General requirements/recommendations of implementing transport/removal tracers for AeroCom Phase III experiments

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In order to diagnose the inter-model differences and the inter-annual variability of characteristics in transport and removal processes for the current AeroCom Phase III model experiments, it is important to implement common tracers of transport and dry/wet removal across all models for all simulated years. These requirements are described below. One-year spin-up is recommended.

1. Transport tracer: CO

We will use CO with prescribed emission and a 50-day lifetime (exponential decay rate = 2.315×10^{-7} s^{-1}) as a common transport tracer for all models and for all simulated years. Sources of CO are from (1) direct emissions from anthropogenic and biomass burning emissions, (2) production from non-methane volatile organic compounds (NMVOC) oxidation, and (3) from methane oxidation. To simplify the tracer implementation, we treat the atmospheric production of CO from all NMVOC oxidation in a manner of direct emission, as described below.

- Prescribed sources:
  - CO from anthropogenic (anthro) emissions: CMIP6, 2010, annual total=617.2 Tg/yr
  - CO from biomass burning (bb) emissions: CMIP6, 2010, annual total=336.8 Tg/yr
  - CO from anthro NMVOC oxidation: Assuming it is in the order of 0.20 of the direct anthropogenic emission of CO (Bian et al., 2007). Annual total = 123.4 Tg/yr
  - CO from bb NMVOC oxidation: Assuming it is in the order of 0.11 of the direct biomass burning (bb) emission of CO (Bian et al., 2007). Annual total = 37.1 Tg/yr
  - CO from biogenic (bio) NMVOC oxidation: Assuming a CO yield of 0.2 from the oxidation of isoprene, monoterpene, and other biogenic NMVOC species (Bian et al., 2007). The CO from biogenic NMVOC is calculated based on the 2010 NMVOC emissions in the GMI model with an annual total of 254.5 Tg/yr
  - CO from CH_4 oxidation: assuming a fixed uniform CH_4 concentration of 1760 ppbv and a CH_4 decay rate = 3.73×10^{-9} s^{-1} (lifetime 8.5 years) to produce CO with a molar yield of 0.86
  - Reference: Bian, H., M. Chin, S.R. Kawa, B. Duncan, A. Arellano, and P. Kasibhatla, Sensitivity of global CO simulations to uncertainties in biomass burning sources, J. Geophys. Res., 112, D23308, doi:10.1029/2006JD008376, 2007

The monthly CO sources from direct anthropogenic and biomass burning emissions and from anthropogenic, biomass burning, and biogenic NMVOC oxidations (note the different spatial resolutions between anthropogenic and biomass burning sources that are kept as the same resolution as the corresponding CMIP6 emissions) can also be downloaded at https://tropo.gsfc.nasa.gov/gocart/products/xchange/aerocom/aerocom3/COtracer/

- *COtracer-em-anthro_monthly_0.5x0.5.nc* (CO from direct anthro emission)
- *COtracer-em-bb_monthly_0.25x0.25.nc* (CO from direct bb emission)
- *COtracer-em-anthronmvoc_monthly_0.5x0.5.nc* (CO from anthro NMVOC oxidation)
- *COtracer-em-bbnmvoc_monthly_0.25x0.25.nc* (CO from bb NMVOC oxidation)
- *COtracer-em-bionmvoc_monthly_0.5x0.5.nc* (CO from bio NMVOC oxidation)

Total source of CO (excluding CO from CH_4 oxidation) as a transport tracer is 1368 Tg/yr, as listed in the table below. **Figure 1** plots the annual average of the five CO sources treated as "emission".

Source	**Direct emission**	**NMVOC oxidation**	**Total (Tg yr^{-1})**
Anthropogenic	616.6	123.3	739.9
Biomass burning	336.8	37.0	373.8
Biogenic	---	254.5	254.5
Total	953.4	414.8	**1368.2**

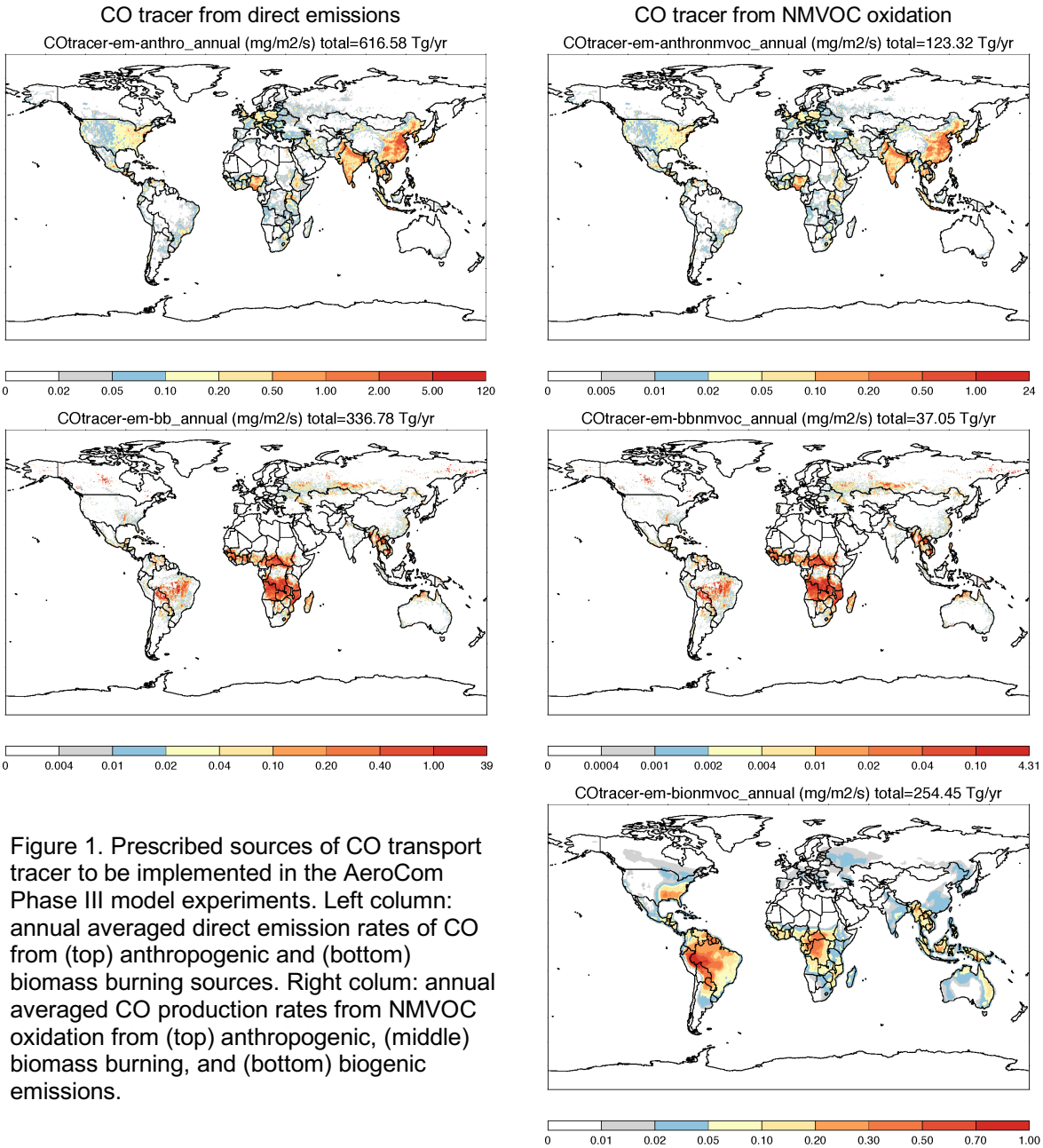

Figure 1. Prescribed sources of CO transport tracer to be implemented in the AeroCom Phase III model experiments. Left column: annual averaged direct emission rates of CO from (top) anthropogenic and (bottom) biomass burning sources. Right colum: annual averaged CO production rates from NMVOC oxidation from (top) anthropogenic, (middle) biomass burning, and (bottom) biogenic emissions.

2. Deposition tracer: ^{210}Pb (lead-210)

^{210}Pb is formed from ^{222}Rn decay and attached to fine-mode aerosols that will experience the same removal processes as soluble aerosols. Prescribed emissions of ^{222}Rn and removals of ^{222}Rn and ^{210}Pb are listed below.

- ^{222}Rn emission from land: The prescribed monthly varying ^{222}Rn emission dataset from Zhang, B. et al., 2019 (modified from Zhang K. et al., 2011) will be used for all simulations. Total annual emission is 14.4 kg/yr.
- ^{210}Pb production from the ^{222}Rn radio-active decay: A fixed first order decay rate of ^{222}Rn at 2.11×10^{-6} s^{-1} (equivalent to 5.5 days of lifetime or 3.8 days of half-life) is prescribed to produce ^{210}Pb. No other removal of ^{222}Rn.
- ^{210}Pb removal: the dry and wet deposition should be implemented in the models in the way as if it were sulfate.
- Reference: (1) Zhang, B., et al., Simulation of Radon-222 with the GEOS-Chem global model: Emissions, Seasonality, and Convective Transport, to be submitted to Atmos. Chem. Phys., 2019; (2) Zhang, K., et al., Radon activity in the lower troposphere and its impact on ionization rate: A global estimate using different radon emissions, Atmos. Chem. Phys., 11(15), 7817–7838, doi:10.5194/acp-11-7817-2011, 2011.

The monthly ^{222}Rn emission from Zhang B. et al. 2019 (modified from Zhang K. et al., 2011) can also be downloaded at
https://tropo.gsfc.nasa.gov/gocart/products/xchange/aerocom/aerocom3/Rn222/

- *Rn222-em_monthly_0.5x0.5.nc*

Figure 2 shows the annual average ^{222}Rn emission rate and its spatial distribution.

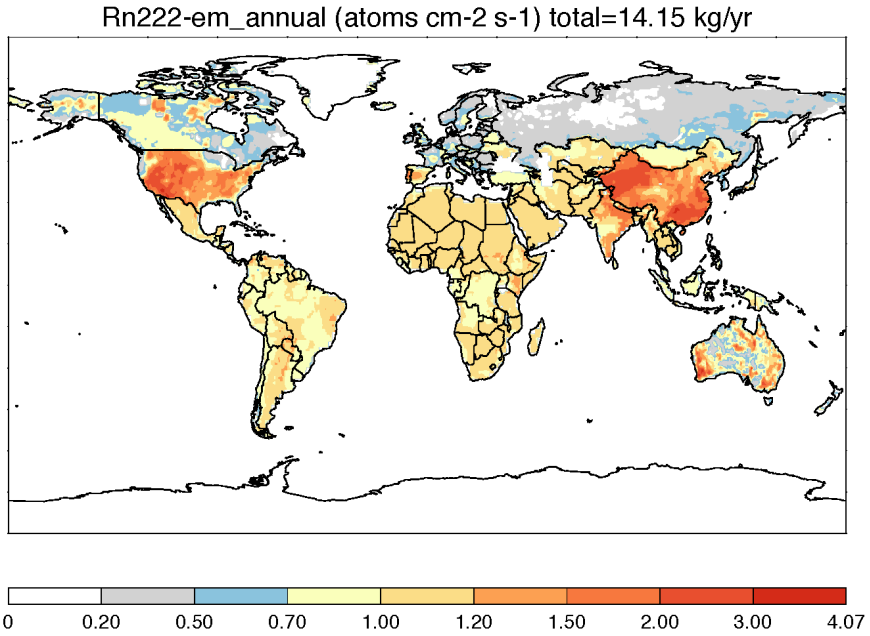

Figure 2. Annual averaged ^{222}Rn emission rate. (Note: 1 mole ^{222}Rn = 222 g = 6.023×10^{23} atoms.)