AeroCom III multi-model comparison:

Update on Biomass Burning Emission Injection Height Experiment (BBEIH)

Xiaohua Pan [1, 2],

Ralph Kahn [2], Mian Chin [2], Hitoshi Matsui [3],

Toshihiko Takemur[4],

Bing Xie [5],Hua Zhang [5],

Maria Val Martin [6]

[1] ADNET systems, INC., USA; [2] NASA GSFC, USA; [3] Nagoya University, Japan; [4] Kyushu University, Japan; [5] China Meteorological Administration, China; [6] University of Sheffield, England

A plume rises over a vineyard in Napa County as the Hennessey Fire burns on Tuesday, Aug. 18, 2020

(AP Photo/Noah Berger)

Why do we care about smoke-emission heights?

1. **Chemical processes** within plumes are sensitive to ambient relative humidity, temperature, smoke-cloud interactions, and photolysis rates – all of which depend on smoke injection height (e.g. PAN).
2. Smoke injected into the free troposphere generally **travels farther downwind** than smoke emitted into the PBL;
3. The **surface concentration** of air pollutants near and downwind of fire sources is sensitive to smoke plume elevation and transport;
4. Both **dry and wet removal process** are more efficient in the PBL than in the free troposphere;
5. **Aerosol-climate interactions** depend on the vertical distribution of smoke (above, in, or below cloud)

The objectives of BBEIH

We aim to address the following scientific questions:

- ❑ To what degree does the aerosol associated with biomass burning impact near-source and downwind conditions?
- ❑ 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
- ❑ In which regions/seasons/surface-types are the aforementioned sensitivities significant?
- ❑ To what extent do the aforementioned sensitivities vary across different models?

Four model experiments

- **BASE**: All emissions including burned-area based on **BB GFED4.1s**, using model-default biomass burning injection height (i.e., smoke distributed within PBL).
- **BBIH**: Same as BASE, but distribute biomass burning emissions vertically constrained by the **MISR** plume injection height weighting function* (Val Martin et al., 2010; 2018).
- **NOBB**: **No biomass burning** emissions.
- **BBEM:** (optional) Same as BASE, but using daily FRP-based **BB FEER** emission.

* Note: MISR observations occur in late morning local time (~10:30 AM ± 1 hr.)

Status of model participation

Model Name/ (lon*lat)	Contact	Email	BASE	BBIH	NOBB	BBEM
BCC-CUACE (2.8*2.8)	Bing Xie, Hua Zhang	xieb@cma.gov.cn	Done	Done	Done	
CAM5-ATRAS (2.5*1.9)	Hitoshi Matsui	matsui@nagoya-u.jp	Done dy (2d)	Done dy(2d)	Done dy(2d)	Done dy(2d)
MIROC-SPRINTARS (0.56*0.56)	Toshihiko Takemur	toshi@riam.kyushu-u.ac.jp	Done dy (2d+3d)	Done dy (2d+3d)	Done dy (2d+3d)	Done dy (2d+3d)
GEOS-i33p2 (0.5*0.5)	Xiaohua Pan	Xiaohua.pan@nasa.gov	Done dy (2d+3d), hr (2d+3d)	Done dy (2d+3d), hr (2d+3d)	Done dy (2d+3d), hr (2d+3d)	Done dy (2d+3d), hr (2d+3d)

Monthly output is the default. Additional output other than monthly:

- dy: daily output
- hr: 3-hourly output (I didn't see anyone else submit this, so I need to follow up later after figuring out how to sample the results according to the flight track).

Preliminary results

Focused events:

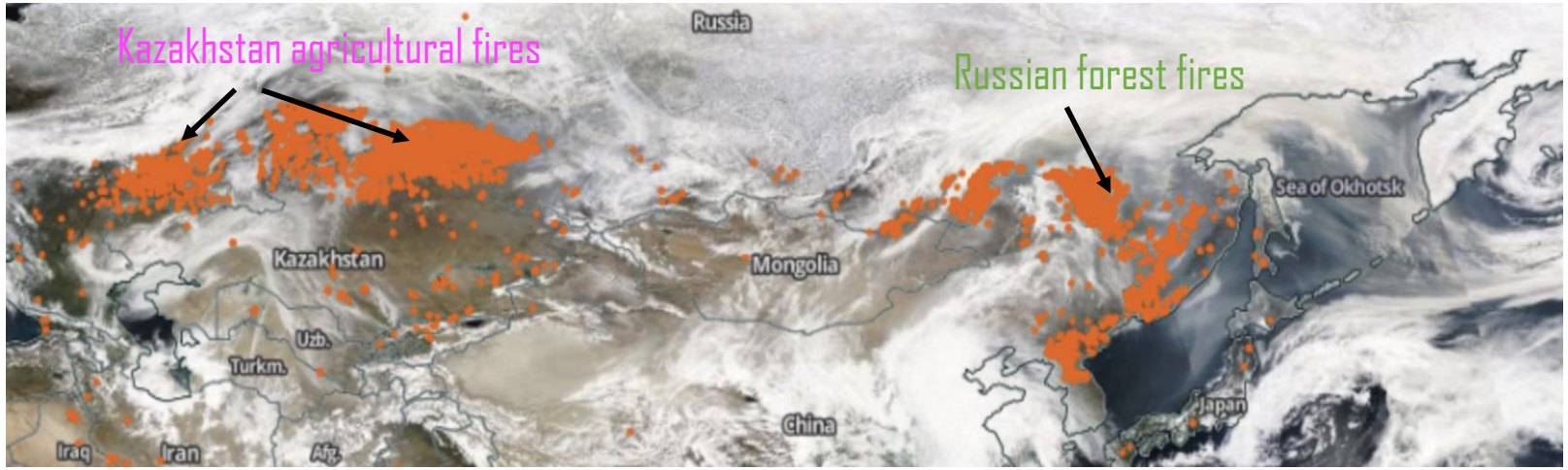
- ❑ Siberia Fires occurred in April 2008

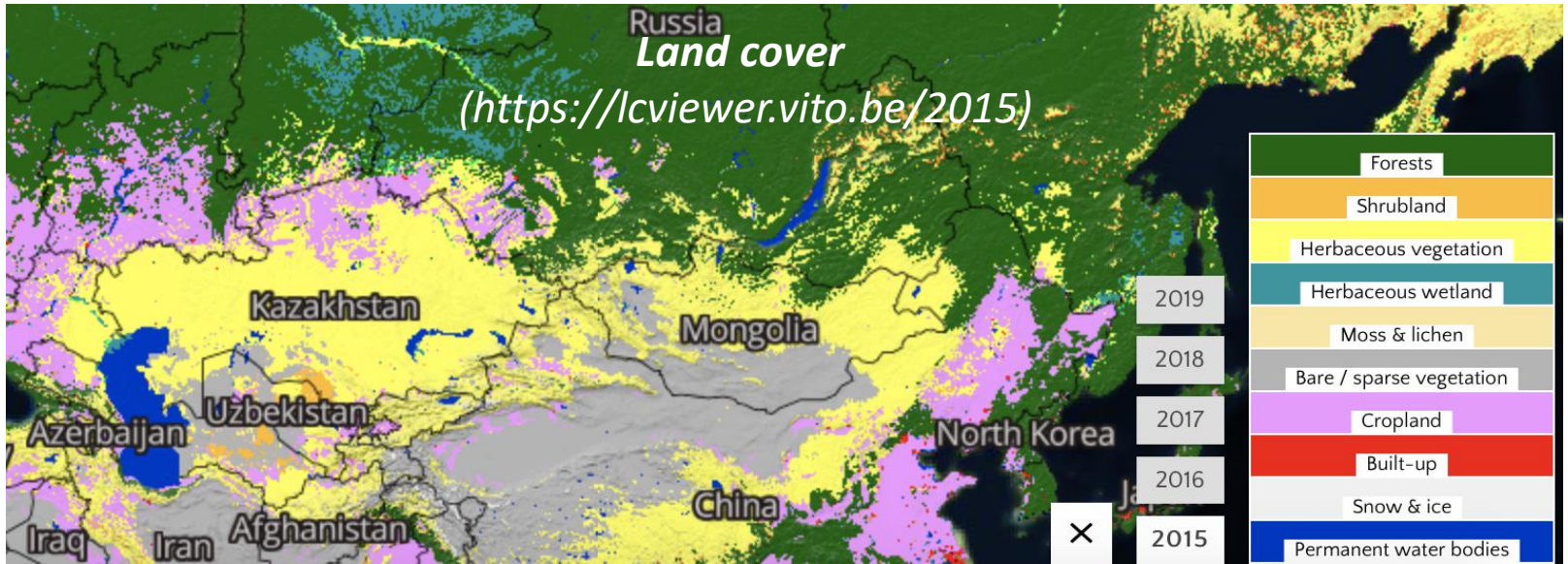
Variables:

- ❑ AOD

RGB image from MODIS-Aqua overlayed with fire detections

by both day and night Aqua and Terra April 2, 2008 (credit: NASA WorldView)

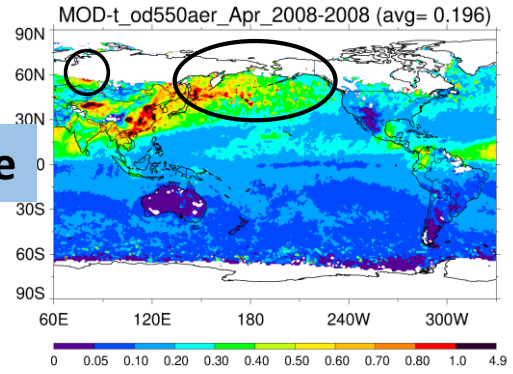




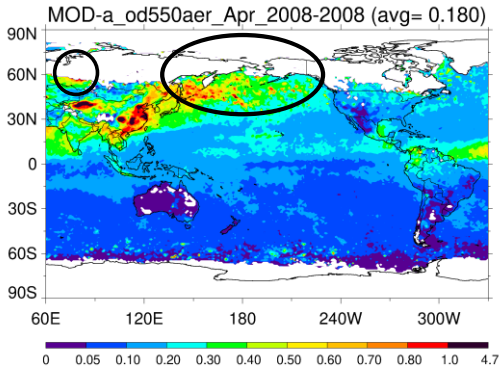
AOD at 550nm in April 2008

Satellite

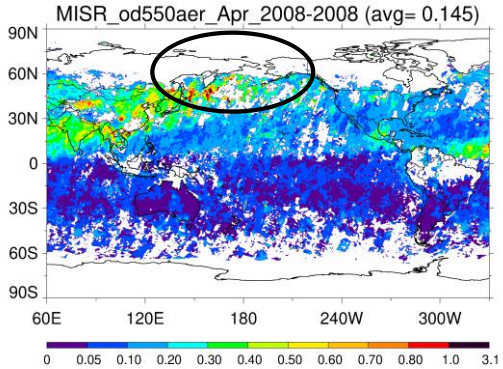
MODIS-Terra



MODIS-Aqua



MISR



Satellite:

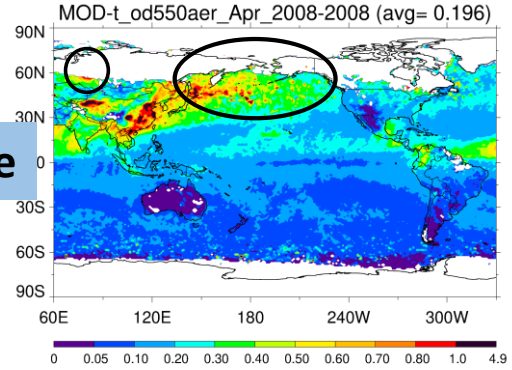
- Strong outflow of aerosols from the north of China towards Sea of Okhotsk and Bering Sea (AOD >0.5)
- Hint of high aerosol loading in Kazakhstan (AOD ~ 1)

AOD at 550nm in April 2008

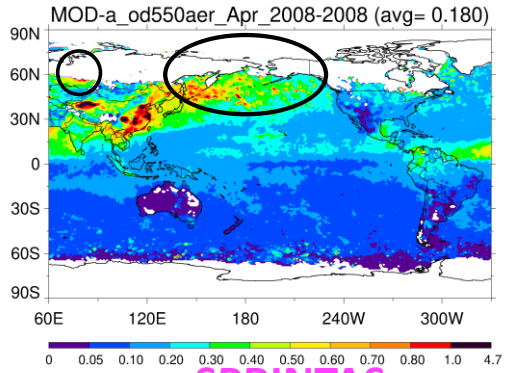
Satellite

BASE

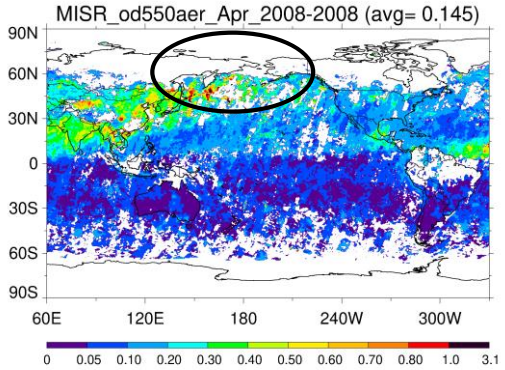
MODIS-Terra



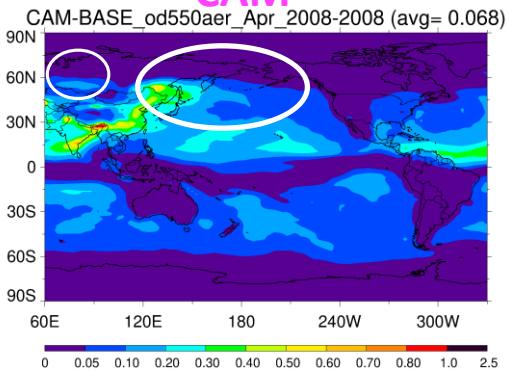
MODIS-Aqua



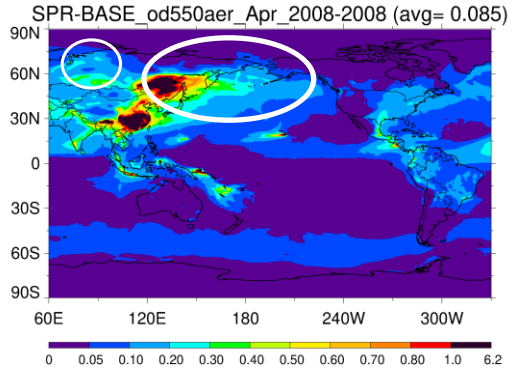
MISR



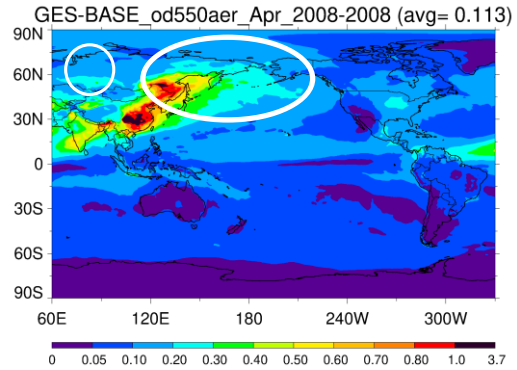
CAM



SPRINTAS



GEOS



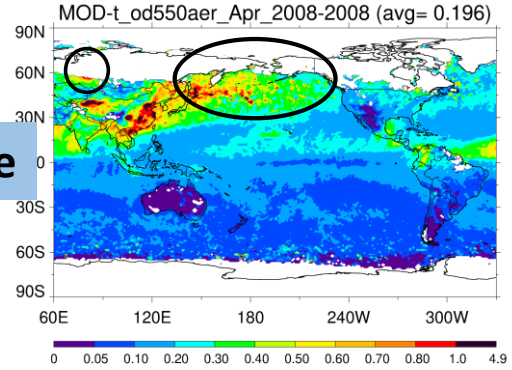
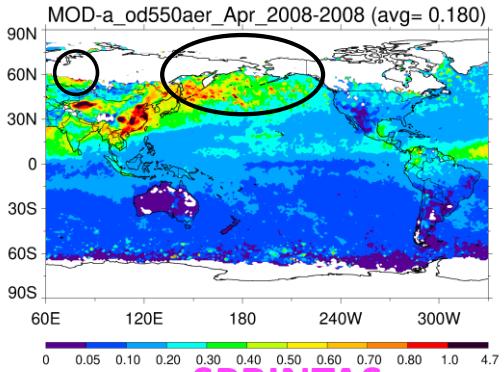
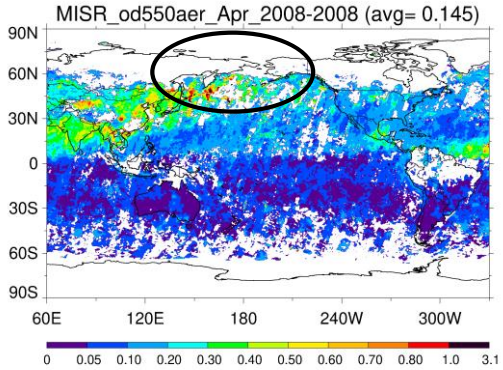
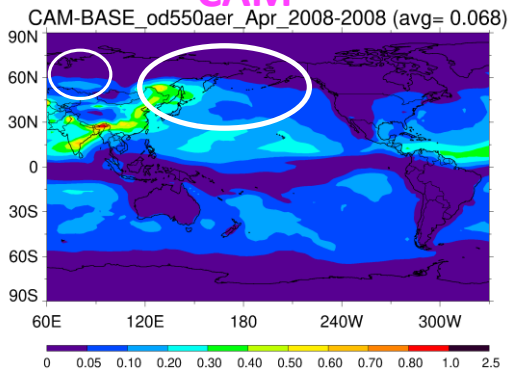
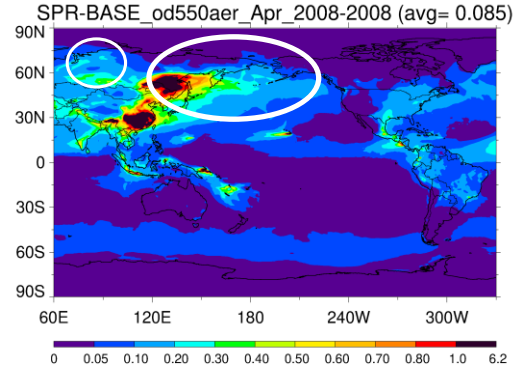
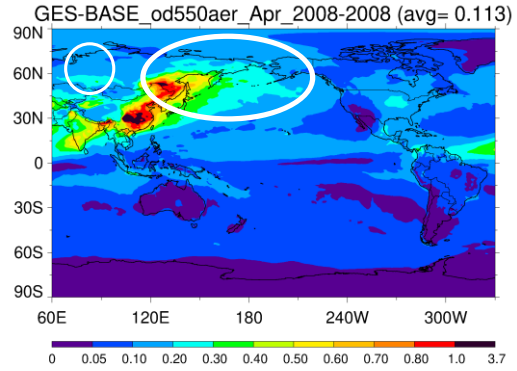
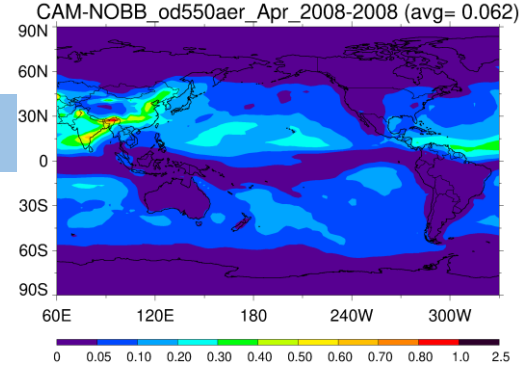
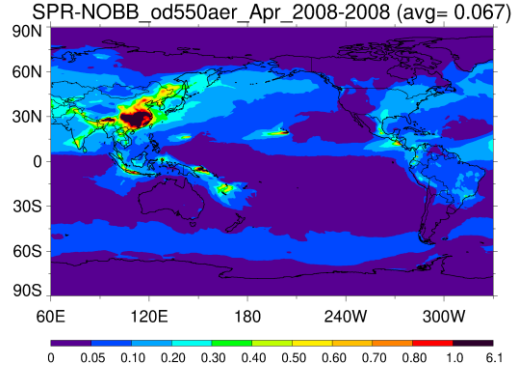
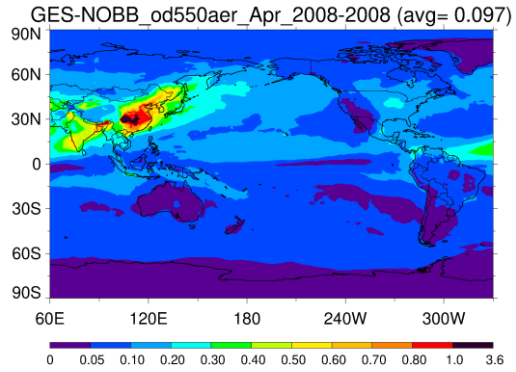
Satellite:

- Strong outflow of aerosols (max AOD ~0.8) from the north of China towards Sea of Okhotsk and Bering Sea
- Hint of high aerosol loading in Kazakhstan (AOD ~ 1)

BASE:

- The outflow of aerosols from the north of China is underestimated (max AOD ~ 0.3)
- Hint of high aerosol loading in Kazakhstan (AOD up to 0.4)

AOD at 550nm in April 2008

	MODIS-Terra	MODIS-Aqua	MISR
Satellite			
BASE	CAM 	SPRINTAS 	GEOS 
NOBB			

Satellite:

- Strong outflow of aerosols (max AOD ~0.8) from the north of China towards Sea of Okhotsk and Bering Sea
- Hint of high aerosol loading in Kazakhstan (AOD ~ 1)

BASE:

- The outflow of aerosols from the north of China is underestimated (max AOD ~ 0.3)
- Hint of high aerosol loading in Kazakhstan (AOD up to 0.4)

NOBB:

- The outflow of anthropogenic and dust aerosols from the north of China is captured

AOD at 550nm in April 2008

Satellite:

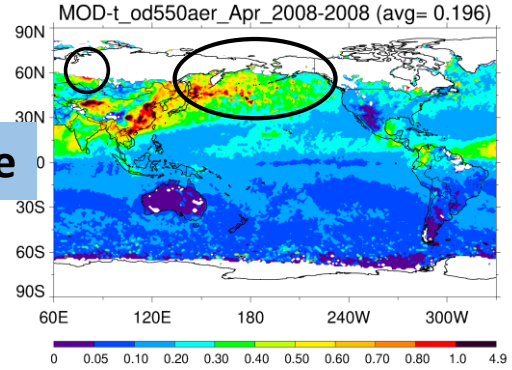
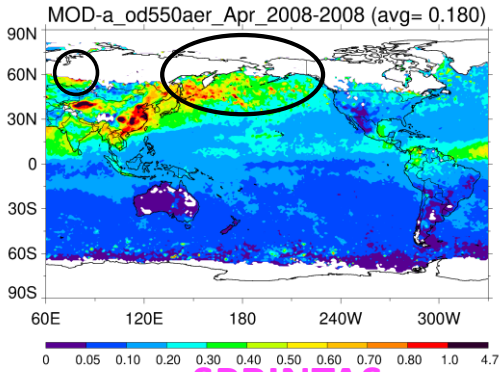
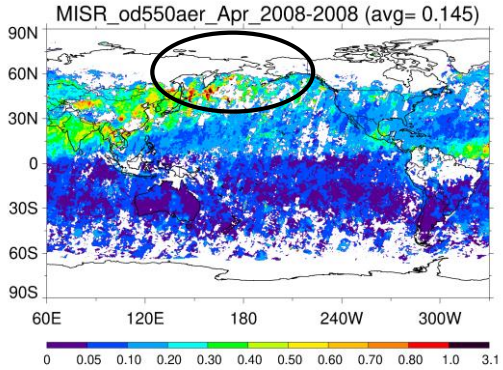
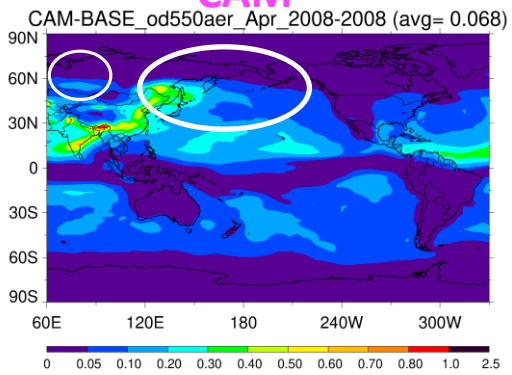
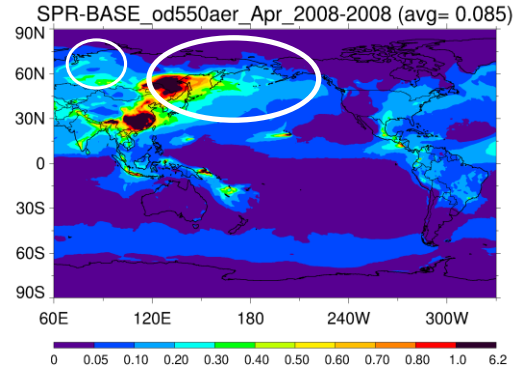
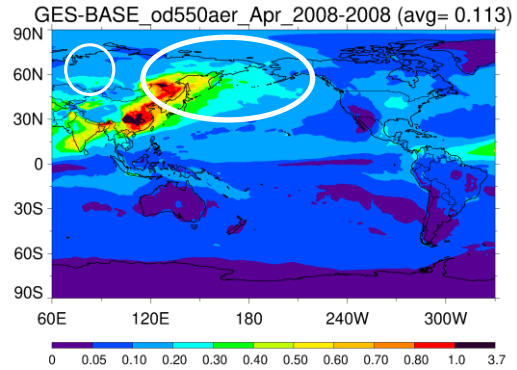
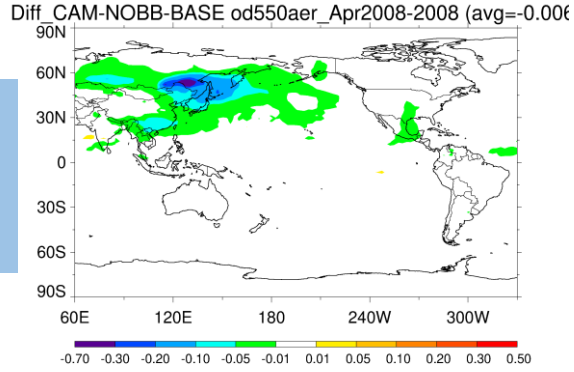
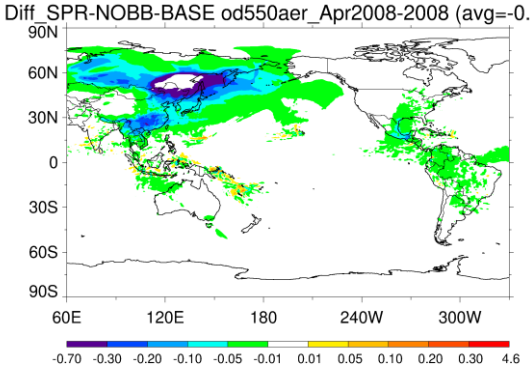
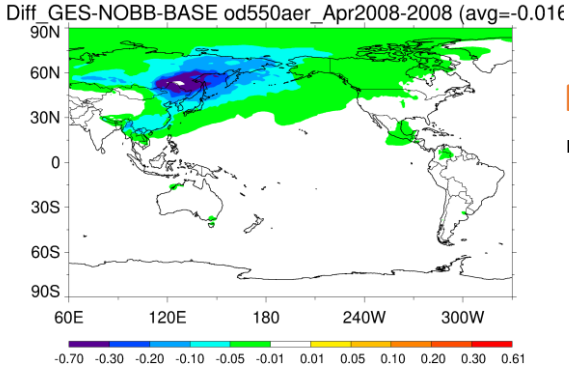
- Strong outflow of aerosols (max AOD ~0.8) from the north of China towards Sea of Okhotsk and Bering Sea
- Hint of high aerosol loading in Kazakhstan (AOD ~ 1)

BASE:

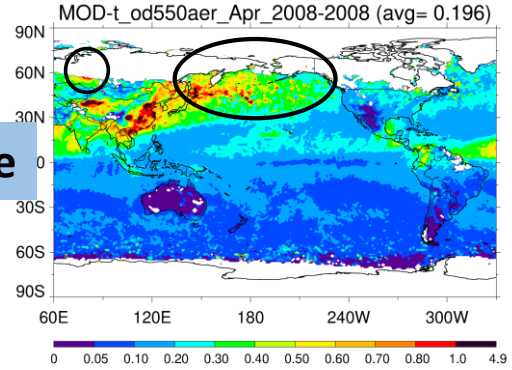
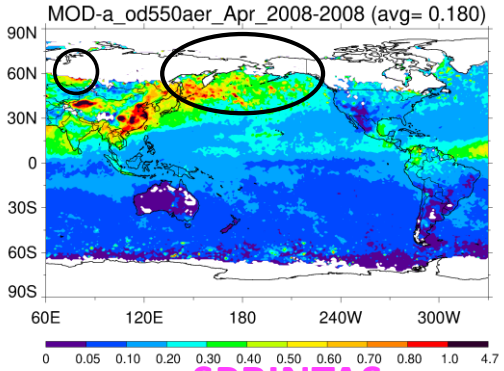
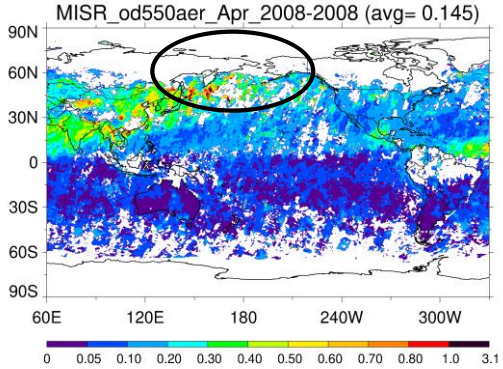
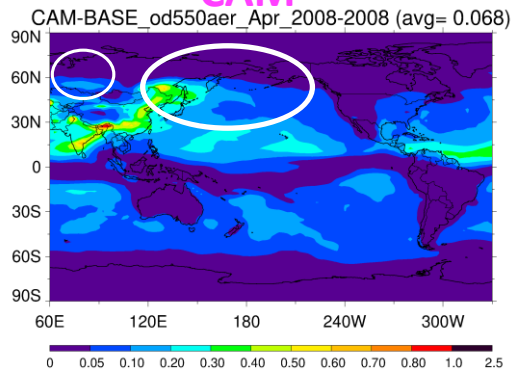
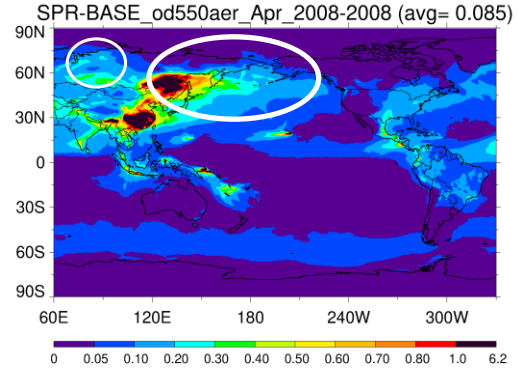
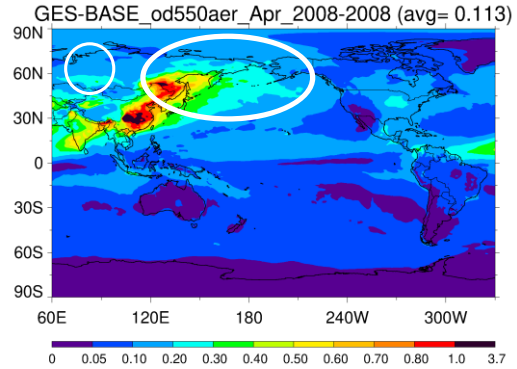
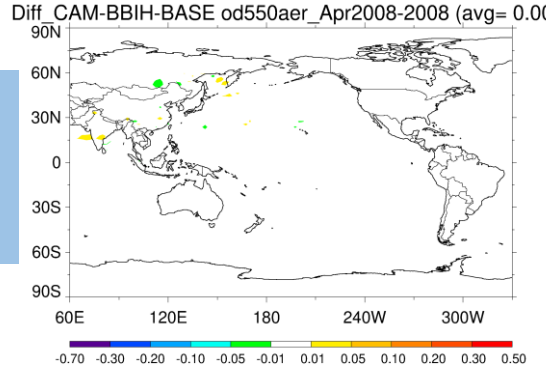
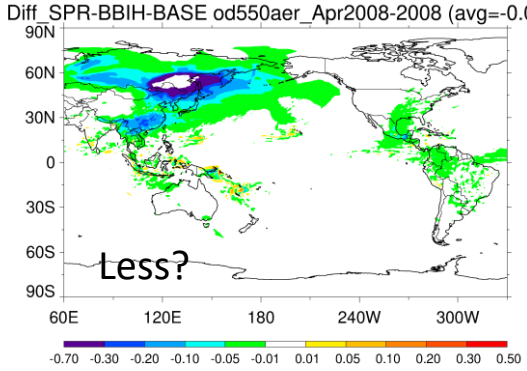
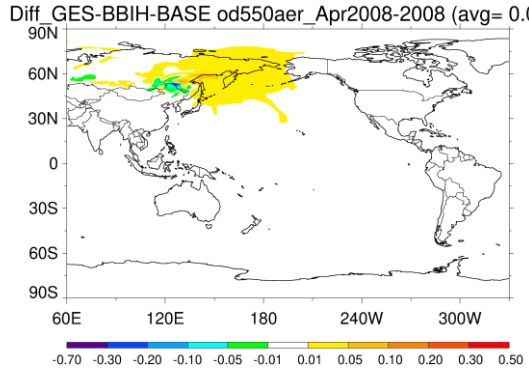
- The outflow of aerosols from the north of China is underestimated (max AOD ~ 0.3)
- Hint of high aerosol loading in Kazakhstan (AOD up to 0.4)

NOBB – BASE → smoke

- The outflow of smoke-aerosols from the north of China is about 0.01-0.2

	MODIS-Terra	MODIS-Aqua	MISR
Satellite			
BASE	CAM 	SPRINTAS 	GEOS 
NOBB - BASE			

AOD at 550nm in April 2008

	MODIS-Terra	MODIS-Aqua	MISR
Satellite			
BASE	CAM 	SPRINTAS 	GEOS 
BBIH - BASE			

Satellite:

- Strong outflow of aerosols (max AOD ~0.8) from the north of China towards Sea of Okhotsk and Bering Sea
- Hint of high aerosol loading in Kazakhstan (AOD ~ 1)

BASE:

- The outflow of aerosols from the north of China is underestimated (max AOD ~ 0.3)
- Hint of high aerosol loading in Kazakhstan (AOD up to 0.4)

BBIH – BASE → MISR plume height

- The outflow of smoke-aerosols from the north of China increased in GEOS by 0.01-0.05, almost no difference in CAM, and less in SPR

AOD at 550nm in April 2008

Satellite:

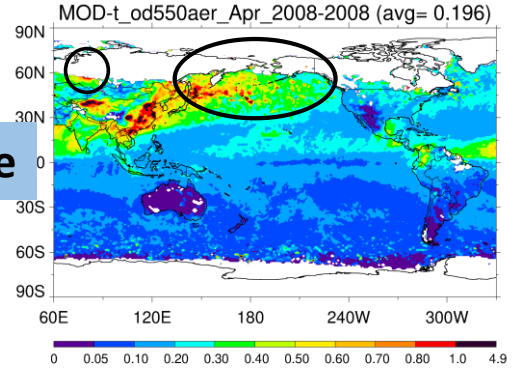
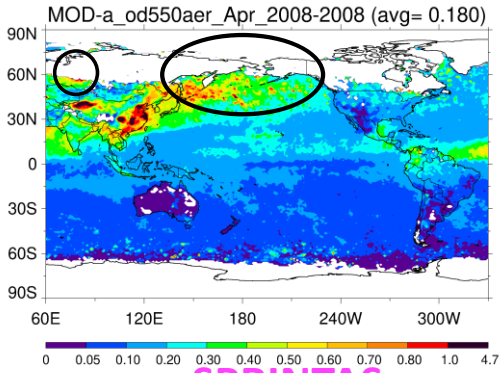
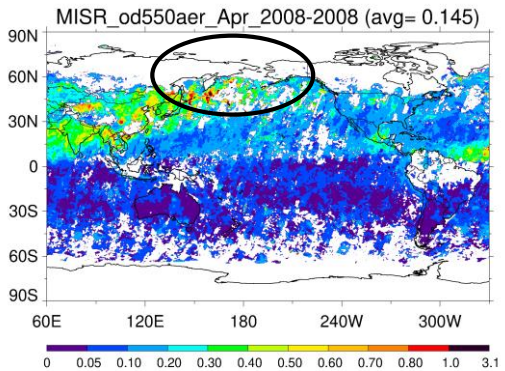
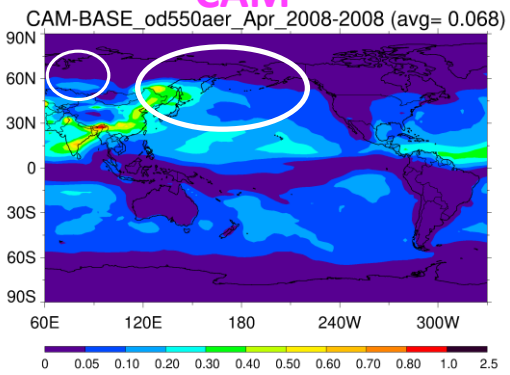
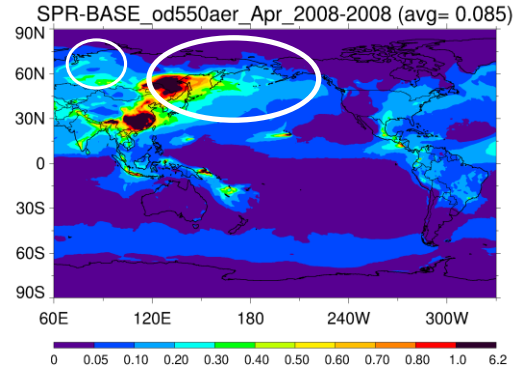
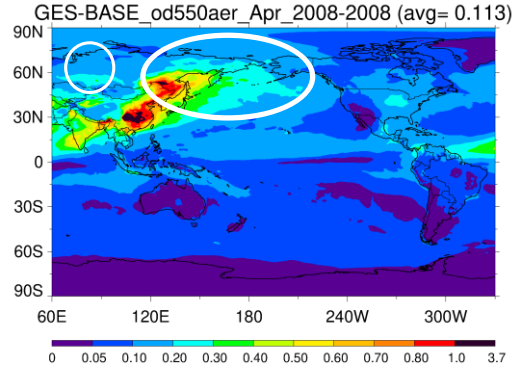
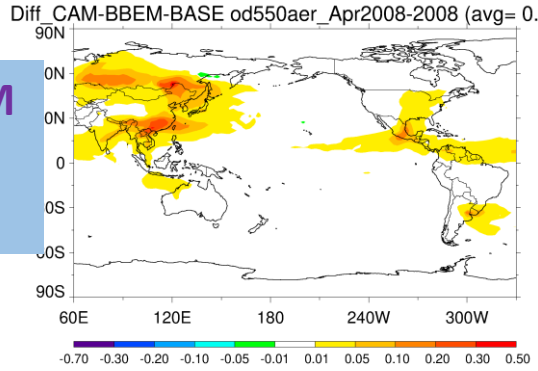
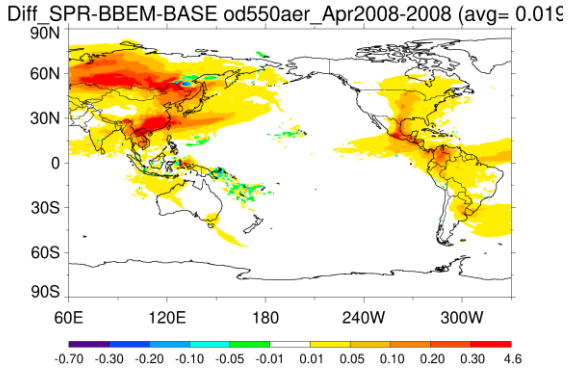
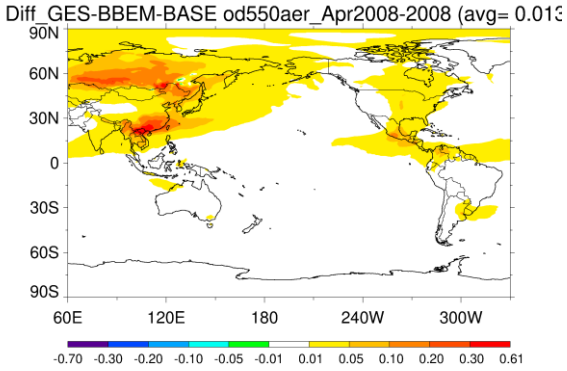
- Strong outflow of aerosols (max AOD ~0.8) from the north of China towards Sea of Okhotsk and Bering Sea
- Hint of high aerosol loading in Kazakhstan (AOD ~ 1)

BASE:

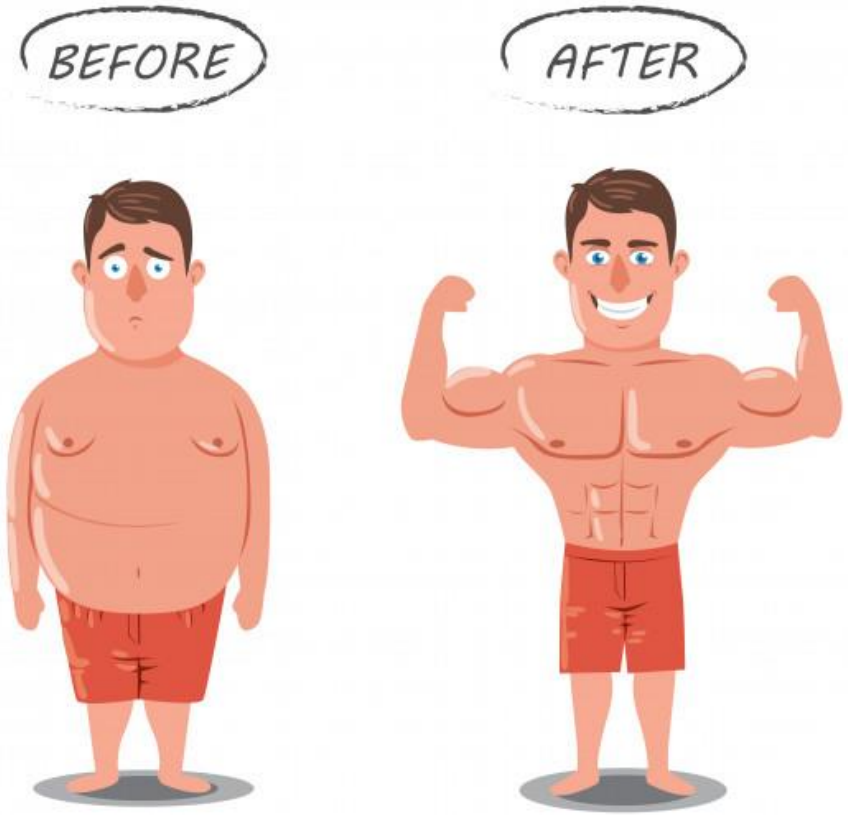
- The outflow of aerosols from the north of China is underestimated (max AOD ~ 0.3)
- Hint of high aerosol loading in Kazakhstan (AOD up to 0.4)

BBEM – BASE → FEER – GFED4s

- The smoke-aerosols from both the fire source regions and the outflow are greater with FEER than with GFED4s across all models by 0.01-0.05

	MODIS-Terra	MODIS-Aqua	MISR
Satellite			
BASE	CAM 	SPRINTAS 	GEOS 
BBEM - BASE			

Thank you



Wiki website: https://wiki.met.no/aerocom/phase3-experiments#biomass_burning_emission_injection_height_experiment_bbeih

Phase III Organizers: Xiaohua Pan, Ralph Kahn, Mian Chin, Maria Val Martin

Contacts: Xiaohua xiaohua.pan@nasa.gov, and Ralph Kahn ralph.kahn@nasa.gov

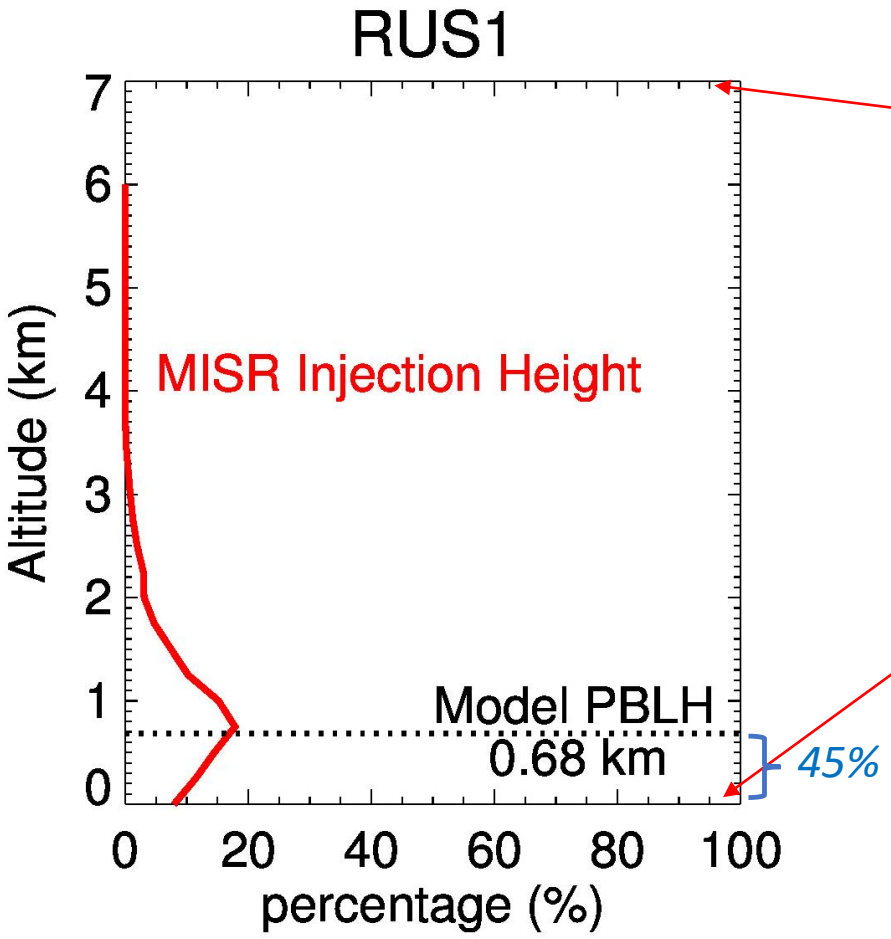
References

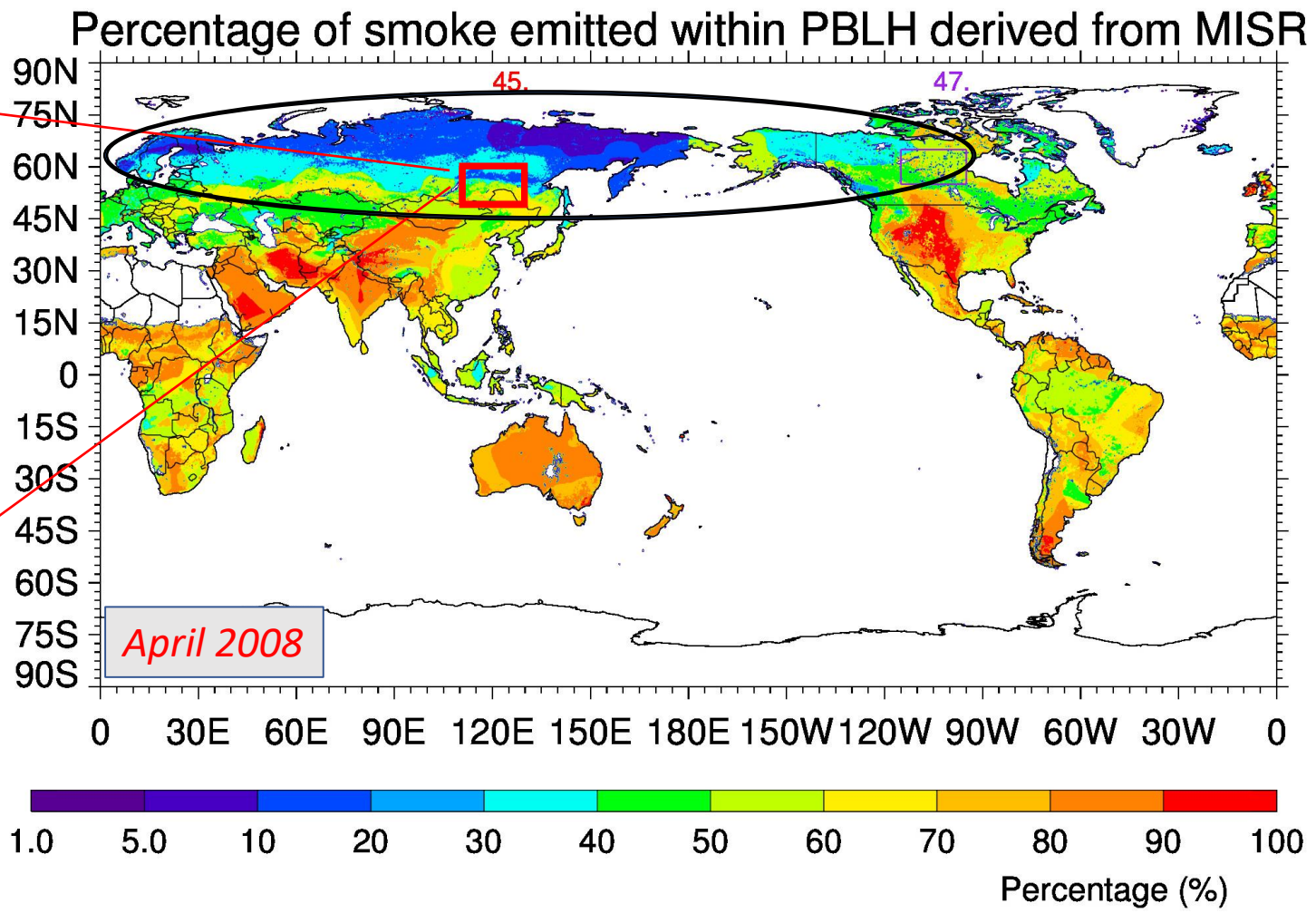
- **Freitas,** S. R., Longo, K. M., Chatfield, R., Latham, D., Silva Dias, M. A. F., Andreae, M. O., Prins, E., Santos, J. C., Gielow, R., and Carvalho Jr., J. A.: Including the sub-grid scale plume rise of vegetation fires in low resolution atmospheric transport models, Atmos. Chem. Phys., 7, 3385-3398, https://doi.org/10.5194/acp-7-3385-2007, 2007.
- ***Gonzalez-Alonso***, L., M. Val Martin, and R.A. Kahn, 2018. Biomass burning smoke heights over the Amazon observed from the space. *Atmosph. Chem. Phys*. 19, 1685–1702, doi: 10.5194/acp-19-1685-2019.
- ***Petrenko,*** M., Kahn, R., Chin, M., & Limbacher, J. (2017). Refined use of satellite aerosol optical depth snapshots to constrain biomass burning emissions in the GOCART model. Journal of Geophysical Research: Atmospheres, 122, 10,983–11,004. https://doi.org/10.1002/2017JD026693.
- ***Pan***, X., Ichoku, C., Chin, M., Bian, H., Darmenov, A., Colarco, P., Ellison, L., Kucsera, T., da Silva, A., Wang, J., Oda, T., and Cui, G.: Six Global Biomass Burning Emission Datasets: Inter-comparison and Application in one Global Aerosol Model, Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2019-475, in review, 2019.
- ***Val Martin***, M. R.A. Kahn, and M. Tosca, 2018. A Global Climatology of Wildfire Smoke Injection Height Derived from Space-based Multi-angle Imaging. *Remote Sensing 10,* 1609; doi:10.3390/rs10101609.
- ***Vernon***, C. J., Bolt, R., Canty, T., and Kahn, R. A.: The impact of MISR-derived injection height initialization on wildfire and volcanic plume dispersion in the HYSPLIT model, Atmos. Meas. Tech., 11, 6289–6307, https://doi.org/10.5194/amt-11-6289-2018, 2018.
- ***Zhu***, L., M. Val Martin, A. Hecobian, M.N. Deeter, L.V. Gatti, R.A. Kahn, and E.V. Fischer, 2018. Development and implementation of a new biomass burning emissions injection height scheme for the GEOS-Chem model. *Geosci. Model Develop*. *11*, 4103–4116, doi:10.5194/gmd-11-4103-2018.

BACKUP

Current limitations of model: NASA GEOS

Val Martin, Kahn & Tosca; 2018

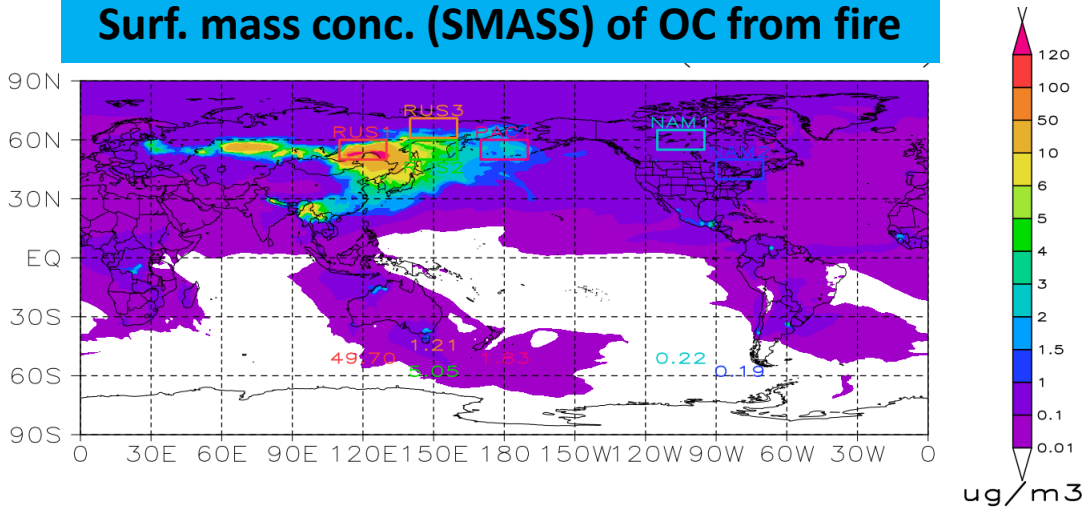




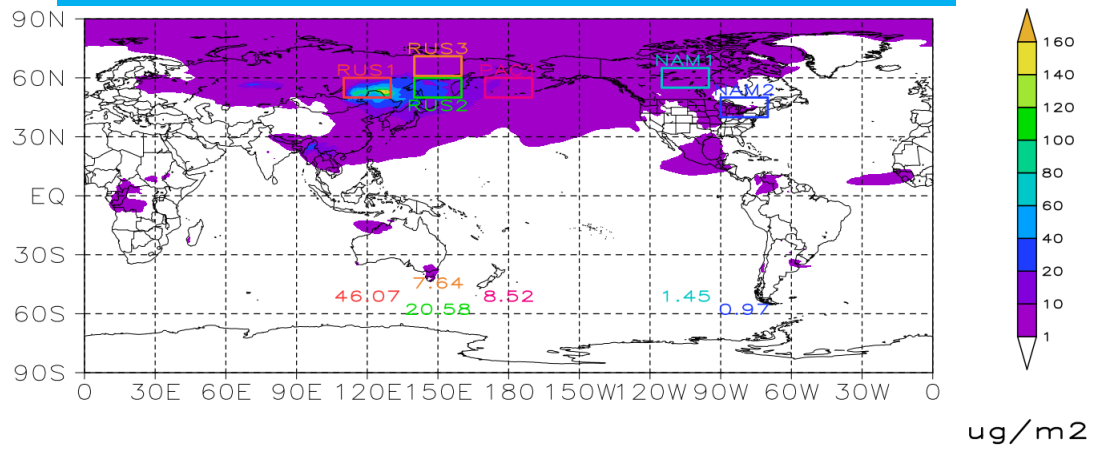
- During April 2008, only 45% of smoke is emitted within PBLH over RUS1.
- However, by default, the GEOS model emits all smoke within PBLH.

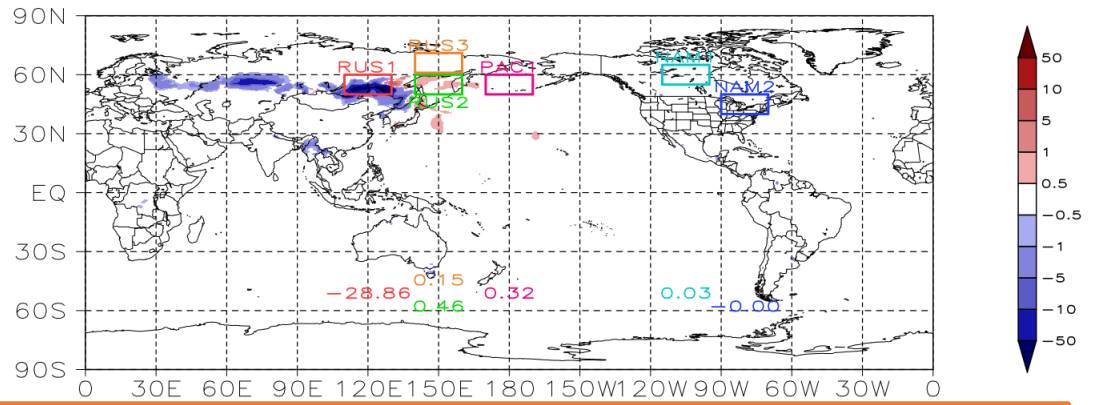
April 2008

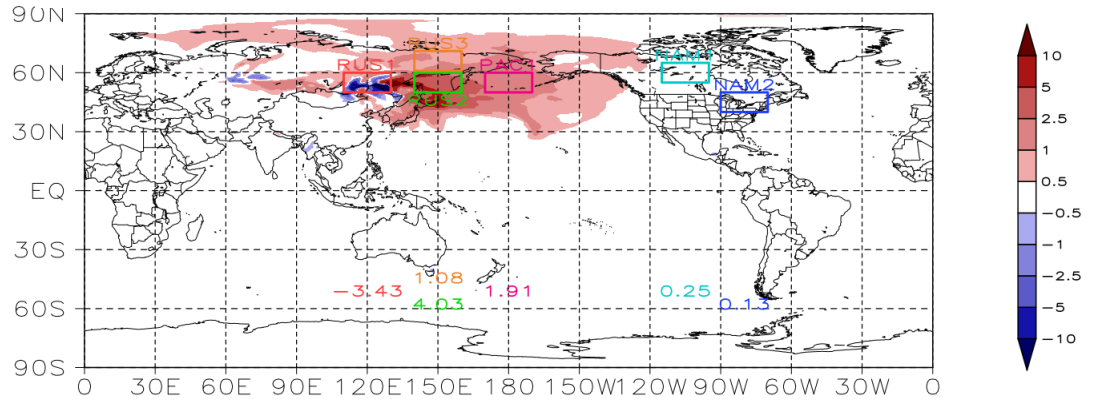
Surf. mass conc. (SMASS) of OC from fire



Column mass load (CMASS) of OC from fire







General impact of Siberia fires (BASE):

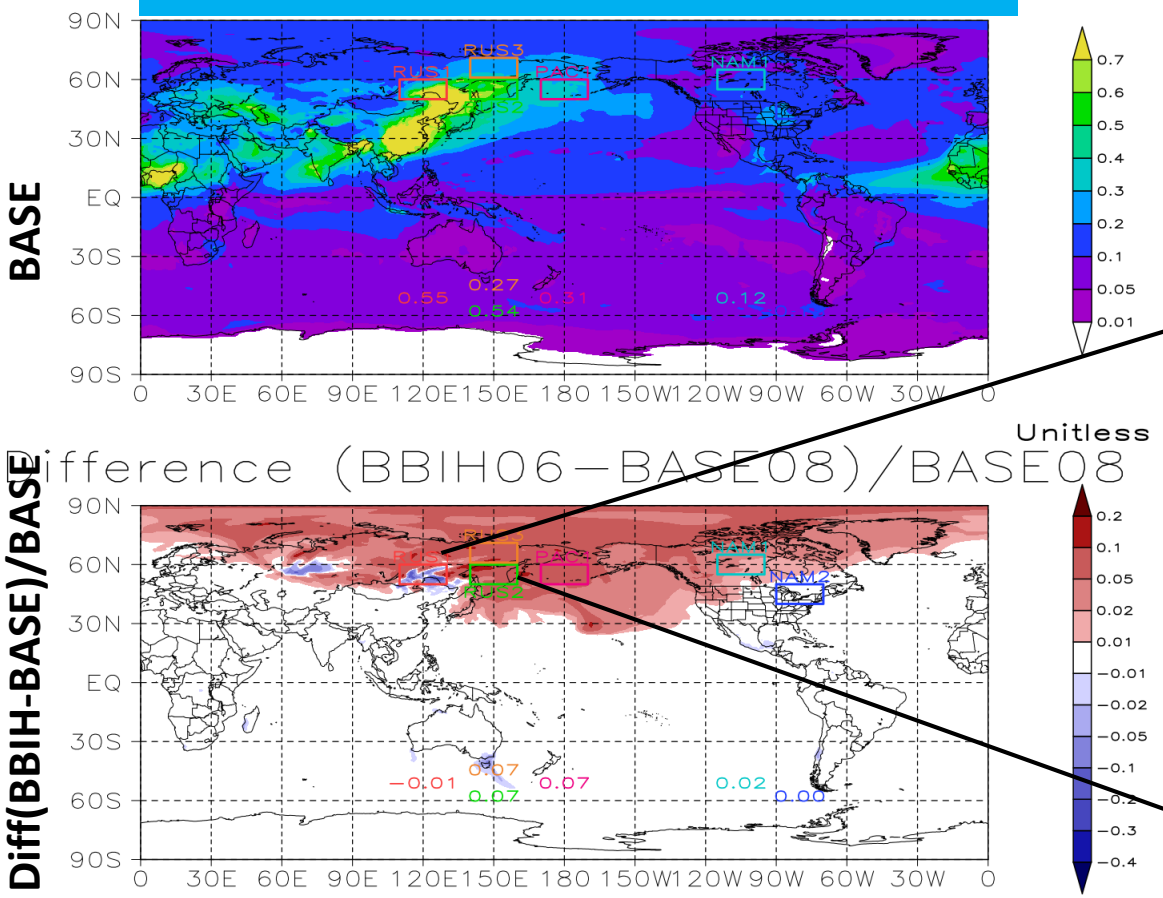
- **SMASS:** enhanced over source region RUS1 by 49.70 ug/m^3, and adjacent downwind regions (RUS2) by 5.05 ug/m^3 , (PAC1) by 1.83 ug/m^3 as well as over the entire northern hemisphere around 0.1-1 ug/m^3.

Difference (BBIH-BASE)

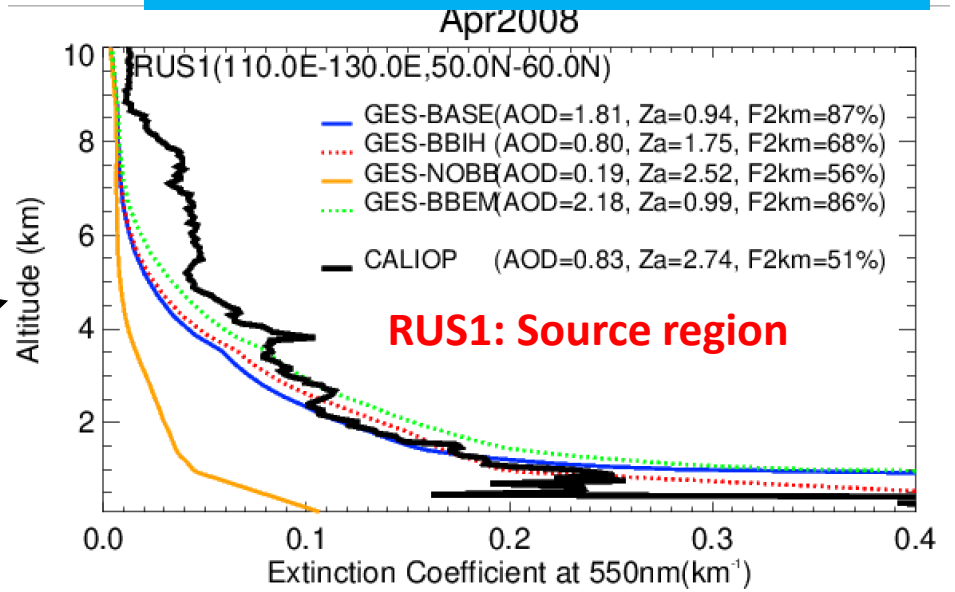
- **SMASS**: Reduced near source region (RUS1) by 28.86 ug m^{-3} ;but enhanced over downwind regions RUS2 by 0.46 ug m^{-3}, and PAC1 by 0.32 ug m^{-3}
- **CMASS**: Reduced close to source region (RUS1) by 3.43 ug m^{-2} but enhanced over downwind region RUS2 by 4.03 ug m^{-2}, PAC1 by 1.91 ug m^{-2}

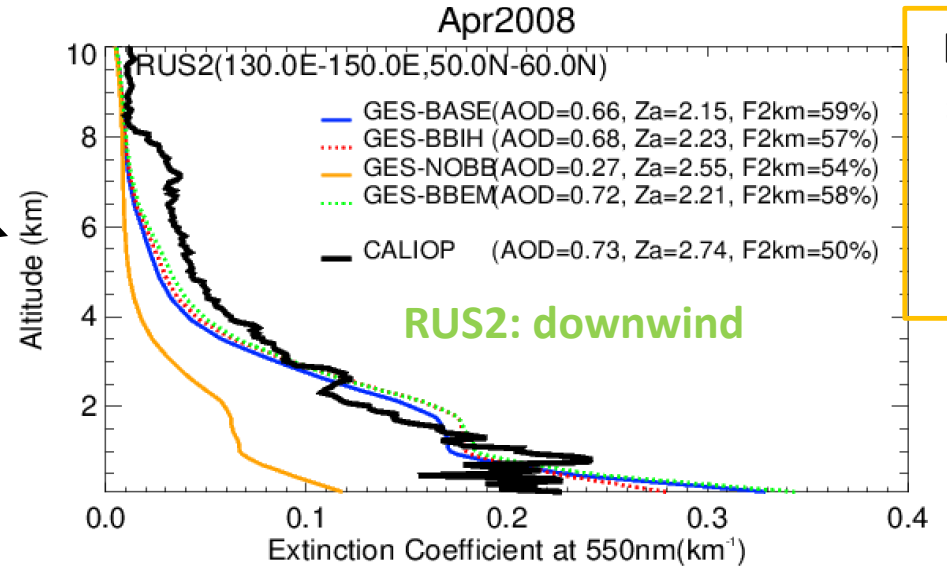
April 2008

Total AOD



Vertical profile of extinction



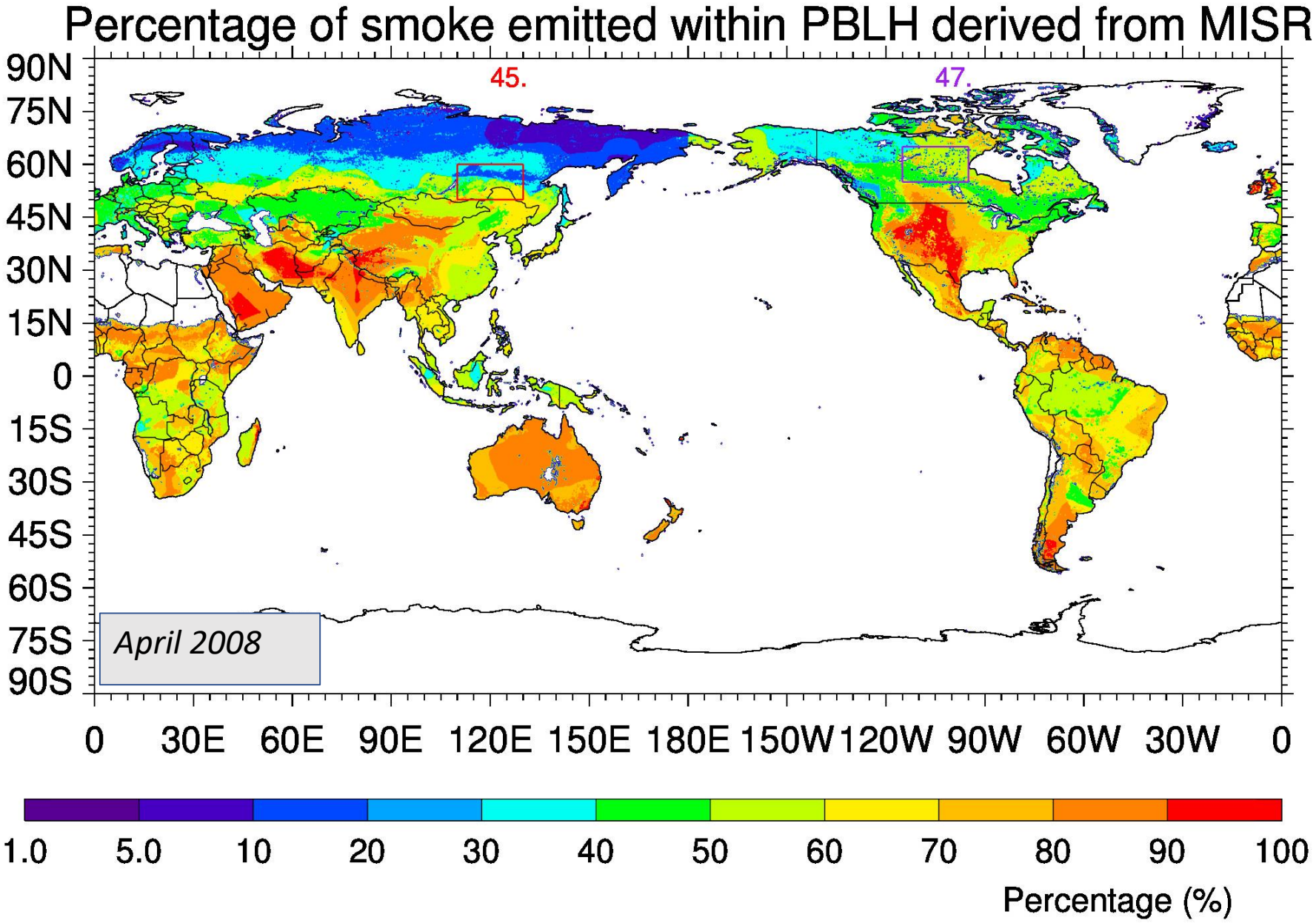


BBIH brings the statistics closer to CALIOP in both RUS1 and RUS2

Difference (BBIH-BASE)/BASE

- Reduced near source region (RUS1) by 1%;but enhanced over downwind regions RUS2 by 7%, RUS3 and PAC1 by 7%, NAM1 by 2%

MISR smoke injection height



Val Martin, Kahn & Tosca; 2018

Bonus:

We will provide a gridded MISR injection height weight function for you!!!
(lon, lat, lev, mon)

Observational datasets used to validate model

- **AOD**

  MODIS, MISR, and AERONET

- **AAOD and AI**

  OMI and OMPS

- **Vertical profile of aerosol extinction profile**

  CALIOP and OMPS

- **Vertical profile of atmospheric composition**
  - USA and Canada: ARCTAS (2008)
  - Russia: ???

- **Surface aerosol concentration network**
  - USA:
    - ✓ EPA: ($PM_{2.5}$, PM_{10})
    - ✓ IMPROVE: 2005-2011, daily, species (BC, OM, aerbext)
  - Canada: ??
  - Russia: ???