

# Reducing uncertainty in black-carbon climate forcing using a new inventory and high-resolution model

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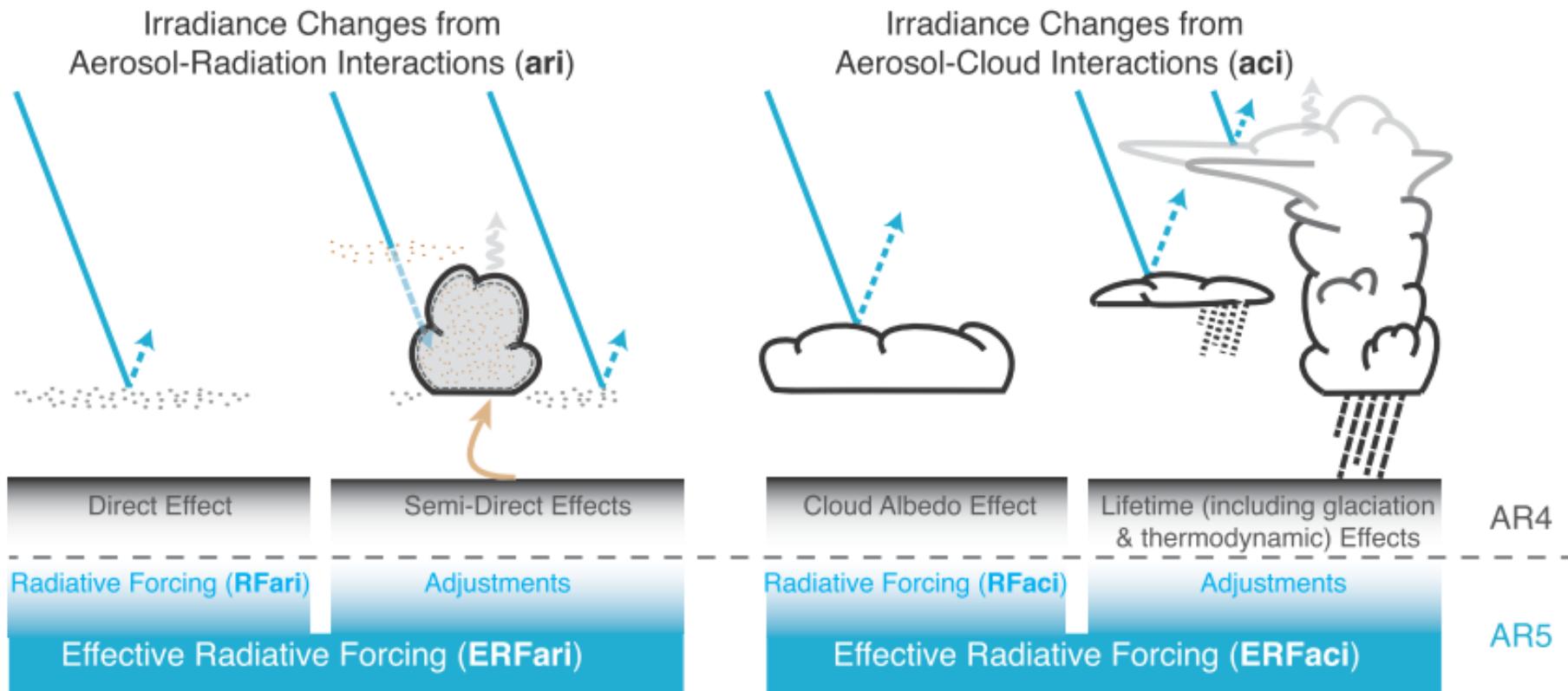
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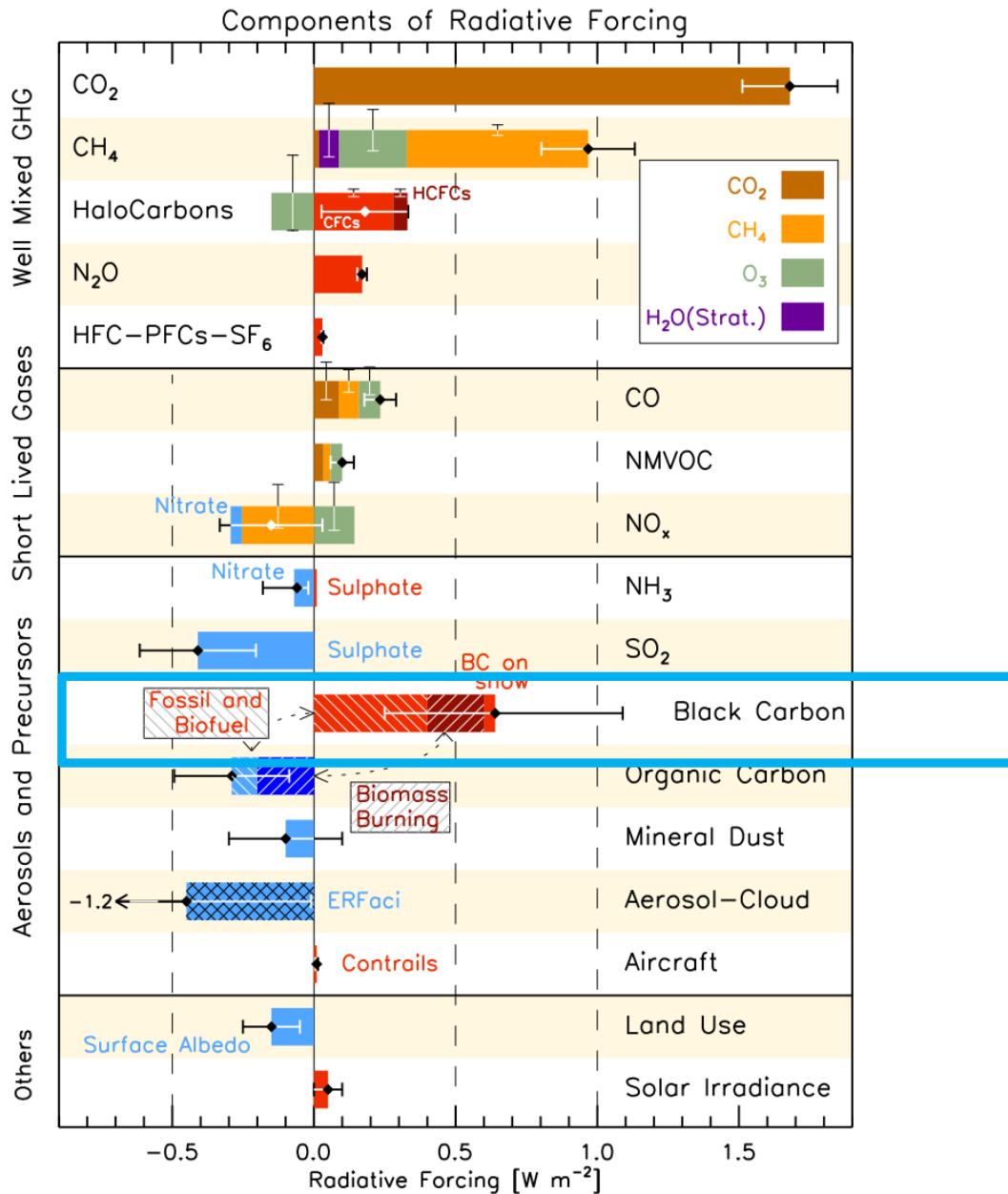
SOFIE, Sep 2015

# Impact of aerosols on the Energy Budget



from IPCC-AR5, 2014

# Role of black carbon in the Climate Change



from IPCC-AR5, 2014

# Direct Radiative forcing (DRF) of BC

$$\begin{aligned}\text{BC DRF} &= E \times L \times \text{MAC}_{\text{BC}} \times \text{AFE} \\ &= \text{BC AAOD} \times \text{AFE}\end{aligned}$$

- E, global emission rate of BC;
- L, global mean lifetime of BC;
- MAC, global mean mass absorption cross section, dependent on the mixing state of BC;
- AFE, global mean absorption forcing efficiency (forcing per AAOD), depending on the vertical profile of BC.
- BC AAOD, global mean aerosol absorption optical depth of BC

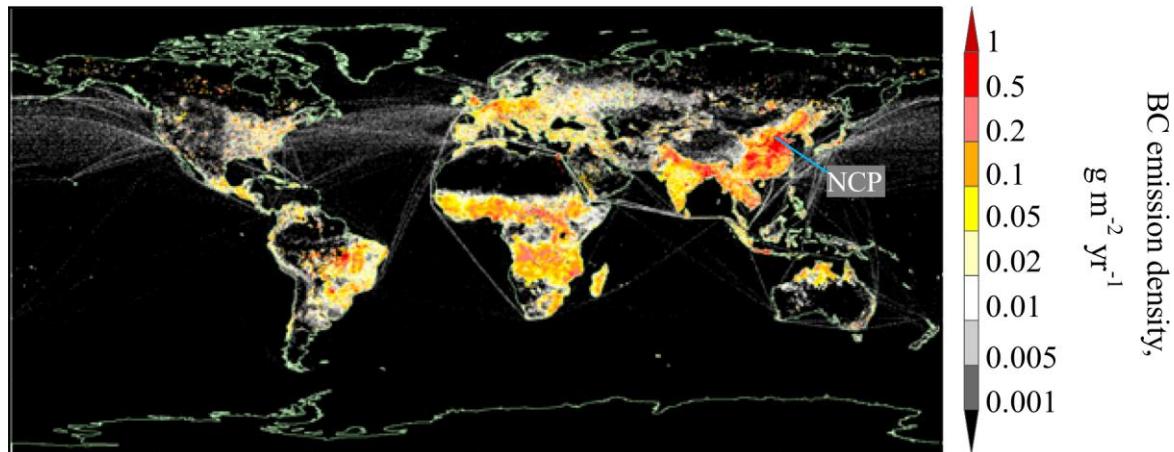
# A huge gap in modeling BC AAOD (8 models)

Region	# Pairs	Model	Observation	
		AeroCom AAOD	AERONET AAOD	Ratio
North America	140–220	0.0024	0.0047	1.96
South America	80–110	0.0049	0.0084	2.49
Middle East	20–35	0.0042	0.0110	2.63
Africa	70–110	0.0052	0.0170	3.29
Europe	90–120	0.0052	0.0083	1.59
EECCA	40–60	0.0079	0.0133	1.68
South Asia	15–20	0.0069	0.0427	6.20
East Asia	30–60	0.0099	0.0280	2.84
Southeast Asia	25–30	0.0053	0.0252	4.75
Japan/Oceania	35–40	0.0015	0.0053	3.57
Polar land	0–6			1.00
All oceans	140–210	0.0049	0.0132	2.04

from Bond et al., JGR, 2013

# Development of a new BC inventory

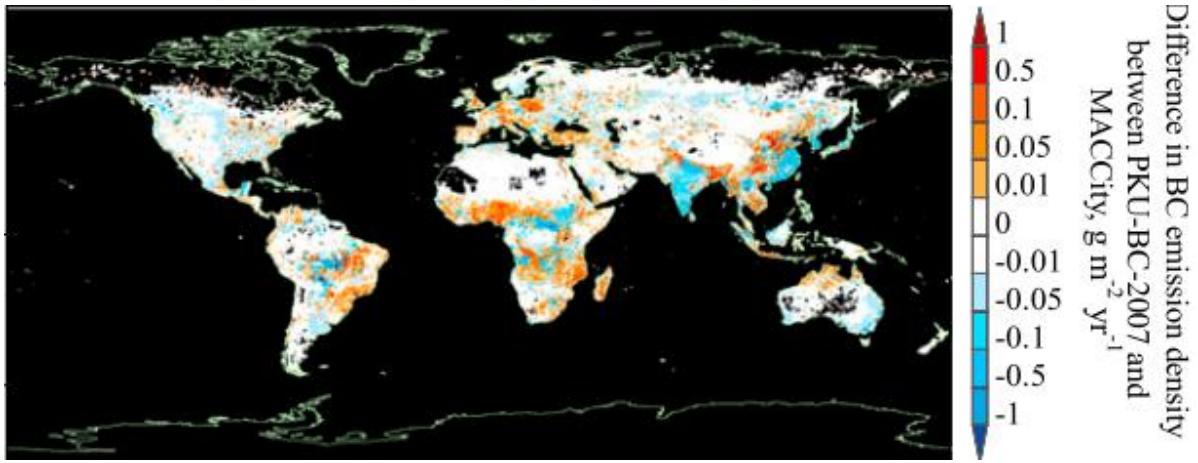
New BC Emission Inventory (PKU-BC)



**Global BC emissions:**

- **PKU-BC: 9.0 Tg / yr**
- **MACCity: 7.4 Tg / yr**

Difference relative to the traditional inventory



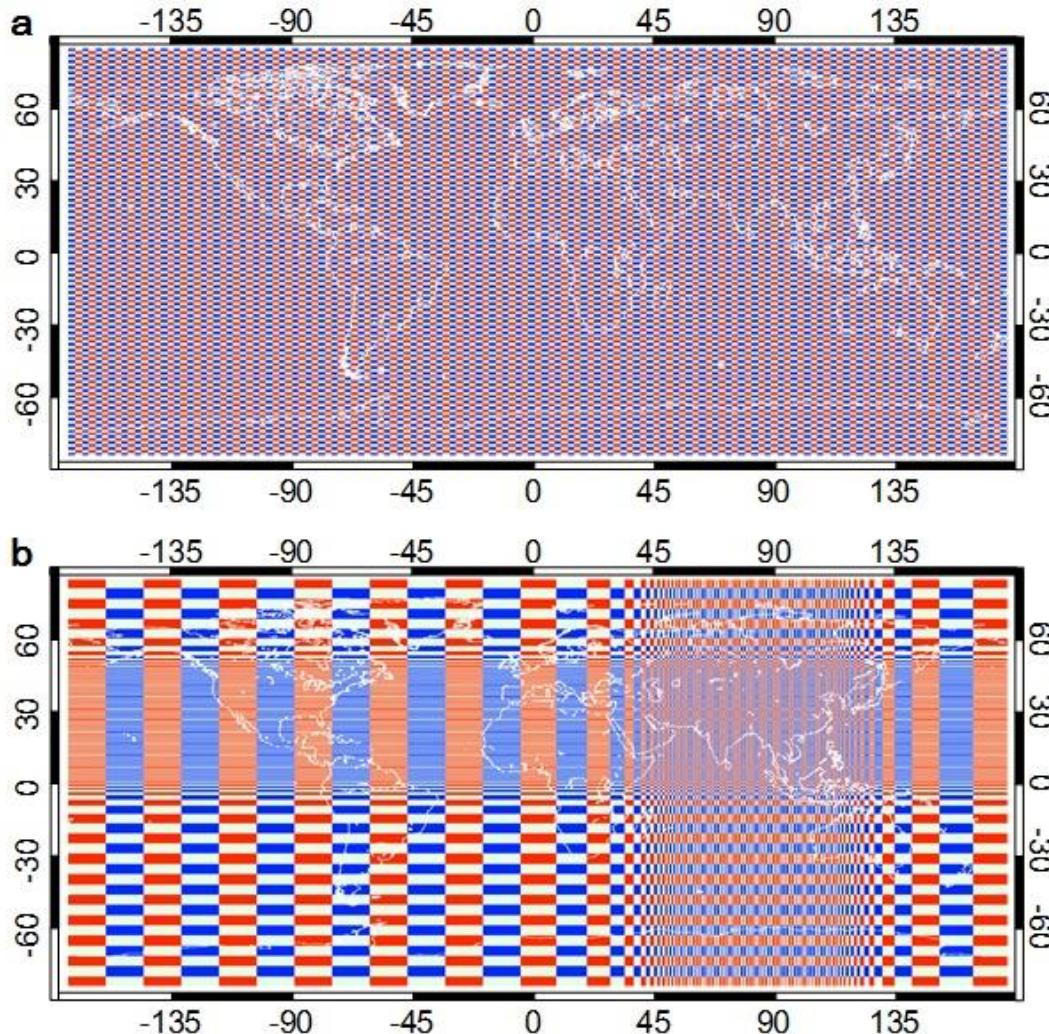
[Wang et al., PNAS, 2014;](#)  
[Wang et al., Environ. Sci. Technol., 2012a,b, 2014;](#)  
[Wang et al., Atmos. Chem. Phys, 2013](#)

# Model simulations

## □ Model resolutions:

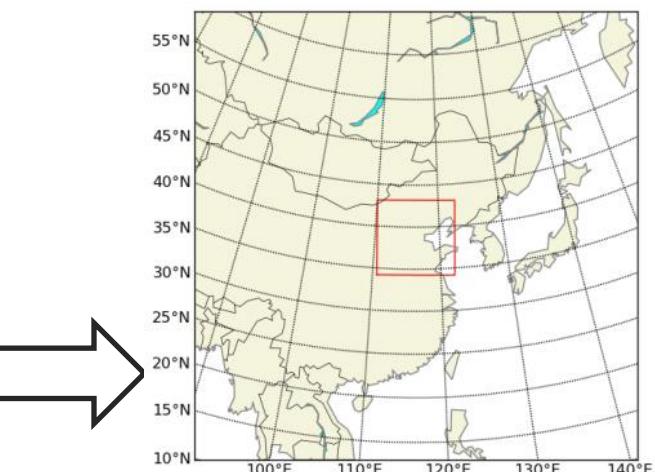
- 1> A global model with a coarse resolution of  $1.27^\circ$  latitude by  $2.50^\circ$  longitude
- 2> A global model zoomed to a resolution of  $0.51^\circ$  latitude by  $0.66^\circ$  in Asia
- 3> A regional CHIMERE model ( $0.1^\circ$  latitude by  $0.1^\circ$  longitude).

# Enhancement of the model resolution



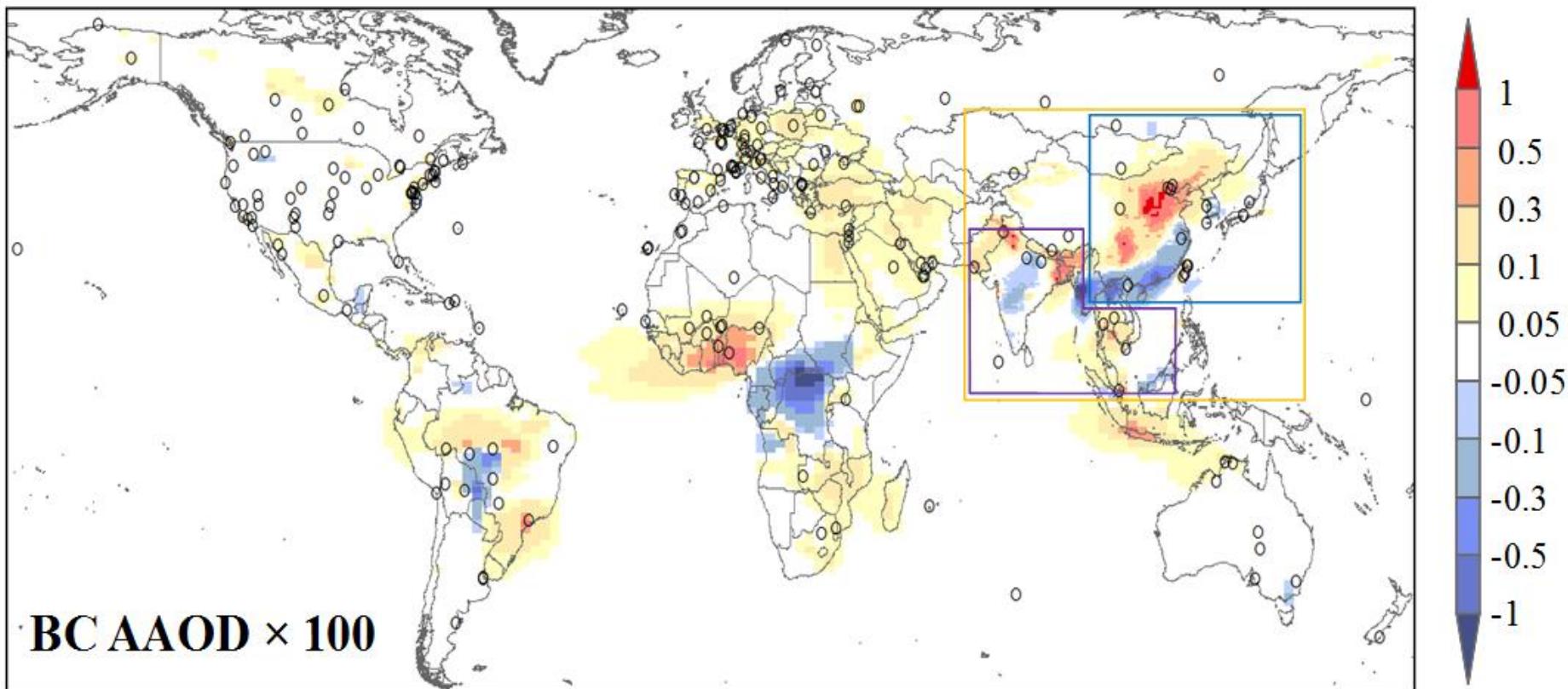
*Global Model LMDZ-OR-INCA*

*Regional Model CHIMERE*



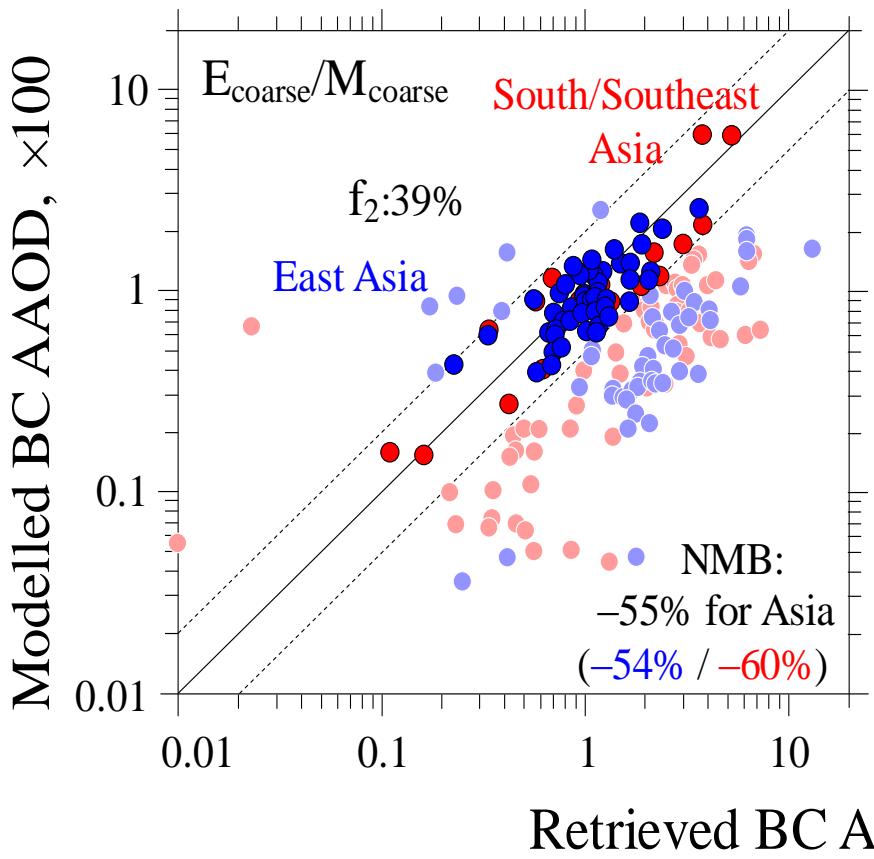
Wang et al., PNAS, 2014

# Change of the BC light absorption (AAOD) by improving the model resolution and emission inventory

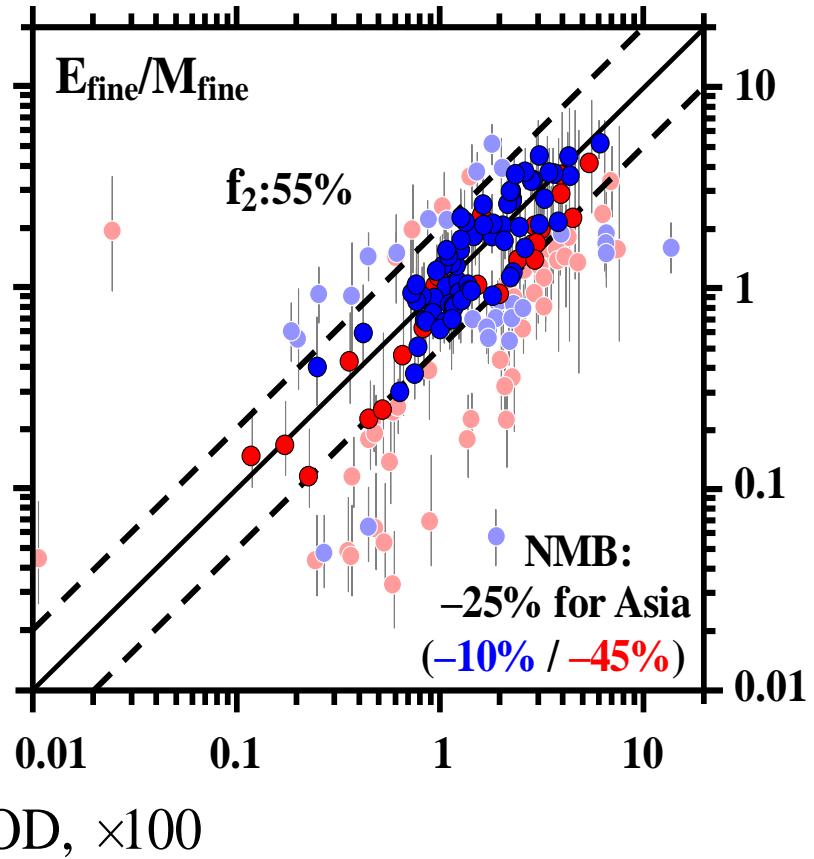


# Comparison of modelled and observed BC light absorption (BC AAOD)

## Before Improvements



## After Improvements



# **Three methods to estimate the BC radiative forcing (RF)**

**The “bottom-up” methods (only trust model).**

**The “top-down” methods (only trust observation).**

**The “data-assimilation” methods (trust both model and observation, making full use of their information by combining the uncertainties).**

# Uncertainty in the “bottom-up” methods

Emissions: from Monte Carlo simulations ([Wang et al., 2014](#));

Lifetime of BC: a relative standard deviation (RSD) of 27% ([Bond et al., 2013](#));

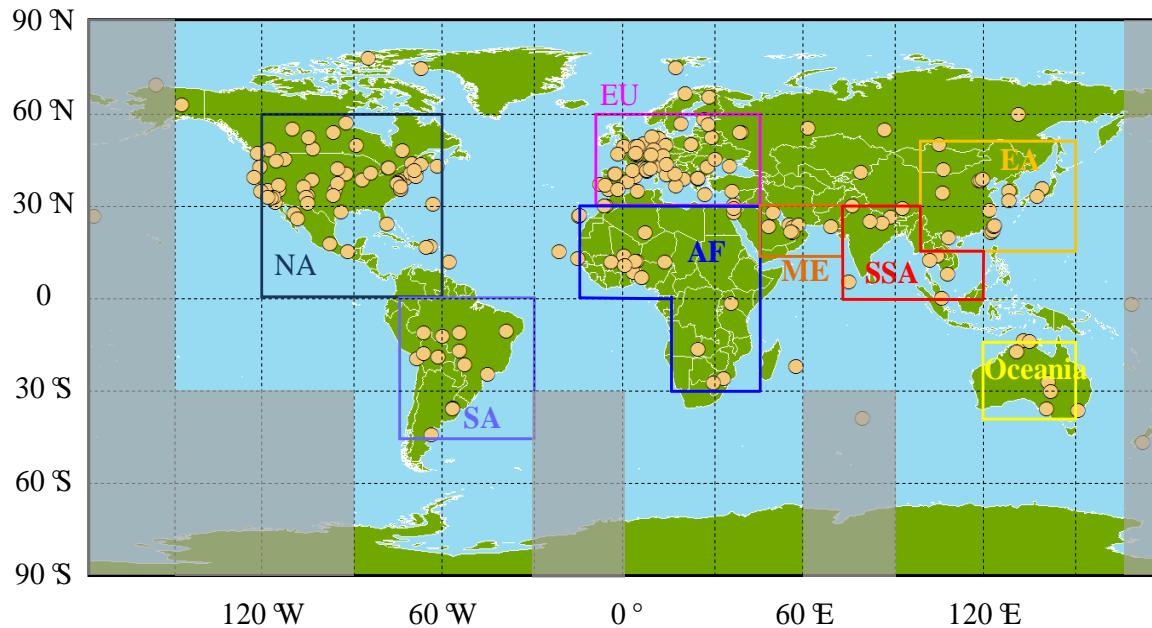
Mass absorption cross section: MAC of BC varies from 4.3 to  $15.0 \text{ m}^2 \text{ g}^{-1}$  among the 16 models ([Bond et al., 2013](#)). After excluding the maximum and minimum values, the average and standard deviation is  $8.5 \pm 2.2 \text{ m}^2 \text{ g}^{-1}$ , so an RSD of 26% is applied for the uncertainty of the BC MAC.

Host model uncertainty: an RSD of 11% ([Stier et al., 2013](#));

Vertical profiles of BC: an RSD of 13% ([Samset et al., 2013](#));

# The “top-down” methods

We used a method close to that used in [Bond et al., JGR, 2013](#). The RF of BC is scaled based on AERONET and HIPPO observation according to 8 continental regions and 3 remote oceanic regions.



# The “data-assimilation” methods

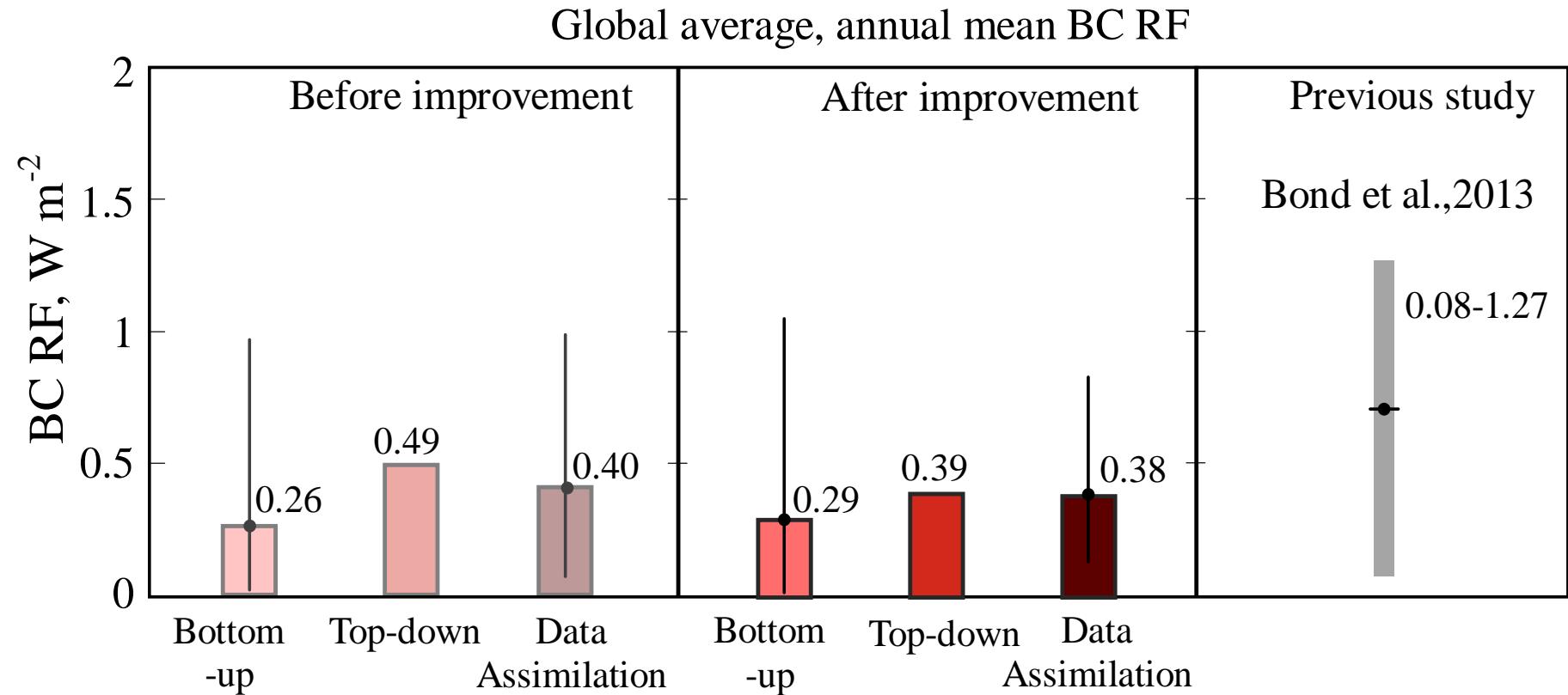
We apply the optimal Bayesian theory to estimate an optimal scaling factor,  $s$ , which is used to scale the BC AAOD or burden and thus RF from the bottom-up method, and its variance,  $V^s$ :

$$s = \frac{V^o}{V^o + V^m} + \frac{V^m}{V^o + V^m} \cdot \frac{o}{m}$$

$$V^s = \frac{V^o \cdot V^m}{V^o + V^m} \cdot \frac{1}{m^2}$$

- ✓  $V^o$  is the error variance of the observations;
- ✓  $V^m$  is the error variance of the model from the bottom-up method;
- ✓  $o$  is the average of the AERONET or HIPPO observations;
- ✓  $m$  is the model average at the AERONET or HIPPO locations.

# Estimated radiative forcing of BC and the uncertainty range (90% confidence)



# Conclusions

1. The bottom-up estimate of BC RF is **0.26 W m<sup>-2</sup>** by a coarse-resolution model and a traditional inventory, and **0.29 W m<sup>-2</sup>** by a high-resolution model and a highly disaggregated inventory.
2. The top-down estimate of BC RF is **0.49 W m<sup>-2</sup>** by a coarse-resolution model and a traditional inventory, and **0.39 W m<sup>-2</sup>** by a high-resolution model and a highly disaggregated inventory. The difference between the bottom-up and top-down estimates is reduced by using the new inventory and high-resolution model.
3. The data-assimilation estimate of BC RF is **0.40 W m<sup>-2</sup>** by a coarse-resolution model and a traditional inventory, and **0.38 W m<sup>-2</sup>** by a high-resolution model and a highly disaggregated inventory. Importantly, the uncertainty is successfully reduced from **0.04-1.02 W m<sup>-2</sup>** to **0.11-0.85 W m<sup>-2</sup>**, indicating that a systematical error is removed.



Thank You

# Publications related to this work

1. Wang, R. Global Emission Inventory and Atmospheric Transport of Black Carbon: Evaluation of the Associated Exposure. 978-3-662-46479-3, Springer Berlin Heidelberg, doi: 10.1007/978-3-662-46479-3.
2. Wang, R.; Tao, S.; Balkanski, Y.; Ciais, P.; Boucher, O.; J.F. Liu, Piao, S.L.; Shen, H.; Vuolo, M.; Chen, H.; Chen, Y.; Cozic, A.; Huang, Y.; Li, B.G.; Li, W.; Shen, G.F.; Wang, B.; Zhang, Y.Y. Exposure to ambient black carbon derived from a unique inventory and high resolution model. Proc. Natl. Acad. Sci. USA. 2014, 111(7), 2459-2463.
3. Wang, R.; Tao, S.; Shen, H.Z.; Huang, Y.; Chen, H.; Balkanski, Y.; Boucher, O.; Ciais, P.; Shen, G.F.; Li, W.; Y. Zhang, Y. Chen, N. Lin, S. Su, B. Li, J. Liu, Li, W. Time trend of global black carbon emissions from 1960 to 2007. Environ. Sci. & Technol. 2014, 48(12), 6780-6787.
4. Wang, R.; Tao, S.; Ciais, P.; Shen, H.Z.; Huang, Y.; Chen, H.; Shen, G.F.; Wang, B.; Li, W.; Zhang, Y.Y.; Lu, Y.; Zhu, D.; Chen, Y.C.; Liu, X. P.; Wang, W. T.; Wang, X. L.; Liu, W. X.; Li, B. G.; Piao, S. L. High resolution mapping of combustion processes and implications for CO<sub>2</sub> emissions. Atmos. Chem. Phys. 2013, 13, 5189-5203.
5. Wang, R.; Tao, S.; W. Wang, J. Liu, H. Shen, Shen, G.F.; Wang, B.; Liu, X.; Li, W.; Huang, Y.; Zhang, Y.Y.; Lu, Y.; Chen, H.; Chen, Y.C.; Wang, C.; Zhu, D.; Wang, X.; Li, B.G.; Li, W.; Ma, J. Black carbon emissions in China from 1949 to 2050. Environ. Sci. & Technol. 2012, 46, 7595-7603.
6. Wang, R.; Tao, S.; H. Shen, X. Wang, B. Li, Shen, G.F.; Wang, B.; Li, W.; Liu, X.; Huang, Y.; Zhang, Y.Y.; Lu, Y.; Ouyang, H. Global emission of black carbon from motor vehicles from 1960 to 2006. Environ. Sci. & Technol. 2012, 46, 1278-1284.