Aerosols in the UTLS: A much needed multi-facet study and a powerful diagnostic for model processes

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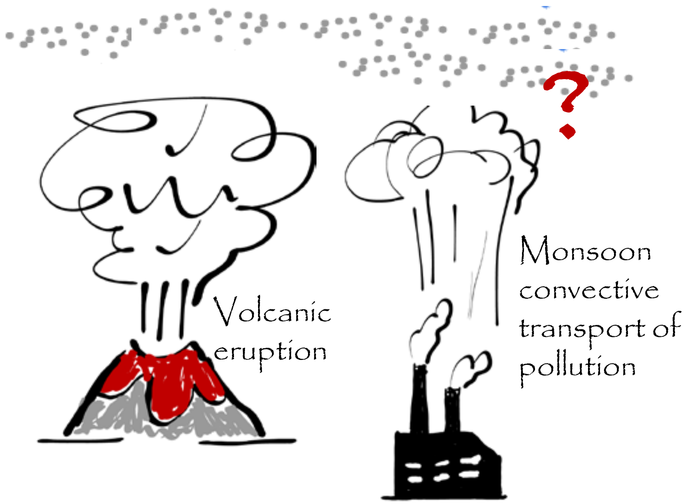
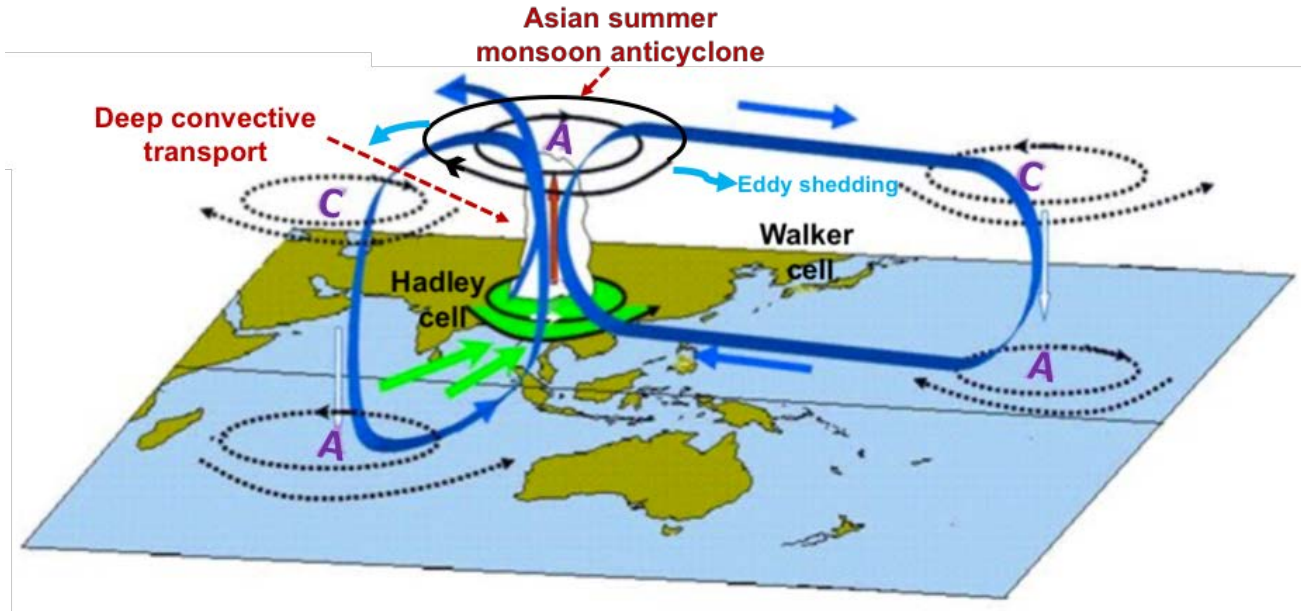
Introduction



- Aerosols play important role in UTLS
  - Perturbing the radiation balance
  - Impacting ice cloud formation
  - Affecting stratospheric chemistry (ozone loss)
- Sources of UTLS aerosols:
- Aerosols are highly heterogeneous in chemical composition and properties
  - Strong convective transport uplifting surface material into the UTLS
  - Direct injection of aerosols and/or precursor gases in the UTLS (e.g., volcanic eruptions, pyroCb)

The Asian summer monsoon (ASM) system is a dominant weather system during the boreal summer

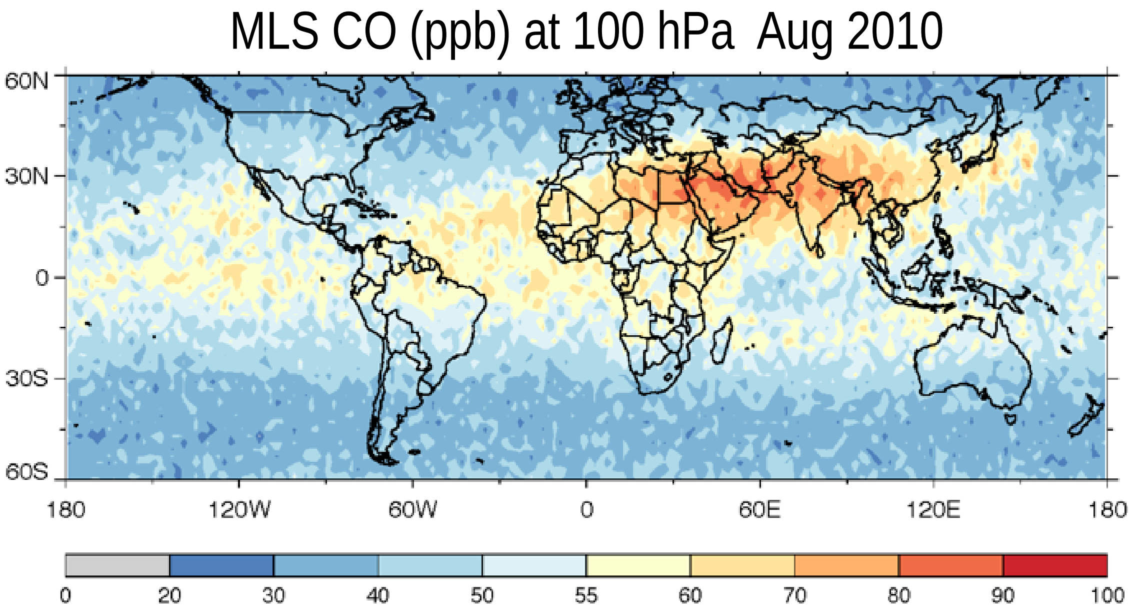


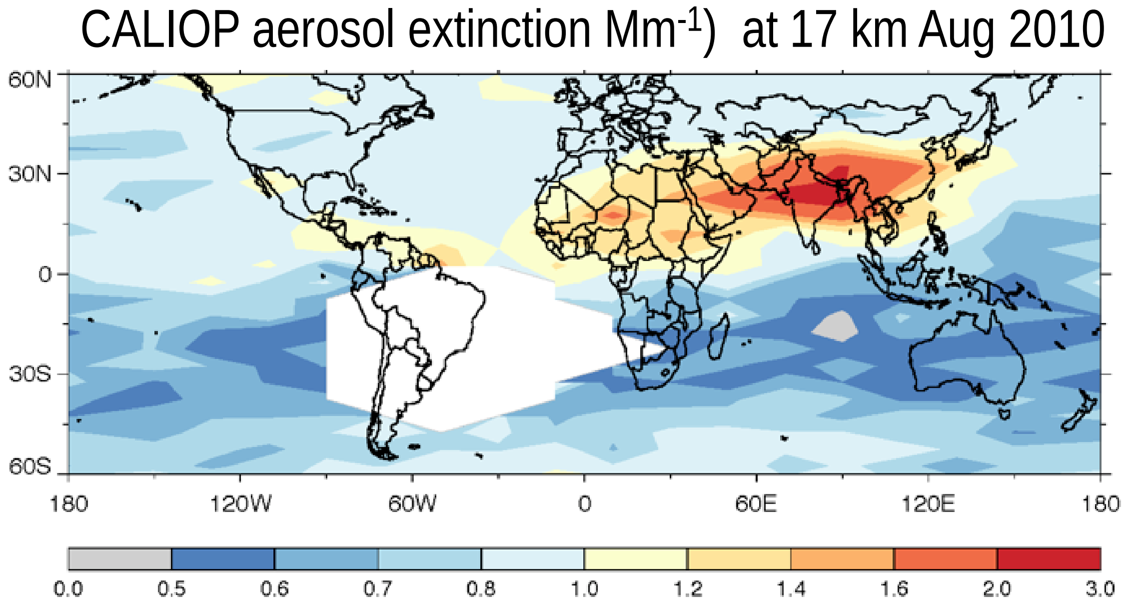
- The ASM system features a low-level cyclonic flow over South and East Asia, coupled with a persistent deep convective motion, and a strong upper level anticyclonic circulation
- The pollutants in the PBL are lifted by the ASM and spread out in the middle to upper troposphere
- The ASM anticyclone frequently sheds eddies to the west and east (eddy-shedding)
- The ASM connects to the large-scale Walker cell and Hadley cell circulations to influence the atmospheric composition in other parts of the world

Satellite observations of ASM transport of pollutants to the UTLS

- The best know examples is the "hot spot" of gaseous pollutants at UTLS over the ASM region observed by satellite, e.g., CO by MLS/Aura

- Uplifting of aerosol to UTLS by ASM is expected to be less efficient because of the wet removal of aerosols by the ASM precipitation; however the same feature is also observed by the CALIOP/CALIPSO every boreal summer

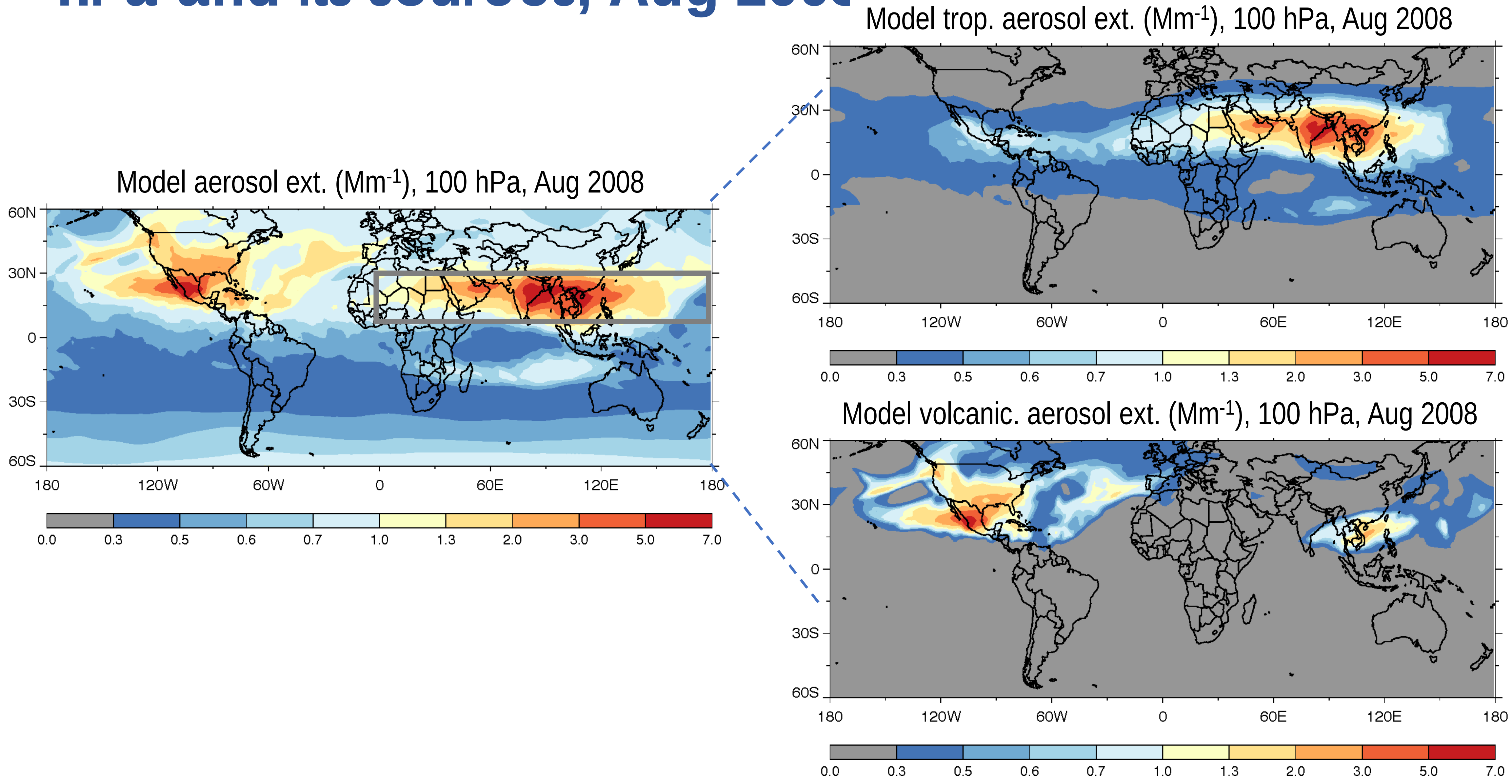




GEOS model simulation as a part of AeroCom III UTLS model experiment

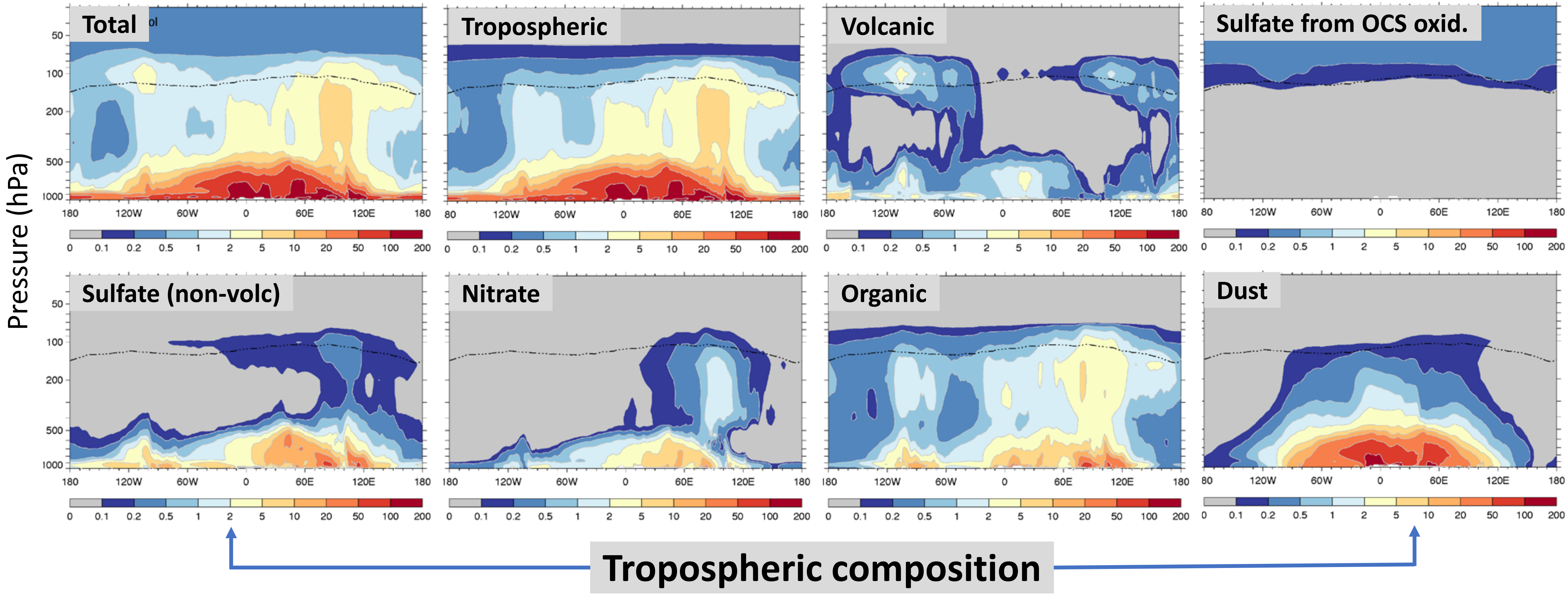
- Model setup:
  - 2000 – 2018, ”replay” with the MERRA2 meteorology
  - 1°lon x 1°lat, 72 levels
  - Species: BC, OA (POA+SOA), NH_4^+, NO_3^-, SO_4^{2-}, dust, sea salt, CO
- Emission:
  - Anthropogenic and biomass burning: CEDS (CMIP6), monthly
  - Volcanic emission: OMI-based, eruptive and degassing (Carn et al., 2015, 2016)
  - Dust, sea salt, biogenic: model-calculated
- Transport tracer CO50, removal tracer Pb-210

Model simulated aerosol extinction (550 nm) at 100 hPa and its sources, Aug 2008



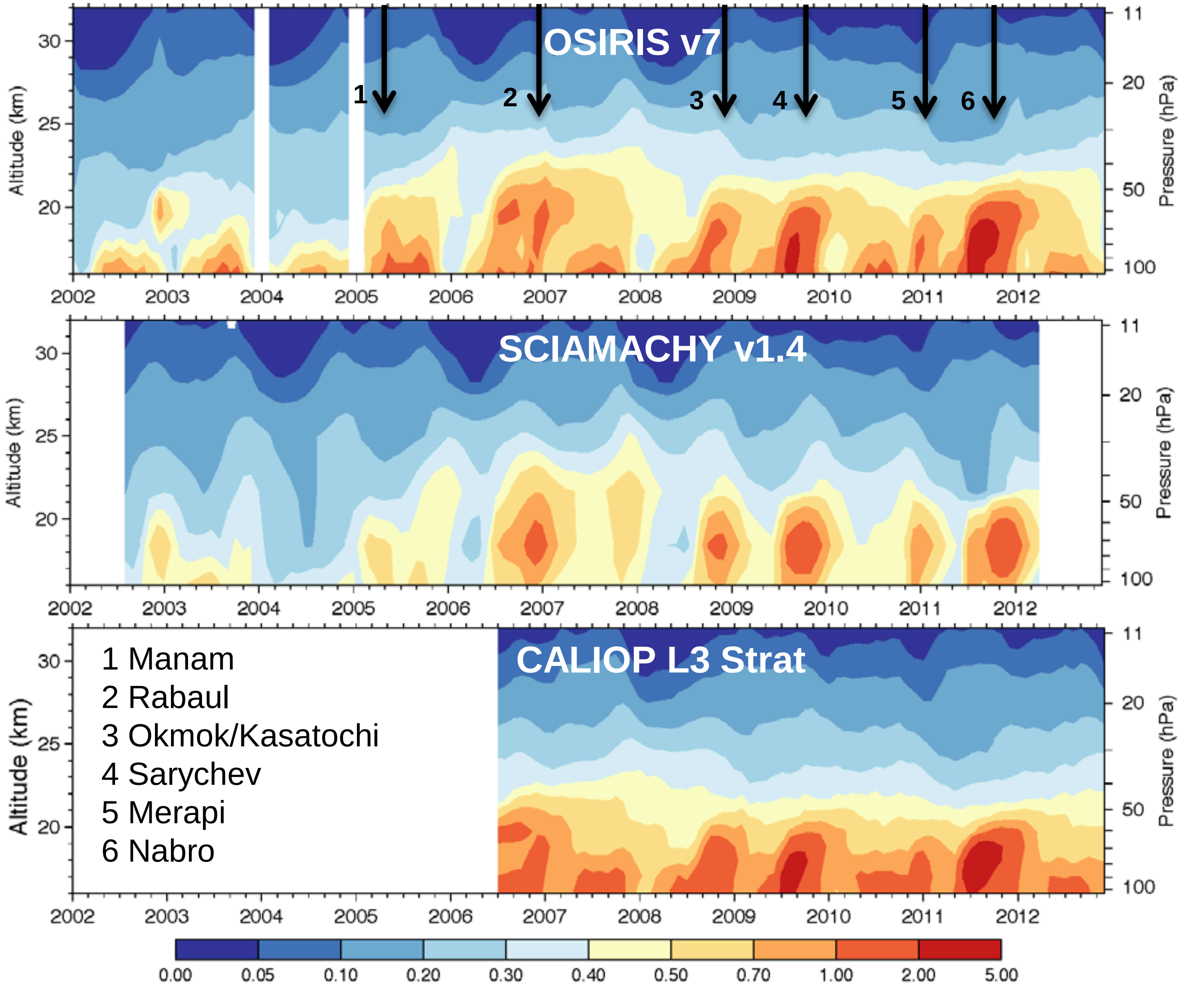
Model simulated longitudinal aerosol extinction (550 nm) profiles averaged over 10°N-30°N, Aug 2008: Aerosol origin and composition

Model aerosol extinction (Mm^{-1}), 10-30N avg, Aug 2008

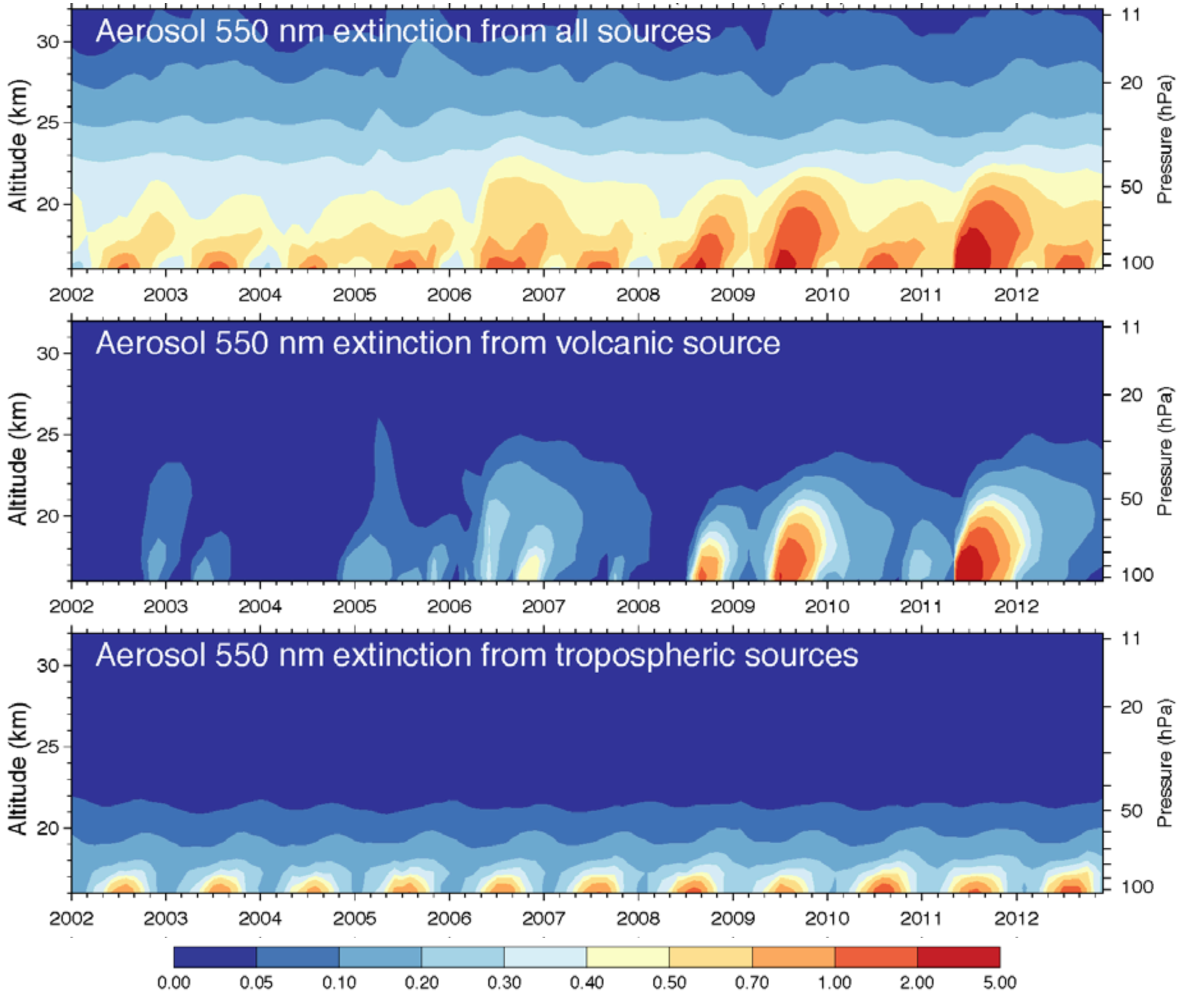


Asian summer monsoon convective transport affects UTLS composition and possibly cirrus cloud formation near the tropopause – example of UTLS aerosol extinction (Mm^{-1}), 10-30N, 2002-2012

Satellite data. 10N-30N zonal mean



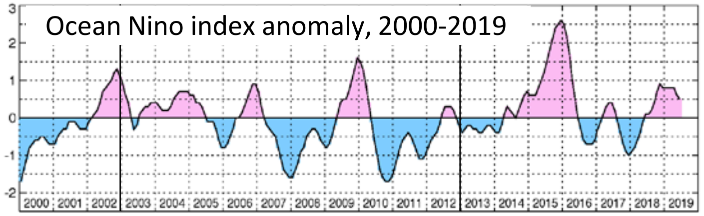
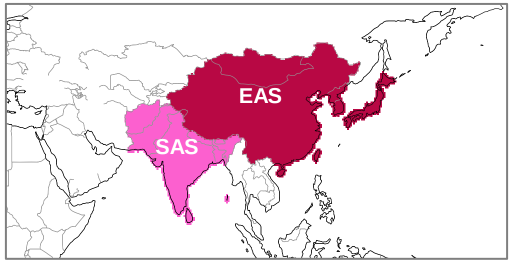
GEOS model simulation, 10N-30N zonal mean



Questions remain:

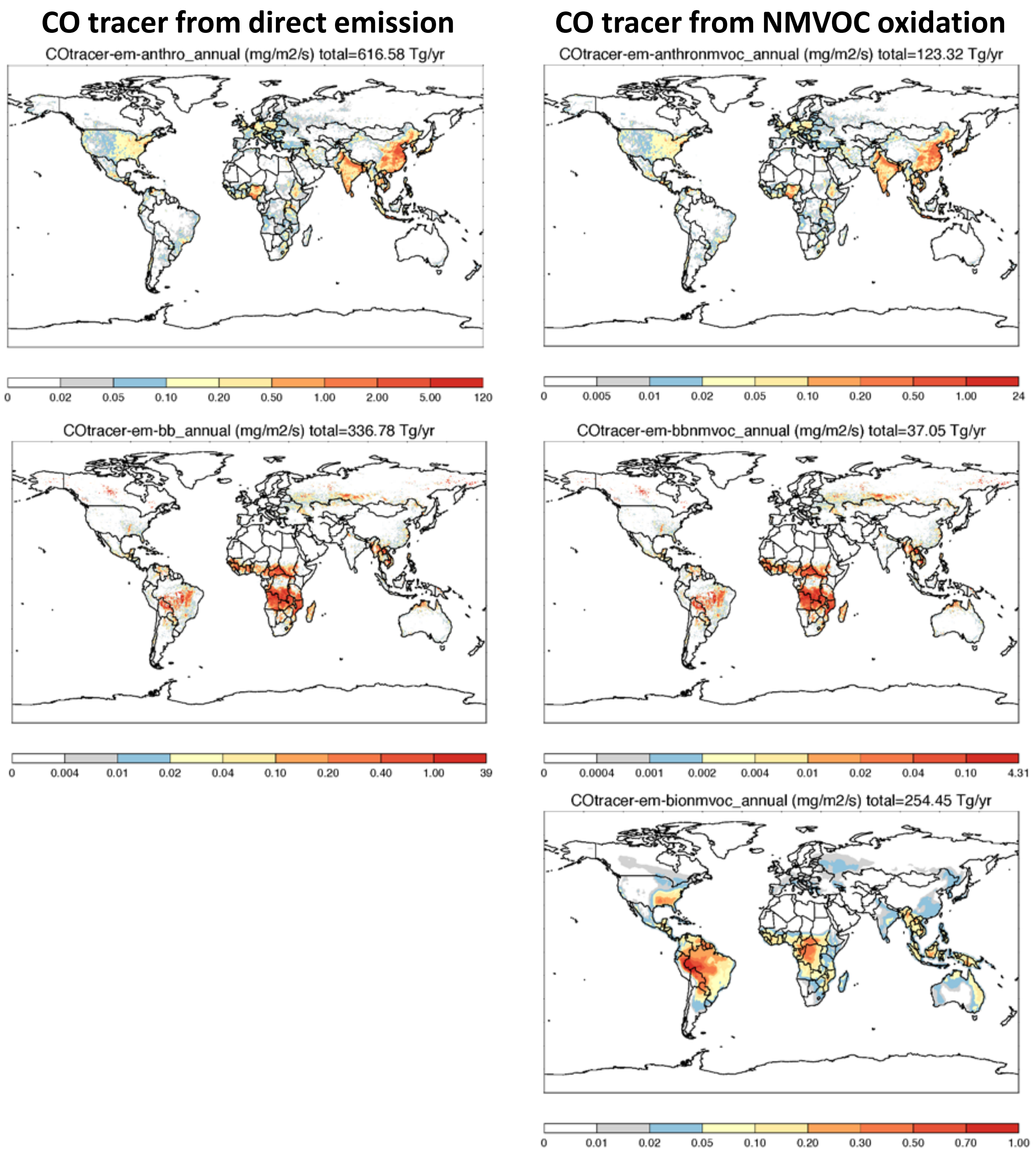
- What are the key transport pathways for tropospheric aerosols into the ASM anticyclone and stratosphere?
- How different is the transport efficiency between the insoluble CO and the soluble aerosols?
- How do the pathways change with climate variability, such as ENSO?
- Which source regions hold the strongest influence over the UTLS composition and trends?
- How different is the aerosol composition in the airmasses originating in different source regions?
- What fractions of aerosols are being produced in the UTLS vs. transported from the lower troposphere or directly injected into the UTLS?
- Is the trend of aerosol or CO in the UTLS consistent with that in the PBL?

AeroCom III UTLS model experiment – Multiple global models investigation of aerosols in the UTLS and answer the questions

Tier 1 model experiments: ▪ Simulation period: ▪ BASE ▪ VOL0 ▪ FIR0 ▪ ANT0	 2003-2012 (10 years) Model simulation with all emissions Same as BASE but with volcanic emissions turned off Same as BASE but with fire emissions turned off Same as BASE but with fossil fuel/biofuel emissions turned off
Tier 2 model experiments: ▪ Simulation period: ▪ BASE ▪ VOL0 ▪ FIR0 ▪ ANT0 ▪ **EAS0** (use region mask) ▪ **SAS0** (use region mask)	 **2000-2018** (19 years, OBO) Model simulation with all emissions Same as BASE but with volcanic emissions turned off Same as BASE but with fire emissions turned off Same as BASE but with fossil fuel/biofuel emissions turned off Same as BASE but with East Asian emissions turned off Same as BASE but with South Asian emissions turned off
Transport tracer:	CO with prescribed sources (provided) and 50-day lifetime (see description in “Tracer for transport” on AeroCom wiki page
Wet/dry deposition tracer:	Pb-210 produced from Rn-222 decay (5.5-day lifetime) with the removal (dry and wet deposition) process same as sulfate (see description in “Tracer for removal” on the AeroCom wiki page)
Output:	File specification on google doc (link) from AeroCom wiki page

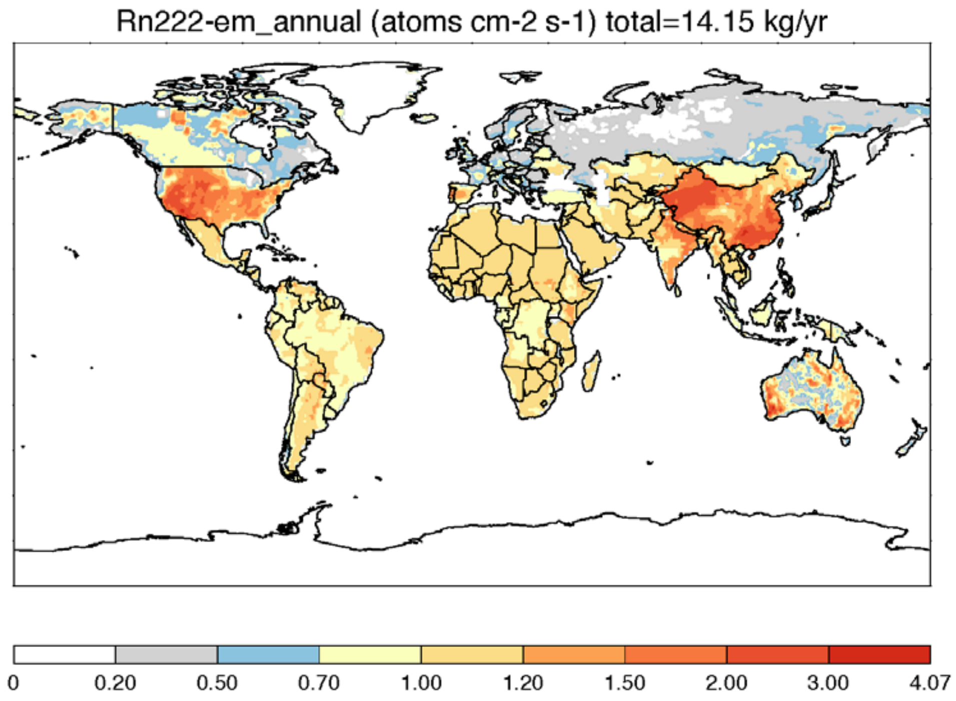
Transport tracer CO50

- Extremely valuable for diagnose:
  - Inter-model differences in transport
  - Inter-annual variability due to transport (driven by different meteorology)
- Prescribed CO sources (mostly 2010 CEDS):
  - Direct emission from anthropogenic and biomass burning (2010 CEDS)
  - Produced from NMVOC oxidation (GMI 2010)
  - CH4 oxidation
- Prescribe CO loss:
  - 50-day decay time



Deposition tracer Pb-210

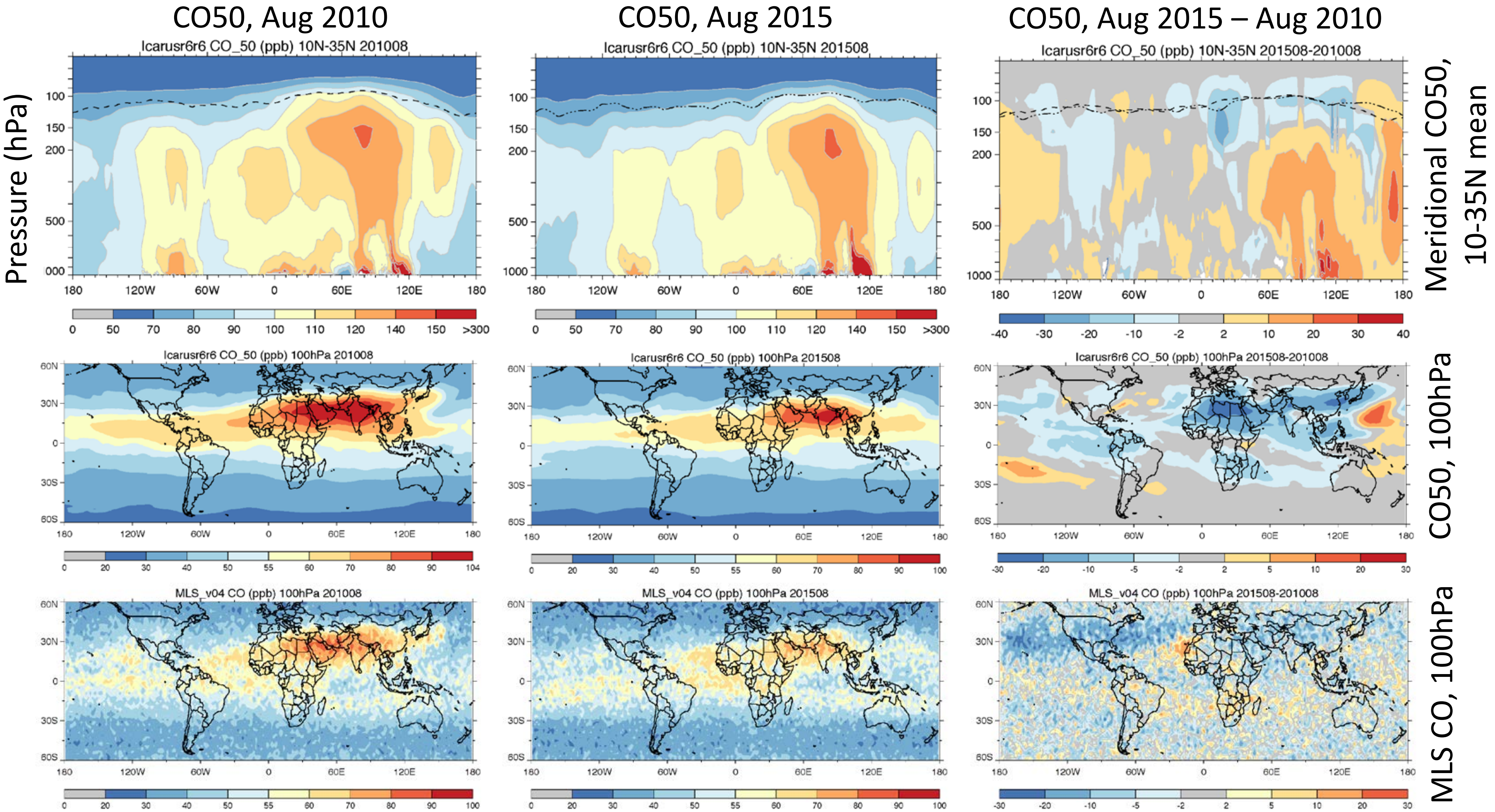
- Extremely valuable for diagnose
  - Inter-model differences in aerosol removal
  - Inter-annual variability due to removal (driven by meteorology)
- Prescribed Pb-210 source and sink:
  - Produced from Rn-222 decay, decay time 5.5 days
  - Removed by dry and wet deposition with the same scheme as of sulfate



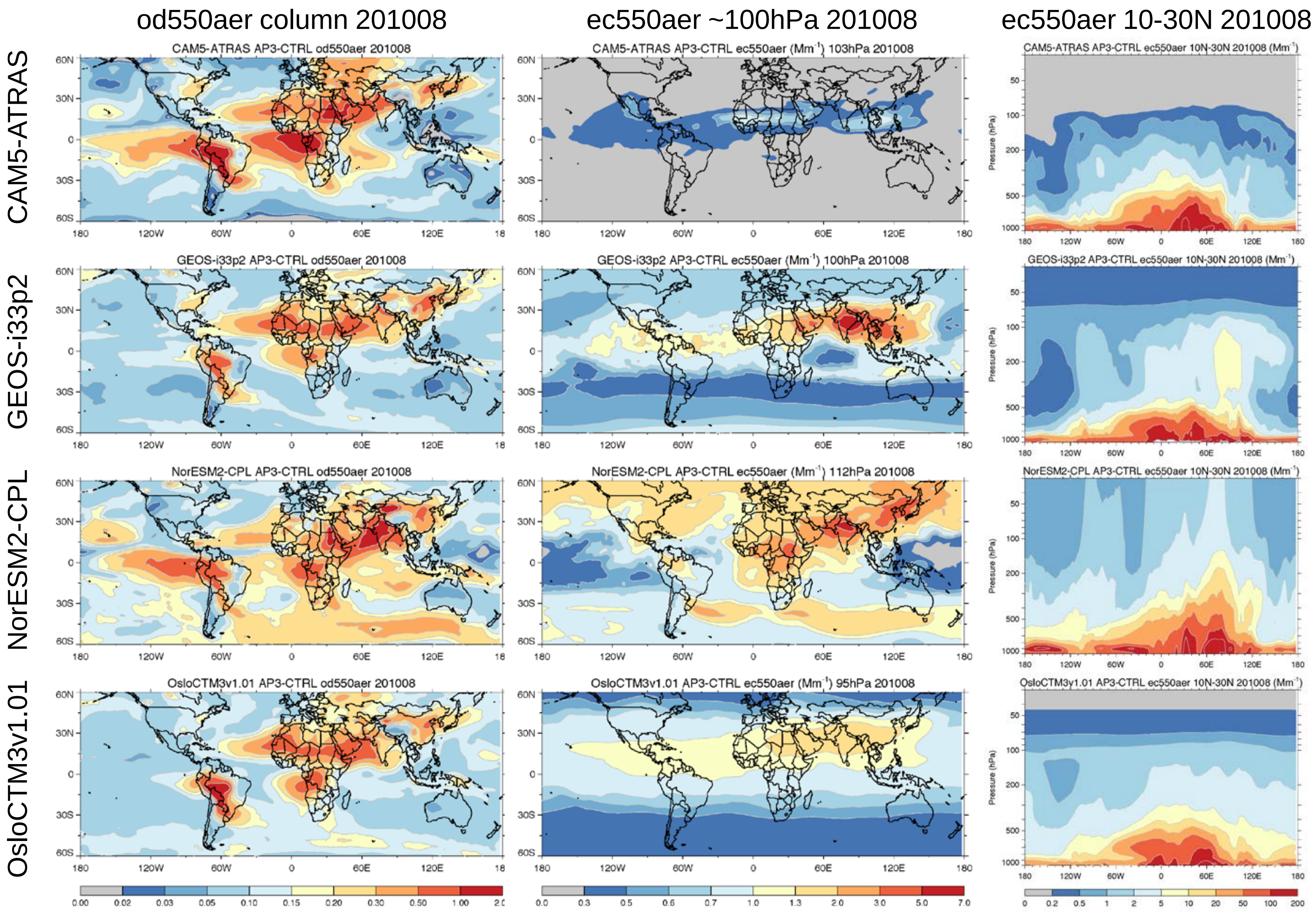
Monthly ^{222}Rn emission from Bo Zhang et al. 2019 (modified from Kai Zhang et al., 2011)

See AeroCom Phase III wiki page under "**Common requirement: Unified transport and deposition tracers**", and a description + file access information at https://wiki.met.no/_media/aerocom/A3_tracer_requirements_v2019-03-01.pdf

Example: Interannual variability of transport to UTLS from the GEOS simulation with CO50



Model diversity of aerosols in the UTLS reflecting the differences in transport and removal processes – first look at four model simulations in 2010 from AP3-CTRL



- *Left column*: total AOD. Models look similar.
- *Middle column*: aerosol extinction at ~100 hPa. Models have large diversity.
- *Right column*: meridional vertical distributions of aerosol extinction in 10-30N latitudinal band. Models show clear difference.

- The model diversity amplifies at higher altitudes. The most important processes determining aerosol vertical distributions are transport (convective + large scale) and wet removal. Also different among models are aerosol composition, chemical process, particle properties, etc.

- **The UTLS model experiment is designed to address the origins of UTLS aerosols, estimate their climate effects, and diagnose the processes causing the model diversity.**

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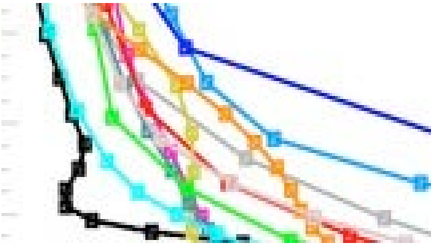
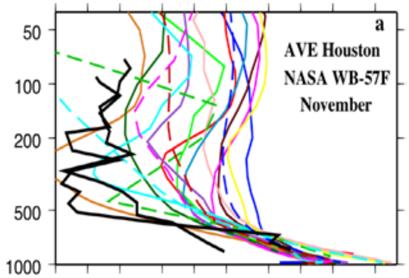
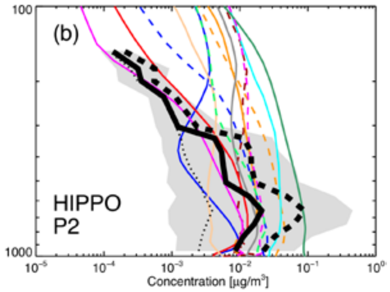
Benefits



- UTLS aerosols and Asian summer monsoon transport is a very interesting topic with many questions to answer
- Large diversity of aerosol vertical profiles have been an standing issue for aerosol models since the beginning, and not much progress has been made since



- The UTLS model experiment will tackle this issue in depth from several angles with satellite and in-situ data
- Such investigation will move toward a better understanding of processes, compositions, and decadal trends of UTLS aerosols and their effects, and also lead to model improvements



- Model output can be used for other AeroCom III topics (e.g., Aircraft general and ATom, TADD, ACAM, Absorption)
- Coordinate with other communities (CCMI, ACAM – see poster of Mian Chin)
- Roster:
  - GEOS, SPRINTARS, GRIMs-GEOSChem, GISS, SILAM (?)… **SIGN UP NOW!**