AeroCom Phase III: Biomass Burning Emission Injection Height experiment (BBEIH)

Wiki website: https://wiki.met.no/aerocom/phase3-experiments#biomass_burning_emission_injection_height_experiment_bbeih
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(if you have interest for performing this experiment, please contacts both Xiaohua and Ralph)

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Importance of biomass burning injection height: Smoke aerosols can adversely affect surface air quality and visibility near emission sources and even hundreds to thousands of km downwind, and thus create health and aviation hazards. They also have impacts on air temperature, cloud properties and precipitation. The environmental impact of smoke aerosols depends not only on the emitted mass, but also on the injection height. This is especially true for large boreal forest fires that often emit smoke above planetary boundary layer (PBL) into the free troposphere and even the lower stratosphere. However, most atmospheric chemistry transport models (CTMs) assume that fire emissions are dispersed only within PBL, or use simple plume-rise parameterizations. The importance of assigning accurate heights to smoke emissions in CTMs derives from three factors: (1) unlike winds in the free troposphere, winds in PBL do not favor smoke to transport over long distances downwind; (2) both dry and wet removal process are more efficient in PBL than in the free troposphere; (3) chemical processes within the plume are sensitive to ambient relative humidity, temperature, smoke-cloud interactions, and photolysis rates – all of which depend on smoke injection height.

The objectives of this project: to test the sensitivity of various model results to biomass burning smoke injection height, where the biomass burning injection height is based on MISR (Val Martin et al., 2010; 2018), as compared to the nominal model value. We aim to answer the following scientific questions:

I. To what extent are model simulations sensitive to the assumed biomass burning injection height, in terms of near-source characteristics and downwind plume evolution: (a) vertical aerosol distribution, (b) near-surface aerosol concentration, (c) aerosol optical depth, and more generally (d) net radiative forcing of BB-related aerosols, (e) BB-related aerosol transport time in the atmosphere, (f) cloud fraction, and (g) precipitation?
II. In which regions/seasons/surface-types are the aforementioned sensitivities significant?
III. To what extent do the aforementioned sensitivities vary across different models?

Methodology and datasets

1. Model experiments:

I. **BASE**: all emissions including GFED4.1s, using model-default biomass burning injection height.

II. **BBIH**: same as BASE but using MISR plume injection height to distribute biomass burning emissions vertically, referring to the instruction in 2e) below.

III. **NOBB**: no biomass burning emissions

IV. **BBEM** (optional): same as BASE, but using daily FEER biomass burning emission instead of GFED4.1s. Daily FEERv1.0-G1.2 biomass burning emissions can be downloaded at https://feer.gsfc.nasa.gov/data/emissions/.

2. Model basic setups:

a) Simulation period: 2008
b) Meteorological fields: SST, wind fields, air temperature, or pressure, are nudged to model's preferred reanalysis data (e.g., MERRA-2 for NASA GEOS model).
c) Anthropogenic emission: monthly CMIP6
d) Biomass burning emission: daily GFED4.1s is used in BASE and BBIH experiments; but daily FEER daily is used in BBEM (model experiments are described in section 2 below).
e) Biomass burning emission injection height: use the fault setting in BASE and BBEM (e.g., distributed uniformly within the planetary boundary layer in NASA GEOS model); but apply the profile data, **misr_global_fire_injection_profile_2008.nc**, to BBIH run.
    - ***How to get it?*** This gridded profile data [longitude, latitude, altitude, month] for 2008 is available at https://croc.gsfc.nasa.gov/gocart/products/xchange/aerocom/aerocom3/misr_global_fire_injection_profile_2008.nc
    - ***What it is?*** A monthly gridded global profile containing fraction (%) of biomass burning emission at each vertical layer for 2008. The horizontal resolution is 0.25 degree, and the vertical resolution is 250 m, from surface to 6 km (total 25 altitudes).

      For your information, the original data (a lookup table) was provided by Maria Val Martin (see Table S4 in Val Martin et al., 2018), based on the MISR plume height statistical data retrieved by the MINX tool from MISR data in 2008, reported as a function of 6 land cover types in 7 geographic regions for each month.
    - ***How to apply it to your model?*** In order to distribute the 3-D [longitude, latitude, time] biomass burning emissions (GFED4.1s) vertically, modelers will have to re-grid/interpolate this gridded profile data to your own lon-lat-alt model grid. Then, at each model vertical level, you will multiple GFED4.1s emission with the fraction (%) provided by this gridded data. The resulting biomass burning emission will become 4-D [longitude, latitude, altitude, time], a similar structure as aircraft emission. ***In other words, this step is actually something like you did when you re-gridded CMIP6 aircraft emission to your model resolution.***
    - ***Still have question,*** *feel free to email:* Xiaohua.pan@nasa.gov

Note:

1) See document in the AeroCom wiki section for locations of the emission files: "Common requirement: Harmonized anthropogenic, biomass burning, and volcanic emission datasets" at https://wiki.met.no/aerocom/phase3-experiments

2) We designed the experiments to be similar to the work by Zhu et al. (2018):

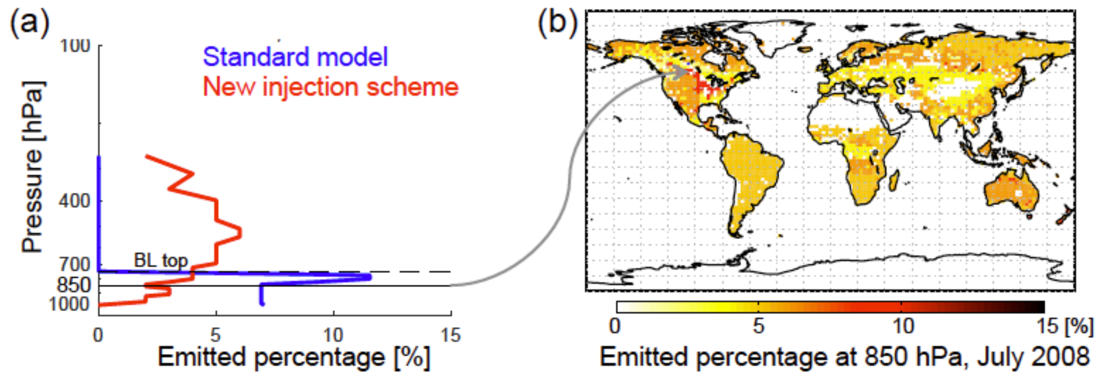

Figure. (a) Vertical profile of the percent of emissions in each model level for a sample location over boreal Canada (56◦ N, 105◦ W) from the public-release version of GEOS-Chem (blue) and the new observationally based injection scheme (red). The dashed line indicates the averaged boundary layer top of this month. The solid black line is at 850 hPa, corresponding to the layer shown in (b). (b) Percent of total-column biomass burning emissions emitted into the 850 hPa layer in each model grid cell for July 2008. Figure from Zhu et al., 2018.

3. **Model output and corresponding observational dataset used for evaluation in 2008:**

a) Vertical coordinate system (ak, bk)

b) 2-D static:

Variable	Variable name [+]	Variable Unit [+]
altitude above sea level	orog	m
area of each grid	area	m^2
Land area fraction	landf	1

c) **2-D variables:**

Variable	Variable name [+]	Variable Unit [+]	Temporal frequency [$]		Observational Datasets
Met. fields					
surface air pressure	ps	Pa	Monthly (Jan-Dec)		
tropopause air pressure	psp	Pa	Monthly (Jan-Dec)		
tropopause altitude	ztp	m	Monthly (Jan-Dec)		
boundary layer depth	bldep	m	Monthly (Jan-Dec)		
Emission					
anthropogenic emission rate of black carbon aerosol mass	emianbc [#]	kg m-2 s-1	Monthly (Jan-Dec)		

biomass burning emission rate of black carbon aerosol mass	emibbbc #	kg m-2 s-1	Monthly (Jan-Dec)		
anthropogenic emission rate of organic matter	emianoa #	kg m-2 s-1	Monthly (Jan-Dec)		
biomass burning emission rate of organic matter	emibboa #	kg m-2 s-1	Monthly (Jan-Dec)		
anthropogenic emission rate of CO	emianco #	kg m-2 s-1	Monthly (Jan-Dec)		
biomass burning emission rate of CO	emibbco #	kg m-2 s-1	Monthly (Jan-Dec)		
Deposition, load, and concentration					
dry deposition rate of black carbon aerosol mass	drybc	kg m-2 s-1	Monthly (Jan-Dec)		
dry deposition rate of organic matter	dryoa	kg m-2 s-1	Monthly (Jan-Dec)		
wet deposition rate of black carbon aerosol mass	wetbc	kg m-2 s-1	Monthly (Jan-Dec)		
wet deposition rate of organic matter	wetoa	kg m-2 s-1	Monthly (Jan-Dec)		
Column black carbon mass load	loadbc	kg m-2	Monthly (Jan-Dec)		
Column organic matter load	loadoa	kg m-2	Monthly (Jan-Dec)		
Column sulfate mass load	loadso4	kg m-2	Monthly (Jan-Dec)		
Column sulfur dioxide mass load	Loadso2	kg m-2	Monthly (Jan-Dec)		
Column nitrate mass load	loadno3	kg m-2	Monthly (Jan-Dec)		
Column ammonium mass load	loadnh4	kg m-2	Monthly (Jan-Dec)		
Surface concentration of BC	sconcbc #	kg m-3	Monthly (Jan-Dec)	Daily (Apr., Jul)	IMPROVE/EPA and other
Surface concentration of OA	sconcoa #	kg m-3	Monthly (Jan-Dec)	Daily (Apr., Jul)	IMPROVE/EPA and other
Surface concentration of SO4	sconcso4 #	kg m-3	Monthly (Jan-Dec)	Daily (Apr., Jul)	IMPROVE/EPA and other
Surface concentration of $PM_{2.5}$	sconcpm25 #	kg m-3	Monthly (Jan-Dec)	Daily (Apr., Jul)	IMPROVE/EPA and other
Optical depth					
ambient aerosol optical thickness at 550 nm	od550aer	1	Monthly (Jan-Dec)	Daily (Apr., Jul)	AERONET, MODIS, MISR
sulfate aod@550nm	od550so4	1	Monthly (Jan-Dec)	Daily (Apr., Jul)	
black carbon aod@550nm	od550bc	1	Monthly (Jan-Dec)	Daily (Apr., Jul)	
organic matter aod@550nm	od550oa	1	Monthly (Jan-Dec)	Daily (Apr., Jul)	

Biomass burning oa aod@550nm	od550bboa [#]	1	Monthly (Jan-Dec)	Daily (Apr., Jul)	
nitrate aod@550nm	od550no3	1	Monthly (Jan-Dec)	Daily (Apr., Jul)	
ambient aerosol absorption optical thickness at 550 nm	abs550aer	1	Monthly (Jan-Dec)	Daily (Apr., Jul)	

d) **3-D variables:** (please don't submit 3-hourly outputs yet, I will send you the code later to sample them into ARCTAS flight tracks)

Variable	Variable name [+]	Variable Unit [+]	Temporal frequency [$]		Observational Datasets
air pressure	pfull	Pa	Monthly (Jan-Dec)	3-hourly (Apr., Jul)	
air pressure at interfaces	phalf	Pa	Monthly (Jan-Dec)	3-hourly (Apr., Jul)	
air temperature	ta	k	Monthly (Jan-Dec)	3-hourly (Apr., Jul)	
air density	rho	kg m-3	Monthly (Jan-Dec)	3-hourly (Apr., Jul)	
grid cell height	dh	m	Monthly (Jan-Dec)	3-hourly (Apr., Jul)	
aerosol_extinction_at_550nm	ec550aer	m-1	Monthly (Jan-Dec)	3-hourly (Apr., Jul)	CALIOP, ARCPAC
CO mixing ratio	mmrco	mole mole-1	Monthly (Jan-Dec)	3-hourly (Apr., Jul)	ARCTAS, ARCPAC
Elemental carbon mass mixing ratio	mmrbc	kg kg-1	Monthly (Jan-Dec)	3-hourly (Apr., Jul)	ARCTAS, ARCPAC

[+] Name required by AEROCOM III
[$] Model output resolution. In all situations, monthly outputs from January to December are required. But daily output, sometime 3-hourly, are required for only April and July to save the disk space, when measurements from ARCTAS field campaign in North America are used to evaluate the model output.
[#] variables not listed in the AeroCom III Excel sheet linked below (https://docs.google.com/spreadsheets/d/1EaZO6_FEH6nDhWKE9PvUNpfVkU9RdR2ZT6ahLL2VVEo/edit?usp=sharing).

Note:

1) Please submit the essential variables listed above (priority as 1 listed in the AeroCom III Excel sheet) except for 3-hourly ones. You can refer to AeroCom III-BBEIH output specifications for detailed information and requirements (https://docs.google.com/spreadsheets/d/1EaZO6_FEH6nDhWKE9PvUNpfVkU9RdR2ZT6ahLL2VVEo/edit?usp=sharing). The required diagnostic fields are listed under column "BBEIH".
2) You may want to save those variables (priority as 2 listed in the AeroCom III Excel sheet) as your output as well for further diagnose, although don't need to submit them yet.

Timetable (tentative)

03.2019 – finalize the experiment plan and send it to the AeroCom group
09.2019 – present preliminary results of one model run at the annual AeroCom meeting
01.2020 – submit multi-model results to AeroCom server
07.2020 – circulate the first draft among co-authors
09.2020 – update the results at the annual AeroCom meeting
12.2020 – submit the manuscript to the peer-reviewed journal

Prototype works

Zhu, L., Val Martin, M., Gatti, L. V., Kahn, R., Hecobian, A., and Fischer, E. V.: Development and implementation of a new biomass burning emissions injection height scheme (BBEIH v1.0) for the **GEOS-Chem model** (v9-01-01), Geosci. Model Dev., 11, 4103-4116, https://doi.org/10.5194/gmd-11-4103-2018, 2018.

References

Kahn, R. A., Chen, Y., Nelson, D. L., Leung, F.-Y., Li, Q., Diner, D. J., and Logan, J. A.: Wildfire smoke injection heights: Two perspectives from space, Geophys. Res. Lett., 35, L04809, https://doi.org/10.1029/2007GL032165, 2008.

Val Martin, M., Logan, J. A., Kahn, R. A., Leung, F.-Y., Nelson, D. L., and Diner, D. J.: Smoke injection heights from fires in North America: analysis of 5 years of satellite observations, Atmos. Chem. Phys., 10, 1491–1510, https://doi.org/10.5194/acp- 10-1491-2010, 2010.

Val Martin, M., R. Kahn, and M. Tosca. 2018. "A Global Analysis of Wildfire Smoke Injection Heights Derived from Space-Based Multi-Angle Imaging." Remote Sensing, **10 (10):** 1609 [10.3390/rs10101609]