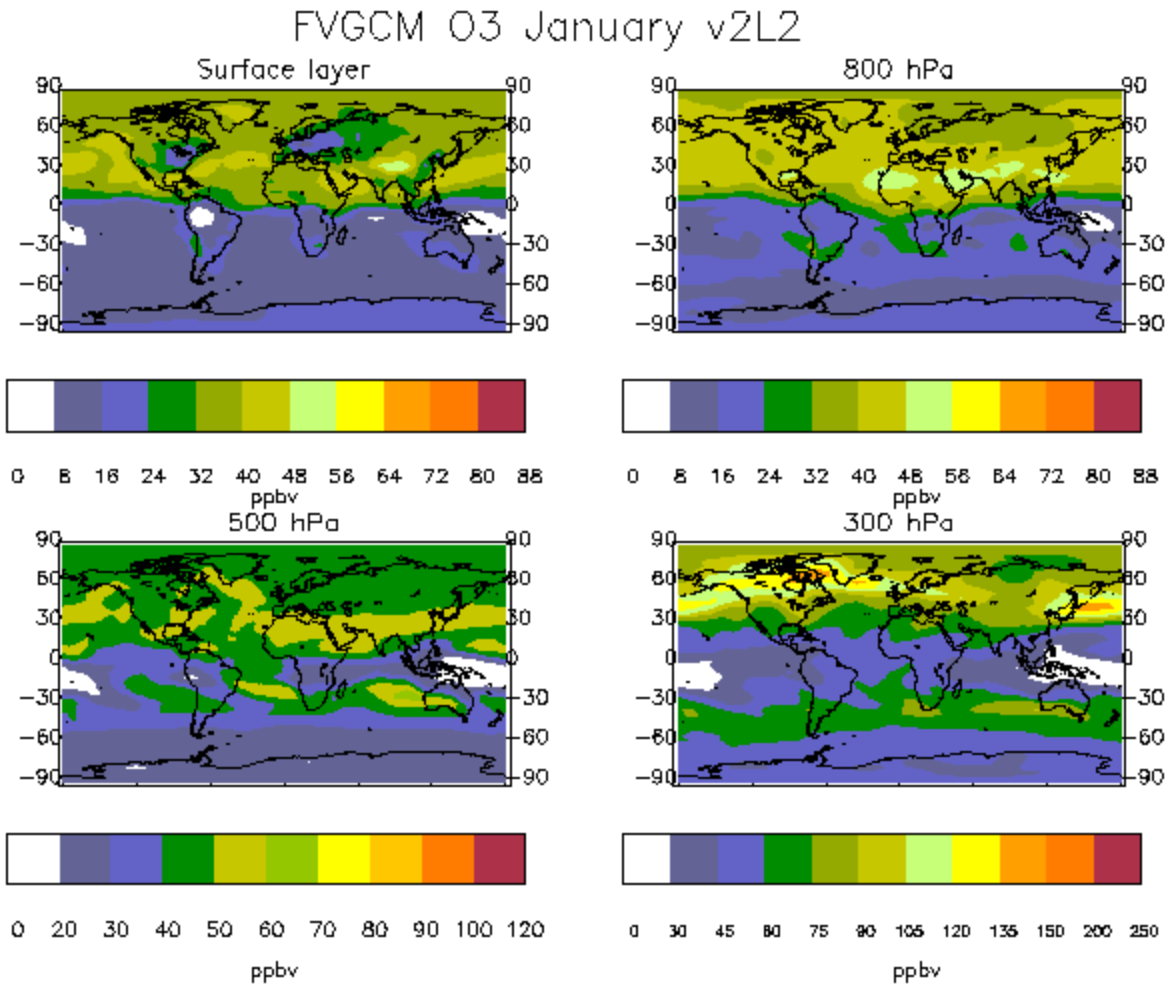

January NOX: DAO_V2L2−DAO_v2B
Surface layer
800 hPa
500 hPa
300 hPa
90
60
30
0
−30
−60
−90
−60 −45 −30 −15 −5 5 15 30 45 60 120 240
−250 −180 −140 −100 −60 −20 20 60 100 140 180 250 500
pptv

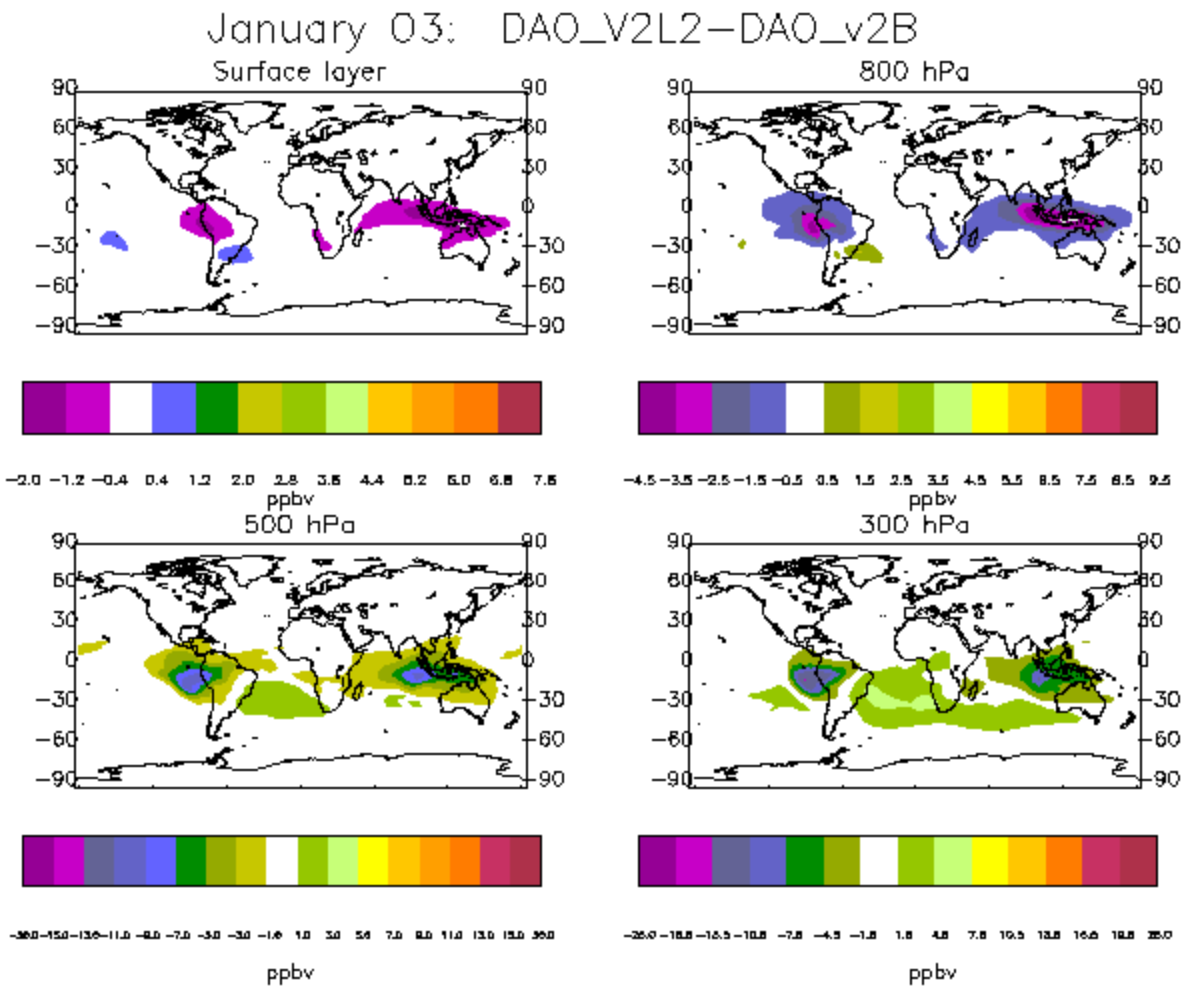

January NOX: GISS_V2L2-GISS_v2B
Surface layer
800 hPa
500 hPa
300 hPa
90
60
30
0
-30
-60
-90
-60 -45 -30 -15 -5 5 15 30 45 60 120 240
-250 -180 -140 -100 -60 -20 20 60 100 140 180 250 500
pptv

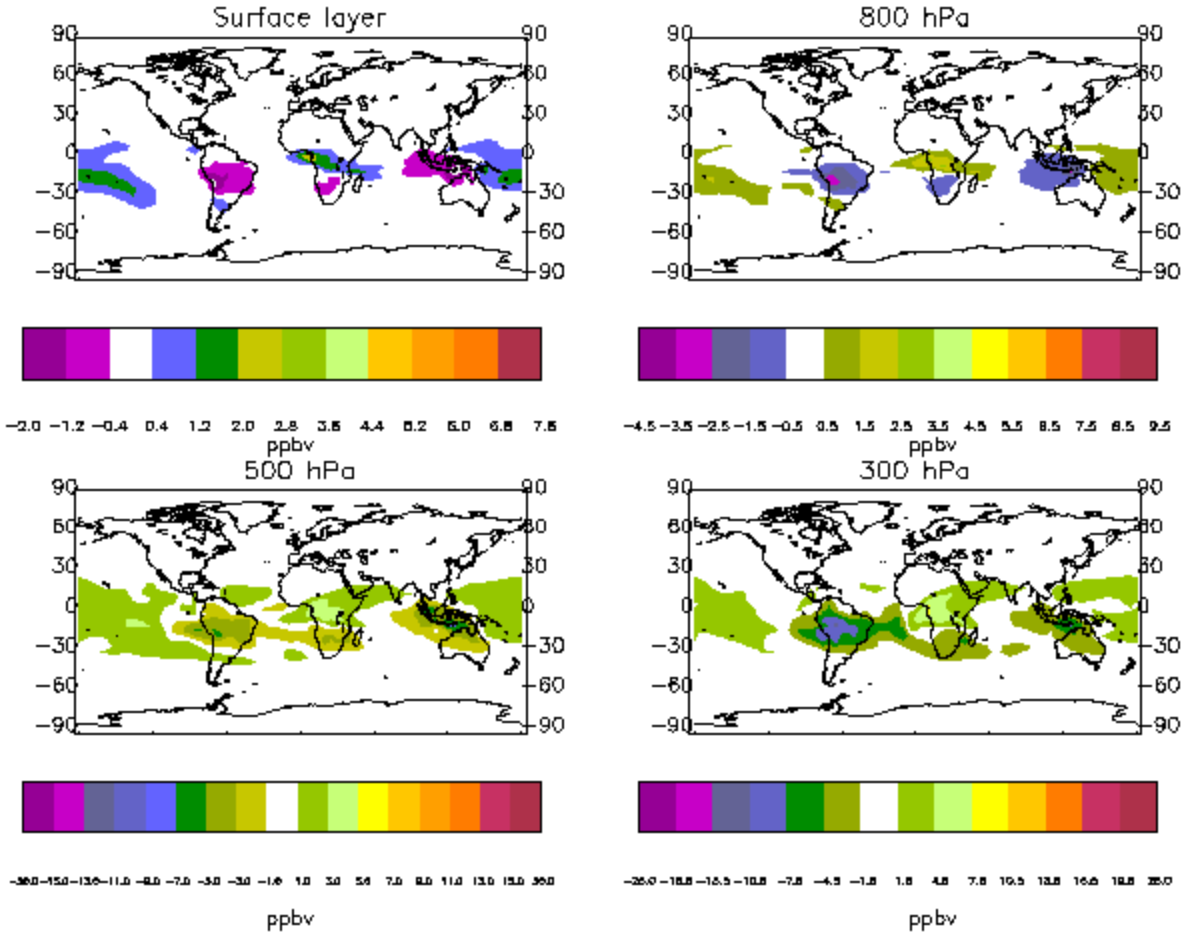

January NOX: FVGCM_V2L2−FVGCM_v2B
Surface layer
800 hPa
500 hPa
300 hPa
90
60
30
0
−30
−60
−90
−60 −45 −30 −15 −5 5 15 30 45 60 120 240
−250 −180 −140 −100 −60 −20 20 60 100 140 180 250 500
pptv

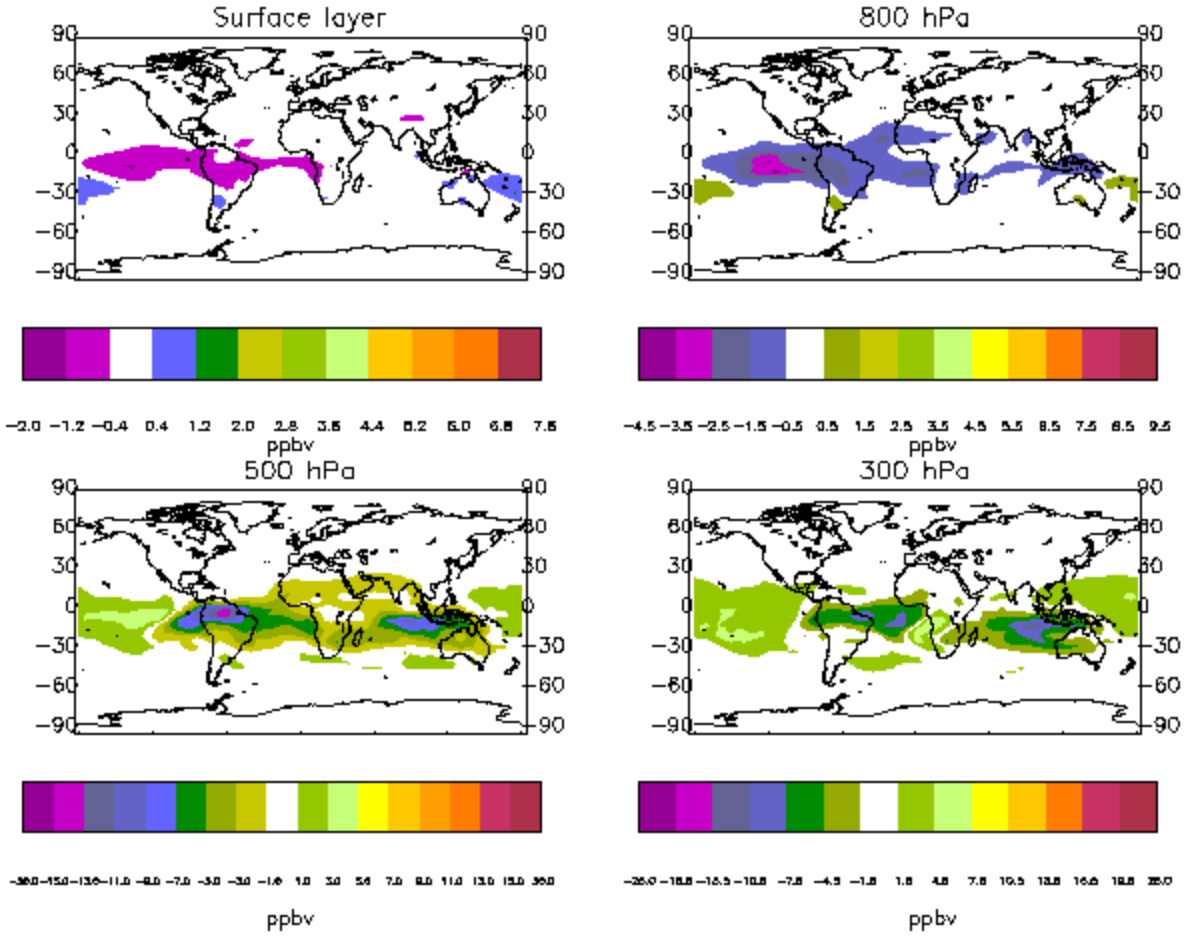

DAO O3 January v2L2
Surface layer
800 hPa
500 hPa
300 hPa
90
60
30
0
-30
-60
-90
0 8 16 24 32 40 48 56 64 72 80 88
ppbv
0 20 30 40 50 60 70 80 90 100 120
ppbv
0 30 45 60 75 90 105 120 135 150 200 250
ppbv


GISS O3 January v2L2
Surface layer
800 hPa
500 hPa
300 hPa
90
60
30
0
-30
-60
-90
0 8 16 24 32 40 48 56 64 72 80 88
ppbv
0 20 30 40 50 60 70 80 90 100 120
ppbv
0 30 45 60 75 90 105 120 135 150 200 250
ppbv


FVGCM O3 January v2L2
Surface layer
800 hPa
500 hPa
300 hPa
90
60
30
0
-30
-60
-90
0 8 16 24 32 40 48 56 64 72 80 88
ppbv
0 20 30 40 50 60 70 80 90 100 120
ppbv
0 30 45 60 75 90 105 120 135 150 200 250
ppbv


January 03: DAO_V2L2−DAO_v2B
Surface layer
800 hPa
500 hPa
300 hPa
90
60
30
0
−30
−60
−90
−2.0 −1.2 −0.4 0.4 1.2 2.0 2.8 3.6 4.4 5.2 6.0 6.8 7.6
−4.5 −3.5 −2.5 −1.5 −0.5 0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5
−30.0 −15.0 −13.0 −11.0 −9.0 −7.0 −5.0 −3.0 −1.0 1.0 3.0 5.0 7.0 9.0 11.0 13.0 15.0 30.0
−25.0 −18.8 −16.5 −10.8 −7.8 −4.5 −1.8 1.8 4.8 7.8 10.5 13.8 16.8 19.8 25.0
ppbv


January 03: GISS_V2L2−GISS_v2B
Surface layer
800 hPa
500 hPa
300 hPa
90
60
30
0
−30
−60
−90
−2.0 −1.2 −0.4 0.4 1.2 2.0 2.8 3.6 4.4 5.2 6.0 6.8 7.6
−4.5 −3.5 −2.5 −1.5 −0.5 0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5
−30.0 −15.0 −13.0 −11.0 −9.0 −7.0 −5.0 −3.0 −1.0 1.0 3.0 5.0 7.0 9.0 11.0 13.0 15.0 30.0
−25.0 −18.8 −16.5 −10.8 −7.8 −4.5 −1.8 1.8 4.8 7.8 10.5 13.8 16.8 19.8 25.0
ppbv


January 03: FVGCM_V2L2−FVGCM_v2B
Surface layer
800 hPa
500 hPa
300 hPa
90
60
30
0
−30
−60
−90
−2.0 −1.2 −0.4 0.4 1.2 2.0 2.8 3.6 4.4 5.2 6.0 6.8 7.6
−4.5 −3.5 −2.5 −1.5 −0.5 0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5
−30.0 −15.0 −13.0 −11.0 −9.0 −7.0 −5.0 −3.0 −1.0 1.0 3.0 5.0 7.0 9.0 11.0 13.0 15.0 30.0
−25.0 −18.0 −16.5 −10.0 −7.0 −4.5 −1.0 1.0 4.0 7.0 10.5 13.0 16.0 19.0 25.0
ppbv