Chemical Transport in the MMF:

Tests and Implications for Climate

Daniele Rosa, Wei-Chun Hsieh, and Bill Collins
Earth and Planetary Science, UC Berkeley

- Objectives
- Tracers of interest
- Experimental strategy
- Data
- Results of tests

Objectives

- Objectively test fidelity of vertical convective-scale transport comparing modeled vs. measured tracers
- Quantify effects of vertical transport on the lifetime of dust and other radiative species

Residence time of aerosols increases with height

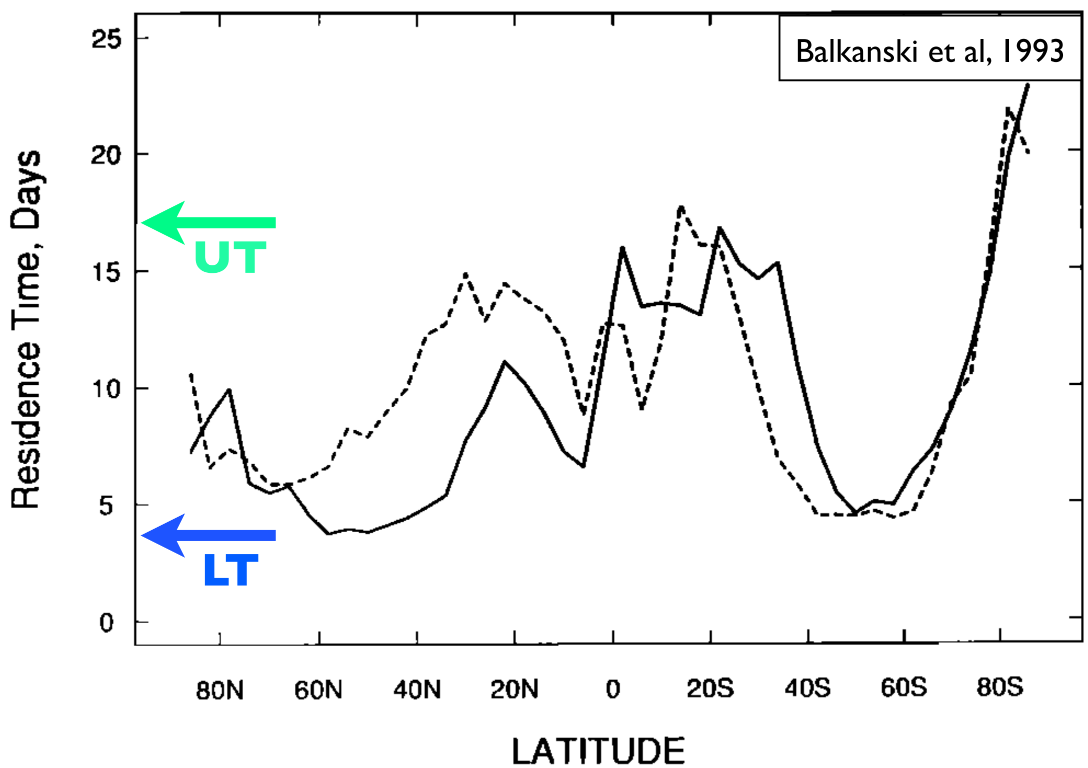


Fig. 9. Zonal mean tropospheric residence time of ^{210}Pb in the model as a function of latitude for January (solid line) and July (dashed line).

- Residence time increases by factor of 4 from lower to upper troposphere.

Tracers and species of interest

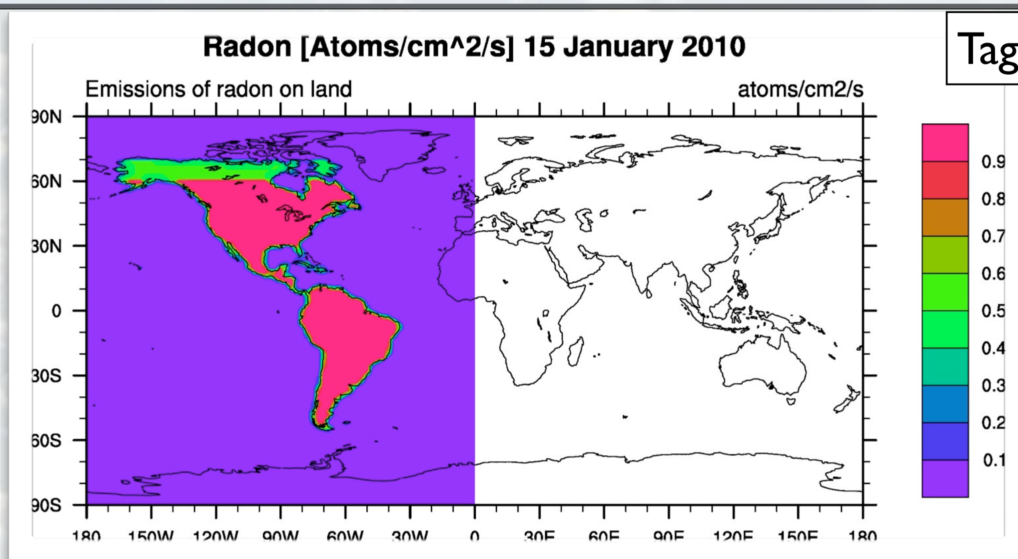
- Chemical tracer species:
  - Radon (Rn)
  - Methyl Iodide (CH_3I)
  - Carbon Monoxide (CO)

Tracers and species of interest

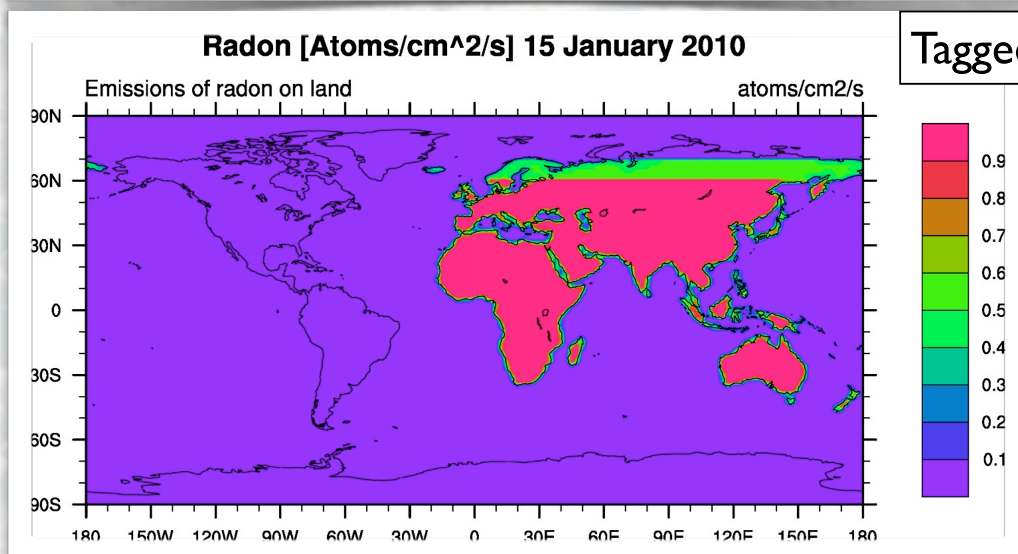
- Chemical tracer species:
  - Radon (Rn) - *Convection over land*
  - Methyl Iodide (CH_3I) - *Convection over oceans & rice*
  - Carbon Monoxide (CO) - *Convection over fires*

Sources of Radon

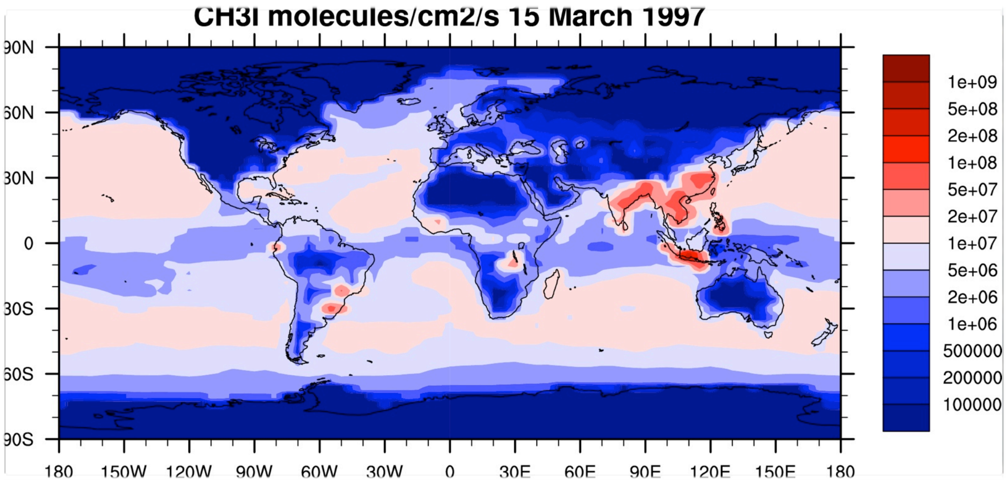
Tagged Rn for Americas



Tagged Rn for Rest of World



Sources of CH_3I and CO

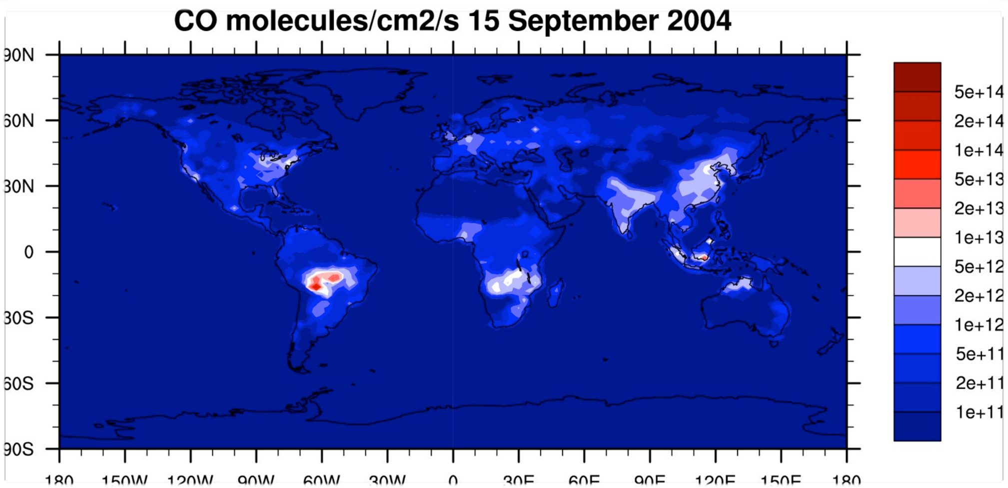


Sources:

- Ocean: 70%
- Rice: 24%
- Biofuel: 4%
- Peat: 2%

Sinks:

- Photolysis: 99%



Sources:

- Burns: 30%
- Fuel use: 55%
- Biogenic: 15%

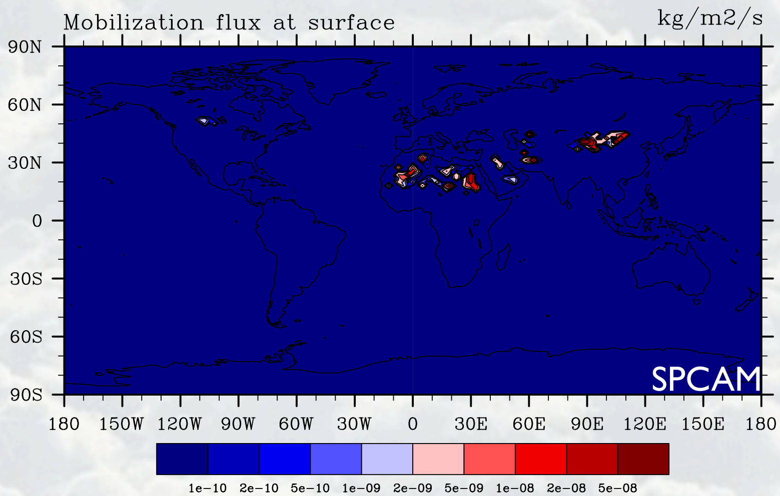
Sinks:

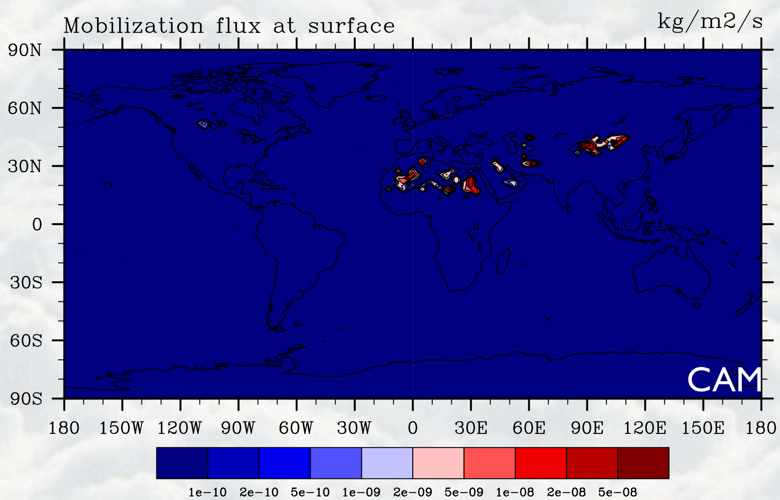
- OH: ~100%

Tracers and species of interest

- Chemical tracer species:
  - Radon (Rn) - *Convection over land*
  - Methyl Iodide (CH_3I) - *Convection over oceans*
  - Carbon Monoxide (CO) - *Convection over fires*
- Soil dust:
  - Dust is a significant natural radiatively active aerosol.
  - Longwave dust forcing increases with altitude.

Sources of dust





- Primary emissions are localized to northern subtropics and midlatitudes.
- Primary sinks are dry deposition and scavenging by precipitation.

Characteristic lifetimes of tracers

- CH_3I: τ~2 days
  - Useful for studying transport on short length/time scales.
- Rn: τ~5.5 days
  - Useful for studying transport on longer scales.
- CO: τ~40 days
  - UT gradient is balanced between convective divergence and photochemical processes.

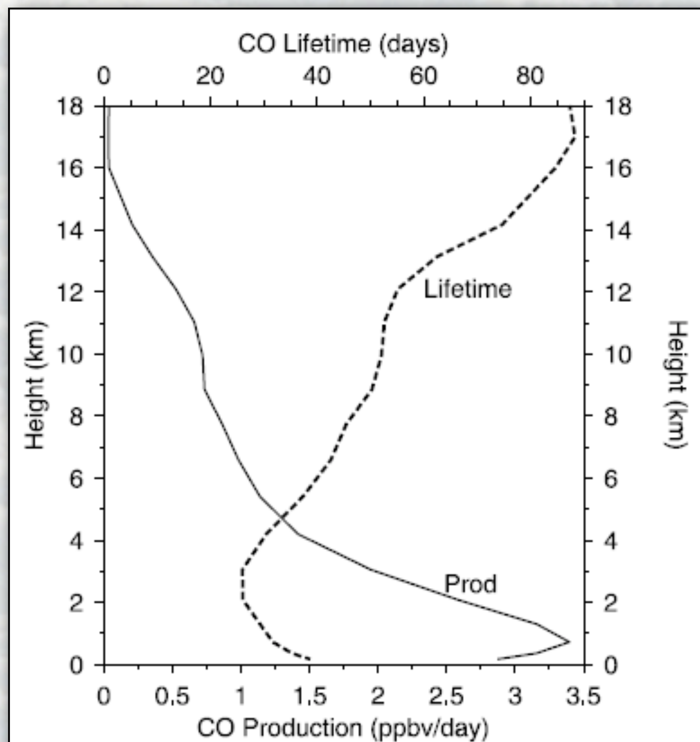
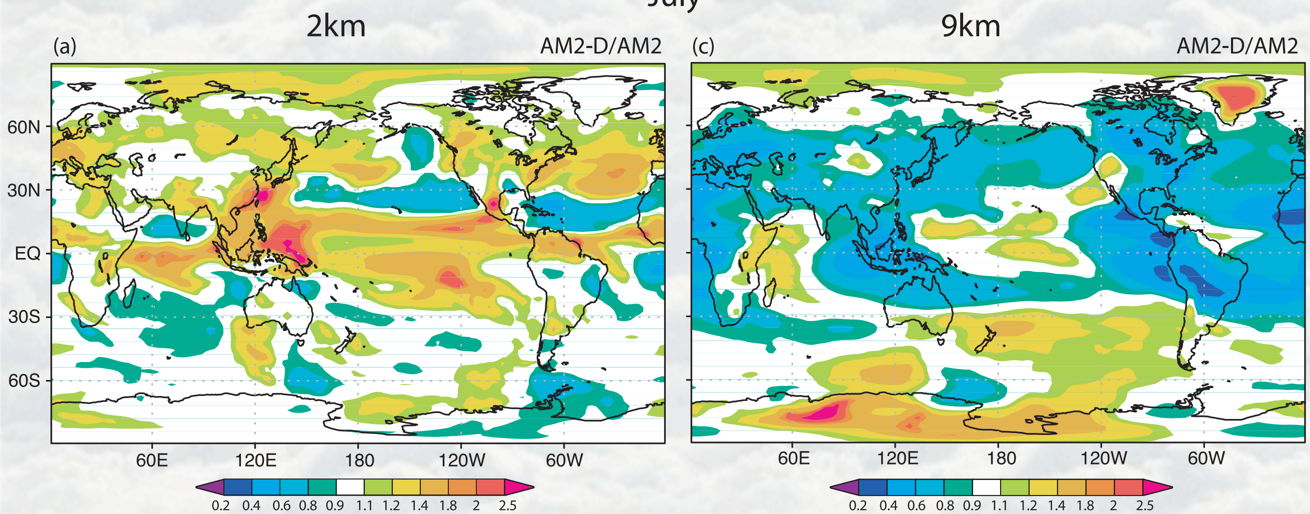


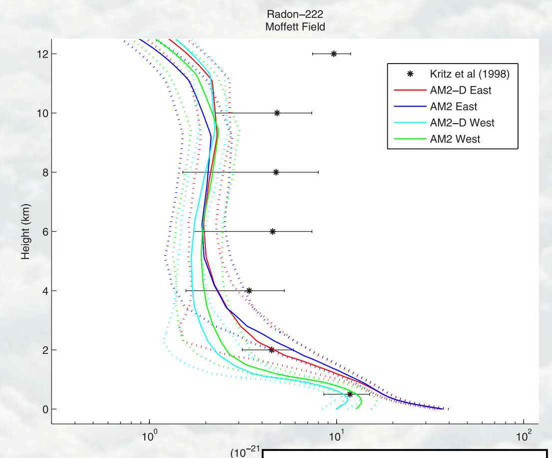
Figure 11. An estimate of the tropical mean production of carbon monoxide, and its lifetime against photochemical loss. These estimates were used in the CONRAD (Emanuel) and TCM (Folkins and Martin) models to calculate the CO profiles shown in Figure 9. Their derivation is described in the text.

Folkins et al, 2006

Earlier studies of tracers for convective transport

Radon - 222
July





Donner et al, 2007

- Tracers help diagnose differences in mass fluxes and detrainment in alternative convective parameterizations.
- Observational tracer comparisons help assess fidelity.

Experimental Strategy

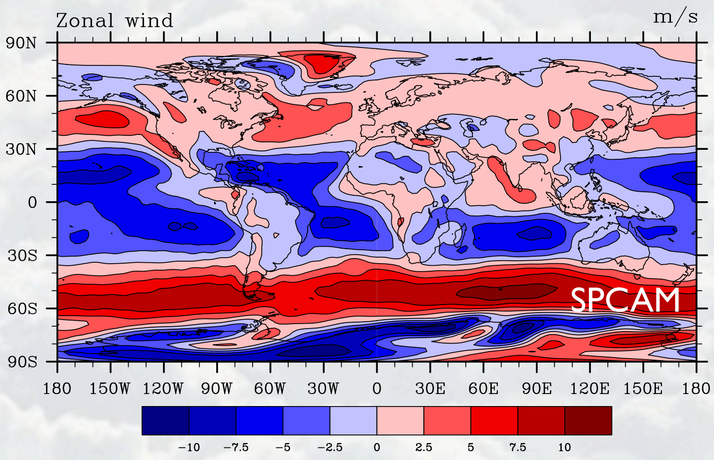
- Control GCM: CAM
- Experimental GCM: SPCAM

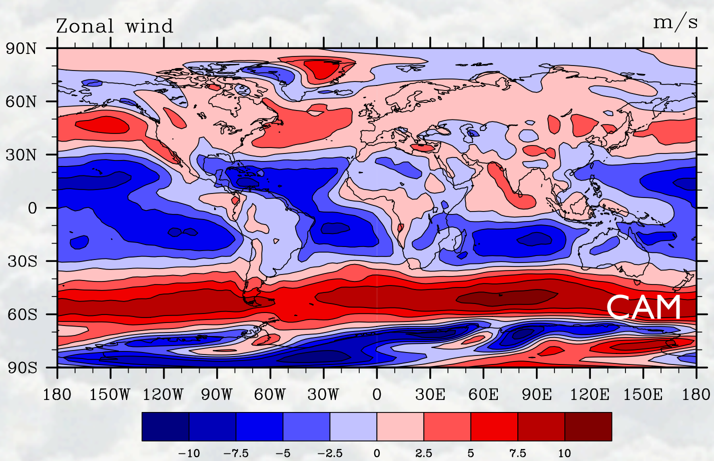
- To isolate effects of cloud-system-scale velocities, GCMs are run as Chemical Transport Models.

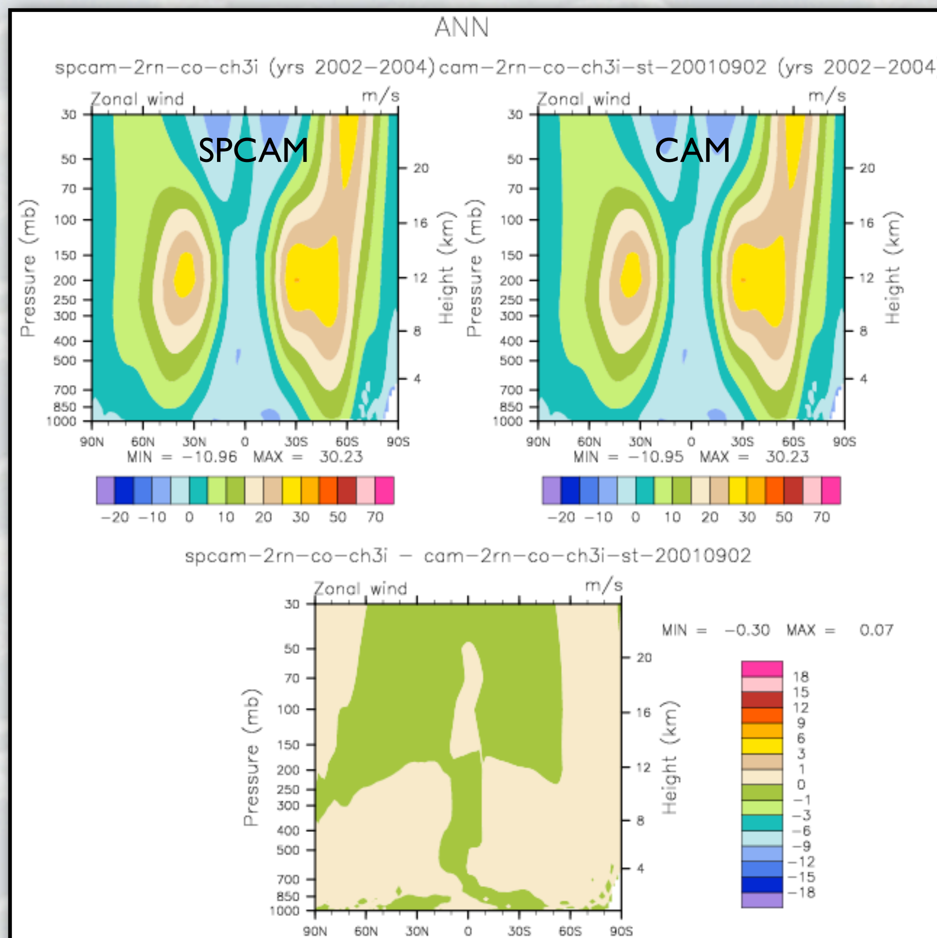
- Large-scale lateral transports by $\overline{v}$ are identical.

- Small-scale vertical transports differ due to physics.

Identical large-scale wind fields

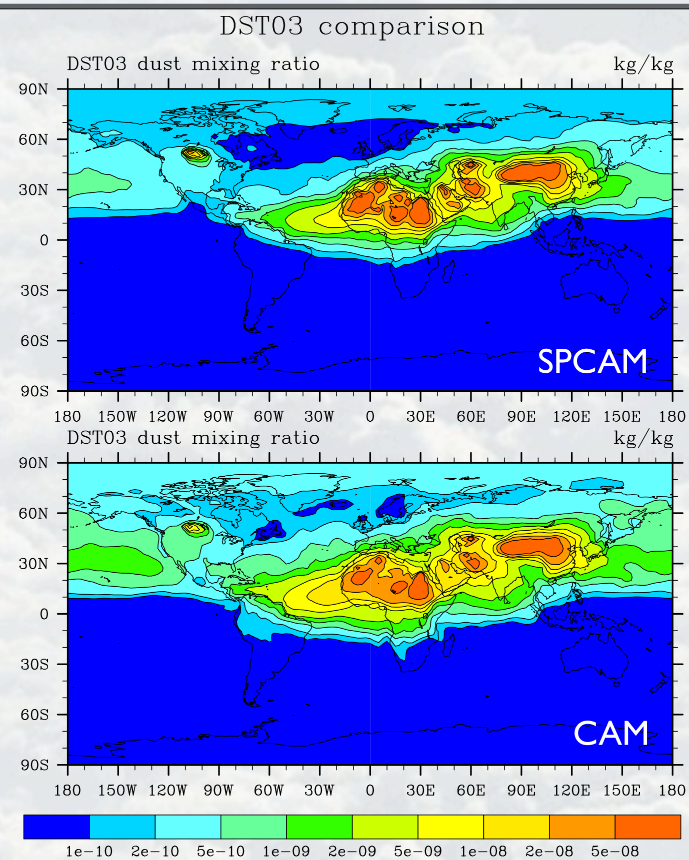






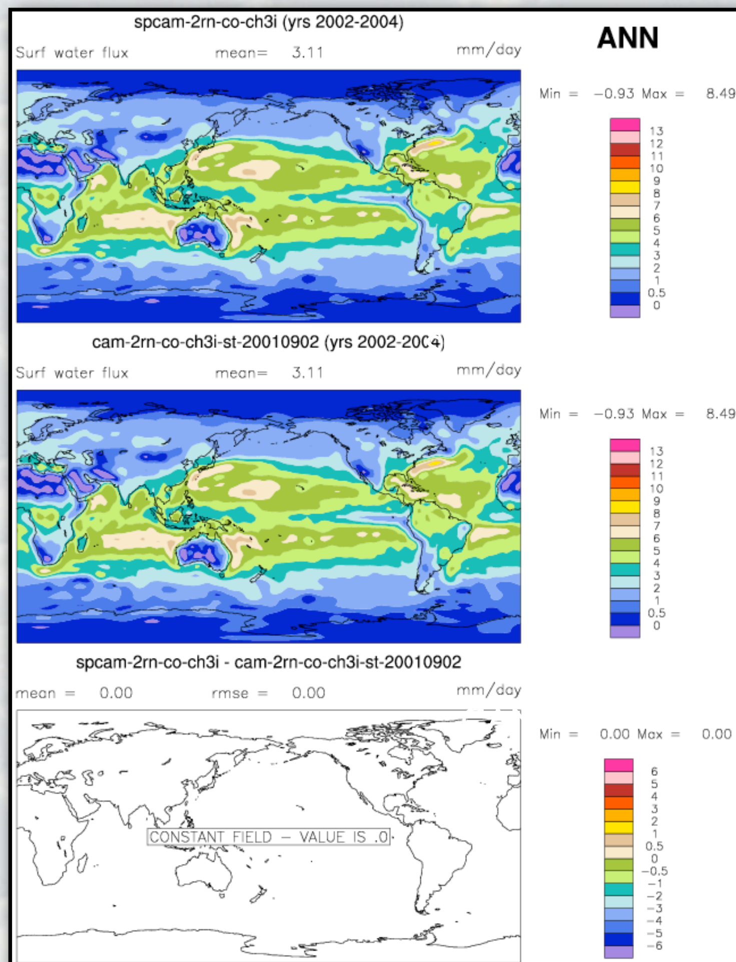
- Surface mobilization and resolved transport are the same.

CTM mode simplifies model↔model tests



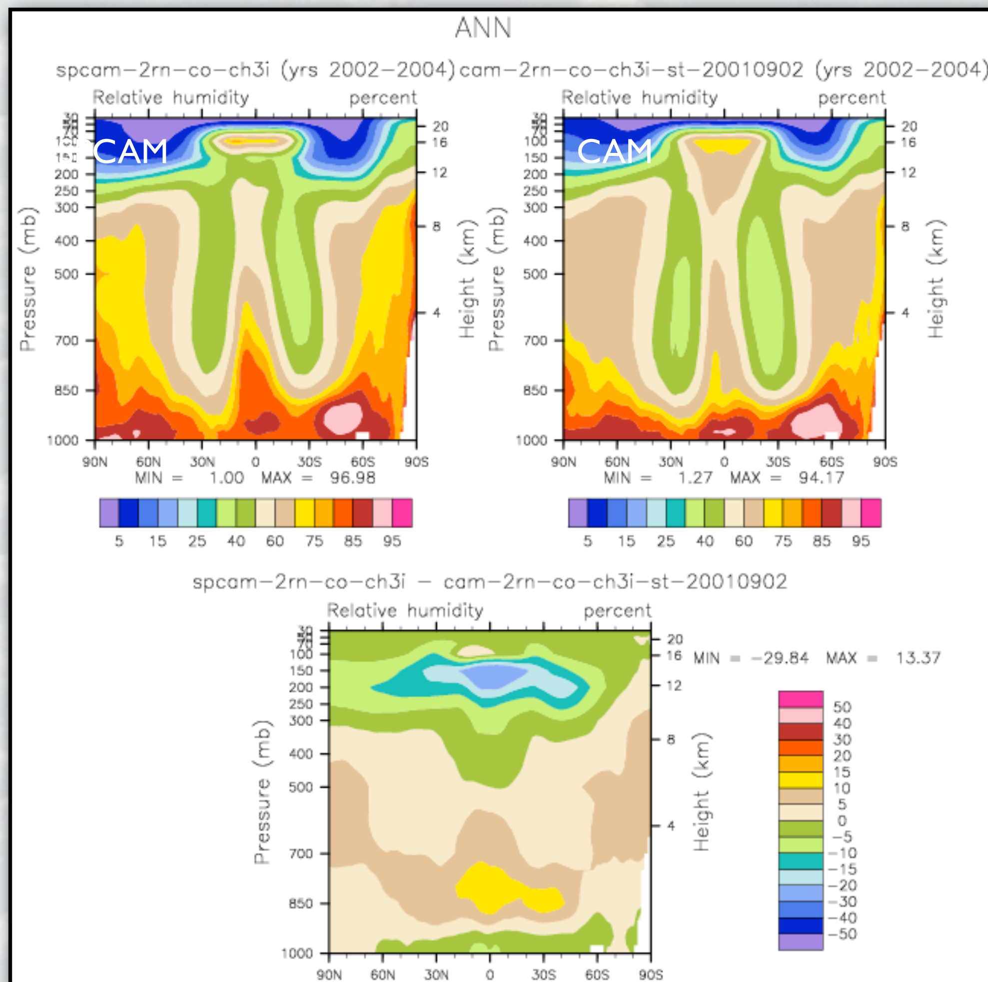
- Large scale meteorology is identical in two models.
- This eliminates feedbacks from physics to large scales, isolating signal from just convective-scale vertical motions.

Sources of atmospheric moisture are identical



- Moisture is controlled via surface water fluxes.

ΔRH due to convective-system scale physics.



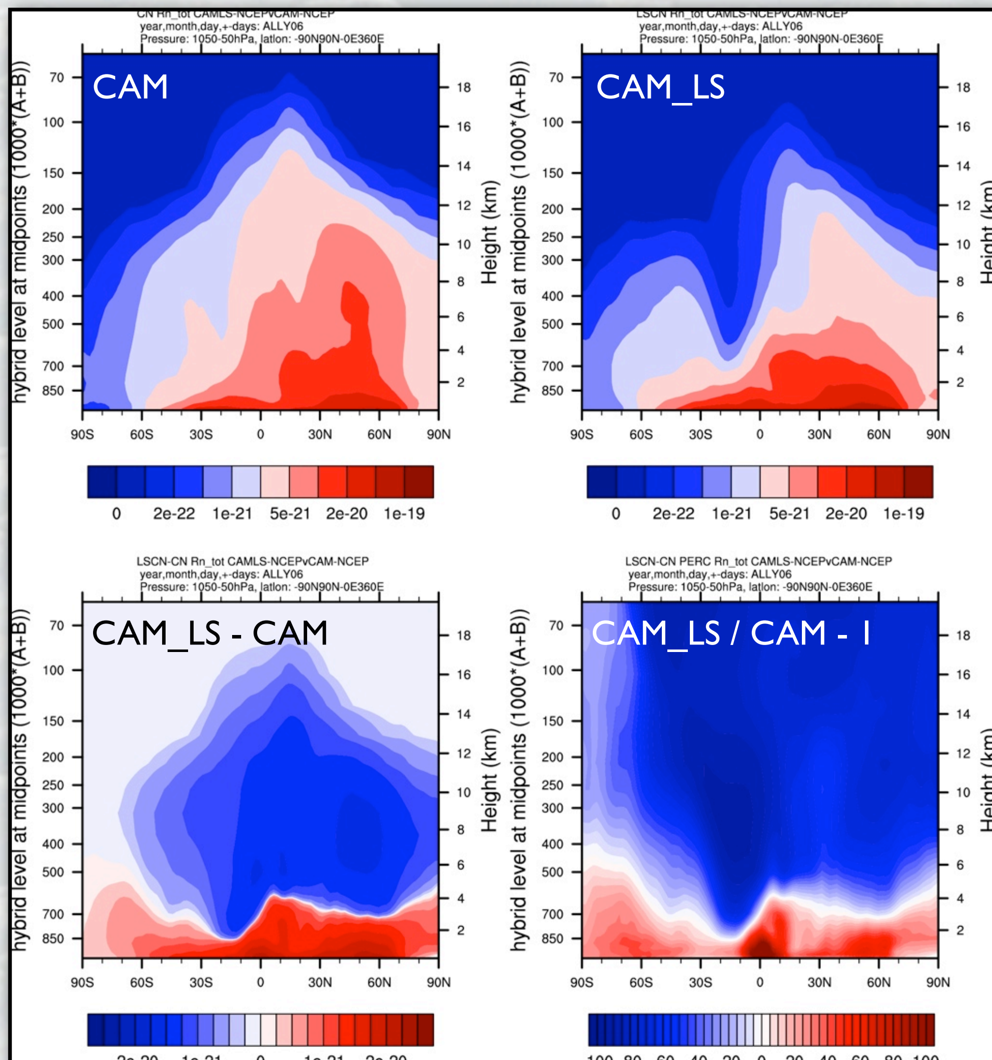
- MMF dries the PBL and UT and moistens the MT.

CTM mode simplifies model↔data tests

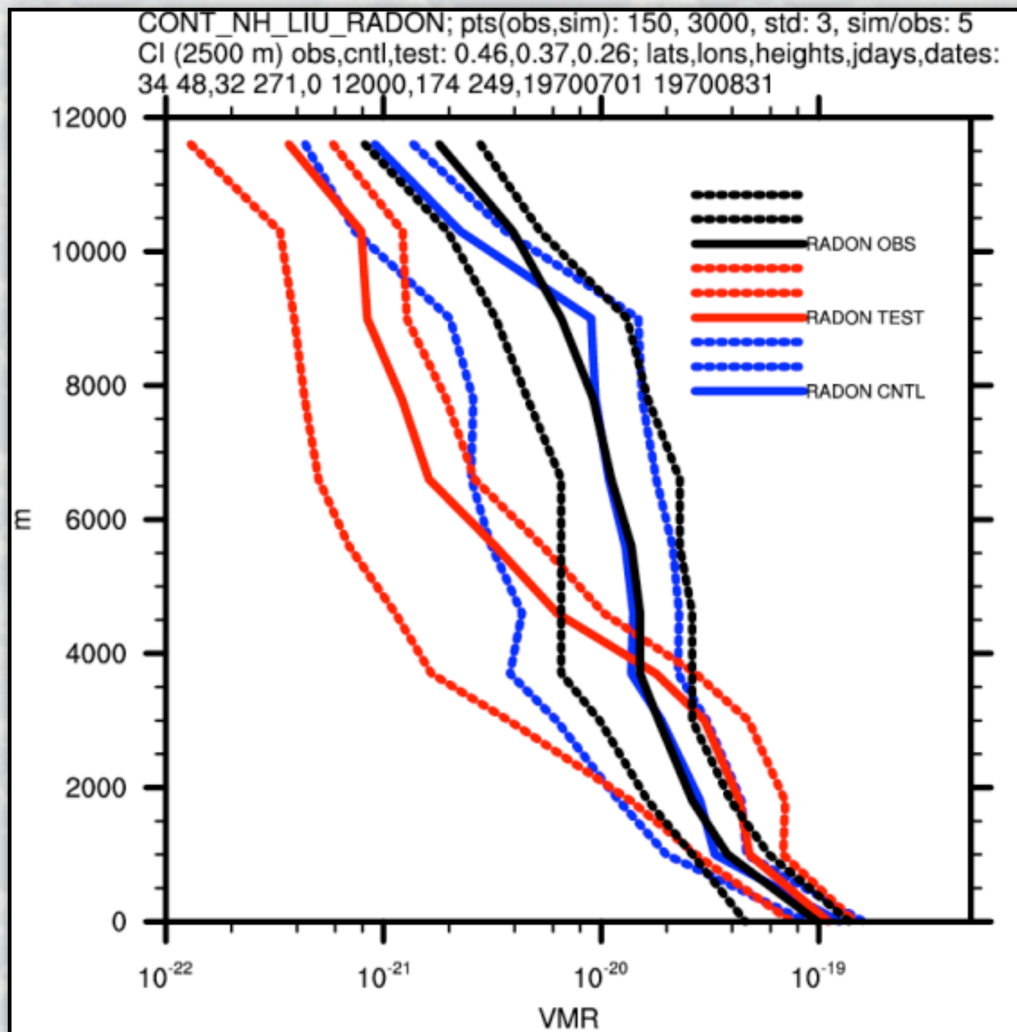
- If reanalysis fields are used for the CTM mode in CAM and SPCAM, this minimizes errors in modeled vs. (one realization of) actual large-scale transport.

- Differences between model and data should be dominated by model physics.

Impacts of convective transport on tracers

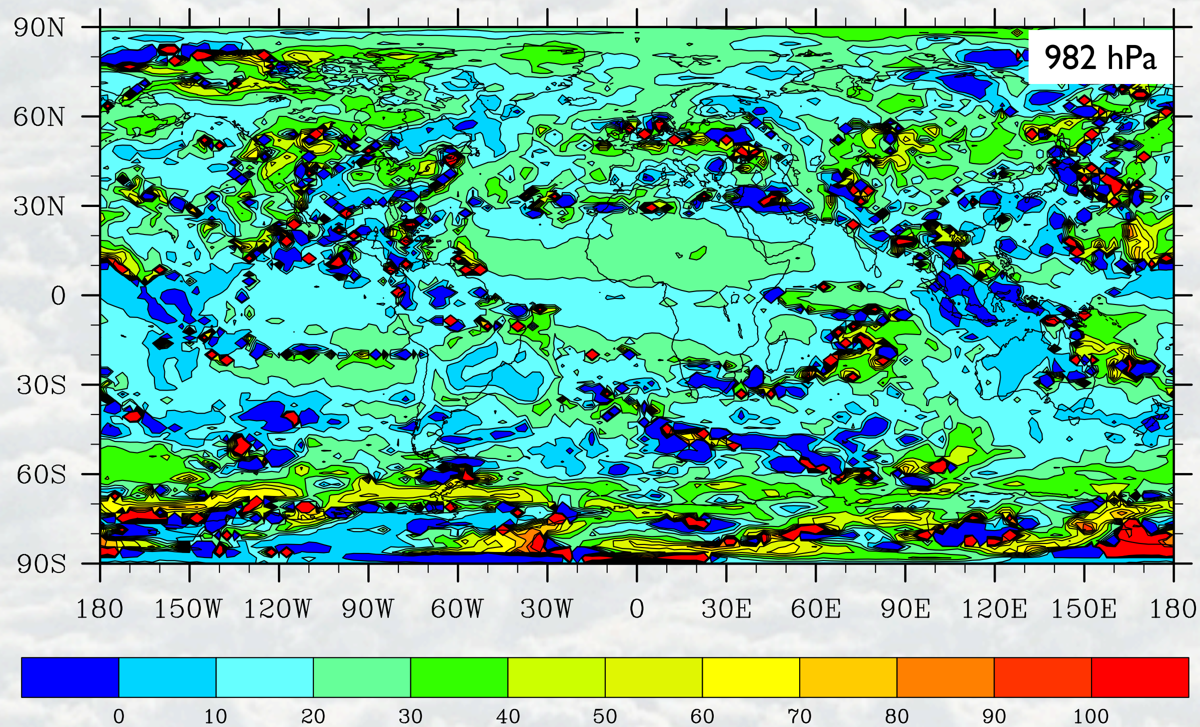


Impact of convective transport on errors relative to observations



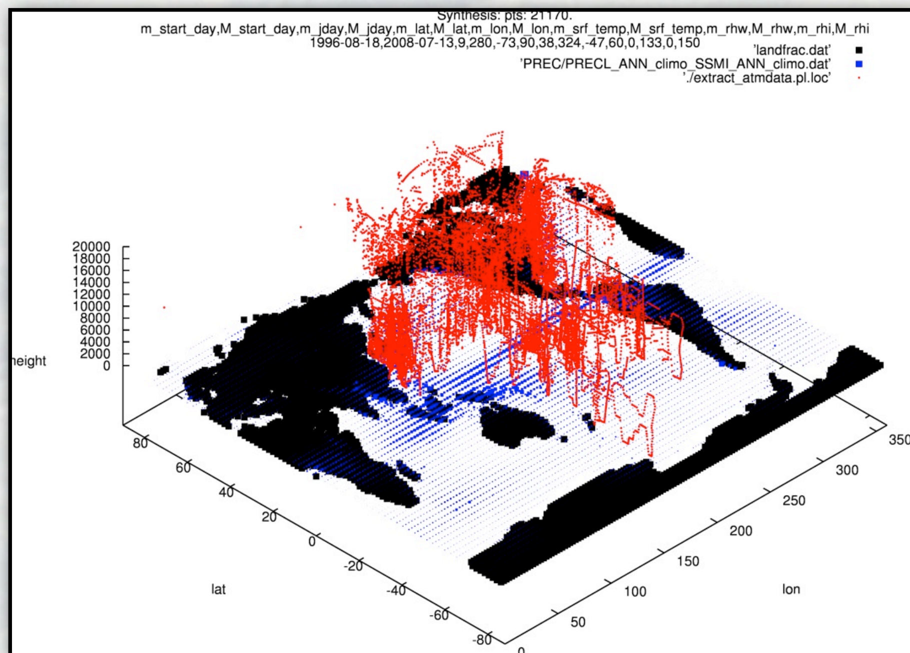
Significant sub-grid dust transport?

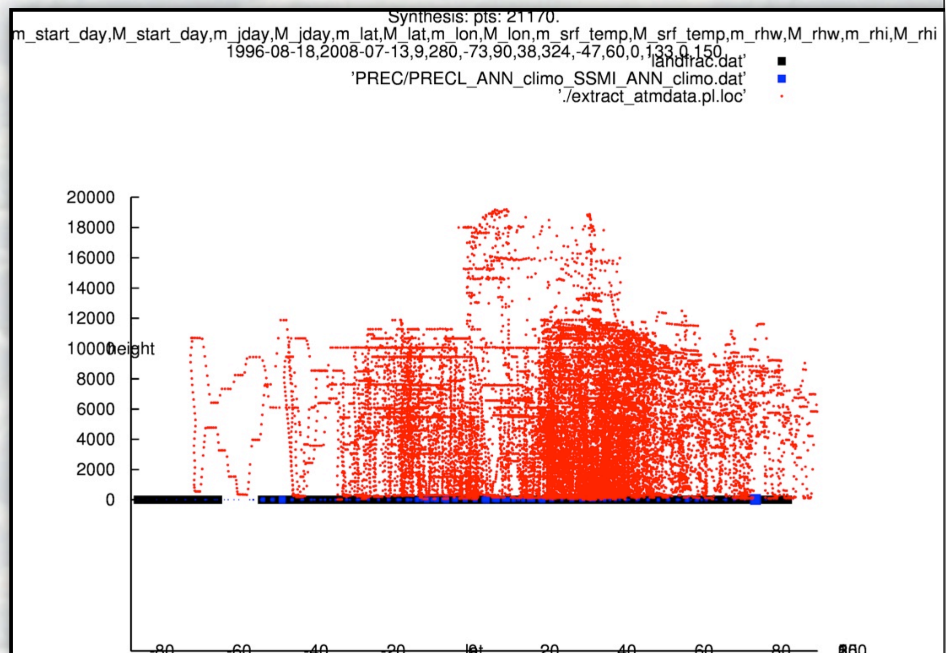
Ratio of sub-grid to cloud-resolved transports for dust size bin 1



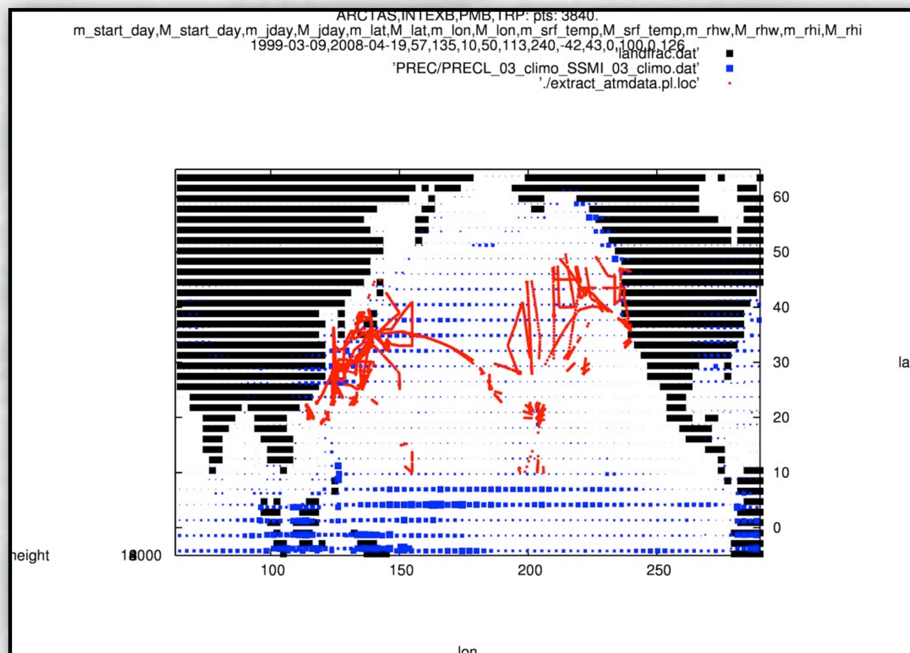
- SGS effects are ≤ 20% to 30% over most of globe.
- Two primary scales are L(GCM) and L(CRM).

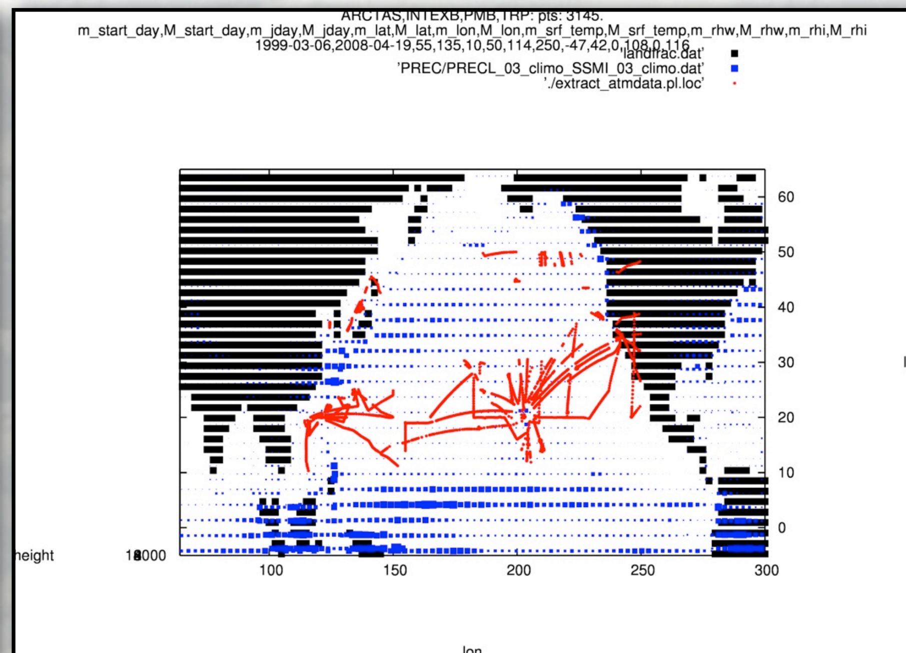
Experimental data for Methyl Iodide



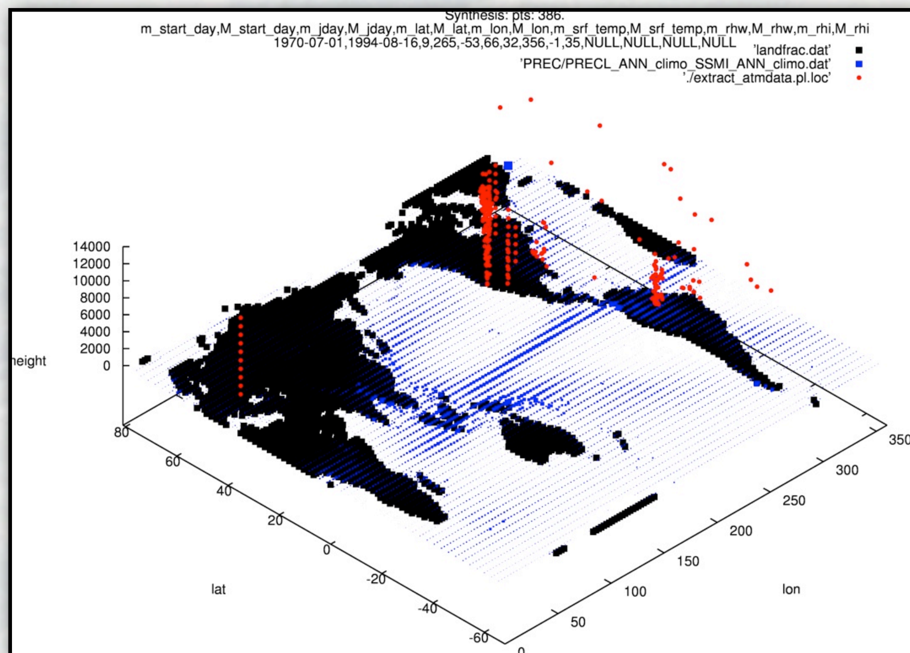


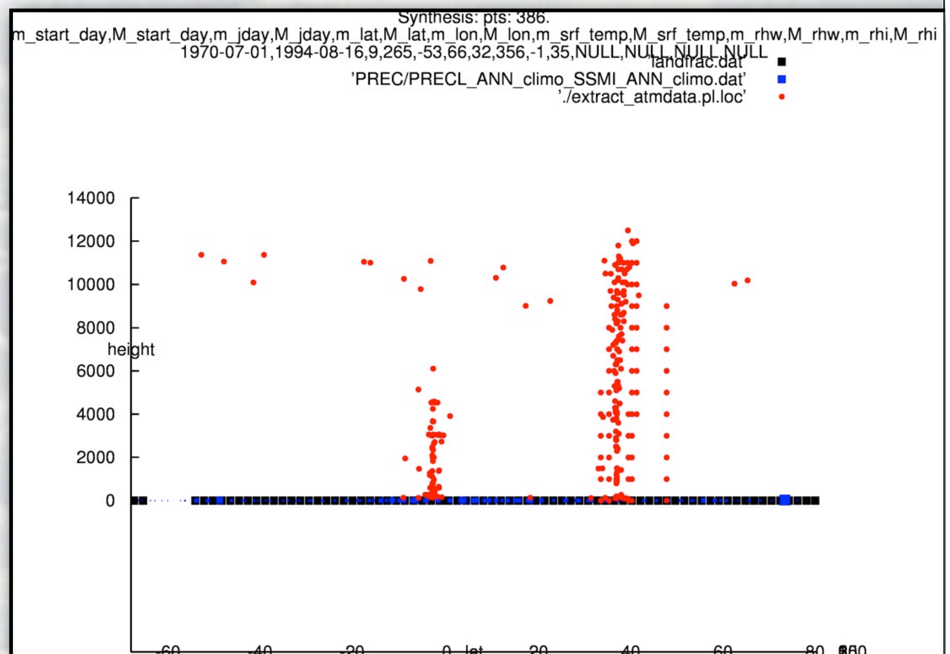
Partitioning by climatological rainfall



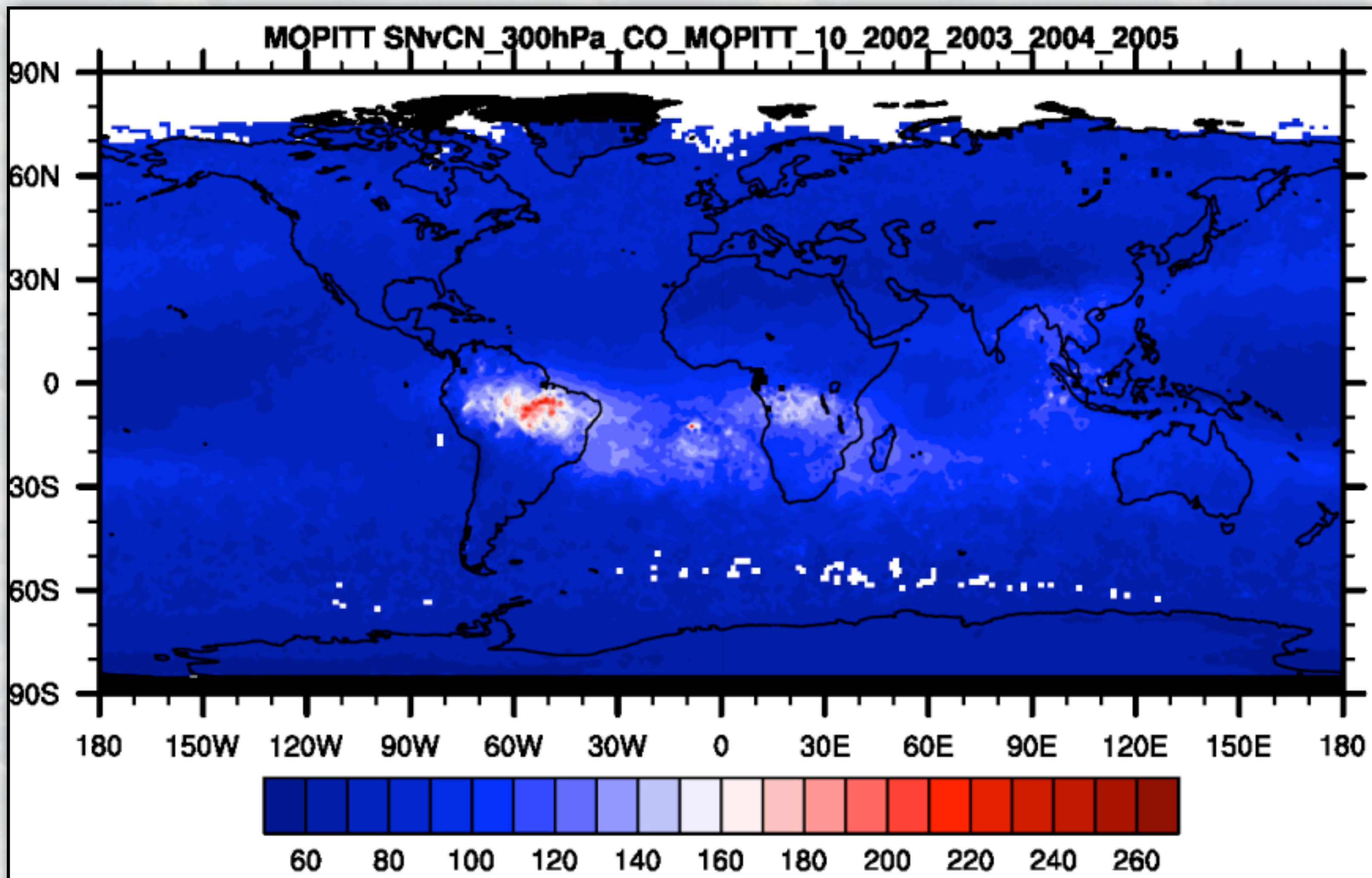


Experimental data for Radon

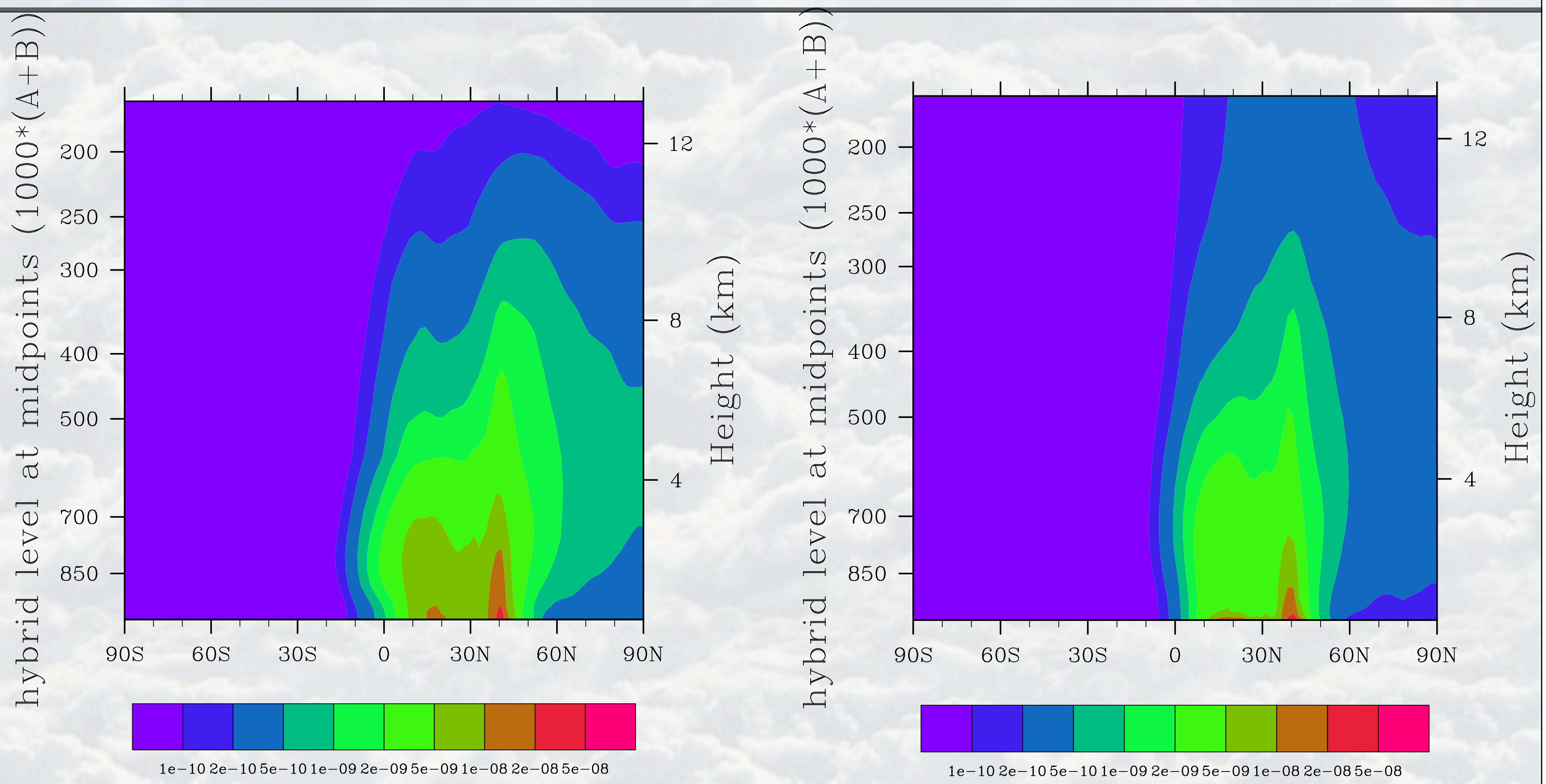




Satellite retrievals for carbon monoxide

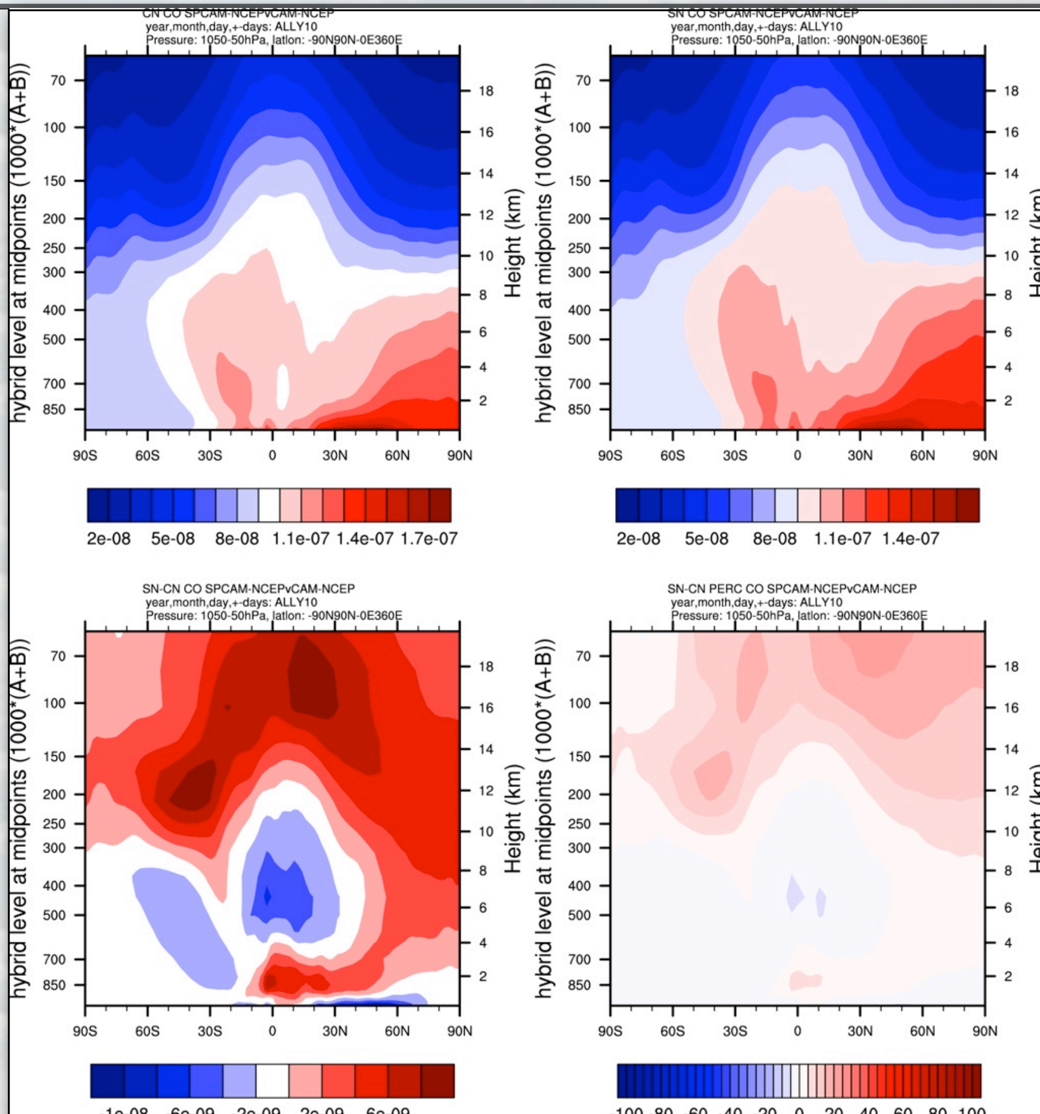


Initial Simulations for Dust

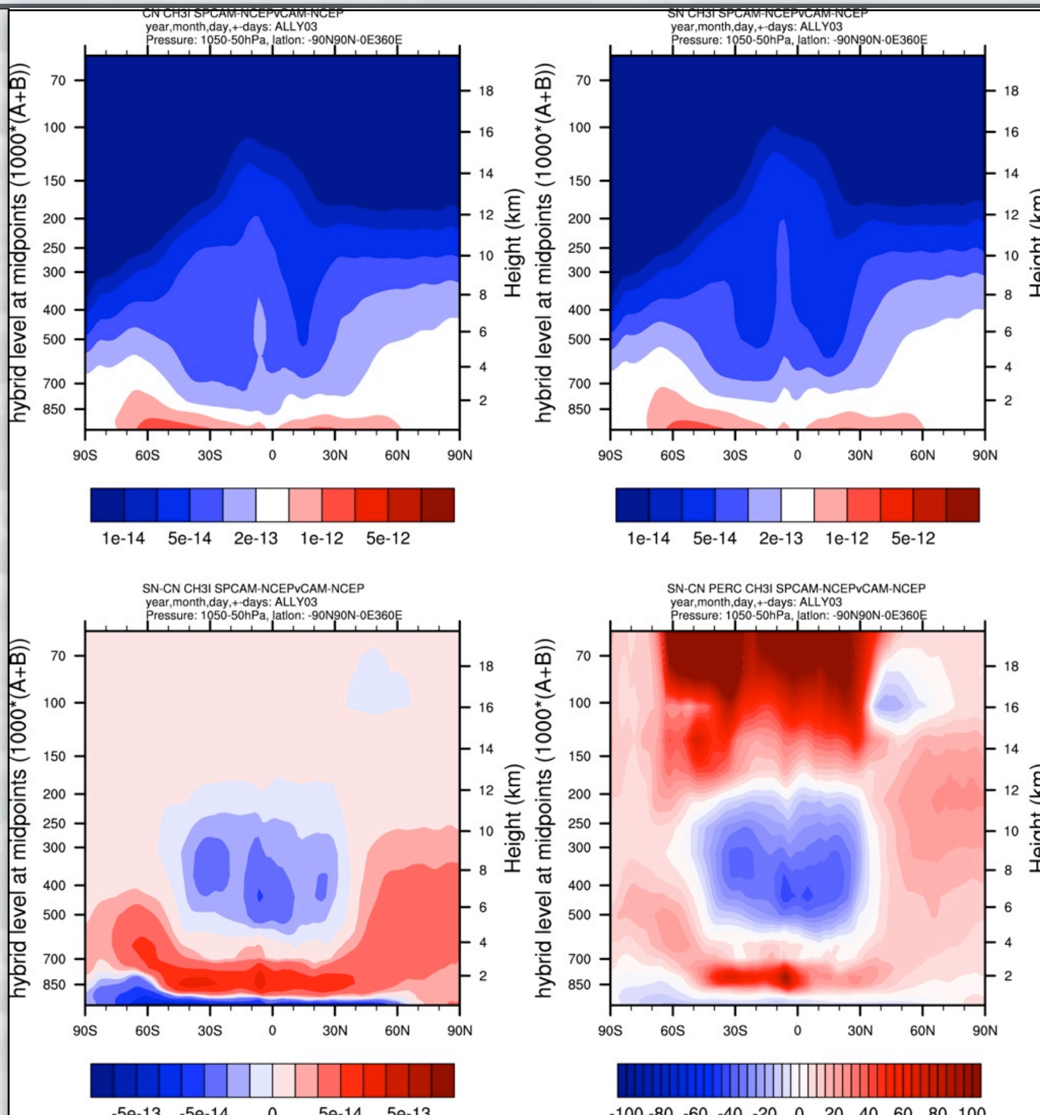


- SPCAM transports less dust to free troposphere, and to high latitudes far from desert sources.

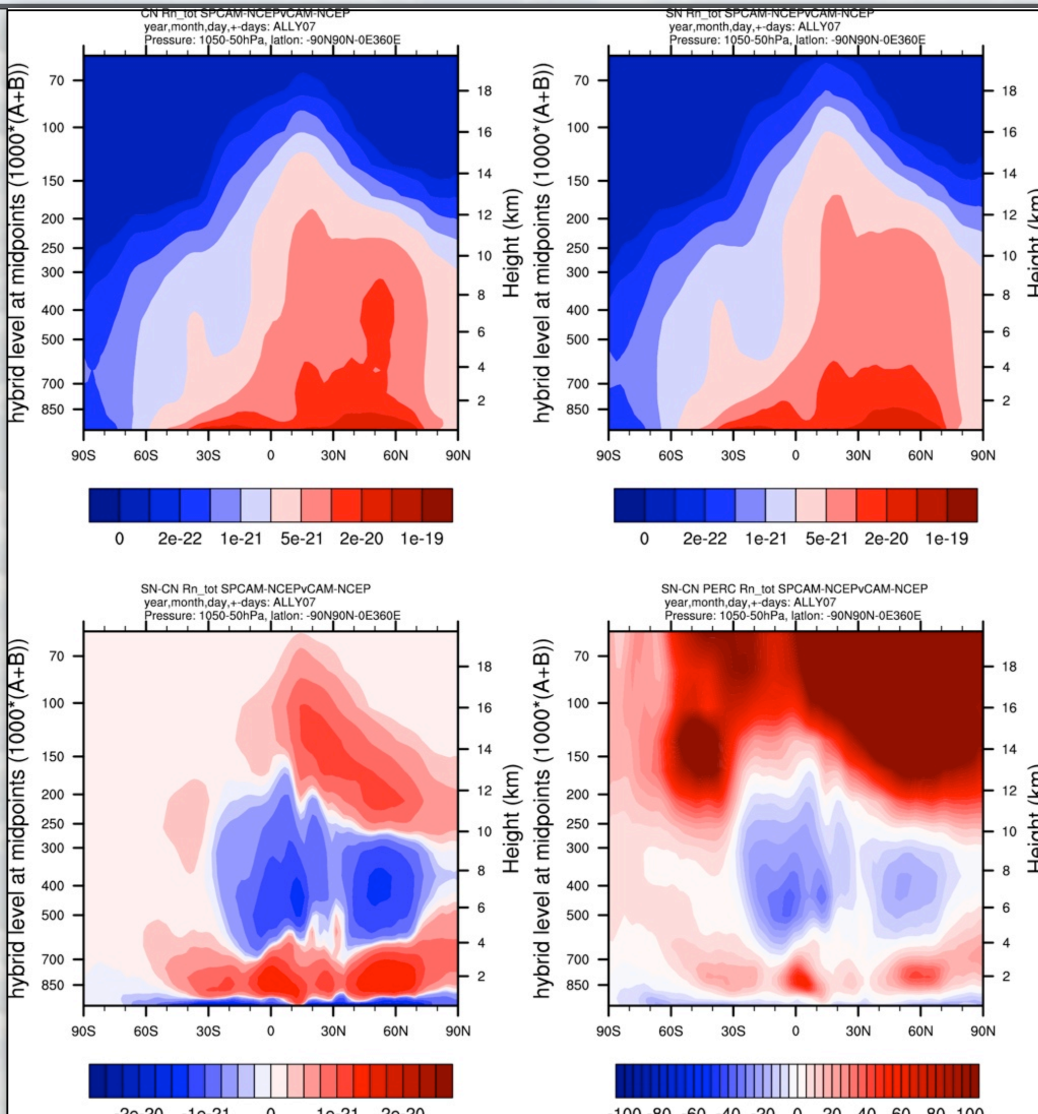
Model differences in Carbon Monoxide



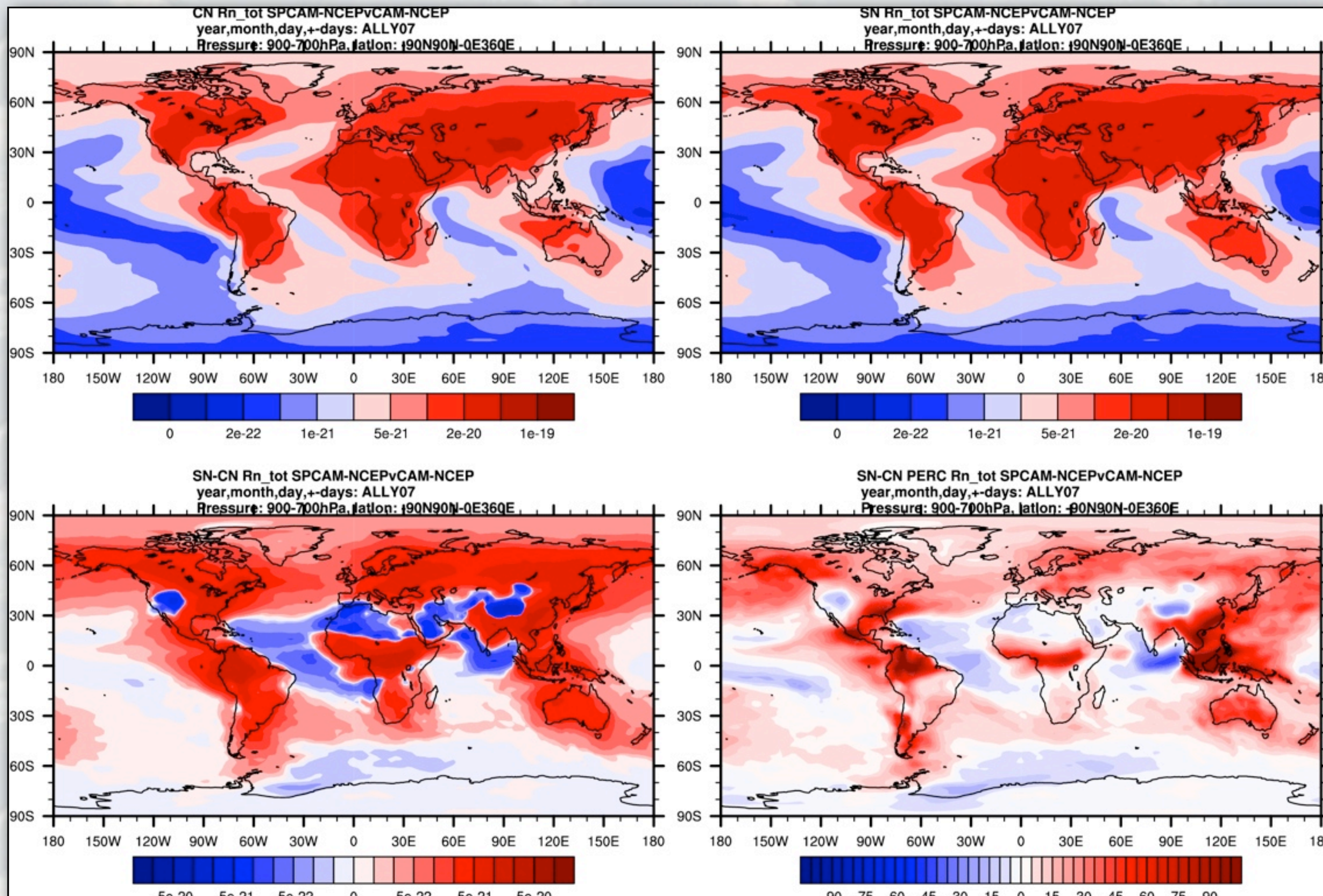
Model differences in Methyl Iodide



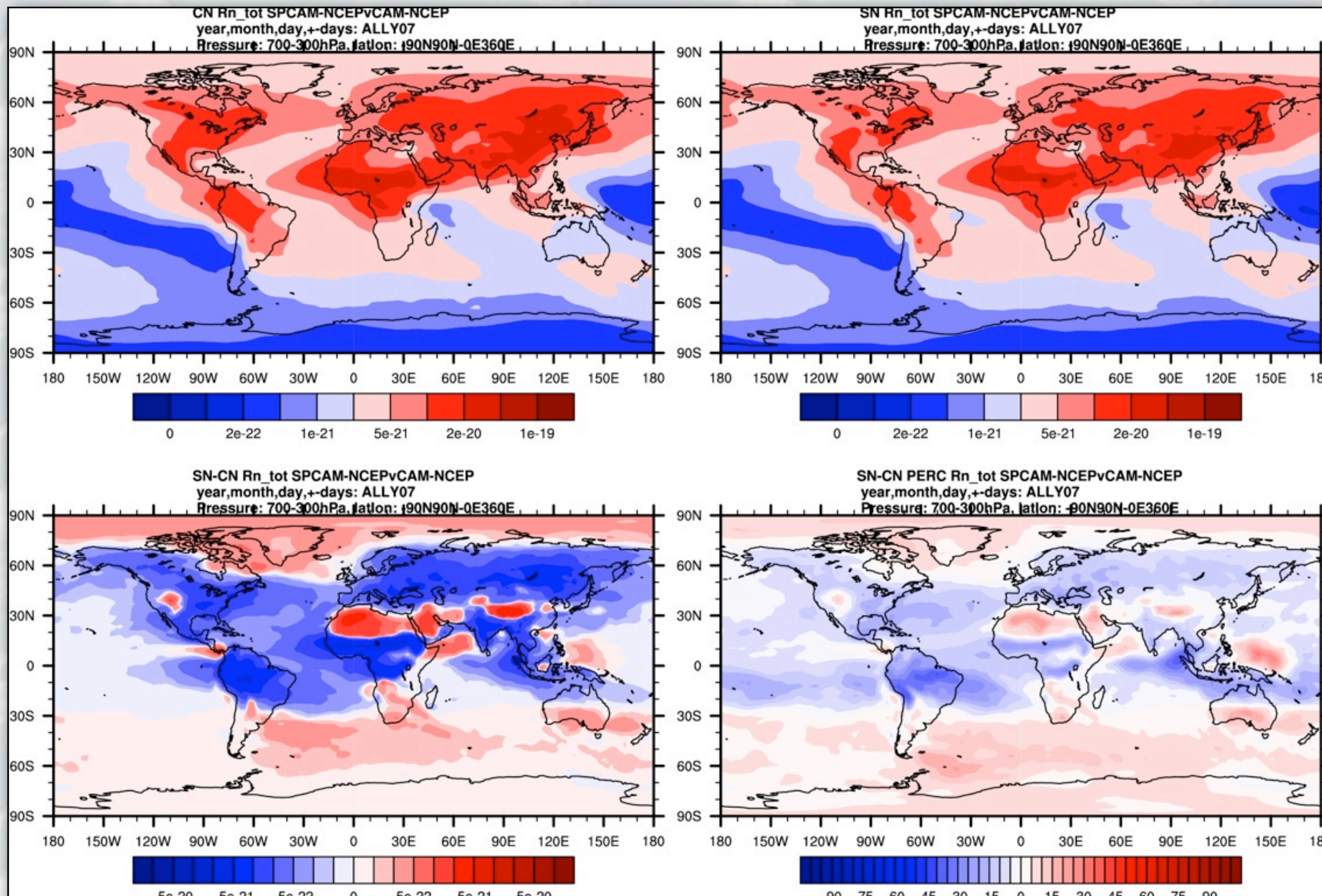
Model differences in Radon



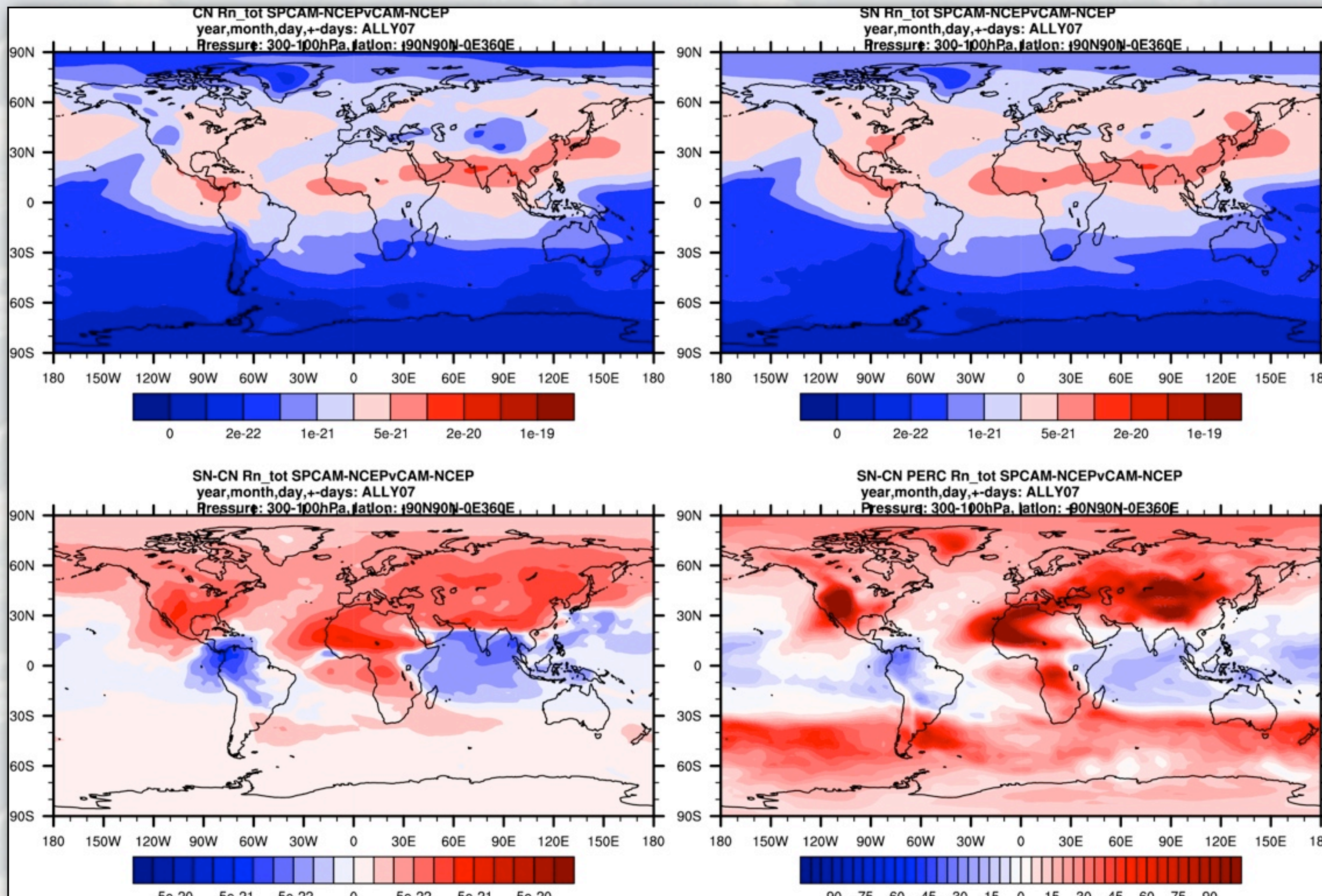
Radon sections: Lower troposphere



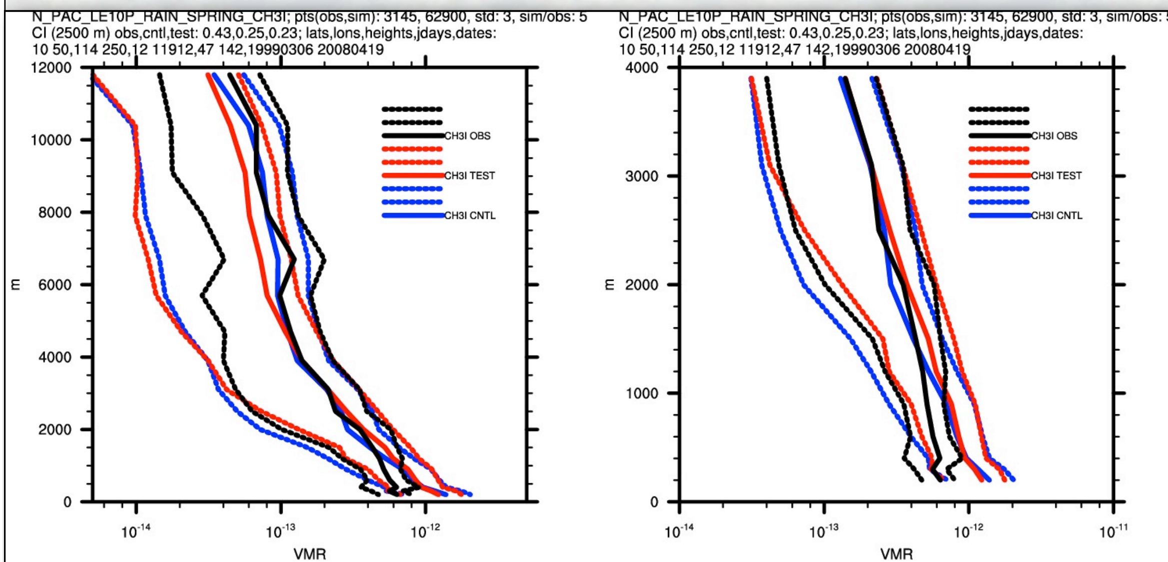
Radon sections: Mid Troposphere

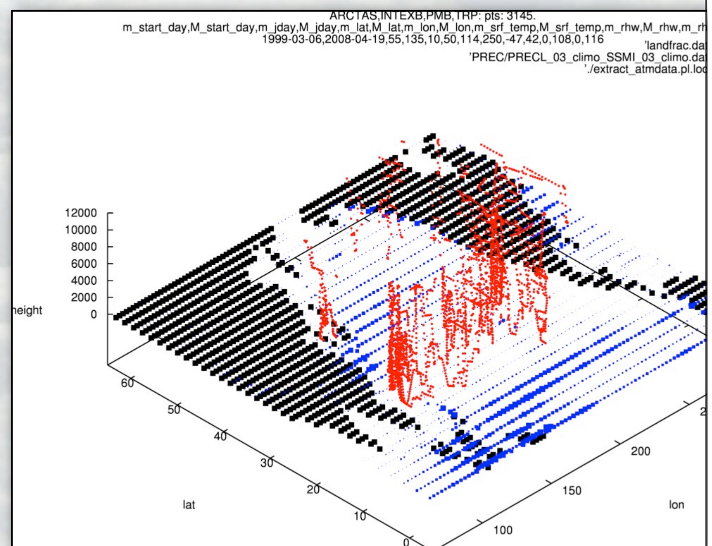


Radon sections: Upper troposphere



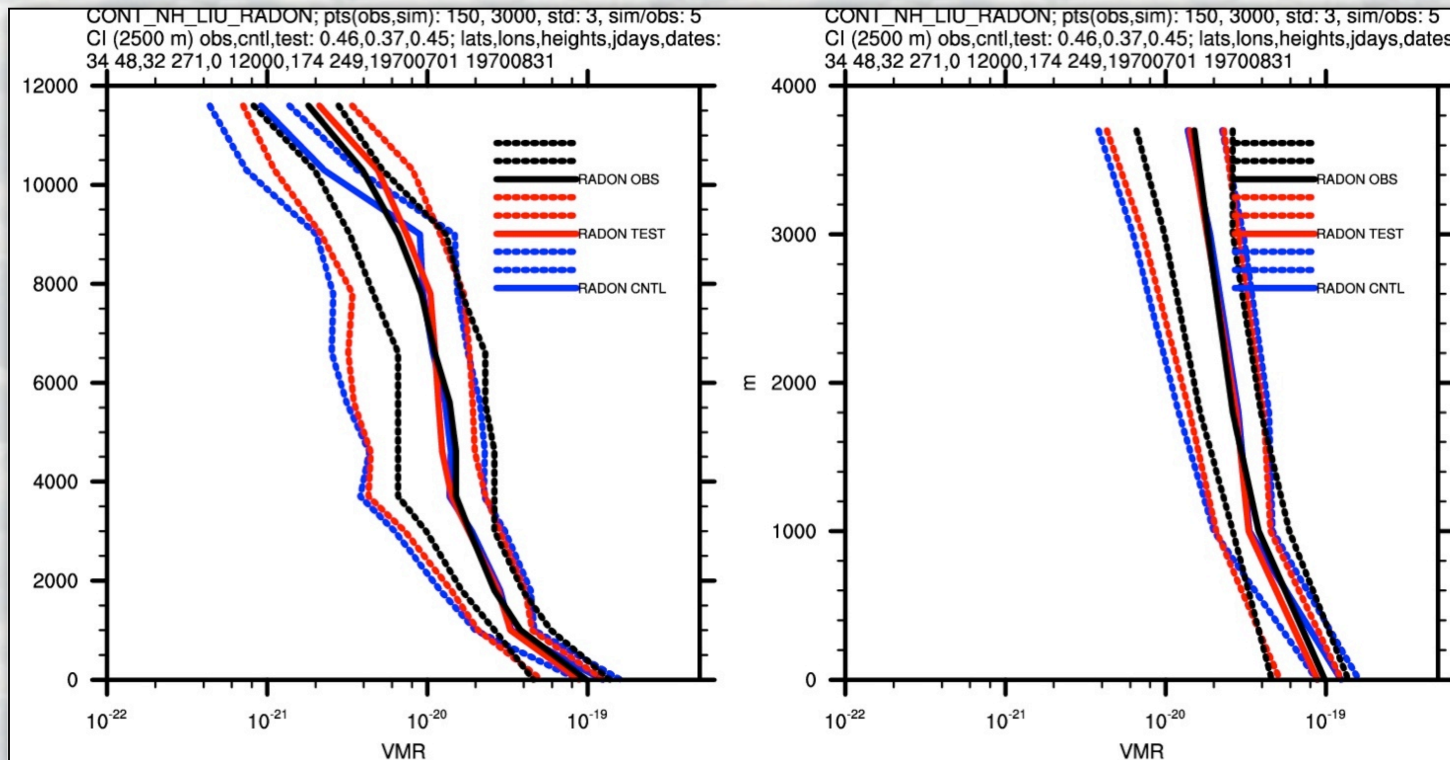
Evaluation of Methyl Iodide Profiles





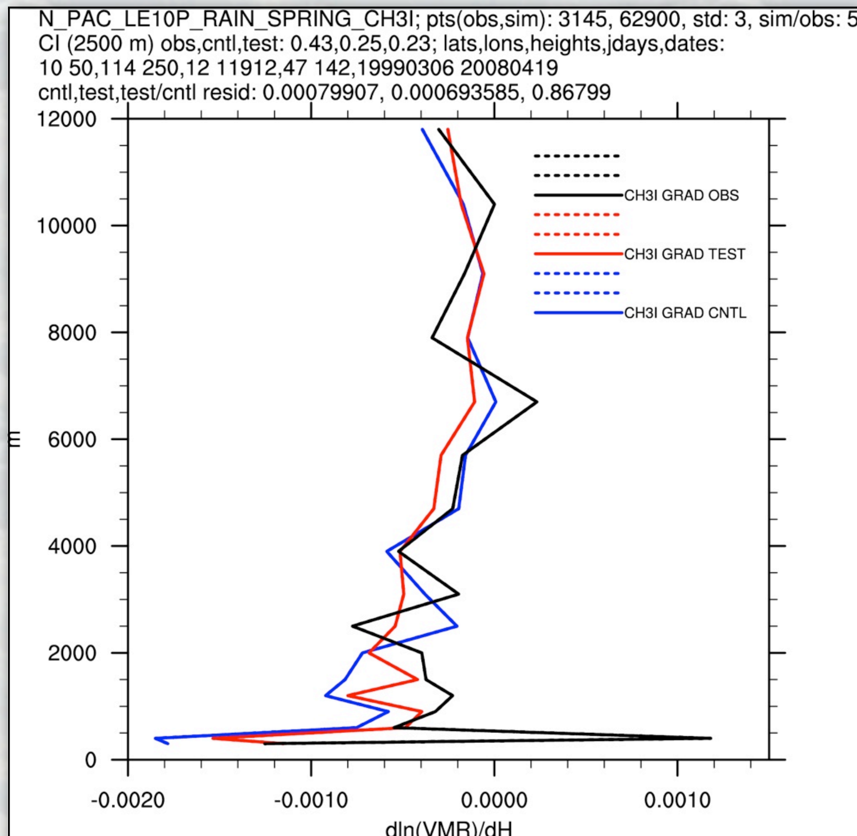
- SPCAM has smaller errors in MBL and lower troposphere.

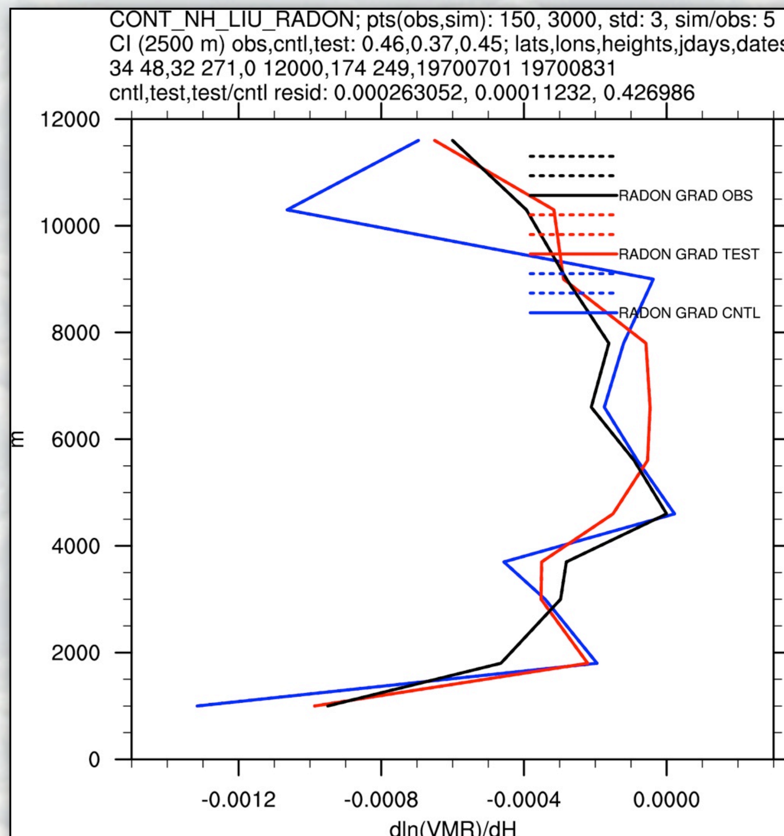
Evaluation of Radon Profiles



- SPCAM has small errors in upper troposphere.

Gradients as measures of transport





- The gradient in fractional changes in concentration measures gain/loss in each layer.

Metrics for fidelity of tracer gradients

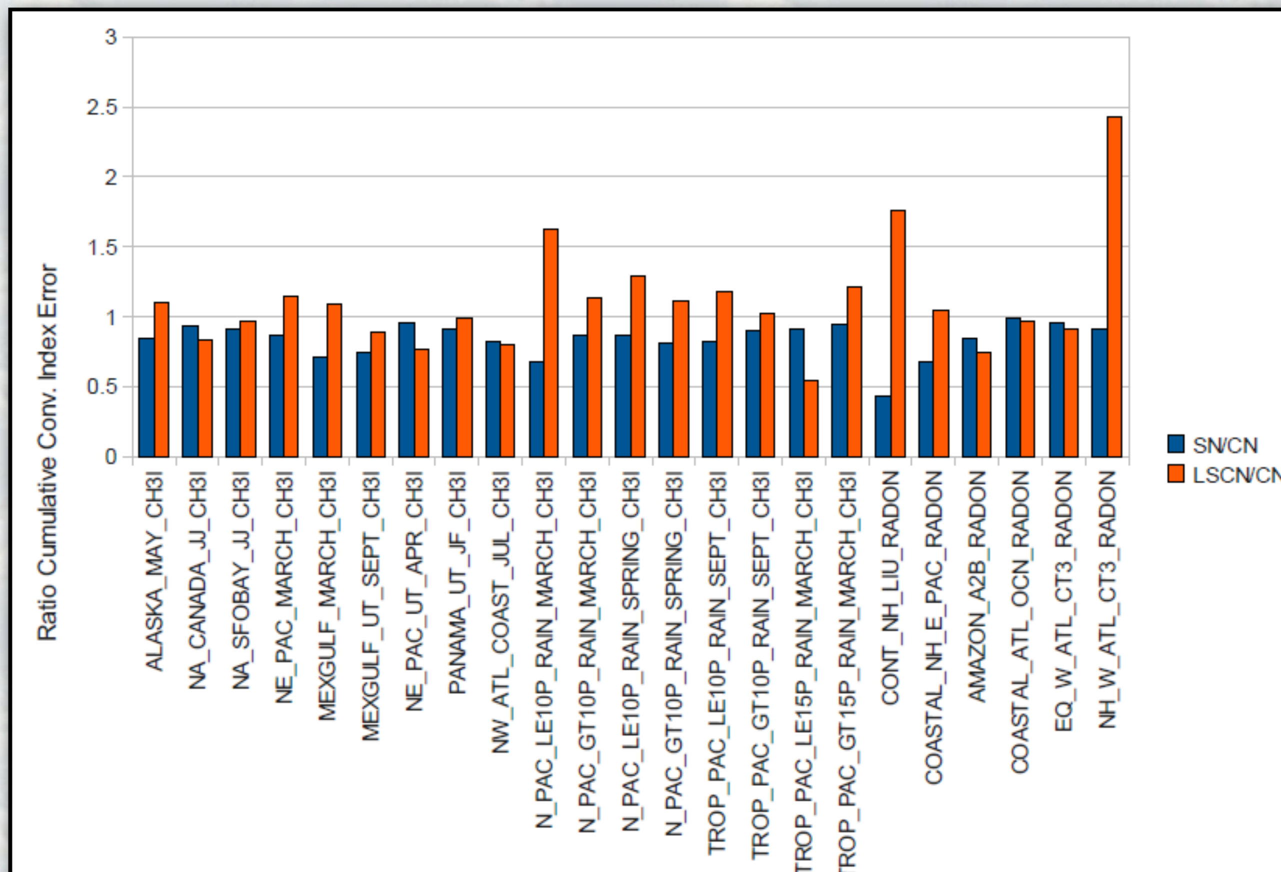
Table 5. Marine Convection Index (MCI) Over the Pacific: Ratio of Upper Tropospheric (UT; 8–12 km) to Lower Tropospheric (LT; 0–2.5 km) CH_3I Concentrations

Region	Campaign	Lifetime,[a] days	MCI (Observed)	MCI (Simulated)
5. North Pacific	PEM-WA	4.8	0.22	0.41
6. Hawaii	PEM-TB	4.4	0.26	0.18
	PEM-TA	4.7	0.20	0.39
8. Philippine Sea	PEM-WB	4.4	0.27	0.31
10. Christmas Island	PEM-TB	4.0	0.32	0.30
	PEM-TA	4.1	0.24	0.37
12. Fiji	PEM-TB	4.3	0.40	0.22
	PEM-TA	4.7	0.16	0.14
13. Tahiti	PEM-TB	4.2	0.34	0.44
	PEM-TA	4.1	0.23	0.19
21. Easter Island	PEM-TB	4.4	0.11	0.11

[a] Mean model lifetime of CH_3I in the 0- to 12-km column (24-hour average).

Bell et al, 2002

Convective indices



- Cumulative convective index error = RMS[δ dln(VMR)/dH].
- Ratio plotted here is CCIE(SPCAM) / CCIE(CAM).

Conclusions

- Analysis of MMF in CTM mode reveals systematic differences in vertical transport due to convective-scale motions.
- These differences appear in all passive tracers simulated to date.
- Changes in model fidelity can be quantified using a *convective index*, a fractional measure of vertical gradients.
- Errors in the indices relative to observations systematically decreases in SPCAM.
- Next steps: Studies of dust and water vapor.