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

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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,

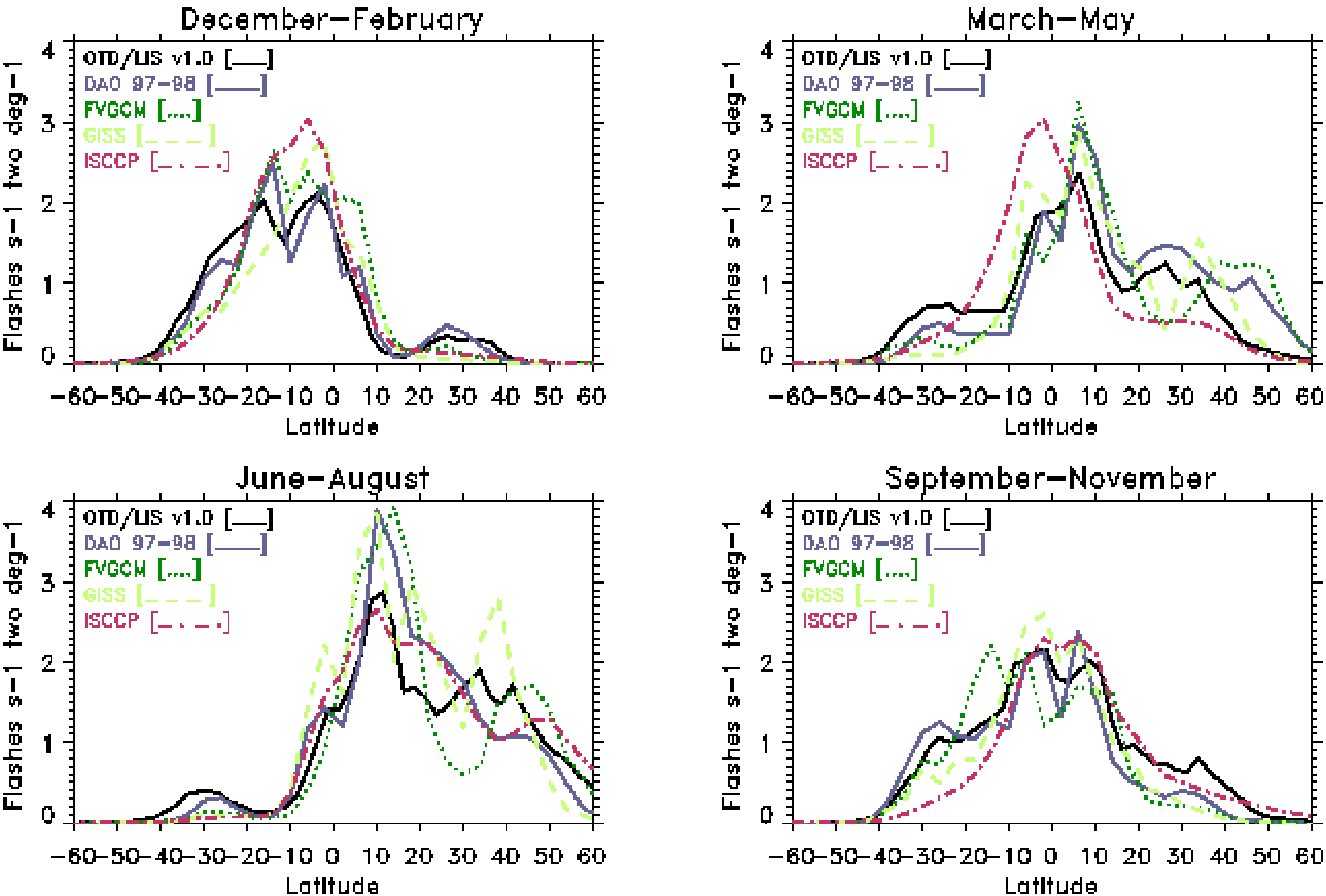
- $y_{fit} = ax_i + b[x_i]^2 + c[x_i]^3$ to relationship between convective mass flux (CLDMAS) and observed CG flash rates [Allen and Pickering, 2002]

- **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), GEOS FVGCM, or GISS GCM [sorted by magnitude]
- Apply polynomial globally (see "bef regional" plot)

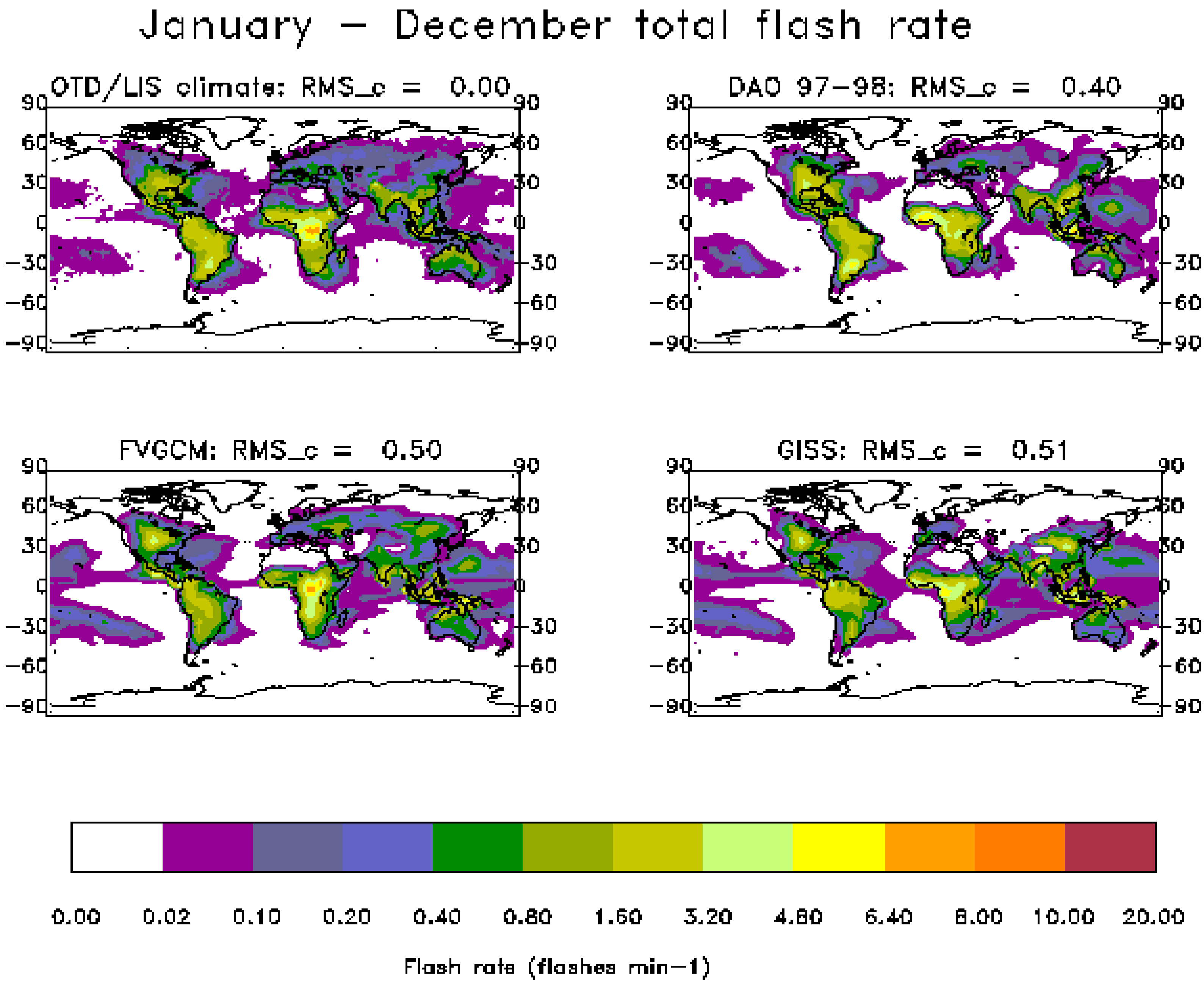
Step 2: Regional adjustments

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

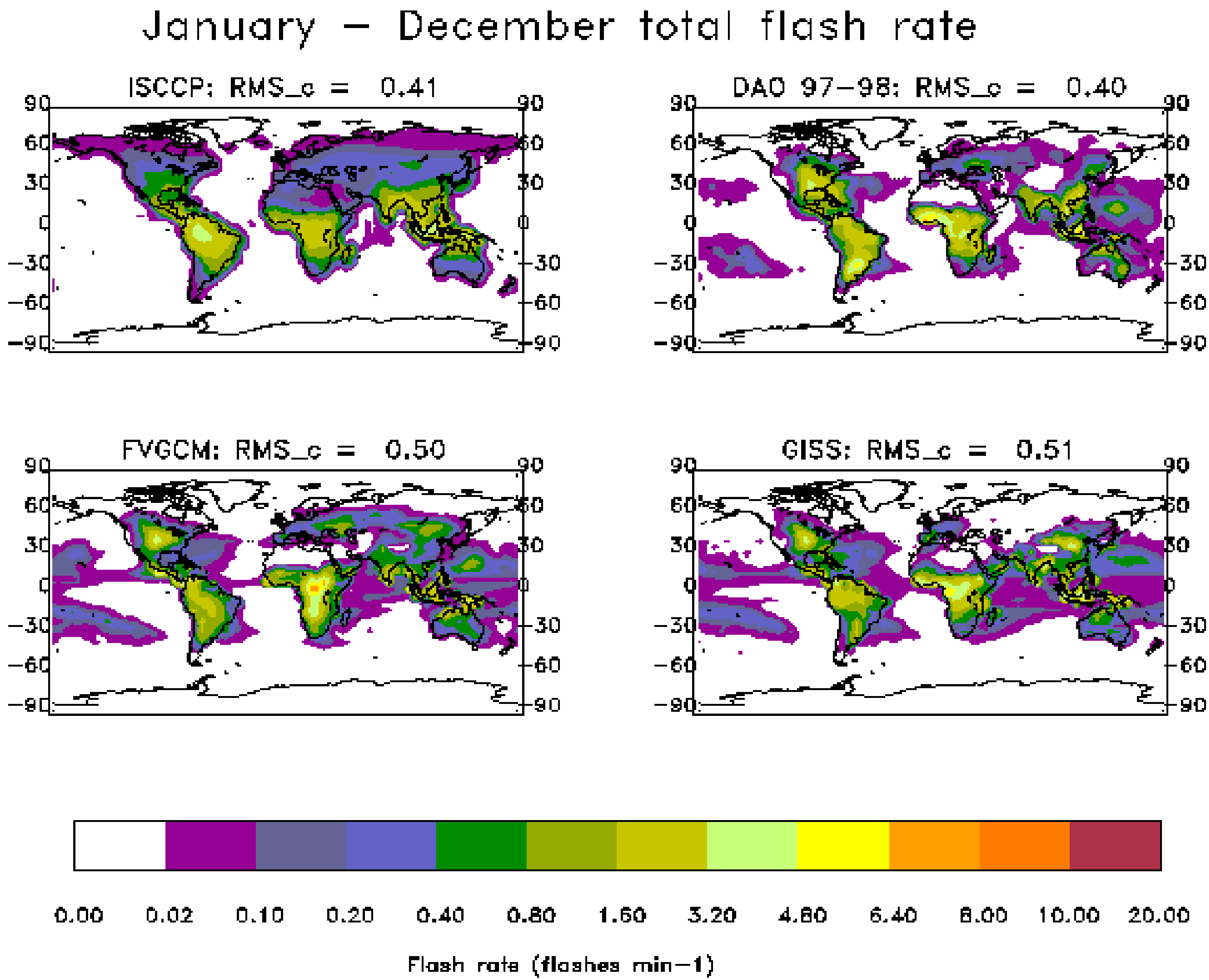
- Adjust tropical-marine (reduce), tropical-continental (increase), midlatitude-continental (increase), and Africa/S.America flash rates to best match climatology. Per-step adjustments limited to between 1/3 and 3.

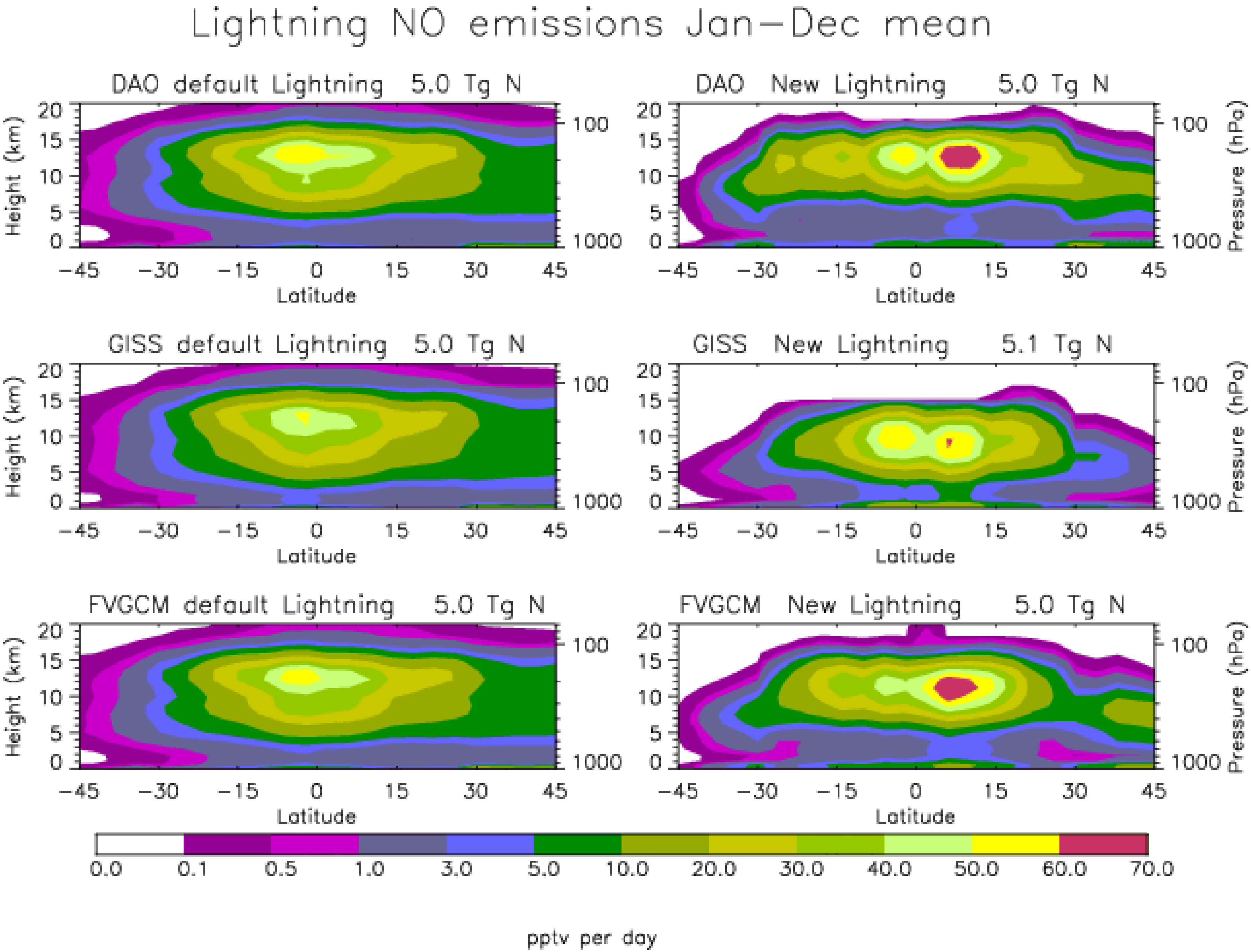

December−February
March−May
June−August
September−November
OTD/LIS v1.0 [___]
DAO 97−98 [___]
FVGCM [....]
GISS [_ _ _]
ISCCP [_ . _ .]
Flashes s−1 two deg−1
Latitude
−60 −50 −40 −30 −20 −10 0 10 20 30 40 50 60
0 1 2 3 4

Flash rate after regional adjustments

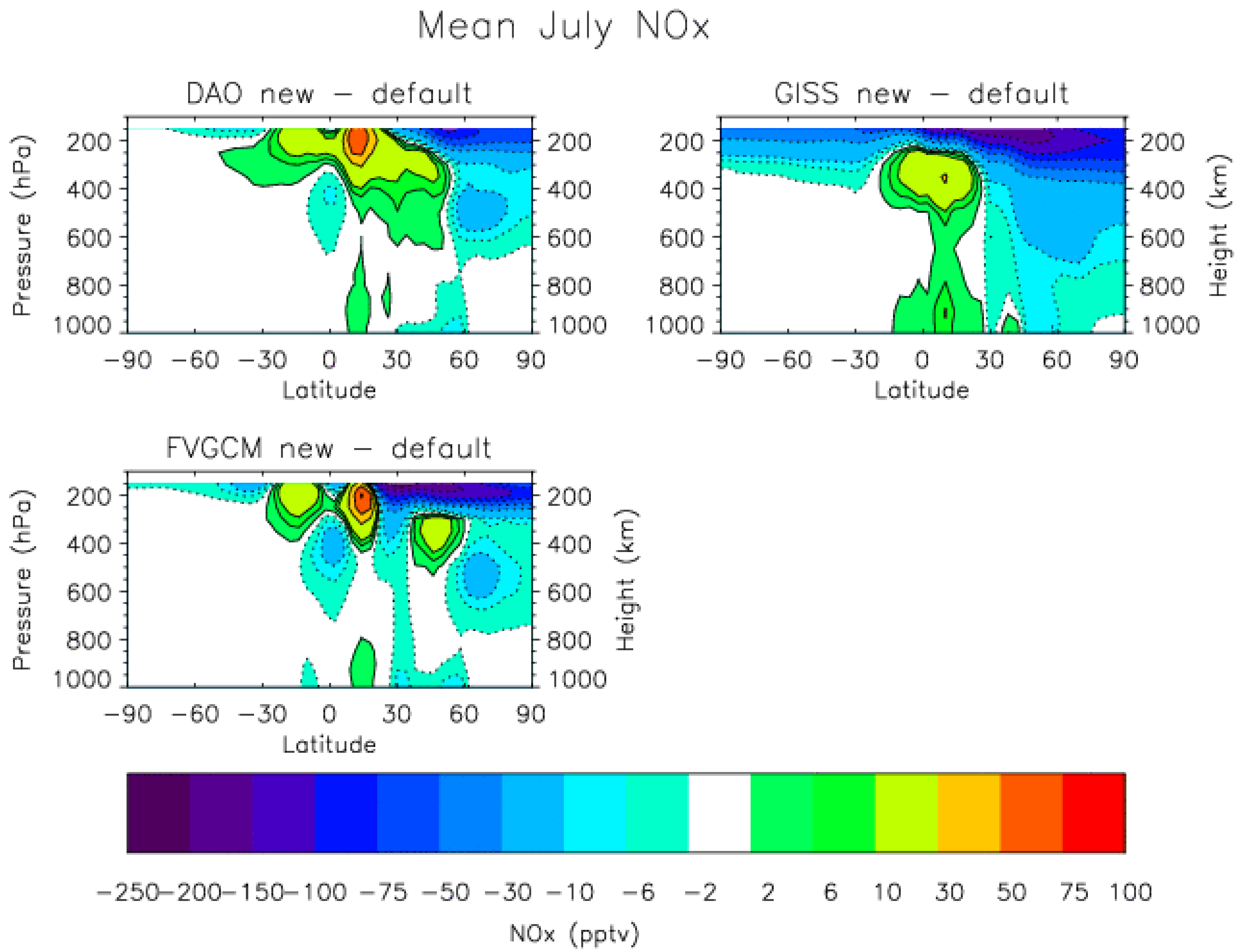


Flash rate after regional adjustments

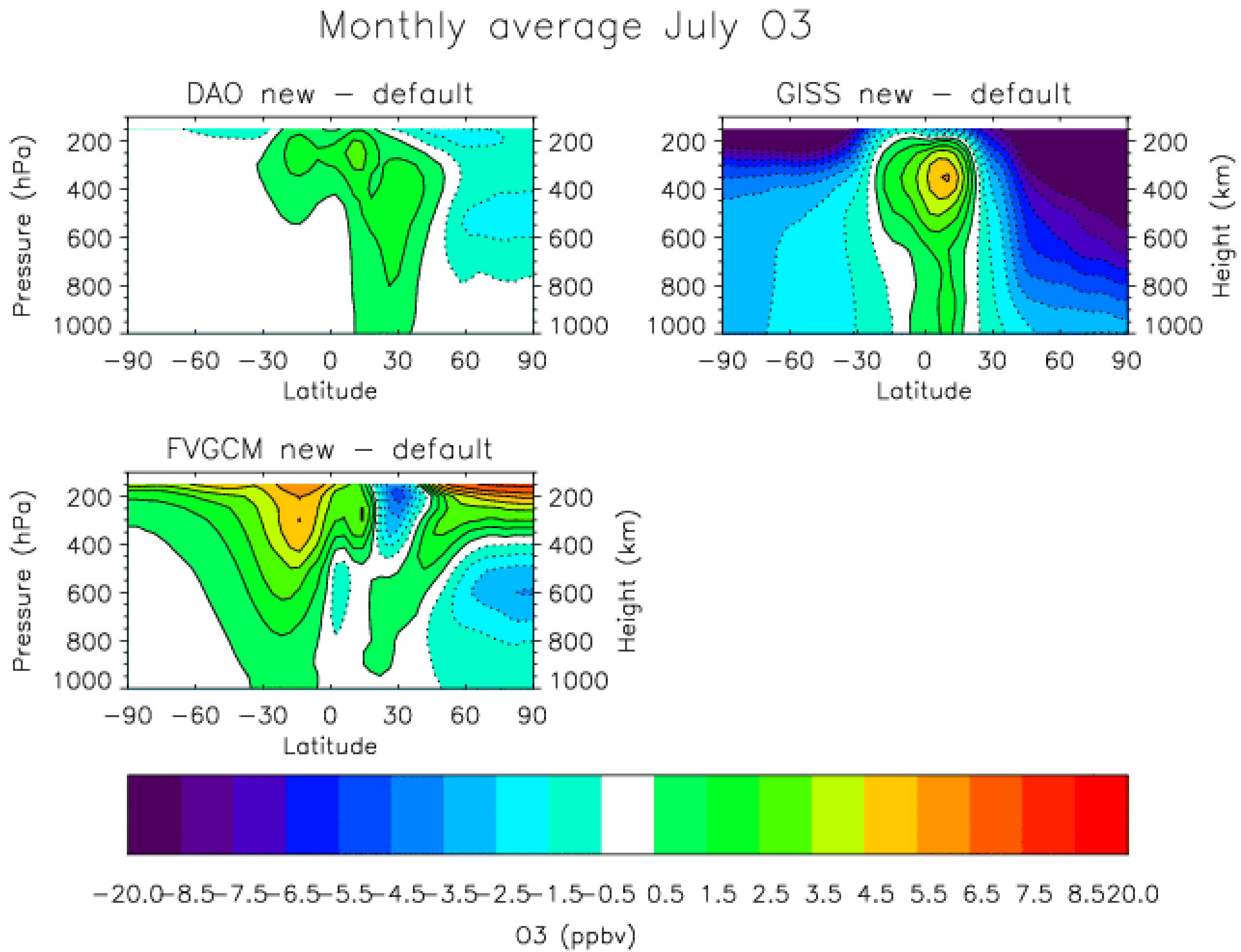


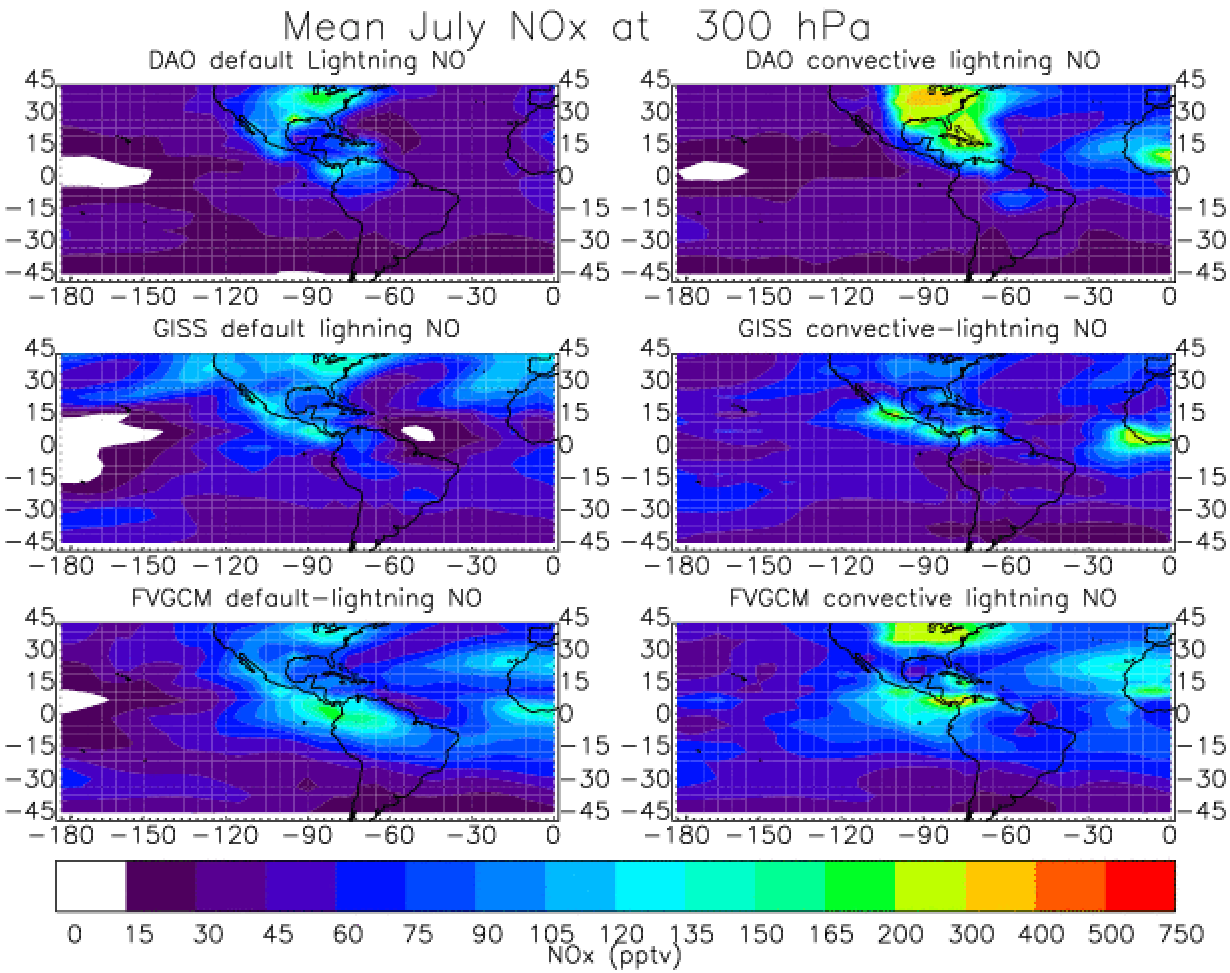


Lightning NO emissions Jan-Dec mean
DAO default Lightning 5.0 Tg N
DAO New Lightning 5.0 Tg N
GISS default Lightning 5.0 Tg N
GISS New Lightning 5.1 Tg N
FVGCM default Lightning 5.0 Tg N
FVGCM New Lightning 5.0 Tg N
Height (km)
Pressure (hPa)
Latitude
-45 -30 -15 0 15 30 45
0 5 10 15 20
100
1000
0.0 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

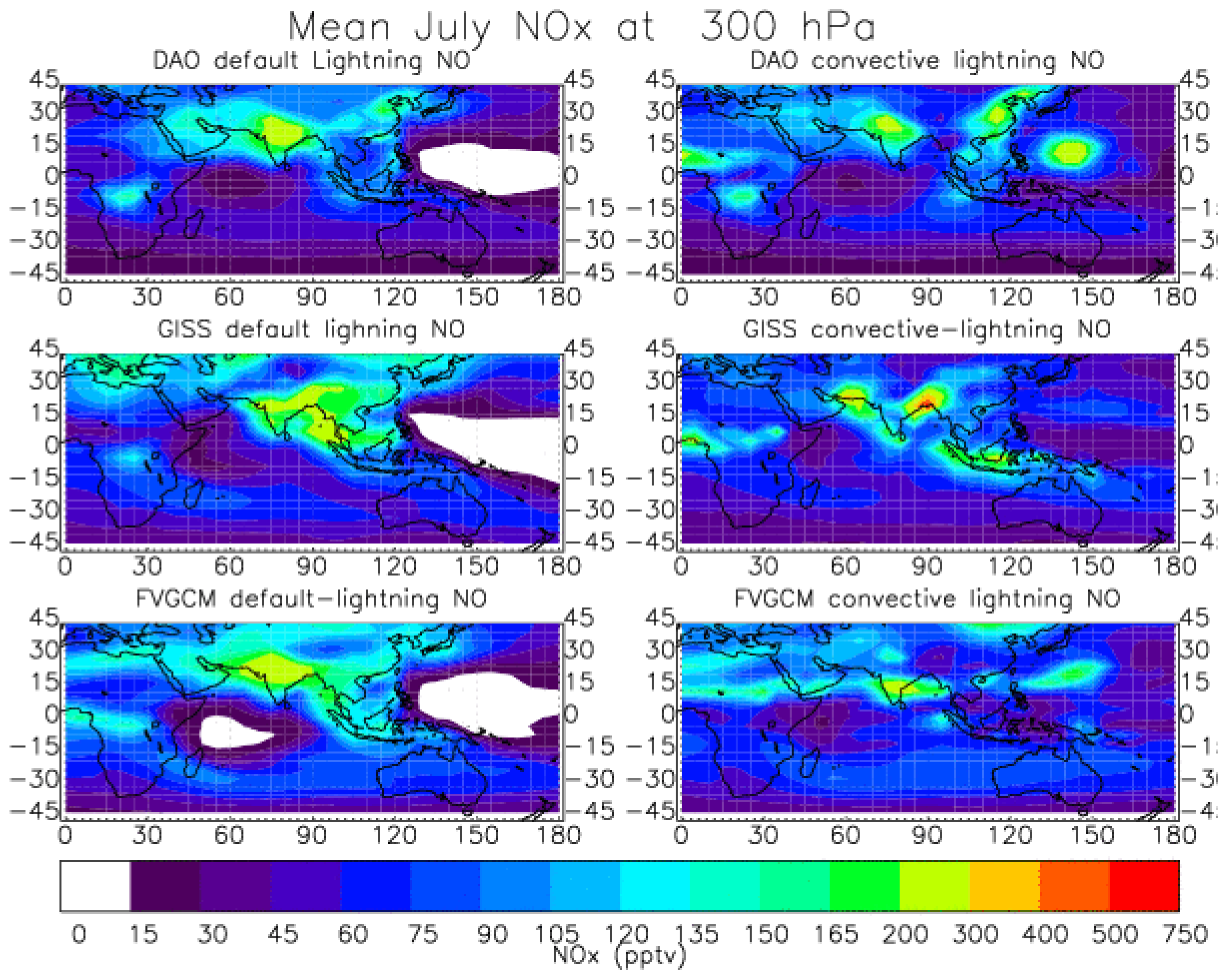


Mean July NOx
DAO new – default
GISS new – default
FVGCM new – default
Pressure (hPa)
Height (km)
200
400
600
800
1000
–90 –60 –30 0 30 60 90
Latitude
–250 –200 –150 –100 –75 –50 –30 –10 –6 –2 2 6 10 30 50 75 100
NOx (pptv)

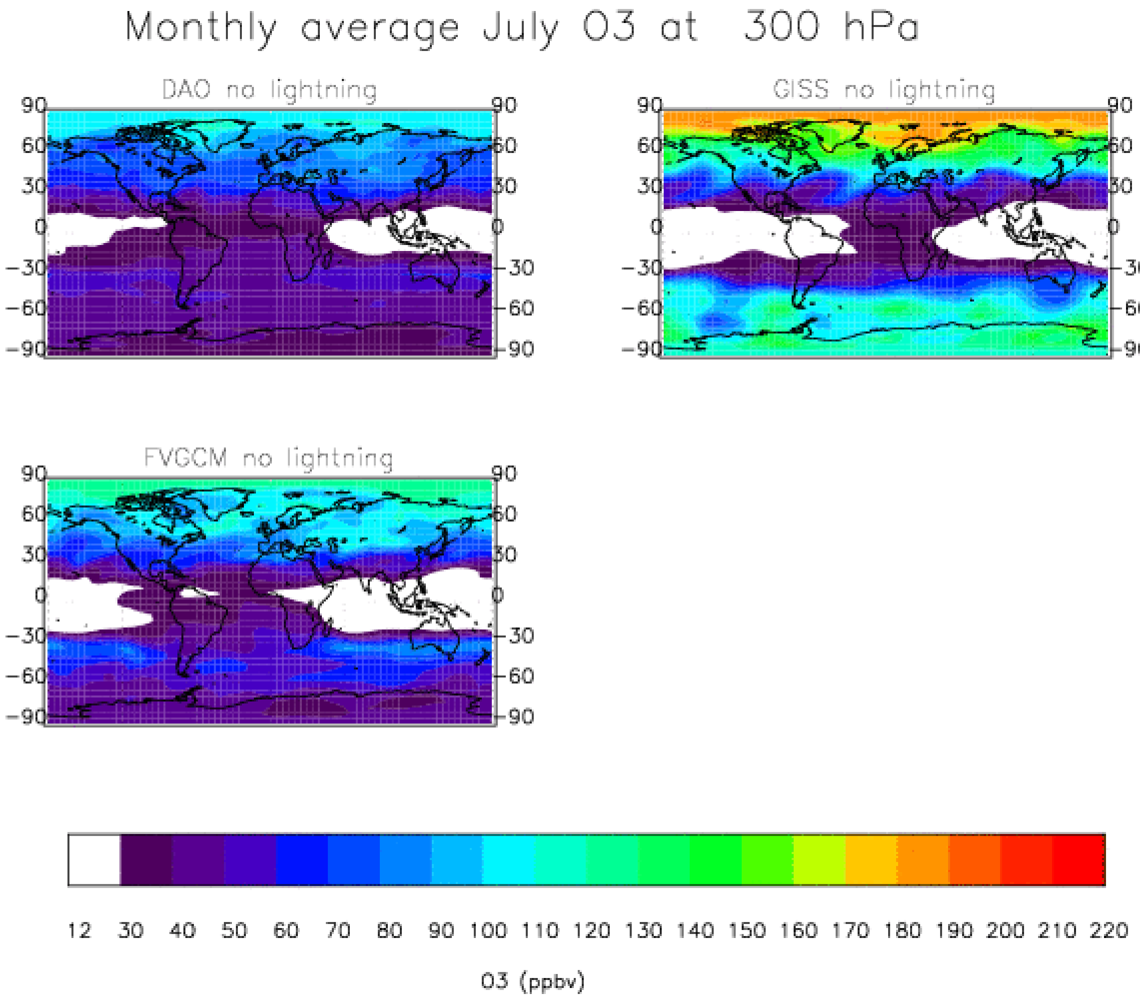

Monthly average July O3
DAO new – default
GISS new – default
FVGCM new – default
Pressure (hPa)
Height (km)
Latitude
–90 –60 –30 0 30 60 90
200 400 600 800 1000
–20.0 –8.5 –7.5 –6.5 –5.5 –4.5 –3.5 –2.5 –1.5 –0.5 0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 20.0
O3 (ppbv)



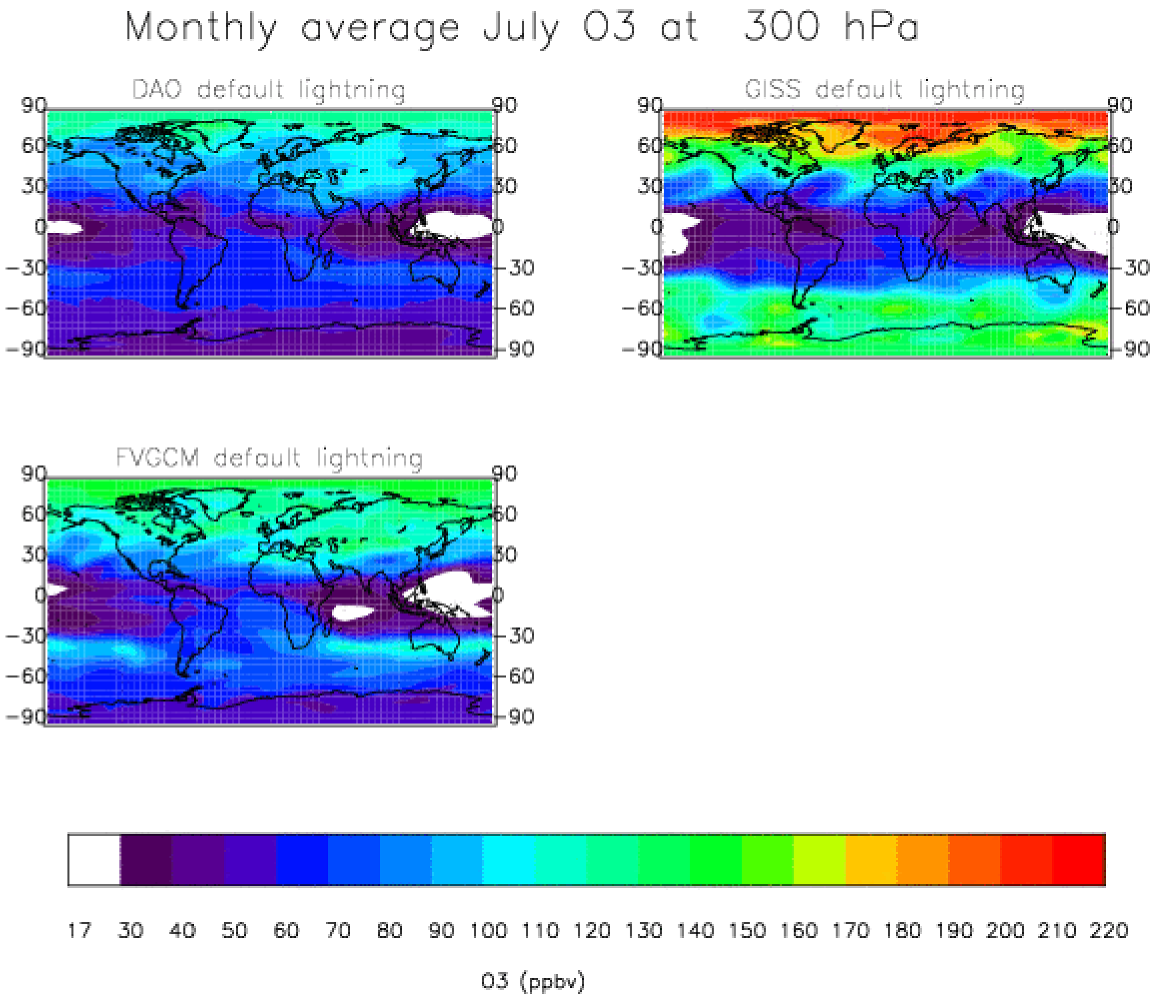
Mean July NOx at 300 hPa
DAO default Lightning NO
DAO convective lightning NO
GISS default lighning NO
GISS convective–lightning NO
FVGCM default–lightning NO
FVGCM convective lightning NO
0 15 30 45 60 75 90 105 120 135 150 165 200 300 400 500 750
NOx (pptv)


Mean July NOx at 300 hPa
DAO default Lightning NO
DAO convective lightning NO
GISS default lighning NO
GISS convective-lightning NO
FVGCM default-lightning NO
FVGCM convective lightning NO
45
30
15
0
-15
-30
-45
0
30
60
90
120
150
180
0 15 30 45 60 75 90 105 120 135 150 165 200 300 400 500 750
NOx (pptv)

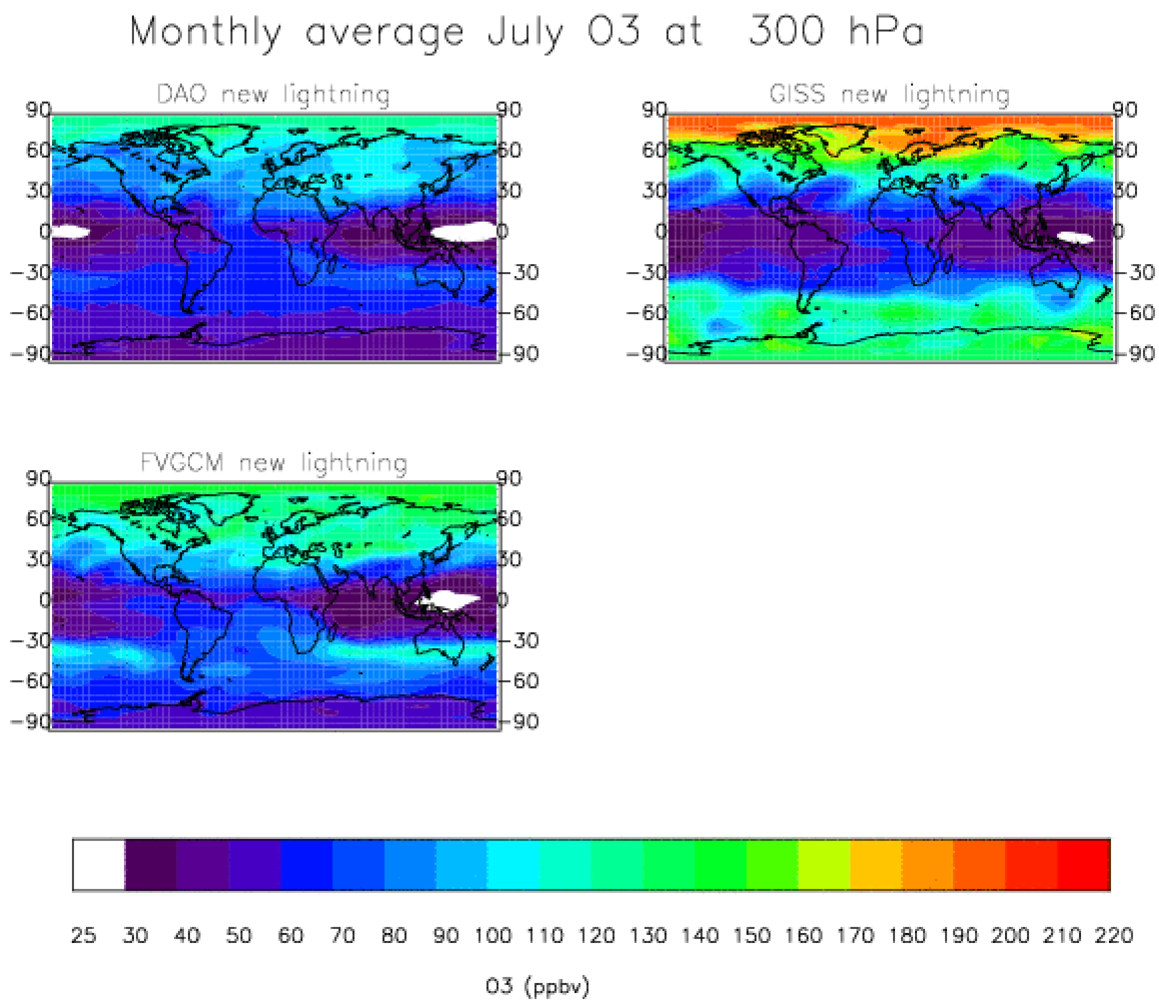
Three GMI Simulations with no lightning



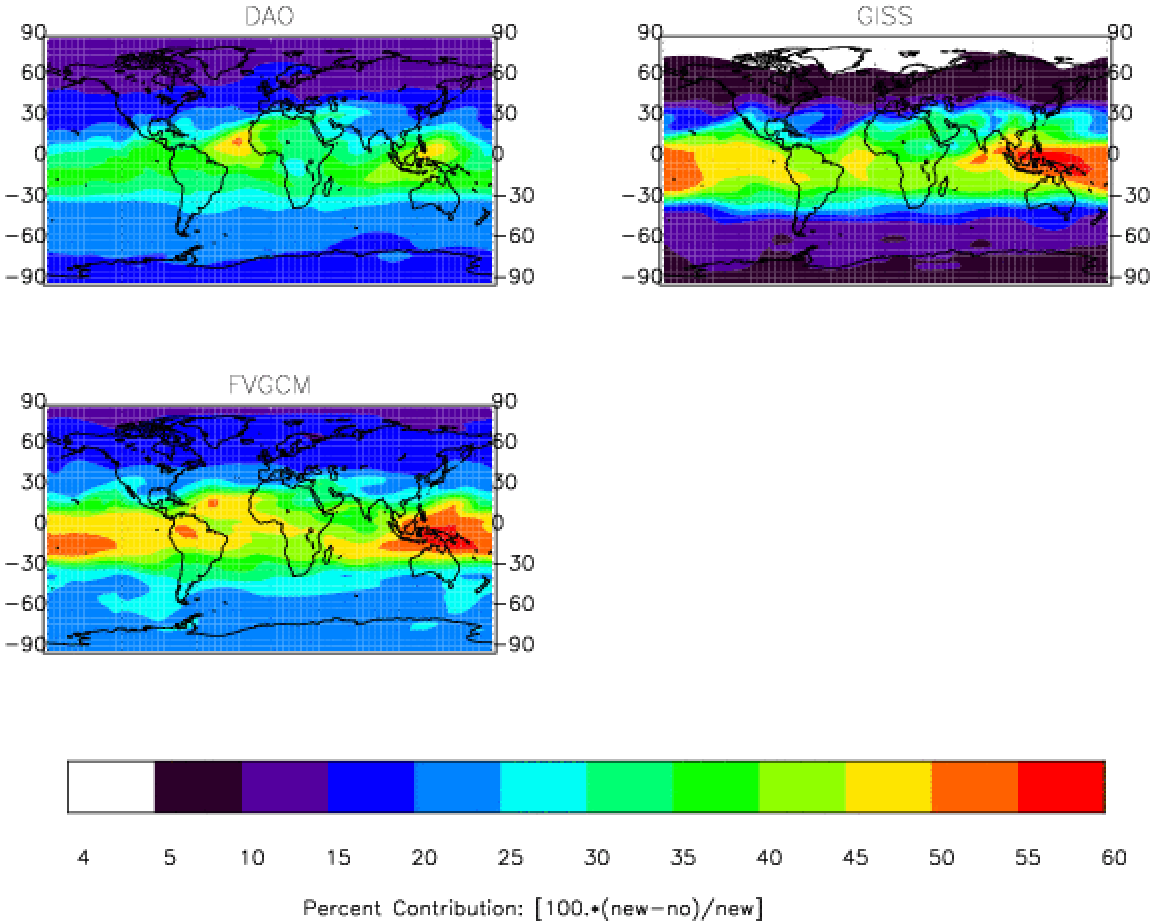
Three GMI Simulations with Default Lightning



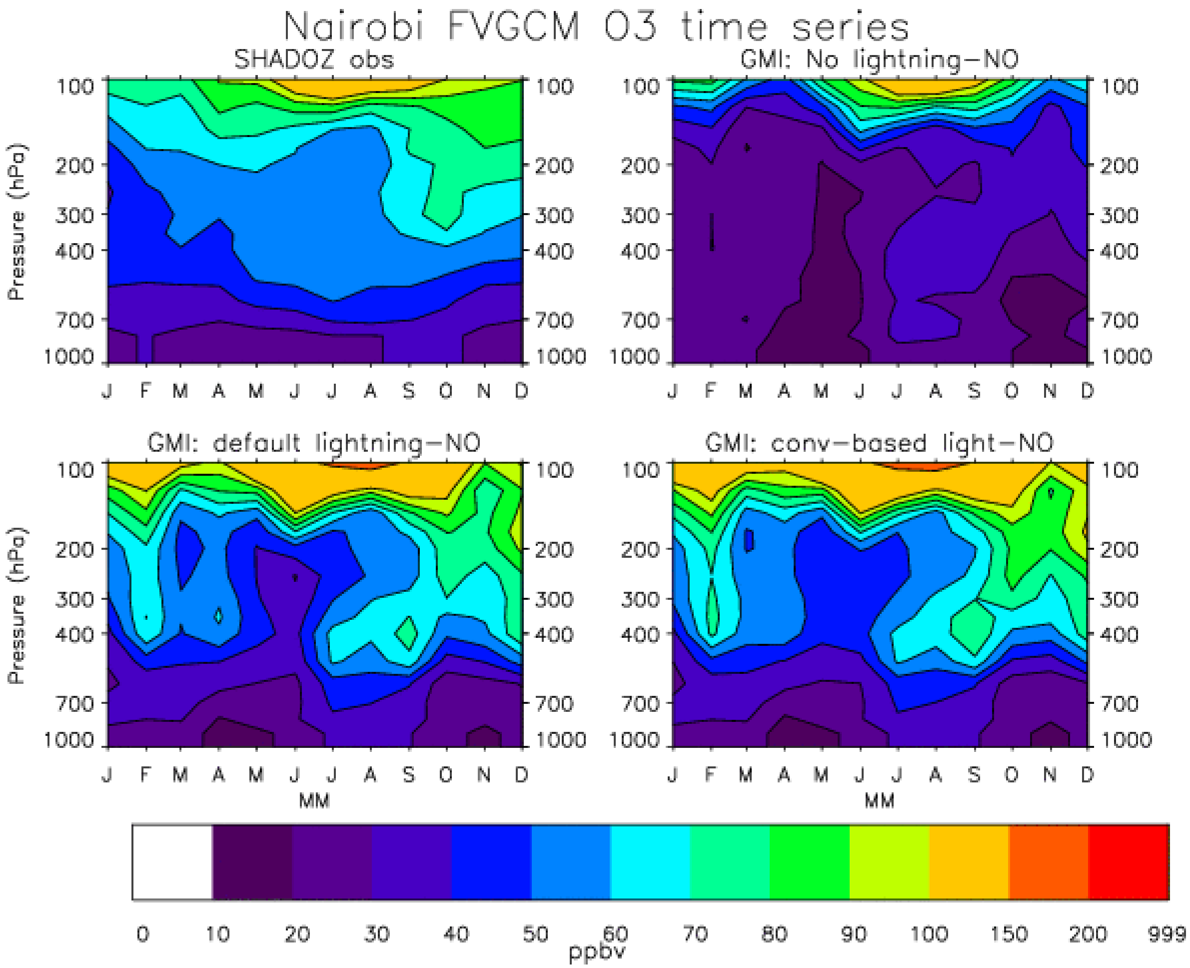
Three GMI Simulations with New Lightning

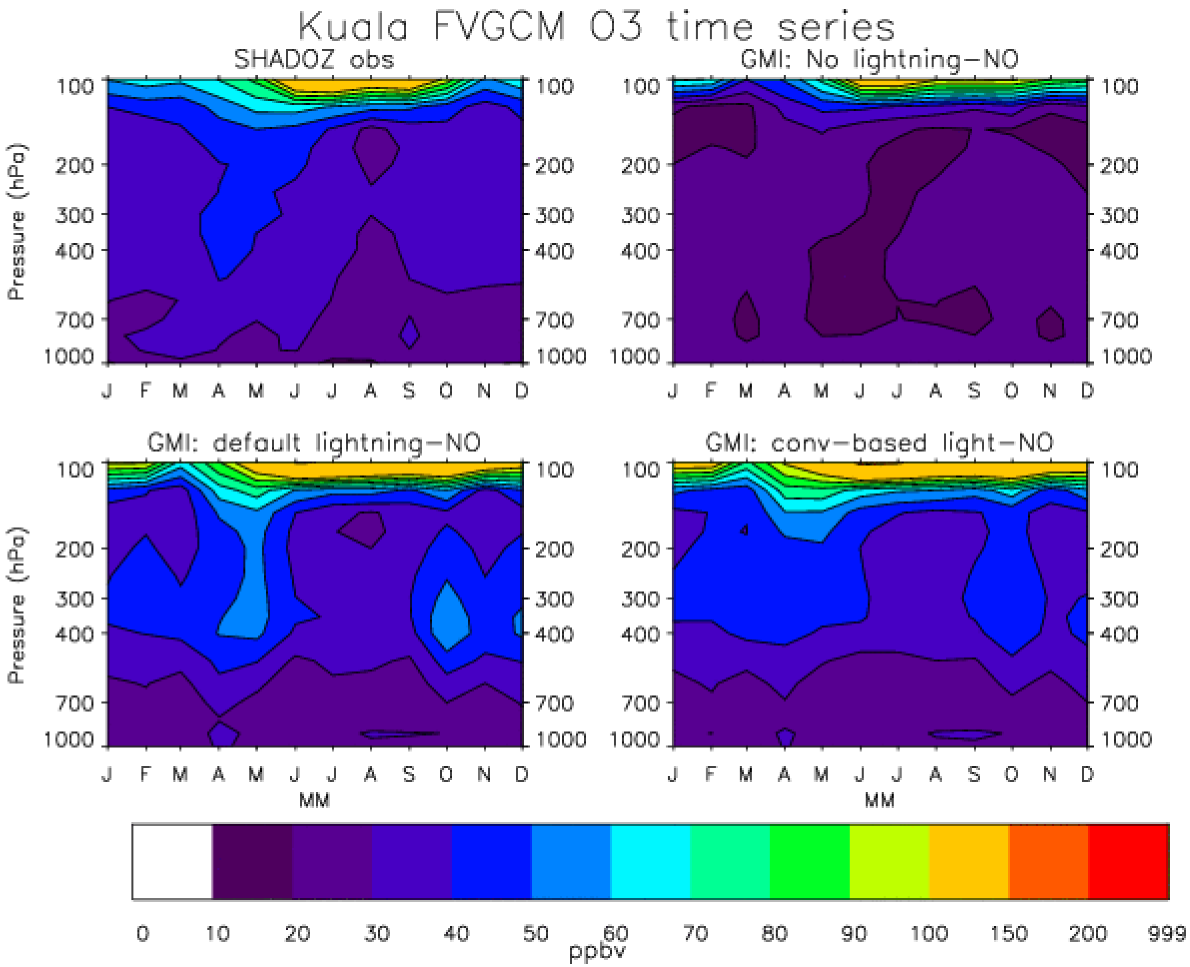


Lightning contribution to O3 at 300 hPa: July

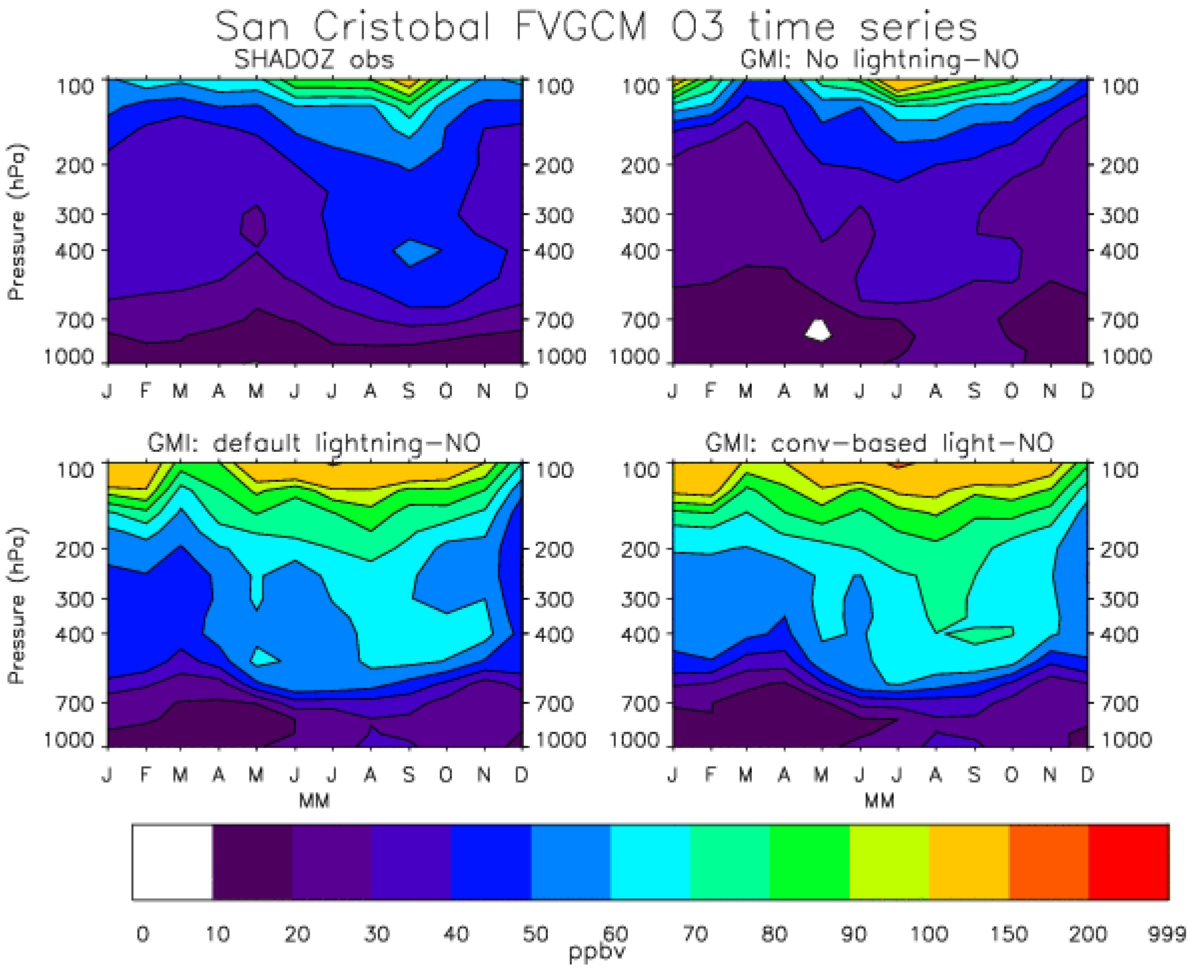


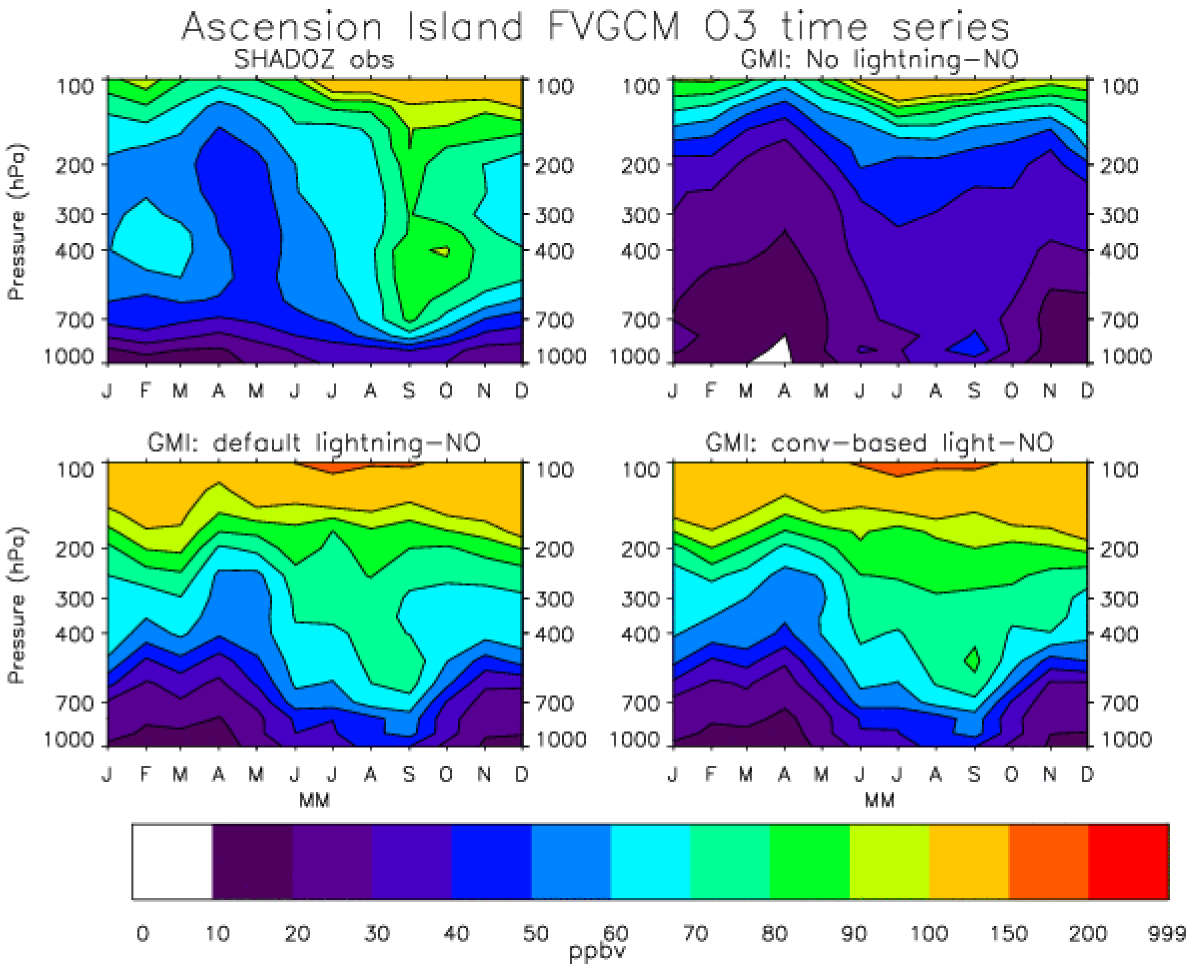
SHADOZ Stations





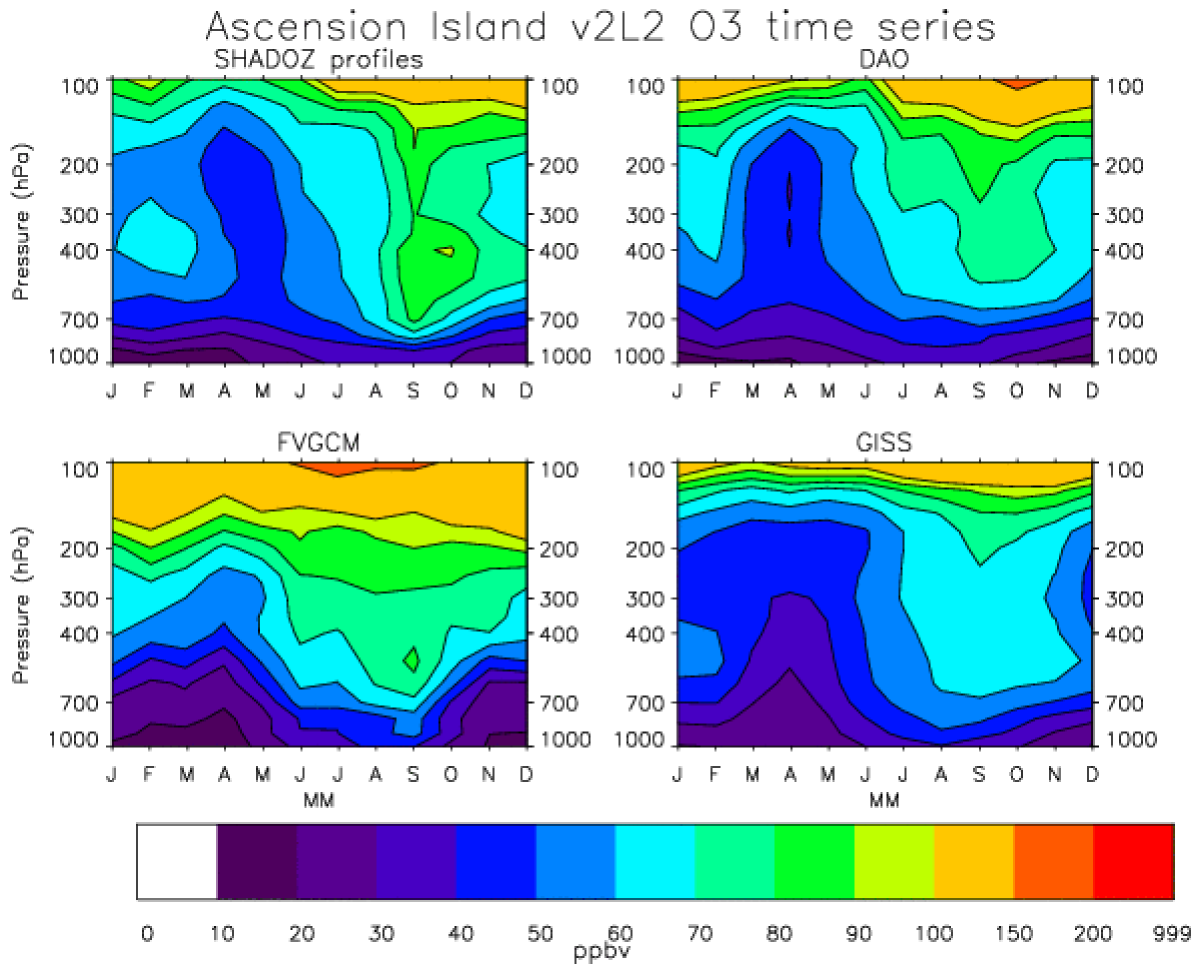
Kuala FVGCM O3 time series
SHADOZ obs
GMI: No lightning-NO
GMI: default lightning-NO
GMI: conv-based light-NO
Pressure (hPa)
100
200
300
400
700
1000
J F M A M J J A S O N D
MM
0 10 20 30 40 50 60 70 80 90 100 150 200 999
ppbv


San Cristobal FVGCM O3 time series
SHADOZ obs
GMI: No lightning-NO
GMI: default lightning-NO
GMI: conv-based light-NO
Pressure (hPa)
100
200
300
400
700
1000
J F M A M J J A S O N D
MM
0 10 20 30 40 50 60 70 80 90 100 150 200 999
ppbv

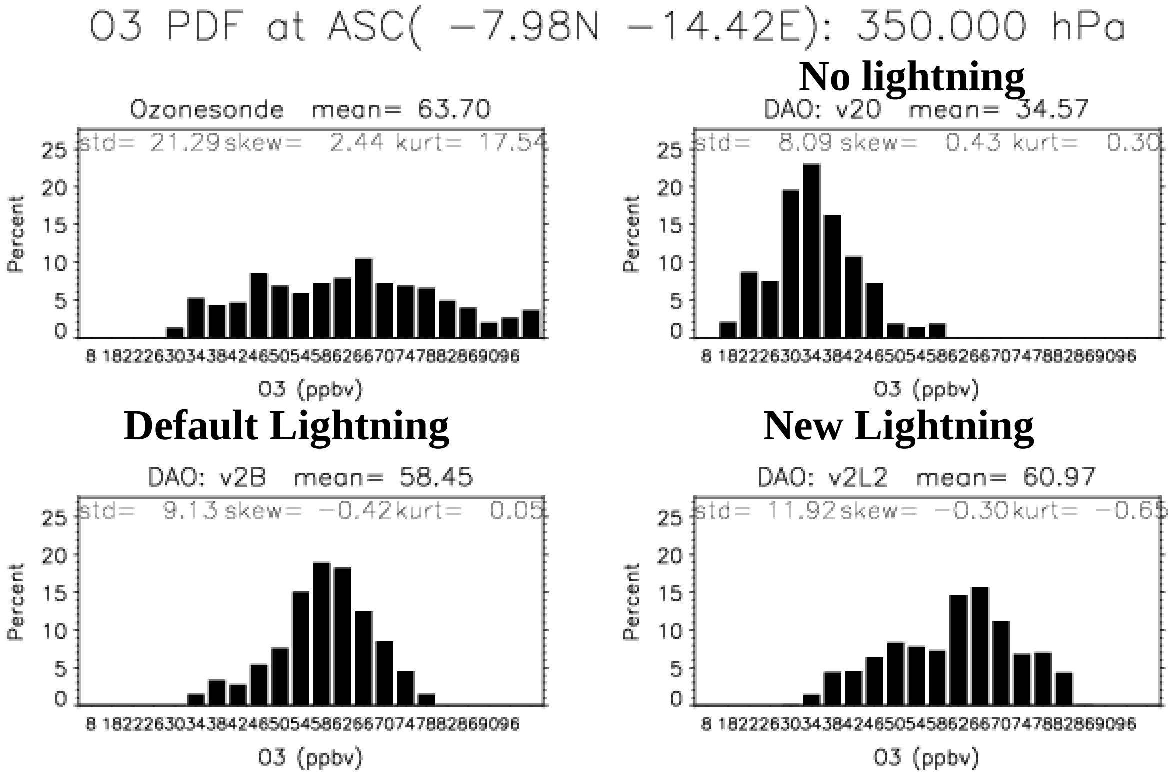


Ascension Island FVGCM O3 time series
SHADOZ obs
GMI: No lightning-NO
GMI: default lightning-NO
GMI: conv-based light-NO
Pressure (hPa)
100
200
300
400
700
1000
J F M A M J J A S O N D
MM
0 10 20 30 40 50 60 70 80 90 100 150 200 999
ppbv

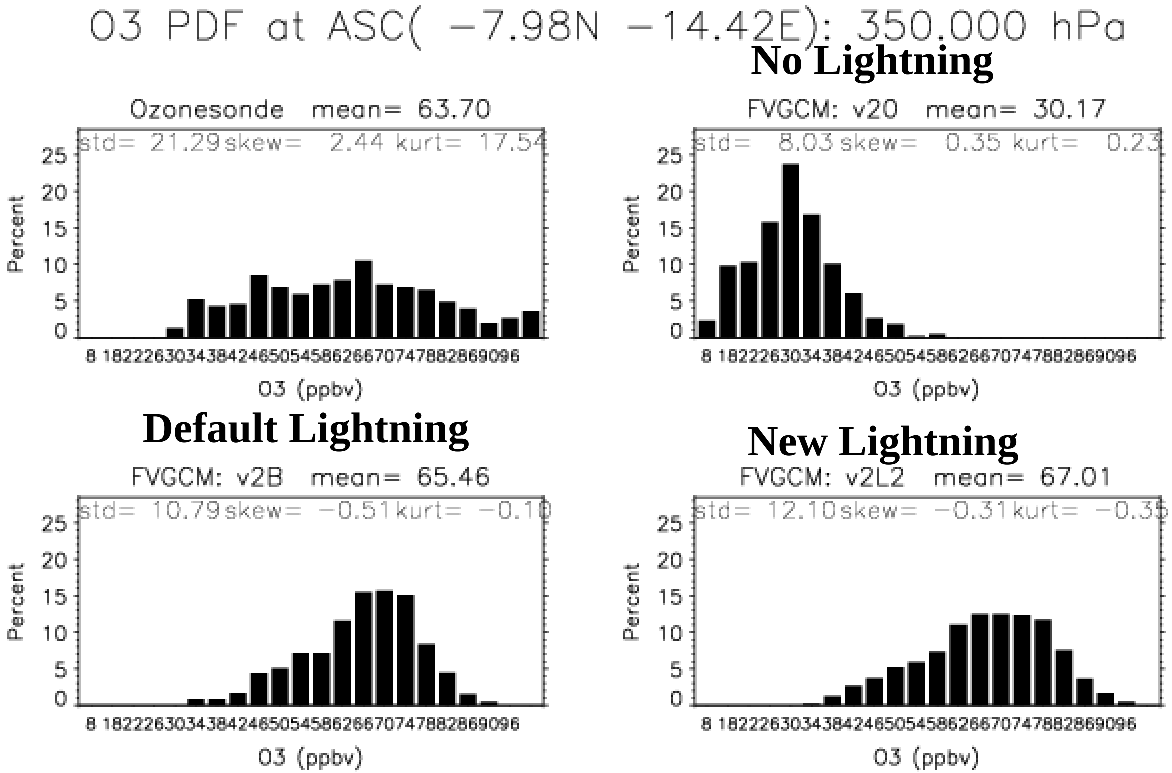
Comparison of New Lightning for Three Met. Fields with Sonde Data



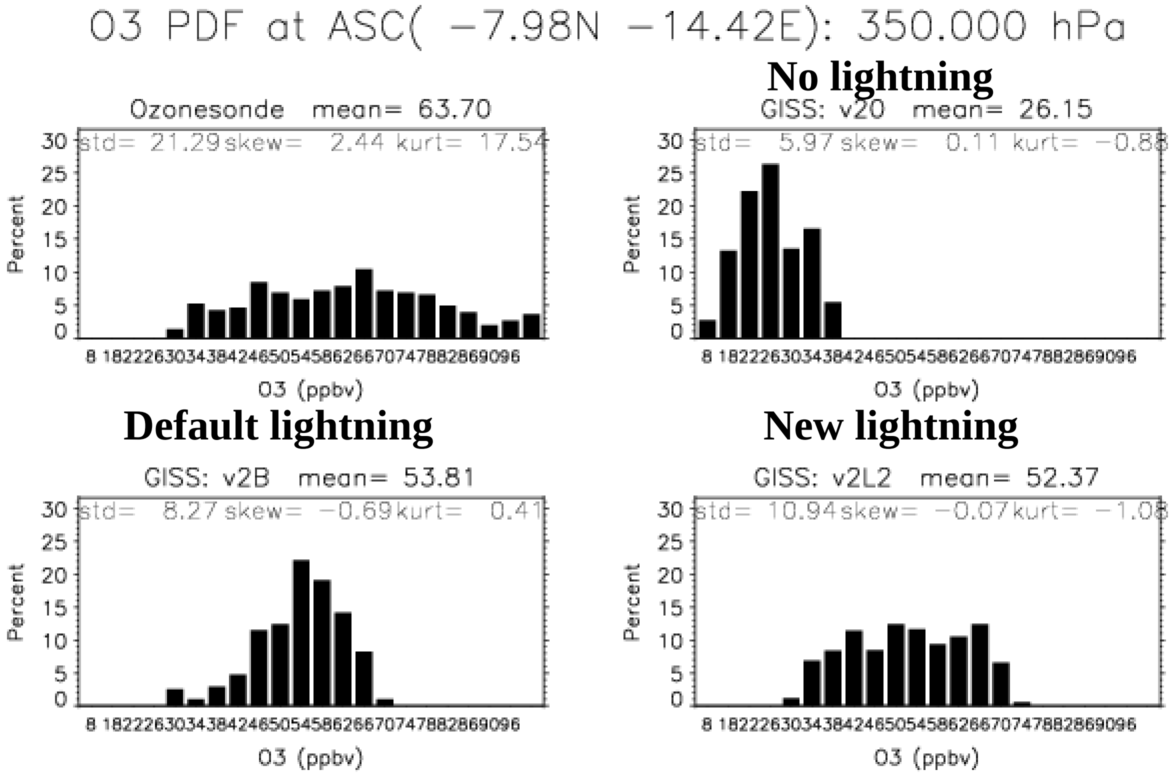
GMI with DAO met fields compared with sondes



GMI with FVGCM met fields compared with sondes



GMI with GISS met fields compared with sondes



Summary

- Relationship between CLDMAS and observed CG flash rates utilized to derive lightning parameterizations for 3 GMI meteorological fields

- Marine-continental and tropical-midlatitude adjustments made to parameterizations in order to best match annual average LIS/OTD flash rates.

- When convective-based lightning NO emissions are used:

  Low GISS cloud top heights constrain lightning NOx emissions to lower altitudes than in default run; lightning contribution to 300 hPa O3 was confined to lower latitudes.

  More lightning NOx in tropical UT than in default run; also in general more O3 throughout troposphere in the tropics

  Lightning contribution to O3 at 300 hPa exceeds 50% at tropical low O3 locations; contribution in midlatitudes is lower in GISS than with other models

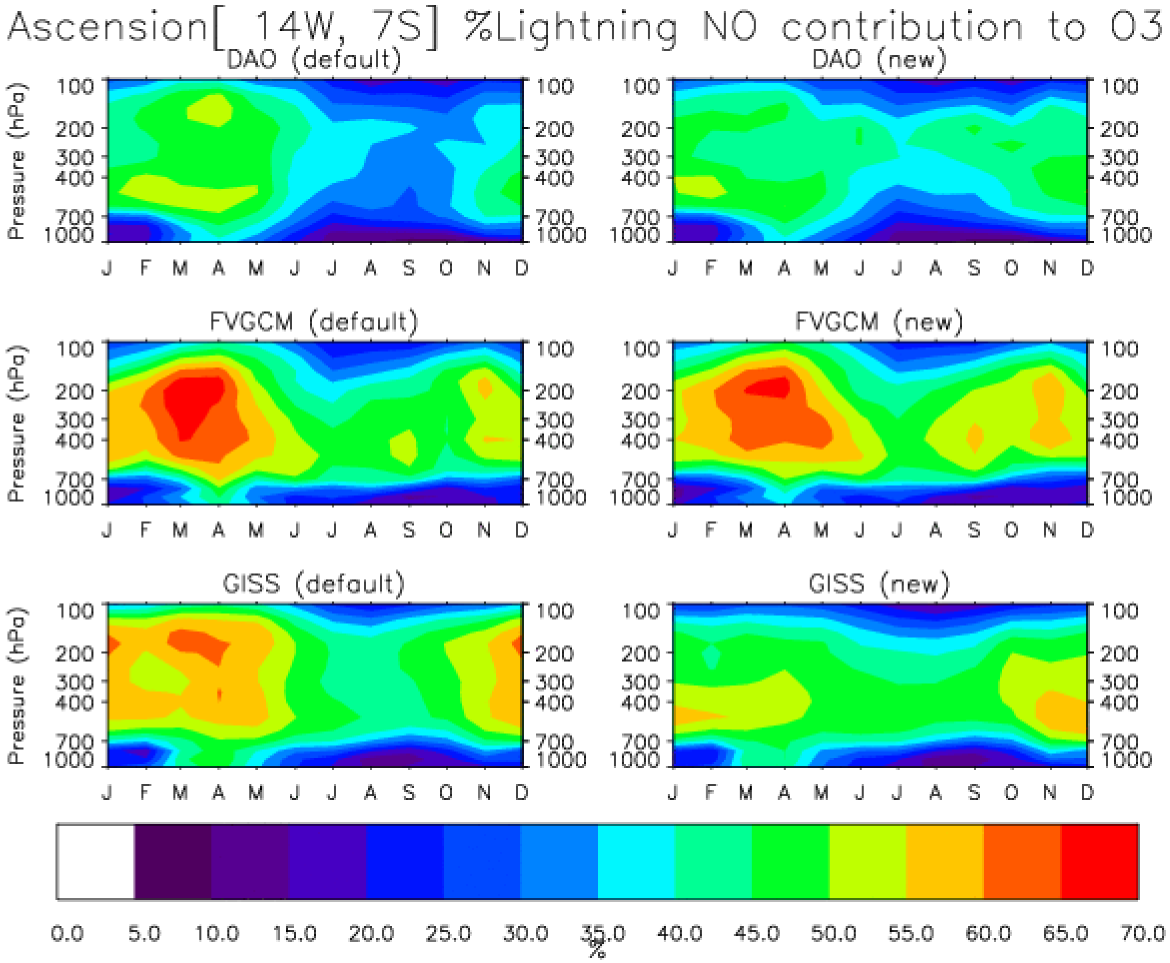
  New lightning improves temporal distribution of O3 at Ascension Island.

  Time series of monthly mean O3 vertical profiles improved at several sites including Kuala Lumpur and Ascension Island

  New lightning still reflects some biases in model convection (Caribbean, Western Pacific)

Extra Slides


SHADOZ Sites
Click on a site to access the data archive.
Heredia
Paramaribo
Cotonou
Nairobi
Kuala Lumpur
San Cristobal
Natal
Malindi
Samoa
Fiji
Watukosek
Ascension
La Réunion
Irene


Ascension[14W, 7S] %Lightning NO contribution to O3
DAO (default)
DAO (new)
FVGCM (default)
FVGCM (new)
GISS (default)
GISS (new)
Pressure (hPa)
100
200
300
400
700
1000
J F M A M J J A S O N D
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0 65.0 70.0
%

GMI off-line tropospheric chemistry model

Modular CTM that is being used to assess the sensitivity of tropospheric photochemistry to 1) driving MET fields, 2) numerical transport algorithms, 3) emission specifications, 4) etc. An understanding of this sensitivity is needed to focus assessments and to interpret their results.

See: http://gmi.gsfc.nasa.gov/gmi.html

In this study, we use v2 of the model: [manuscript in preparation, 2006]

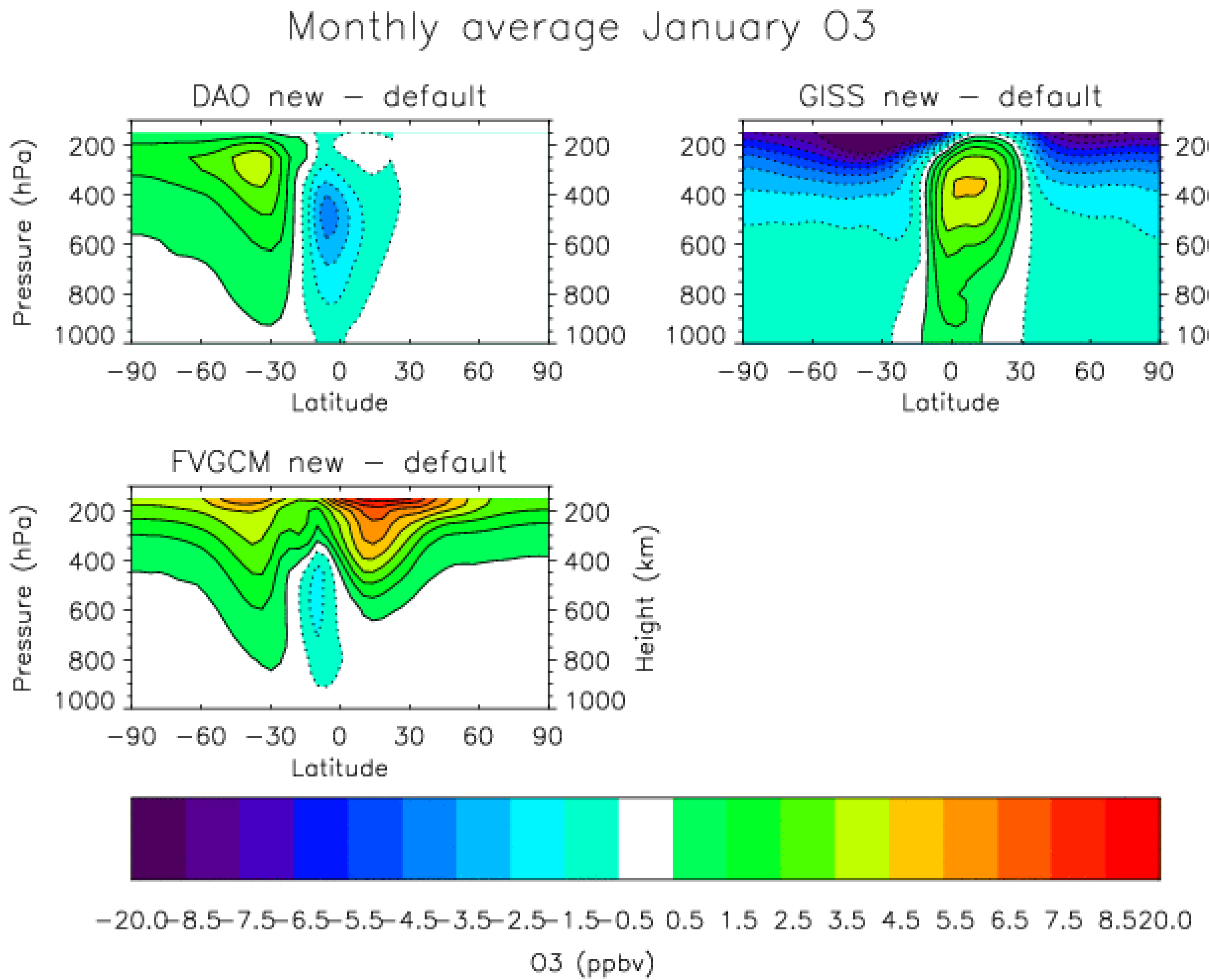
Advection: Lin and Rood (1996)

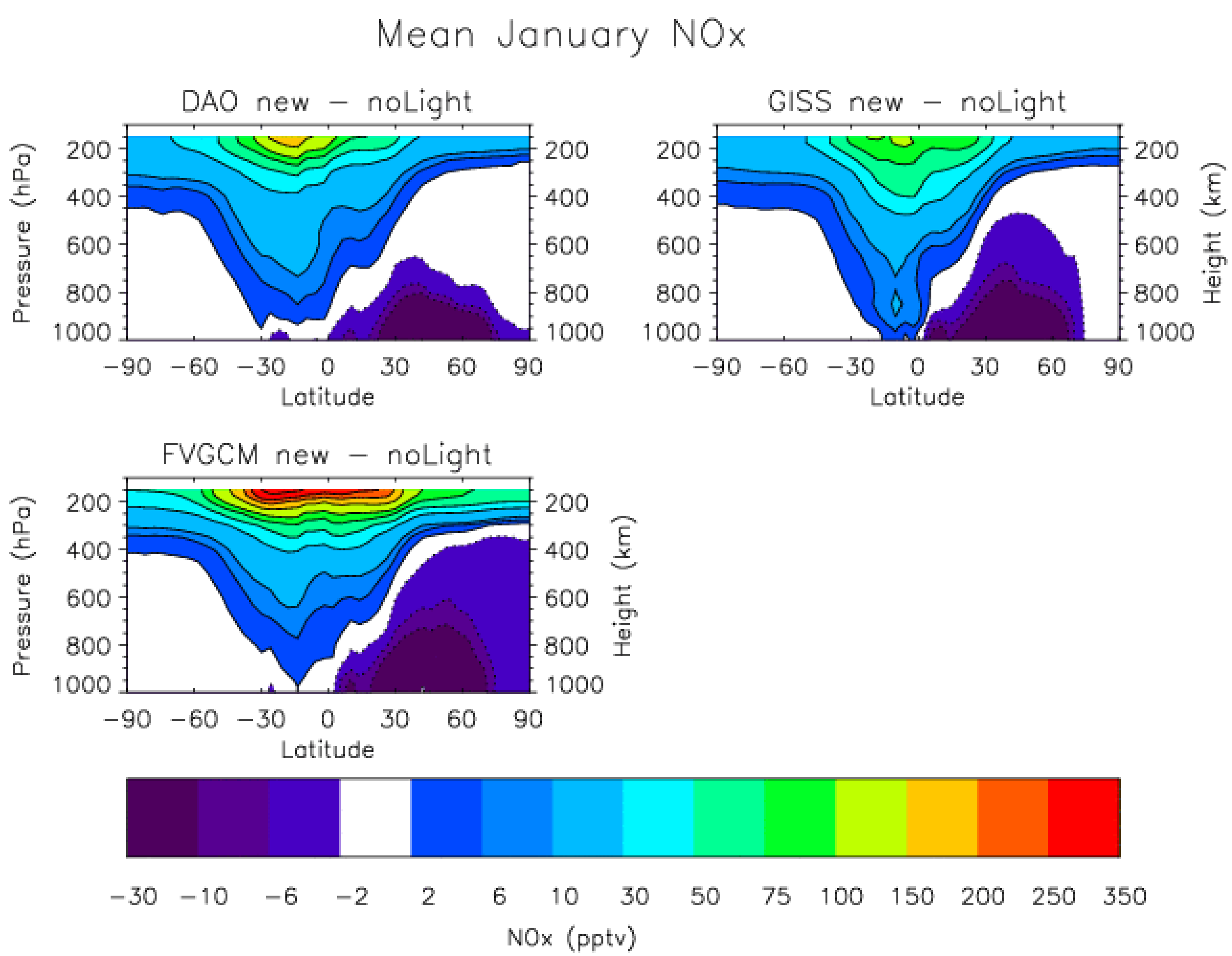
Chemistry: “Harvard” mechanism

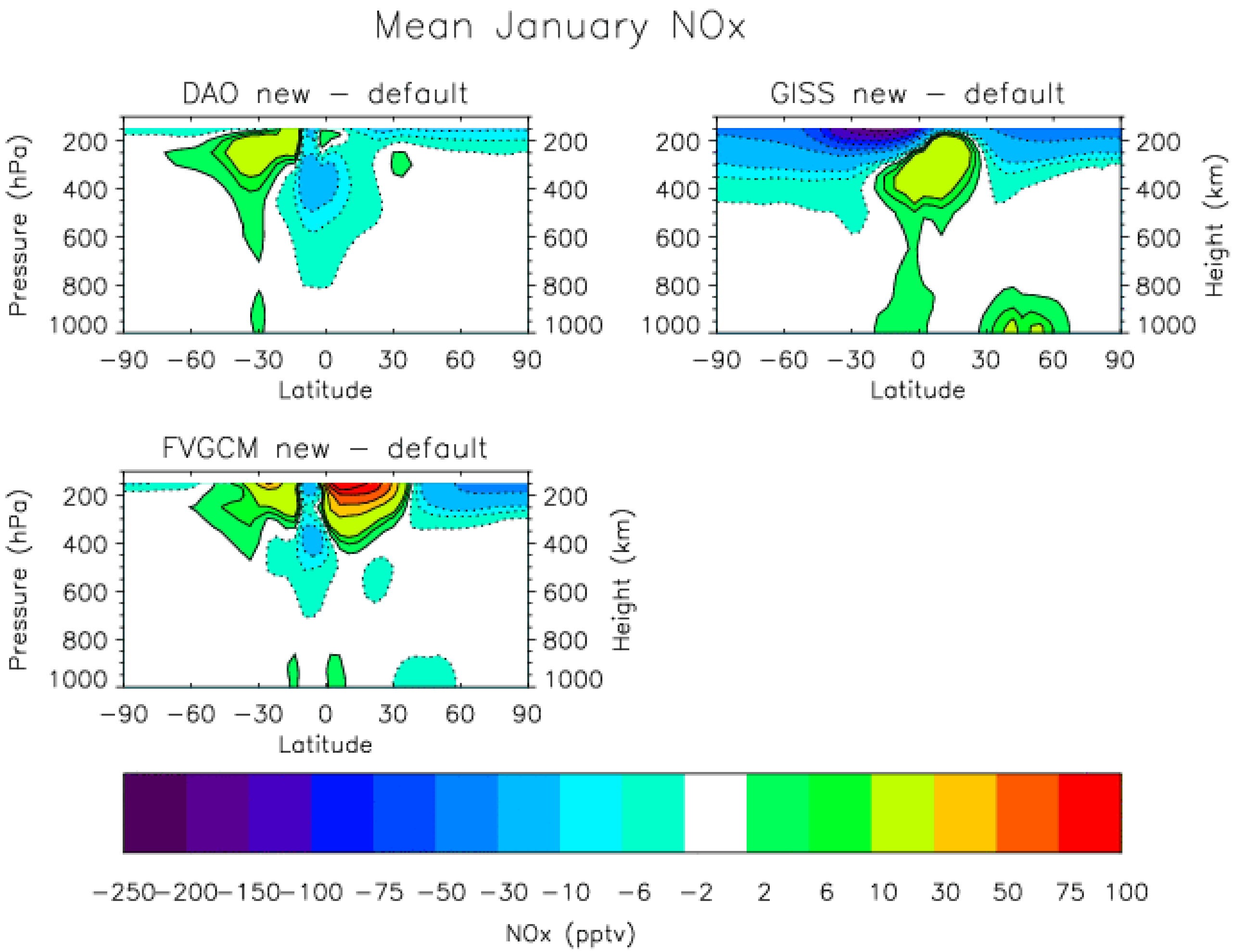
Physics: Consistent with driving GCM

Meteorological fields: **GEOS-STRAT**, GEOS-FVGCM, GISS II’ GCM

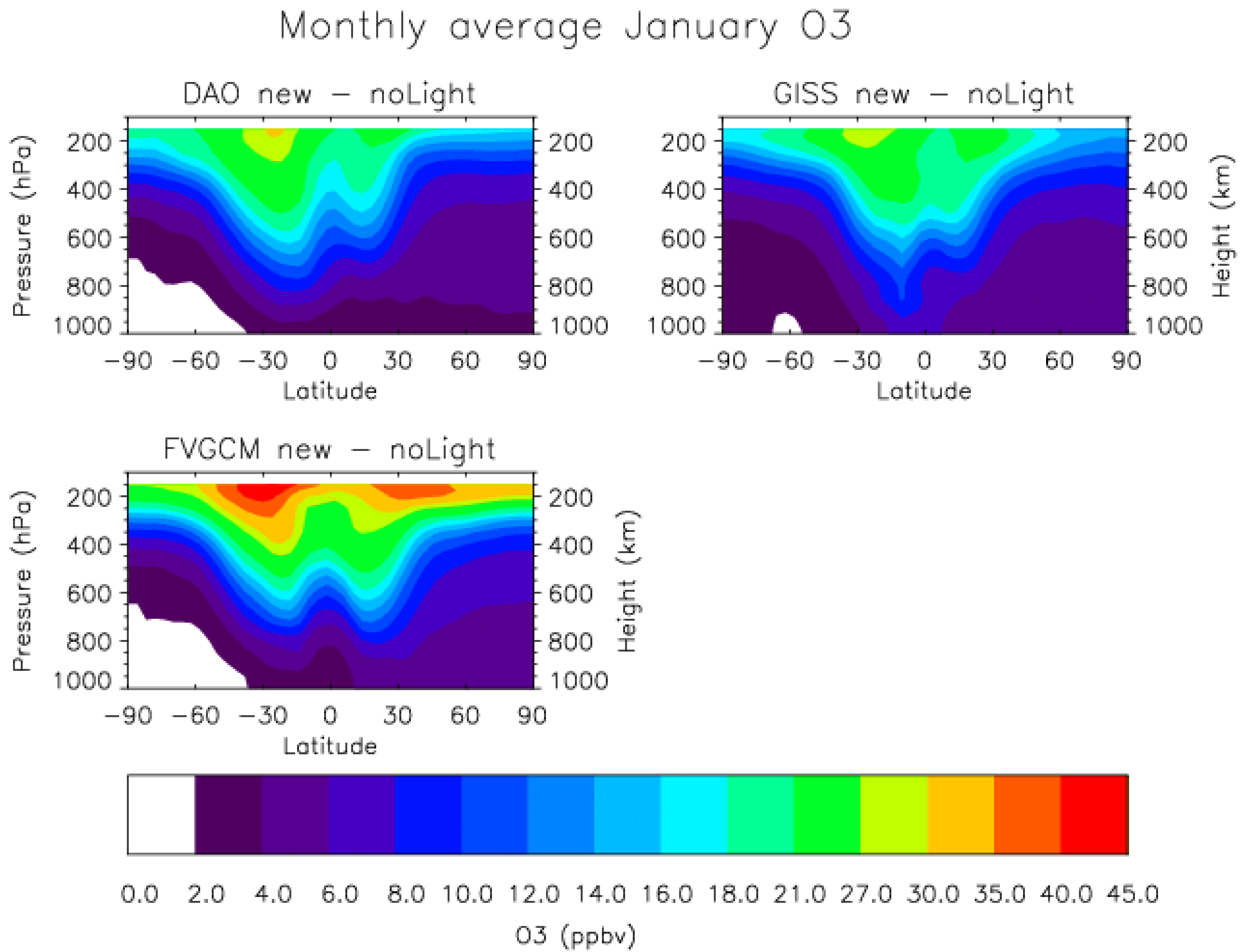
Lightning NO emissions (none vs. climatological vs. convection-based)

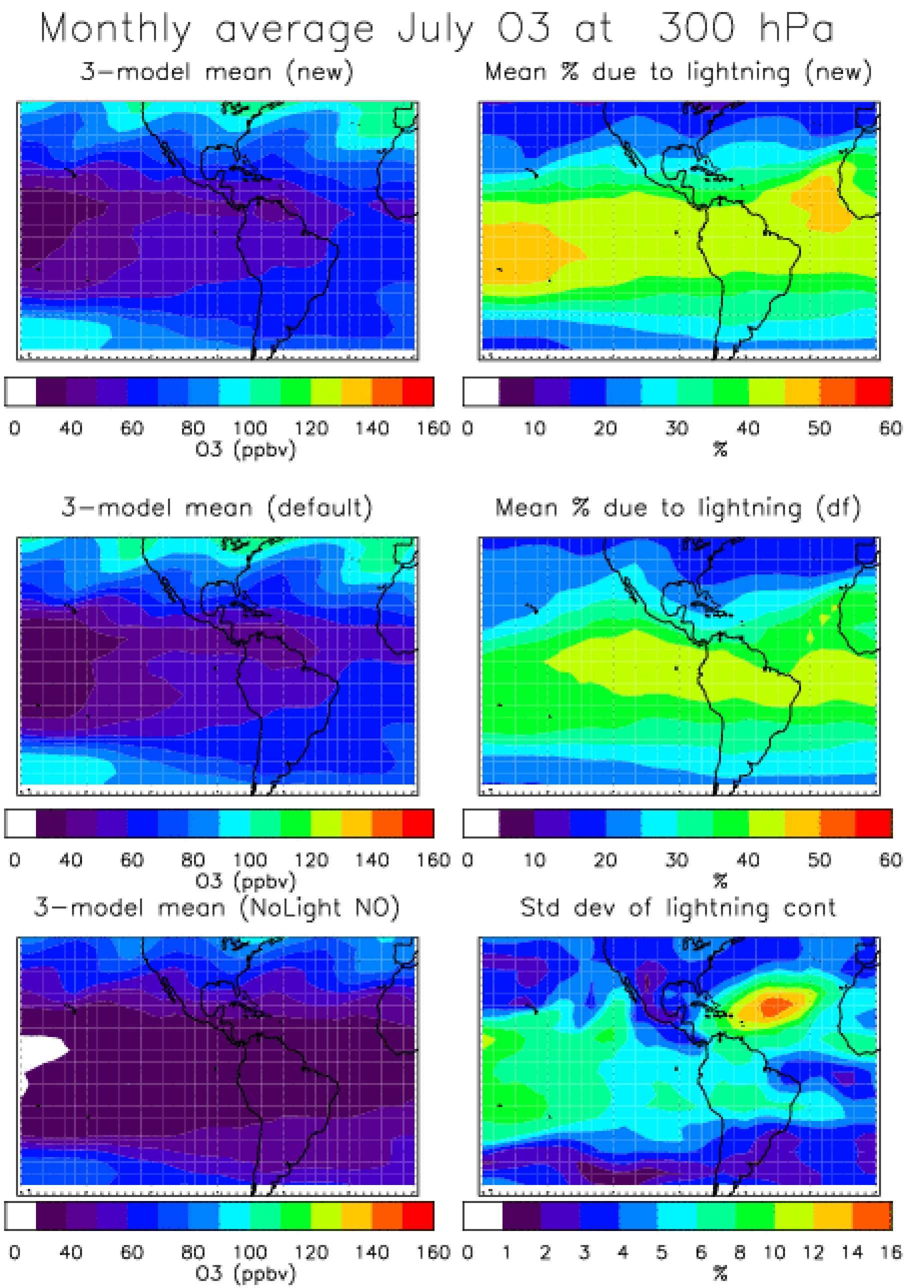

Monthly average January O3
DAO new – default
GISS new – default
FVGCM new – default
Pressure (hPa)
Height (km)
Latitude
−90 −60 −30 0 30 60 90
200 400 600 800 1000
−20.0 −8.5 −7.5 −6.5 −5.5 −4.5 −3.5 −2.5 −1.5 −0.5 0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 20.0
O3 (ppbv)


Mean January NOx
DAO new – noLight
GISS new – noLight
FVGCM new – noLight
Pressure (hPa)
Height (km)
Latitude
200
400
600
800
1000
–90
–60
–30
0
30
60
90
–30
–10
–6
–2
2
6
10
30
50
75
100
150
200
250
350
NOx (pptv)

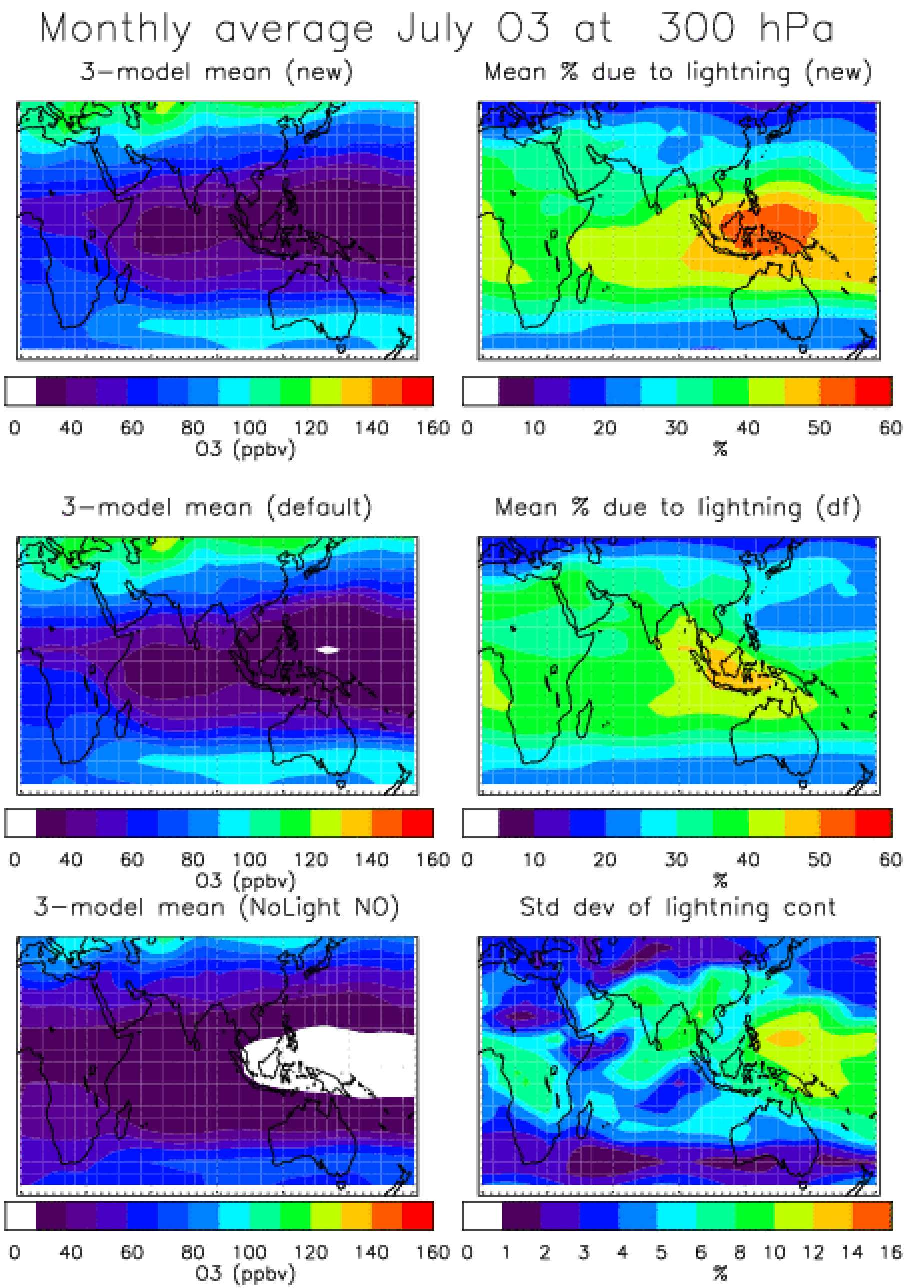


Mean January NOx
DAO new − default
GISS new − default
FVGCM new − default
Pressure (hPa)
Height (km)
200
400
600
800
1000
−90 −60 −30 0 30 60 90
Latitude
−250 −200 −150 −100 −75 −50 −30 −10 −6 −2 2 6 10 30 50 75 100
NOx (pptv)


Monthly average January O3
DAO new – noLight
GISS new – noLight
FVGCM new – noLight
Pressure (hPa)
Height (km)
Latitude
200
400
600
800
1000
–90 –60 –30 0 30 60 90
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0 16.0 18.0 21.0 27.0 30.0 35.0 40.0 45.0
O3 (ppbv)



Monthly average July O3 at 300 hPa
3-model mean (new)
Mean % due to lightning (new)
0 40 60 80 100 120 140 160
O3 (ppbv)
0 10 20 30 40 50 60
%
3-model mean (default)
Mean % due to lightning (df)
0 40 60 80 100 120 140 160
O3 (ppbv)
0 10 20 30 40 50 60
%
3-model mean (NoLight NO)
Std dev of lightning cont
0 40 60 80 100 120 140 160
O3 (ppbv)
0 1 2 3 4 5 6 8 10 12 14 16
%



Monthly average July O3 at 300 hPa
3-model mean (new)
Mean % due to lightning (new)
0 40 60 80 100 120 140 160
O3 (ppbv)
0 10 20 30 40 50 60
%
3-model mean (default)
Mean % due to lightning (df)
0 40 60 80 100 120 140 160
O3 (ppbv)
0 10 20 30 40 50 60
%
3-model mean (NoLight NO)
Std dev of lightning cont
0 40 60 80 100 120 140 160
O3 (ppbv)
0 1 2 3 4 5 6 8 10 12 14 16
%

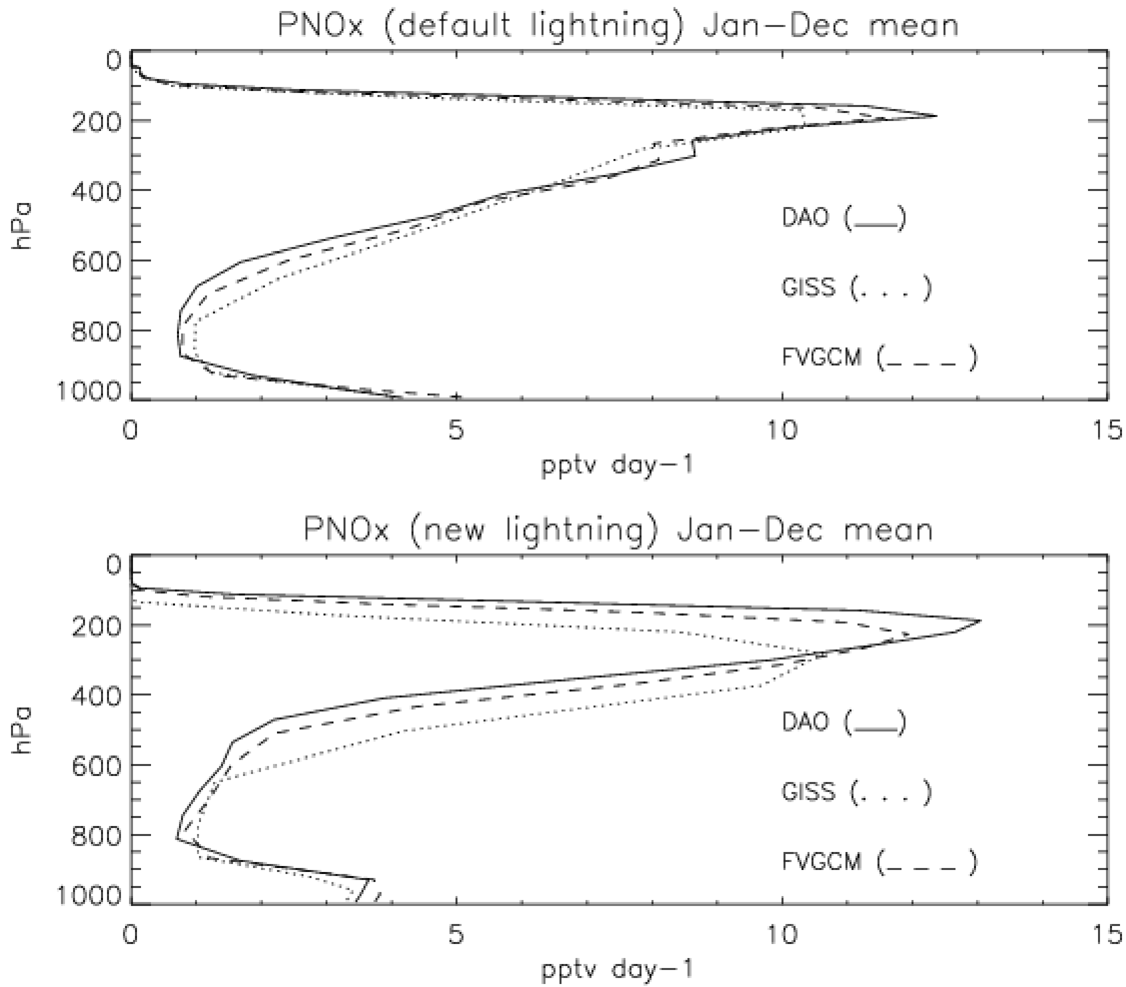
Motivation/Preview

- Production of NO by lightning is an important part of the tropical budget of NOx; whose concentration is the rate-limiting factor in O3 production in much of the non-boundary layer troposphere.

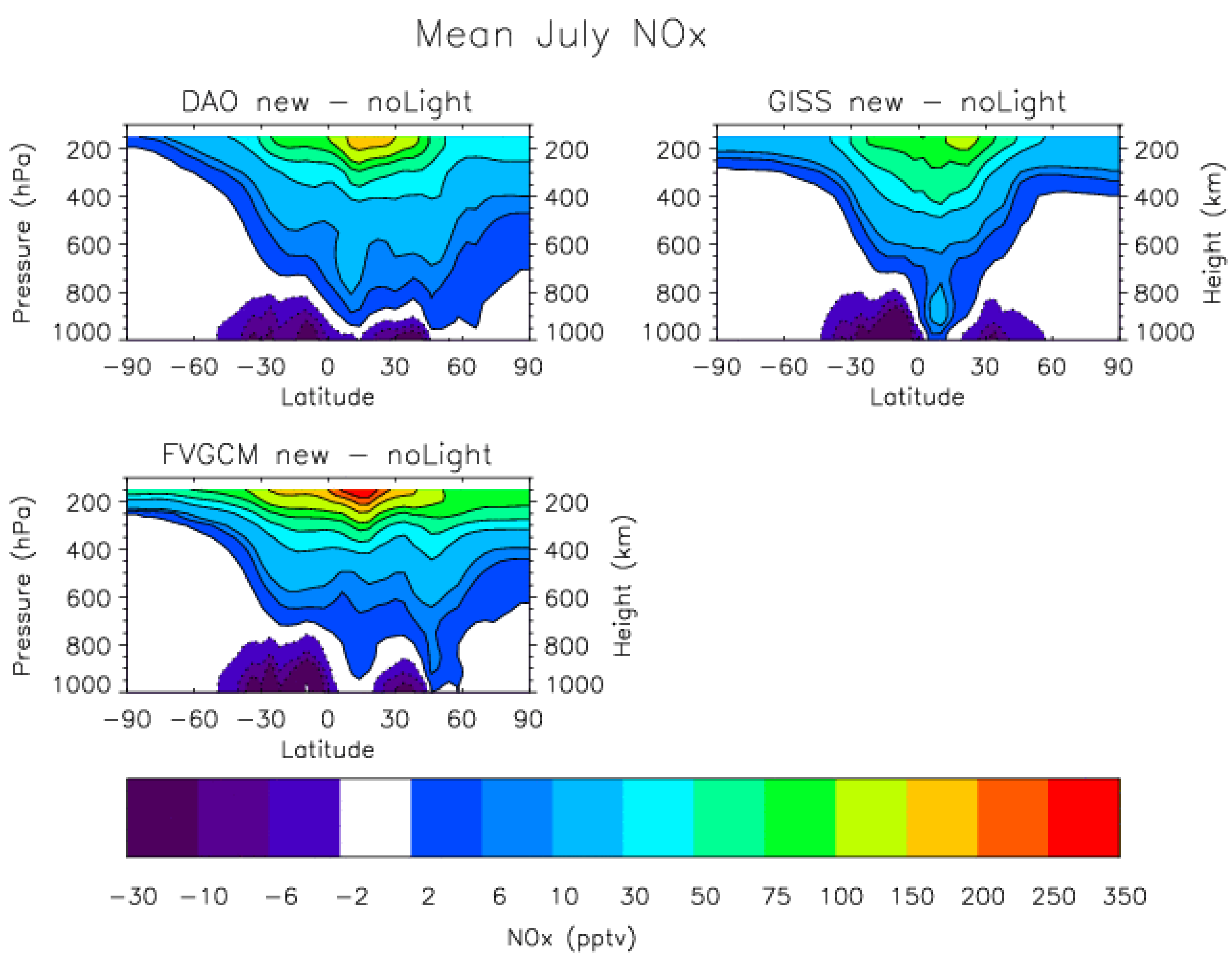
- The default version of the GMI CTM uses gridded monthly climatological values of lightning NO emission.

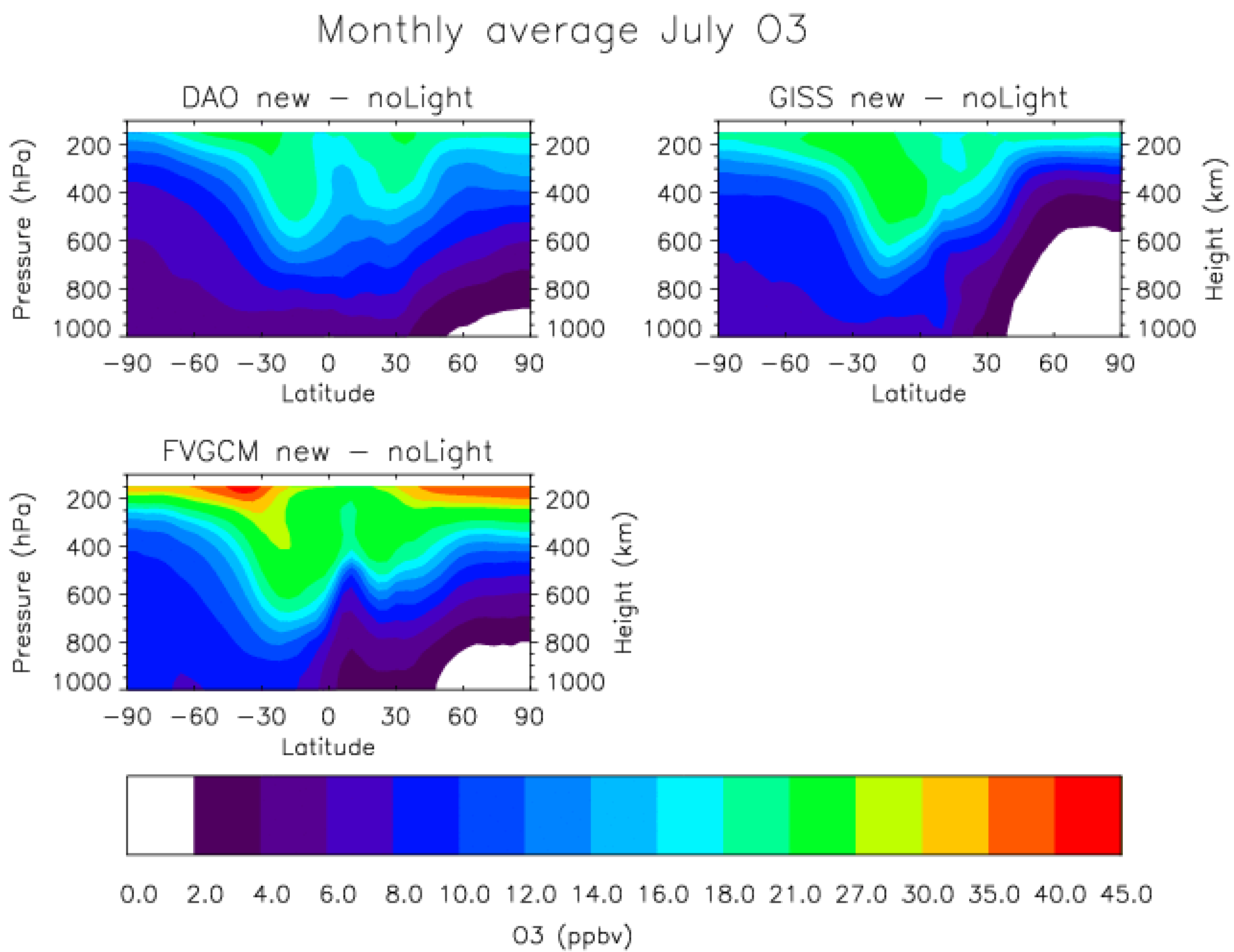
- In most instances, these model-independent climatological values of lightning NO injection do not match in space or time with the location of model convection.

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

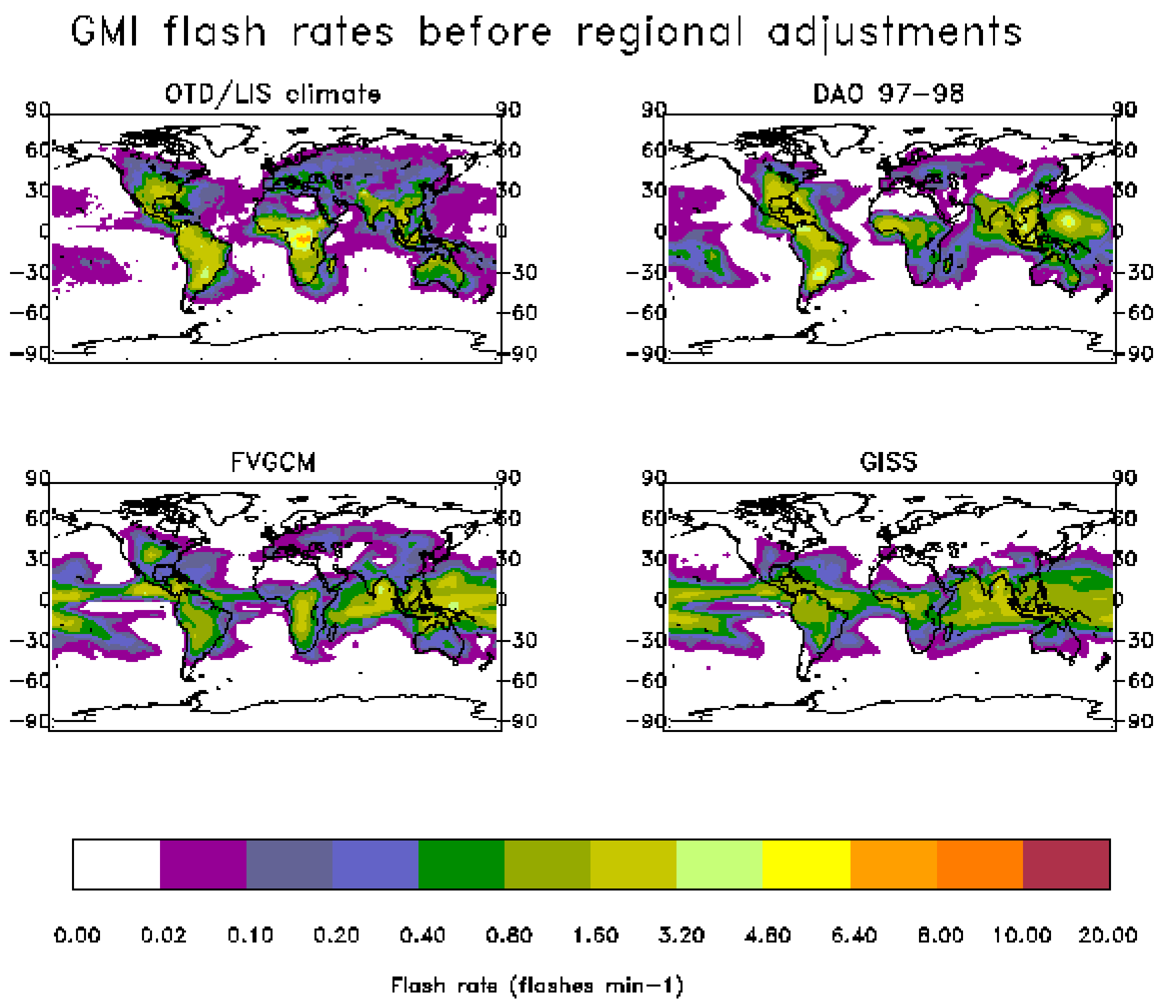


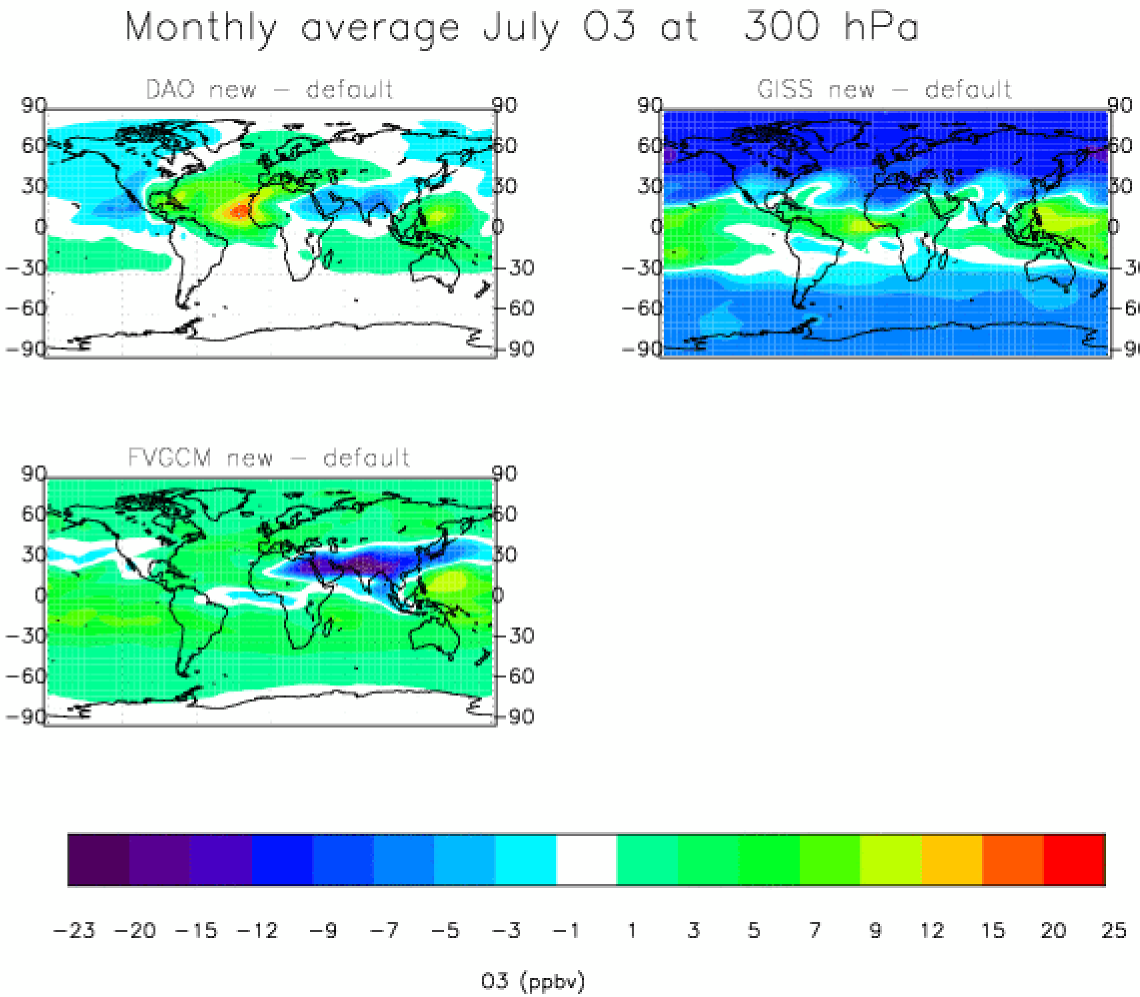
PNOx (default lightning) Jan−Dec mean
hPa
pptv day−1
DAO (——)
GISS (. . .)
FVGCM (_ _ _)
PNOx (new lightning) Jan−Dec mean
hPa
pptv day−1
DAO (——)
GISS (. . .)
FVGCM (_ _ _)


Mean July NOx
DAO new – noLight
GISS new – noLight
FVGCM new – noLight
Pressure (hPa)
Height (km)
Latitude
200
400
600
800
1000
−90 −60 −30 0 30 60 90
−30 −10 −6 −2 2 6 10 30 50 75 100 150 200 250 350
NOx (pptv)

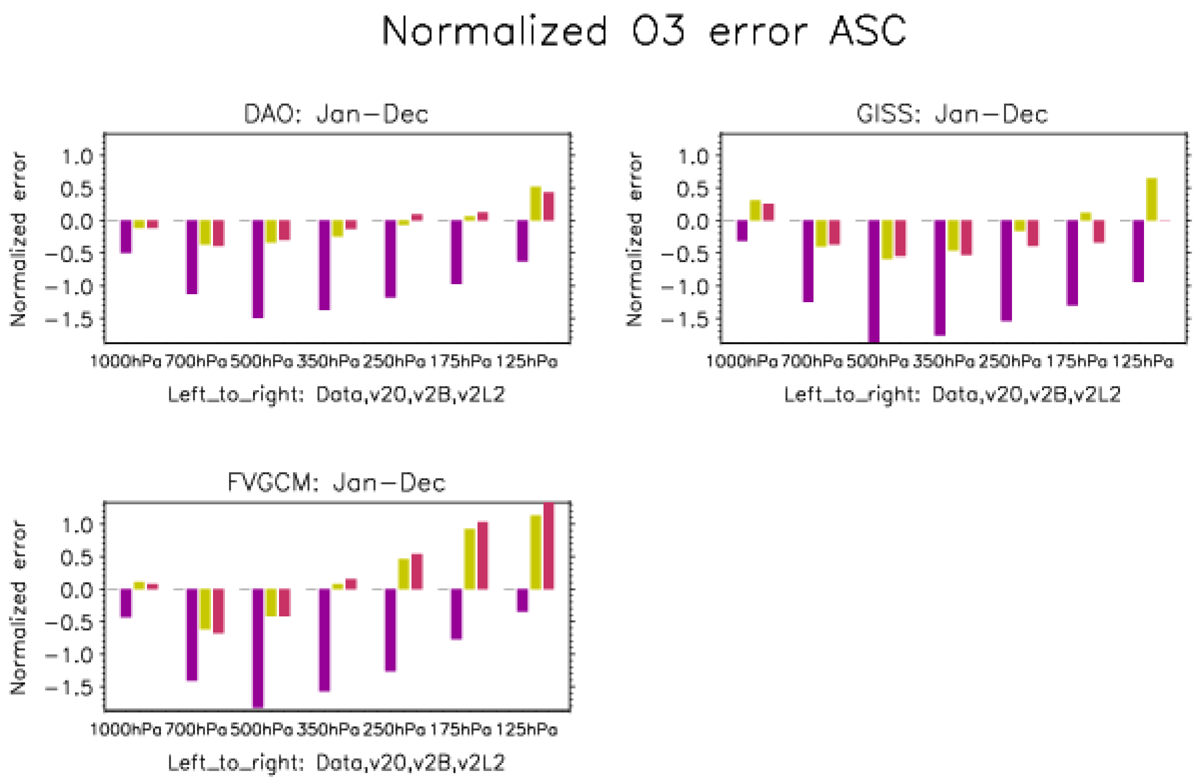


Monthly average July O3
DAO new – noLight
GISS new – noLight
FVGCM new – noLight
Pressure (hPa)
Height (km)
Latitude
200
400
600
800
1000
−90 −60 −30 0 30 60 90
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0 16.0 18.0 21.0 27.0 30.0 35.0 40.0 45.0
O3 (ppbv)


GMI flash rates before regional adjustments
OTD/LIS climate
DAO 97-98
FVGCM
GISS
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)



Monthly average July 03 at 300 hPa
DAO new – default
GISS new – default
FVGCM new – default
90
60
30
0
−30
−60
−90
−23 −20 −15 −12 −9 −7 −5 −3 −1 1 3 5 7 9 12 15 20 25
O3 (ppbv)


Normalized O3 error ASC
DAO: Jan–Dec
GISS: Jan–Dec
FVGCM: Jan–Dec
Normalized error
1.0
0.5
0.0
−0.5
−1.0
−1.5
1000hPa 700hPa 500hPa 350hPa 250hPa 175hPa 125hPa
Left_to_right: Data,v20,v2B,v2L2