Using beryllium-7 to assess cross-tropopause transport in global models

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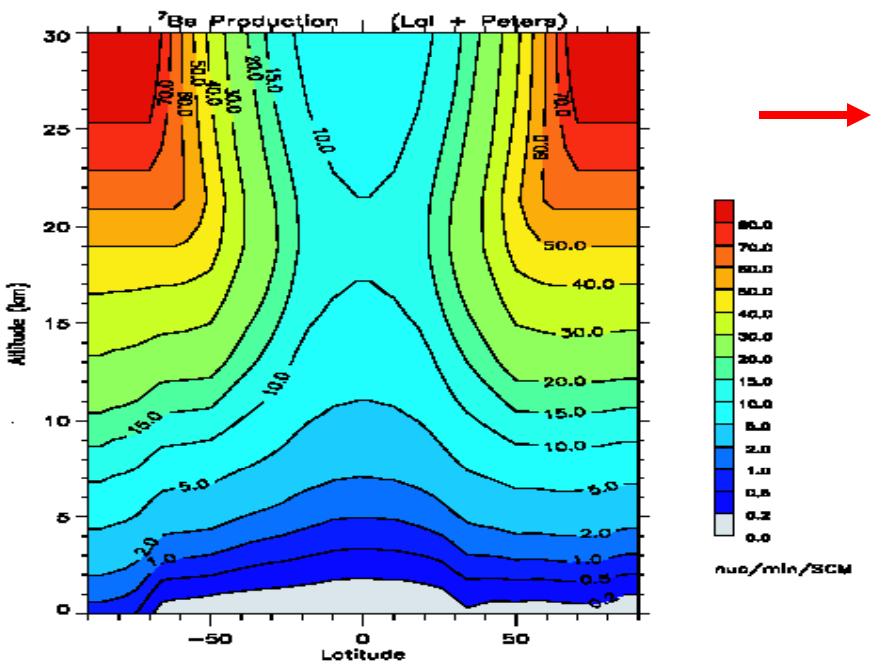
GMI Science Team Meeting, Sept. 9, 2010

Beryllium-7 (^{7}Be)

- Radionuclide; Radioactive half-life: 53.3 days
- Produced by cosmic ray spallation reactions in UT/LS; Source maximum at +/- 60 degrees
- Attaches immediately to available **submicron aerosols**; scavenged in troposphere
- Useful aerosol tracer for testing wet deposition processes in the model
- Tests the model's capability to describe **stratosphere-to-troposphere transport & subsidence in the troposphere**.



– the Lal and Peters [1967] source for 1958 (solar maximum year)

– We estimate an average solar year value simply by averaging the long-term records of ^{7}Be observations, then multiply by 0.72 to correct to the 1958 solar max source [Koch et al., 1996].

Motivation & Objective

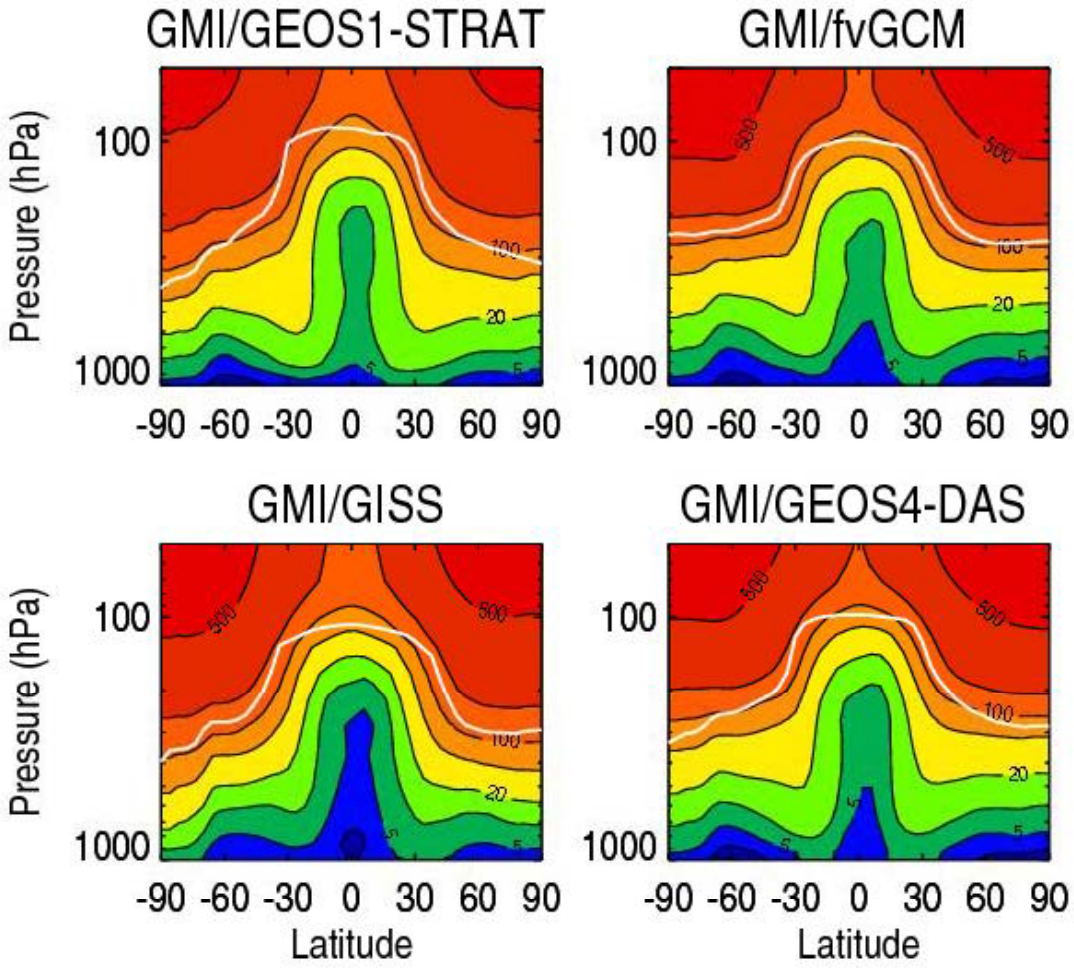
- Reasonably representing the stratosphere-troposphere exchange (STE) flux of ozone is important for global models of tropospheric chemistry. However, this flux usually varies from model to model.

- Two simple models for simulating stratospheric ozone in 3-D CTM [McLinden et al., JGR 2000]: Synthetic ozone (Synoz) and linearized ozone (Linoz). Linoz requires the meteorological fields/model have a reasonable representation of STE.

- Global Modeling Initiative (GMI) CTM: driven by four different set of input meteorological data: GEOS1-STRAT, GISS II' GCM, fvGCM, and GEOS-4 (http://gmi.gsfc.nasa.gov).
- AM2-Chem: AM2 chemistry-climate model (GFDL/NOAA)
- GEOS-Chem: driven by GEOS-3, GEOS-4, and GEOS-5.

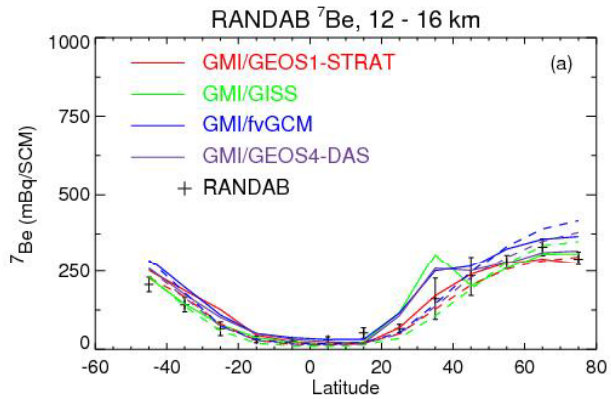
- Research questions:
  - Can cosmogenic ^{7}Be, a radionuclide aerosol tracer, be used routinely to assess cross-tropopause transport in global models?
  - Is cross-tropopause transport in GEOS-5 DAS reasonable?

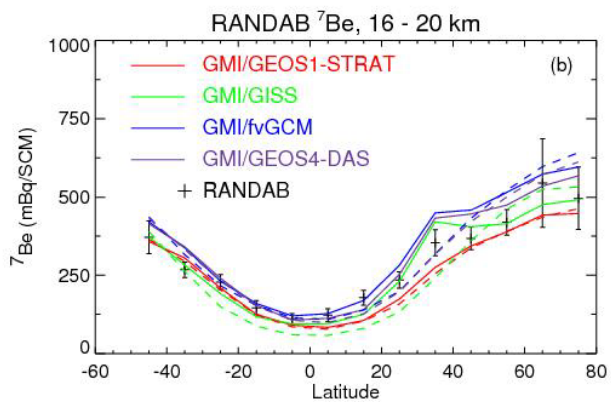
GMI simulated annual zonal mean mixing ratios (mBq/SCM) of ^{7}Be

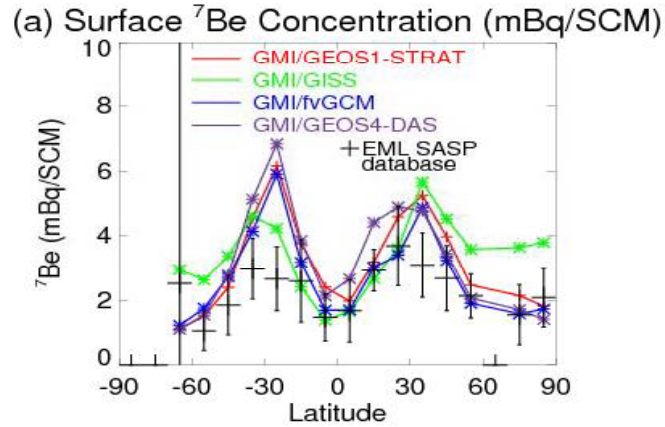


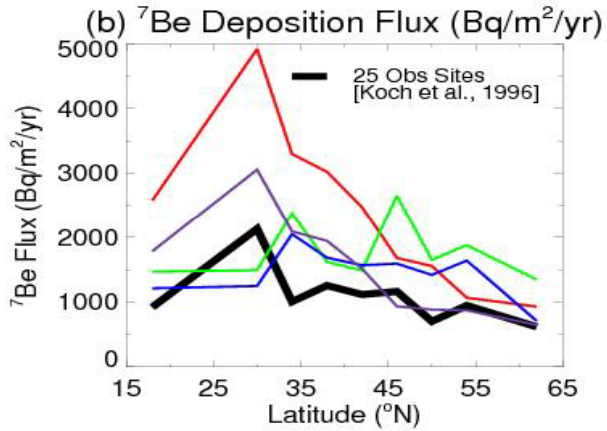
- **All four simulations overall show a similar pattern of tropospheric distribution.**
- **It appears that the GEOS1-STRAT simulation gives the highest concentration in the subtropics and the GISS simulation shows the highest concentrations at high latitudes.**

Evaluation of GMI ^{7}Be simulation results with UT/LS and surface data







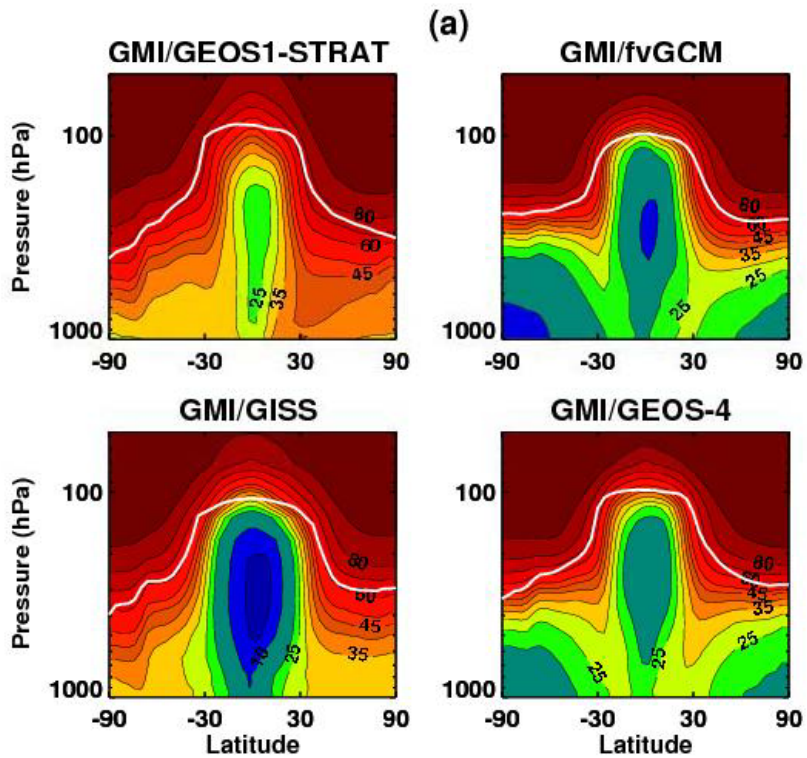


- **^{7}Be observations were corrected to the 1958 solar maximum source [Koch et al., 1996].**

- **Latitudinal trends are well simulated at the surface and in the UT/LS.**

- **GEOS1-STRAT overestimates ^{7}Be deposition fluxes at mid-latitudes and subtropics; GISS II' overestimates at high latitudes. fvGCM and GEOS-4 compare better to the observed ^{7}Be deposition fluxes.**

Assess and adjust ^{7}Be cross-tropopause flux (GMI CTM)



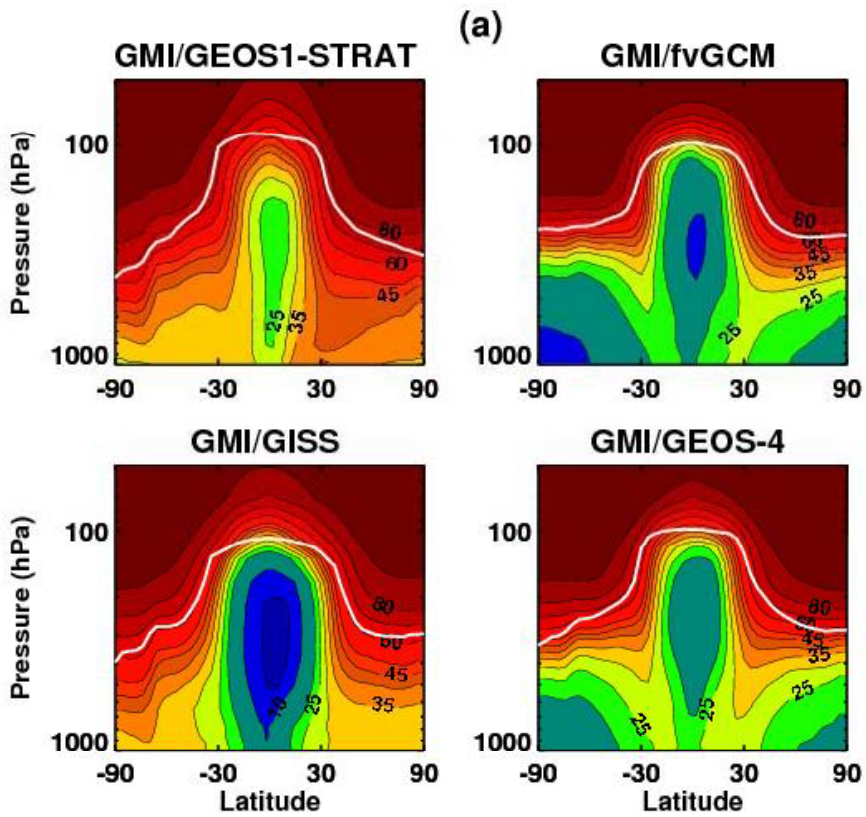
- Observed ^{7}Be / ^{90}Sr ratio → 23-27% of ^{7}Be in surface air at NH mid lat is of strat. origin [Dutkiewicz and Husain, 1985; referred to as DH85].

- To correct excessive STE in the simulations, we reduce cross-tropopause transport flux by artificially scaling down the strat. ^{7}Be source in the simulation of tropospheric ^{7}Be (not strat. ^{7}Be) [Liu et al., 2001].

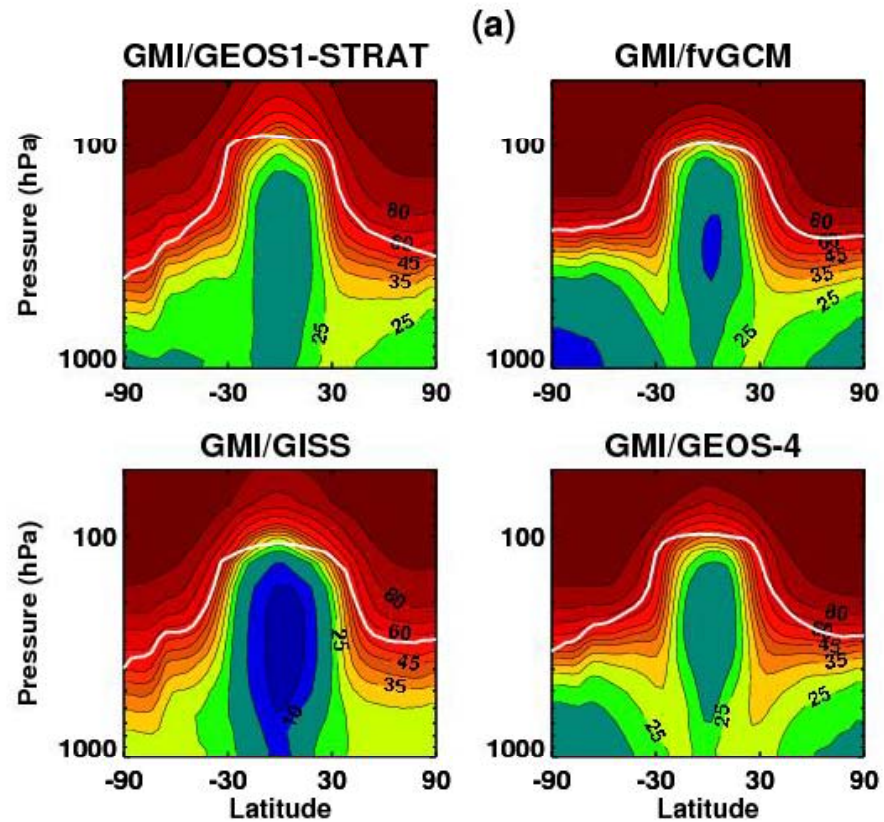
- The scaling factor *A* is determined by: $A = (1-0.25)/0.25 * F / (1-F)$ where *F* is the model calculated fraction of surface air of strat. origin at NH mid latitude (see Fig. above).
- F = 0.39 (DAO), 0.31 (GISS), 0.23 (fvGCM), 0.25 (GEOS-4);
  A = 1.92 (DAO), 1.35 (GISS), ~1.00 (fvGCM), 1.00 (GEOS-4);
  F and A are sensitive to the location of tropopause;
  WMO thermal tropopause is used.

Adjustment of ^{7}Be cross-tropopause flux (GMI CTM)

Before adjustment



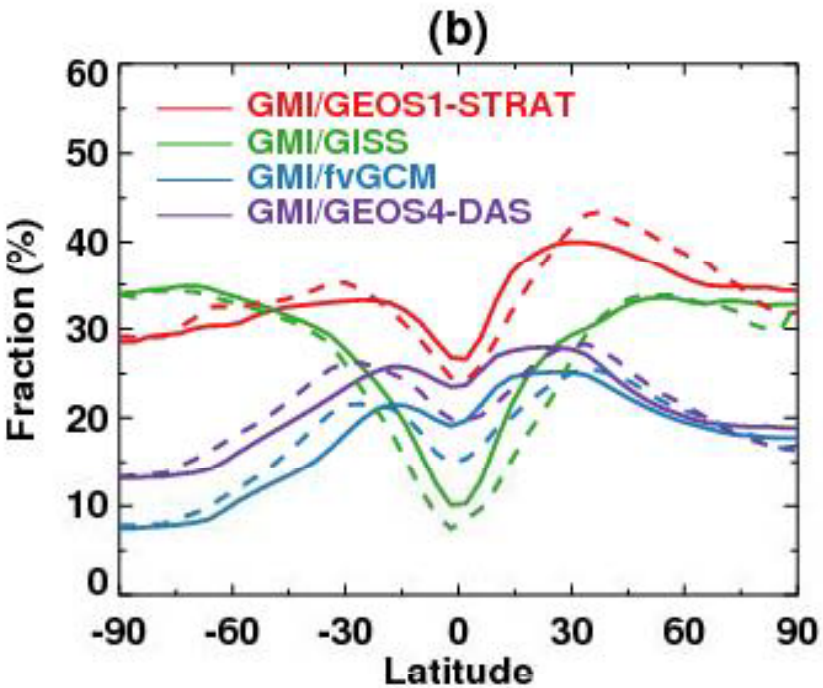
After adjustment



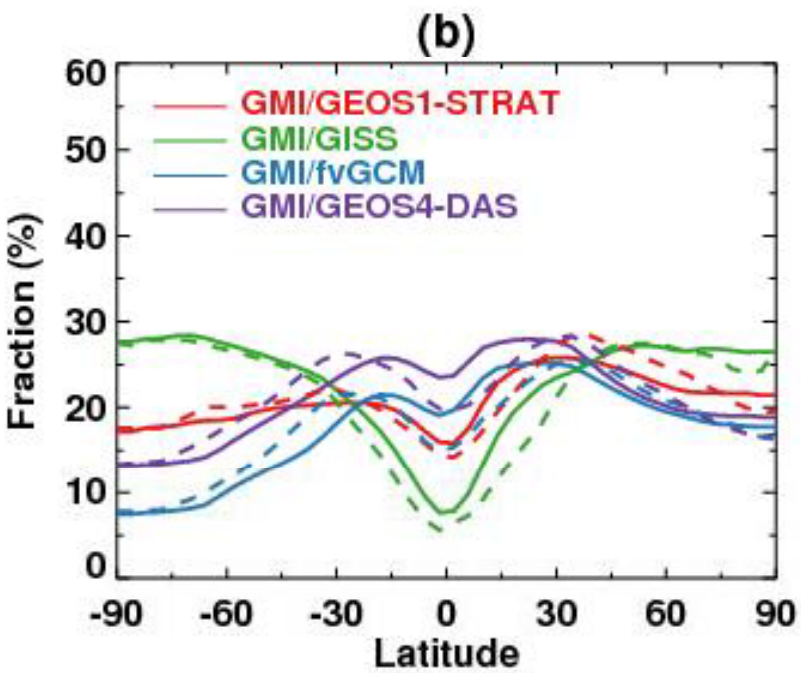
- **Indeed, after adjustment of ^{7}Be x-tropopause flux (for GEOS1-STRAT and GISS II' only), ~25% of ^{7}Be in surface air at NH mid lat is of strat. origin.**

Adjustment of ^{7}Be cross-tropopause flux (GMI CTM)

Before adjustment



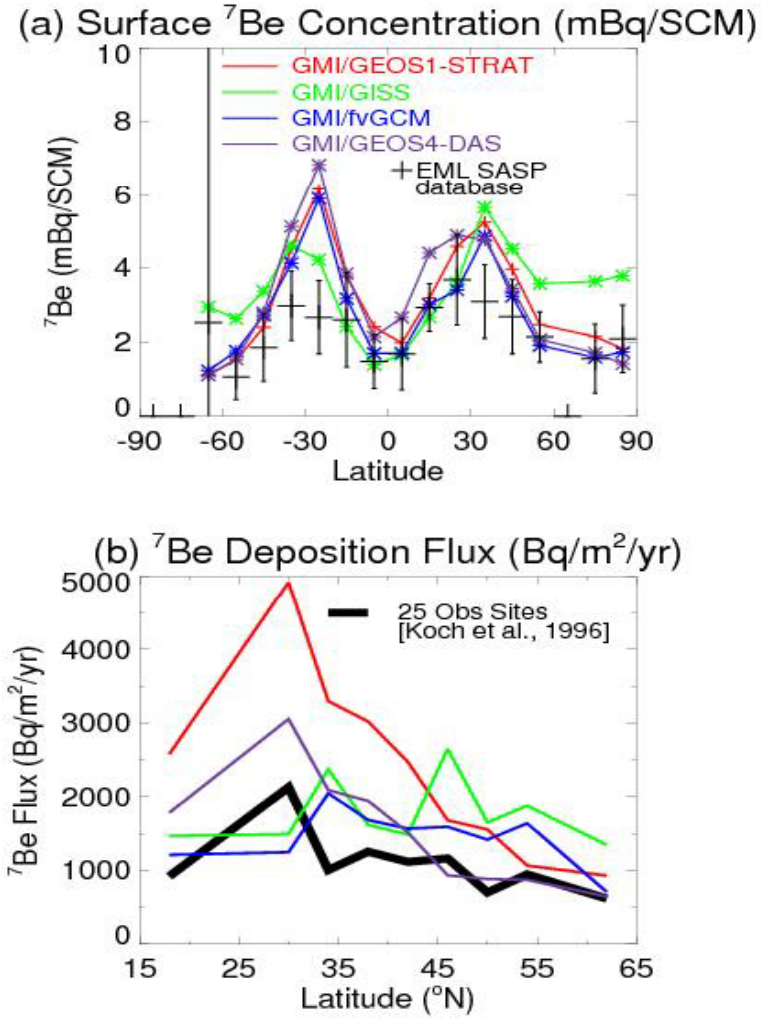
After adjustment



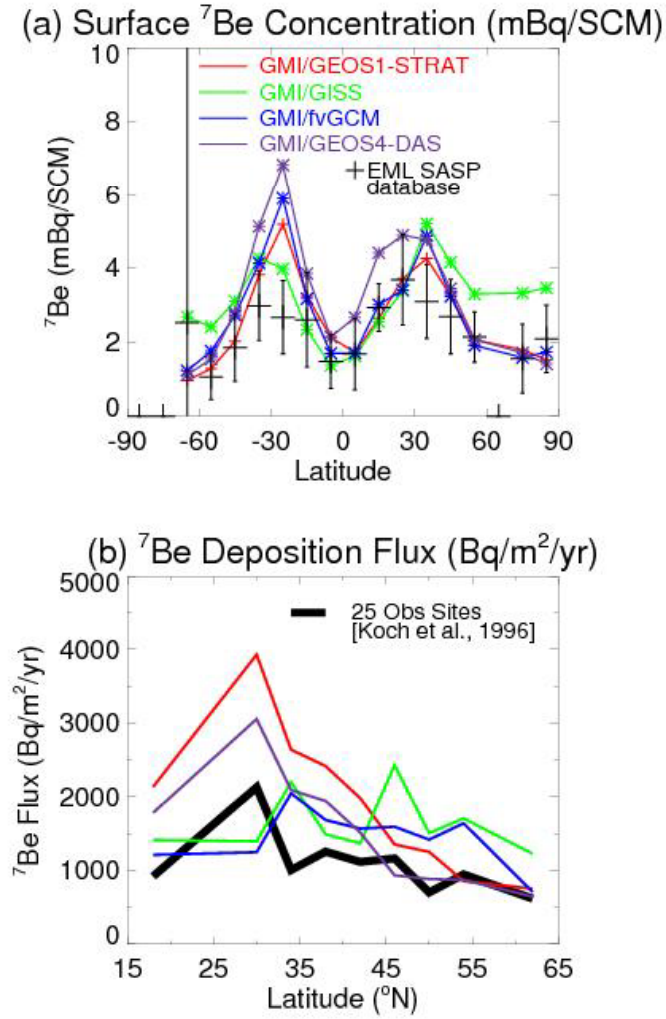
- **Indeed, after adjustment of ^{7}Be cross-tropopause flux, ~25% of ^{7}Be in surface air at NH mid lat is of strat. origin.**

Effect of adjustment of ^{7}Be cross-tropopause flux (GMI CTM)

Before adjustment

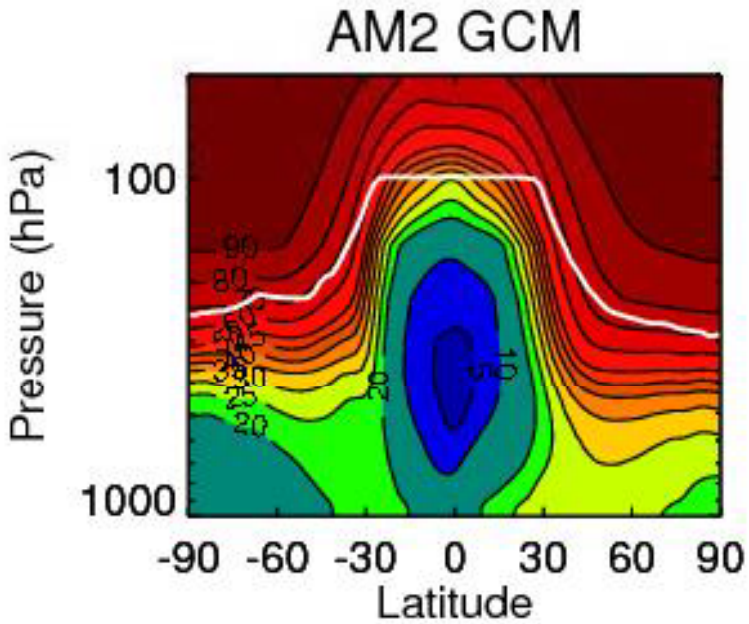


After adjustment



- **Model (GEOS1-STRAT and GISS II') ^{7}Be deposition fluxes are improved after adjustment but GEOS1-STRAT is still too large in the subtropics. Possible contributing factors: uncertainties in the diagnosed location of tropopause, ice particle gravitational settling, etc.**

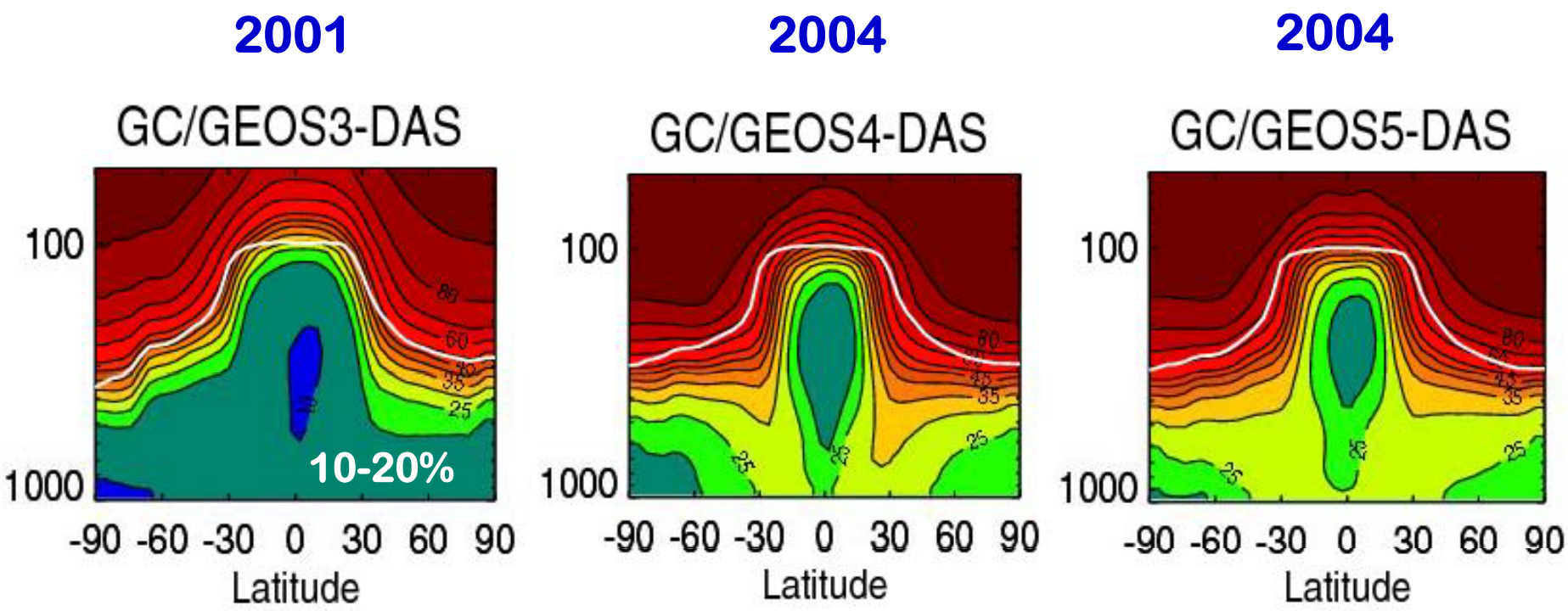
Cross-tropopause transport of ^{7}Be in AM2-Chem (year 1987)



- **The AM2-Chem diagnosed stratospheric fraction of surface ^{7}Be at NH mid-latitudes (~25-30%) qualitatively agrees with the DH85 criterion when the tropopause layer is included as part of the troposphere.**

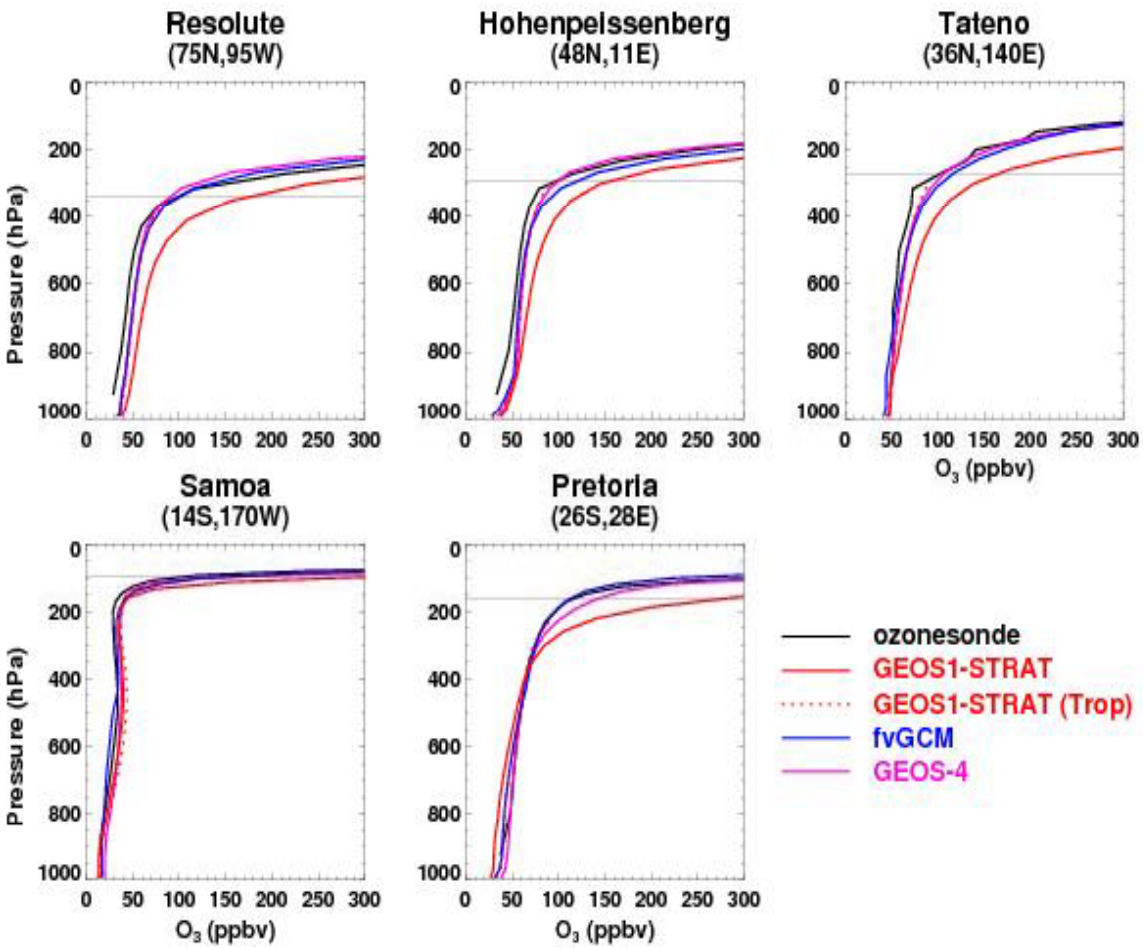
- **Using ^{7}Be to diagnose cross-tropopause transport in the model requires relatively high vertical resolution around the tropopause region.**

Stratospheric fraction (%) of ^{7}Be (GEOS-Chem)



- Slower x-tropopause transport in GEOS-3 than in GEOS-4 and GEOS-5.
- Overall GEOS-5 and GEOS-4 represent STE reasonably well - it is appropriate to implement "Linoz" ozone in both models.
- GEOS-5 shows smaller STE influence in the mid-troposphere than GEOS-4.

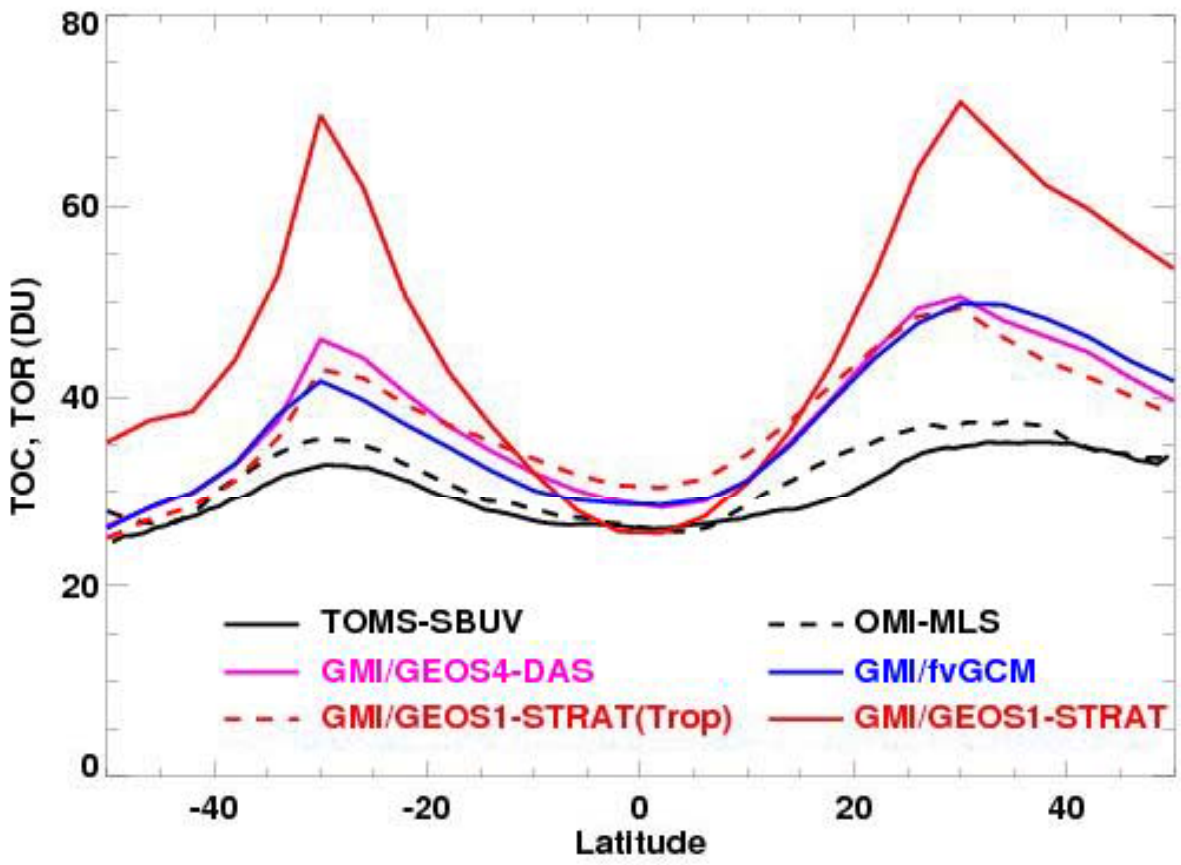
Comparisons of GMI simulated trop O_3 profiles (color lines) with ozonesonde observations (black)



- **GMI/GEOS1-STRAT Combo model produces excessive ozone in the troposphere at all latitudes except in the tropics;**
- **GMI/GEOS1-STRAT Trop model (with Synoz) corrects the problem.**

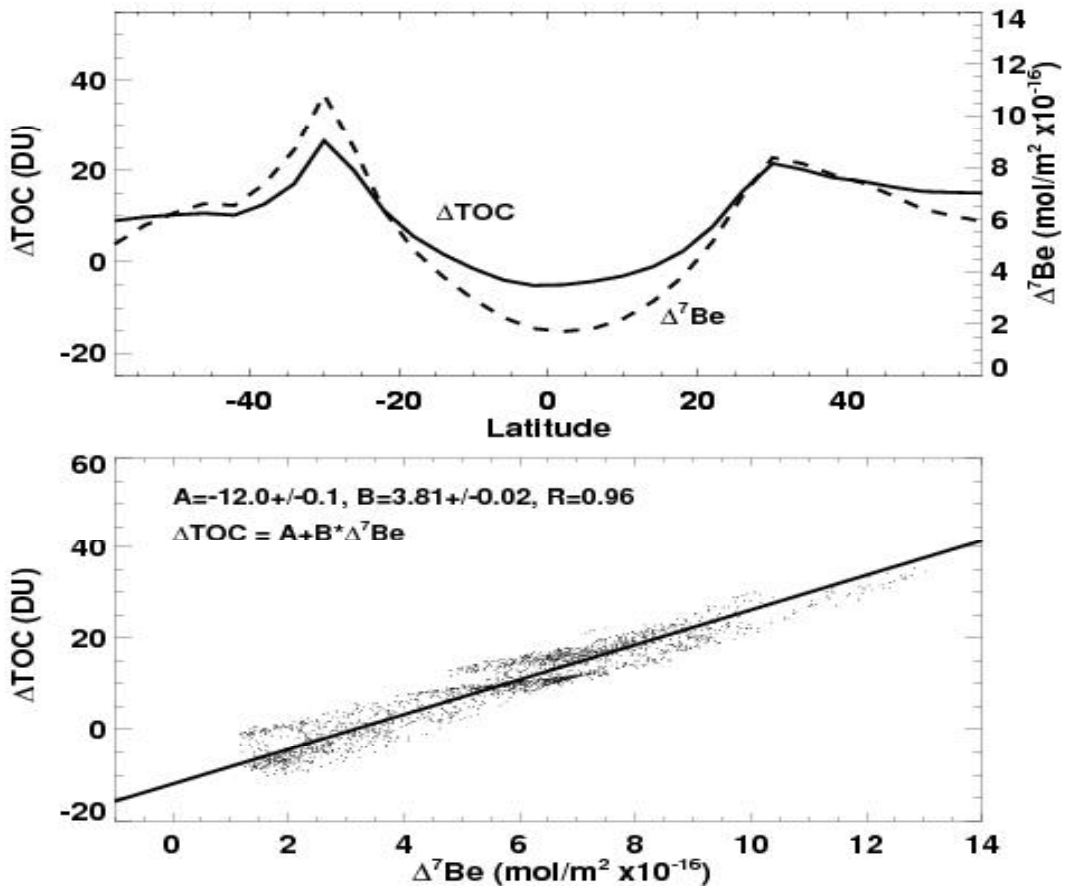
- **Results are in line with the relative magnitudes of cross-tropopause transport efficiencies of ^{7}Be in the three meteorological fields.**

GMI Combo simulated annual zonal mean trop O_3 column (TOC in DU) compared with observed trop O_3 residuals (Oct 2004-July 2008 average) from TOMS/SBUV and OMI/MLS



- **The excessive estimate by GMI/GEOS1-STRAT with maxima at 30N & 30S suggests too fast downward transport of ozone from the stratosphere.**

(a). Latitudinal variations of annual zonal mean ^{7}Be overestimate (delta ^{7}Be) and TOC overestimate (delta TOC) as simulated by GMI/GEOS1-STRAT; (b). The correlation between the global distributions of delta ^{7}Be and delta TOC.



- **The location of overestimated ozone follows that of overestimated ^{7}Be, with both maxima near 30N and 30S.**
- **The strong correlation between delta ^{7}Be and delta TOC implies that ^{7}Be is a good indicator of cross-tropopause transport of ozone.**

Summary and Conclusions
(submitted to *J. Geophys. Res.*, 2010)
http://research.nianet.org/~hyl

- **The atmospheric distributions of ^{7}Be are simulated with GMI CTM driven by GEOS-STRAT, GISS-II', fvGCM, and GEOS-4 DAS meteorological fields. Results are evaluated with UT/LS and surface data.**

- **We showed that excessive cross-tropopause transport of ^{7}Be corresponds to overestimated stratospheric contribution to tropospheric ozone, as constrained by ozonesonde, surface and satellite observations.**

- **We recommend that the DH85 constraint for ^{7}Be and observed ^{7}Be total deposition fluxes be used routinely as a first-order assessment of cross-tropopause transport in global models. Such applications require relatively high vertical resolution around the tropopause region.**

- **GEOS-5 DAS represents STE reasonably well and it is appropriate to implement "Linoz" ozone in GMI CTM or GEOS-Chem driven by GEOS-5 DAS.**

Acknowledgements

- supported by NASA MAP & partly by NOAA GFDL
- programming support - GMI “core” team
- GEOS-Chem – Harvard group with support from ACMAP
- supercomputing resources – NASA NCCS, GFDL