Impact of aging process for black carbon aerosol on its distribution and radiative forcing

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Acknowledgement : RECCA/MEXT/SALSA, MOE/A-1101,NIES/CGER

Black Carbon (BC) and "BC Aging"

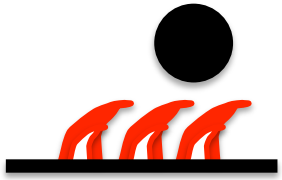
BC radiative forcing (BC-RF)

+0.20±0.15 W m^{-2} (fossil fuel BC)
+0.03±0.12 W m^{-2} (biomass burning)
by IPCC-AR4 report (2007)

BC distribution
Emission, transport, deposition,
Aging process (pure BC →aged BC)

BC optical property
Mie calculation

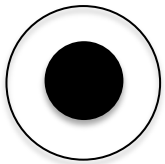
Water-Insoluble BC (WIBC)



Emission
(burning)

Condensation/coagulation
Chemical reactions

Water-soluble BC (WSBC)



"Ratio of WIBC:WSBC"

"Attached compounds in WSBC"

Treatment of BC aging process and BC mixing state in GCM

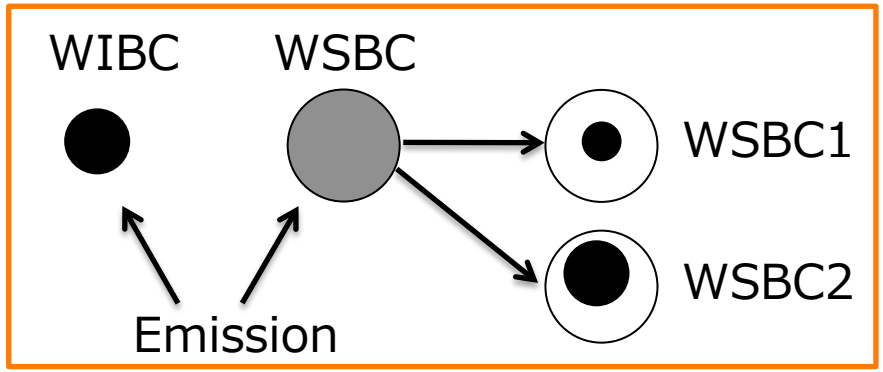
- Explicitly analyze aerosol dynamic processes
  [e.g., Stier et al., 2005; Kirkevag et al., 2005]
  → Larger CPU time
- Parameterization for climate models
  1. No aging but internally mixed just after emissions [Takemura et al., 2005]
  2. Aging with a constant conversion rate [e.g., Chin et al., 2002 and many other studies]
  3. Aging with a conversion rate depending on various factors
     (i.e., BC amount, condensed gas, …) [e.g., Oshima and Koike, 2011]
- Mixing state in the WSBC particles: BC+OC, BC+SO4, BC+others, …

Uncertainty of the BC-RF: +0.08~+0.36 W m^{-2} (Schulz et al., 2006)
→ Question: How impact of the difference in the treatment of the BC aging among the parameterizations?

Method: Different three parameterizations of the BC aging process are implemented into a global aerosol model coupled to GCM ("MIROC-SPRINTARS").

Method 1: Original SPRINTARS 'ORIG'

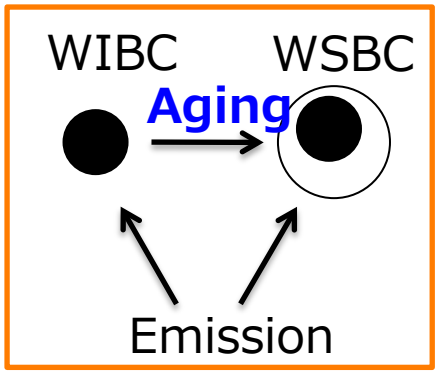
- Three-type BC: WIBC, WSBC(OC/BC=0.3), WSBC(OC/BC=0.15)
- Emission
  - WIBC: 50% of Fossil fuel combustion:
  - WSBC: Others (Biomass Burning)
- Treatment of mixing
  - Assume: Internally mixed BC particle with OC just after its emission (within 1 model timestep; 20 min for T42)
  - No aging process in the atmosphere
  - That means some of OC is internally mixed with BC in WSBC.



The partition is diagnostic by the fraction of BC and OC in the grid.

Method 2 and 3: BC Aging parameterizations

- Two-type BC: WIBC & WSBC
- Emission
  - WIBC: 80% of BC emission
  - WSBC: 20% of BC emission
- Treatment of mixing
  - Atmospheric aging process as follows:



$$\left[WIBC\right](t) = \left[WIBC\right](t-1) \times \exp\left(-\frac{t}{\tau_{BC}}\right)$$

$$\left[WSBC\right](t) = \left[WIBC\right](t-1)\left(1-\exp\left(-\frac{t}{\tau_{BC}}\right)\right)$$

τ_{BC} : conversion rate of BC from hydrophobic to hydrophilic (e-folding time)

←determined by different ways in Method 2&3.

Determination of the conversion ratio

Method 2 or 'AGF' (Traditional methods by Cooke et al., 1996)

$$\tau_{BC} = const.$$

=1.2 day (in this study)
→ WSBC comprise only BC

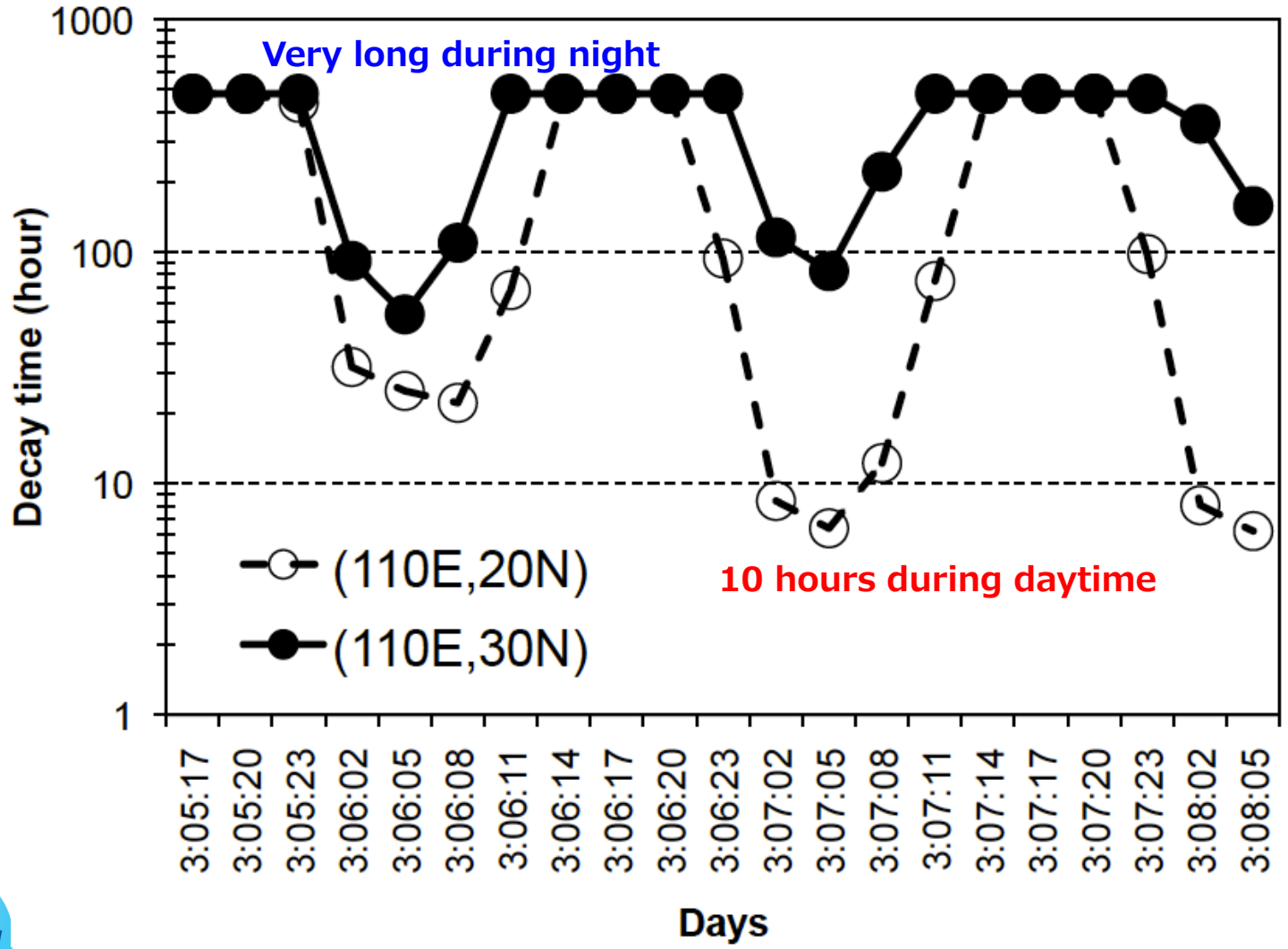
Method 3 or 'AGV' (Oshima and Koike, 2011)

$$\tau_{BC} = \frac{a}{\nu_c}$$

=Depending on (1) total aerosol, (2) BC, (3) H_2SO_4, a=0.37 [Oshima and Koike, 2011]
→SO_4 in the WSBC is prognostic.

$$\begin{cases} \nu_c = \dfrac{\partial m_{BC}}{\partial t}\dfrac{1}{\left[BC_{total}\right]} & \text{: coating rate of BC normalized by BC mass concentration in per hour} \\ \dfrac{\partial m_{BC}}{\partial t} = \dfrac{\sum_j N_{BC_j}}{\sum_i N_{total\_aerosol_i}}\left[H_2SO_4\right]\dfrac{60\times 60}{dt(s)} & \text{dt=20 min in this study} \end{cases}$$

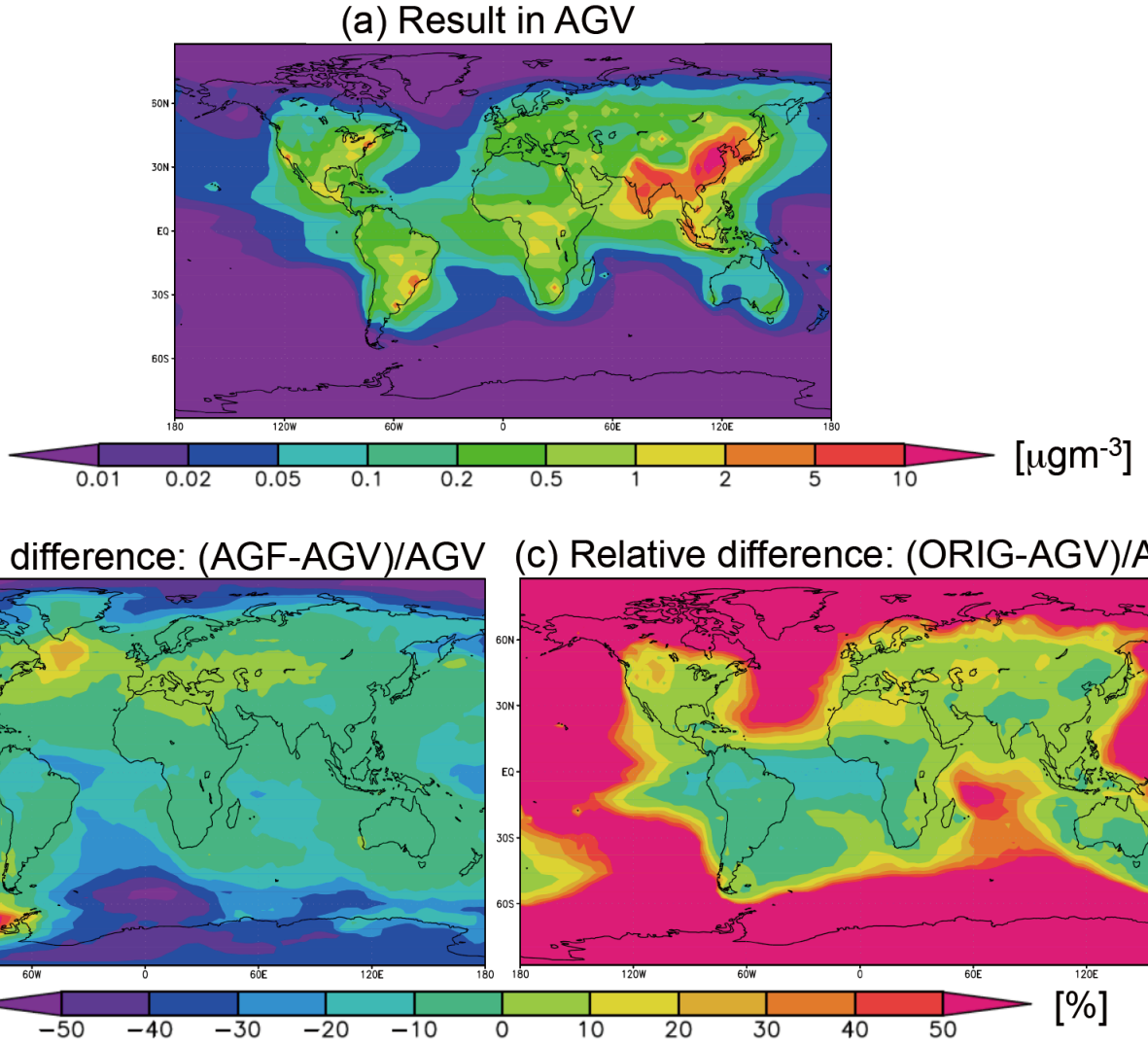
Conversion rate by method 3 (AGV)



Emissions and Properties in physics & optics

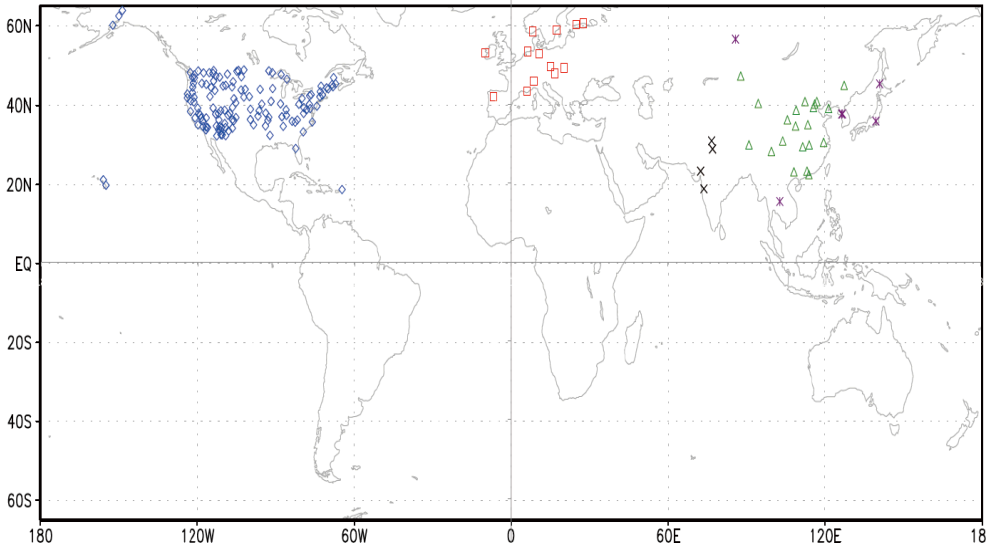
- Emission:
  - Emission inventories are those prepared and described by *Goto et al.* (2011a; 2011c), where the anthropogenic BC emission flux is interpolated from: the EMEP emission inventory over Europe, Streets et al. (2003) over Asia, and Takemura et al. (2005) in other regions. With this BC emission inventory, the simulated BC concentrations over India are closer to the observed ones compared to the results using the different emission inventories [Goto et al., 2011c].
- Method 1 (Original SPRINTARS; ORIG)
  - WIBC: D=23.6nm, sigma=2.0, no wet growth, 8.34m^2/g (ext, 550nm), 6.54m^2/g (abs, 550nm)
  - WSBC: D=200nm, sigma=2.0, wet growth, 4.5-5.0m^2/g (ext, 550nm), 20.0-21.4m^2/g (ext, RH=90%, 550nm), 0.8-1.0m^2/g (abs,550nm), 1.2-1.5m^2/g (abs, 550nm)
  - Hess et al. (1998), Takemura et al. (2000)
- Method 2 and 3 (AGF and AGV)
  - WIBC: D=185nm,sigma=1.53, no wet growth, 9.22m^2/g (ext, 550nm), 6.20m^2/g (abs, 550nm)
  - WSBC: D=220nm, sigma=1.53, wet growth, 6.61m^2/g (ext, 550nm), 14.97m^2/g (ext, RH=90%, 550nm), 4.26m^2/g (abs, 550nm), 5.97m^2/g (abs, 550nm)
  - Moteki et al. (2007), Omar et al. (2005), McMeeking et al. (2010)

Annual averaged BC mass concentration @surface

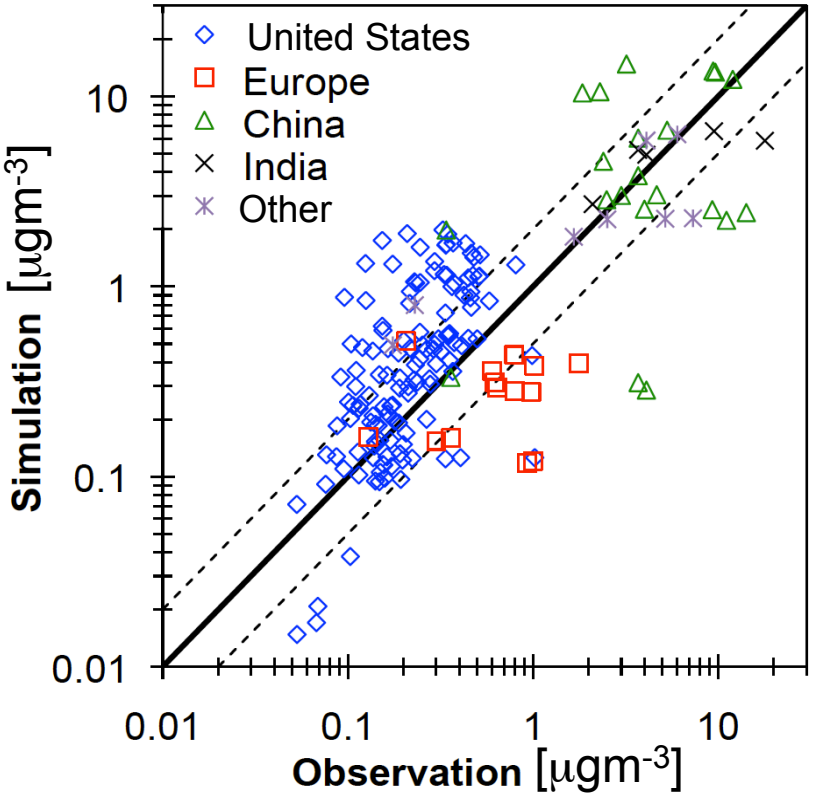


Annual averaged BC mass concentration @surface

(a) Site map of BC measurement



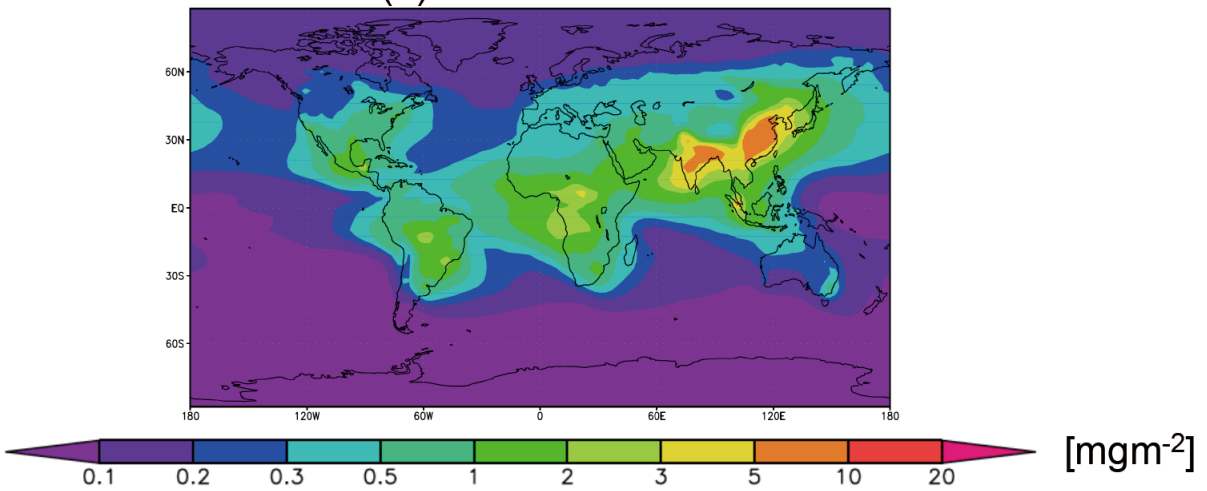
(b) BC mass concentration



United States: IMPROVE
Europe: EMEP
China: X.Y.Zhang et al. (2008)
India: Goto et al. (2011)

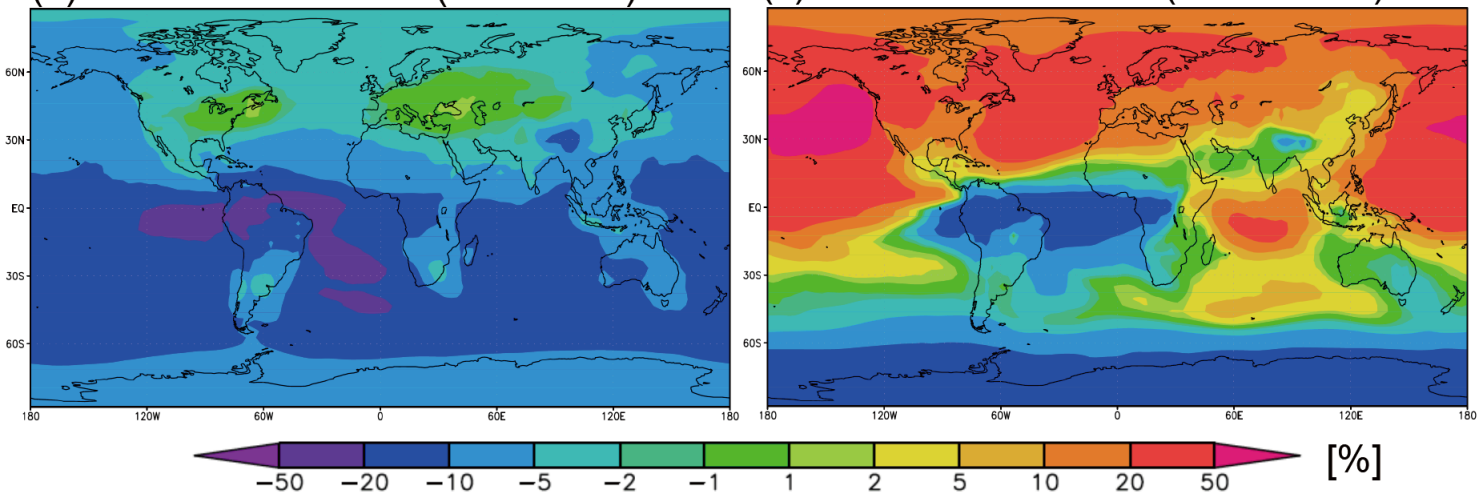
Annual averaged BC column burden

(a) Result in AGV

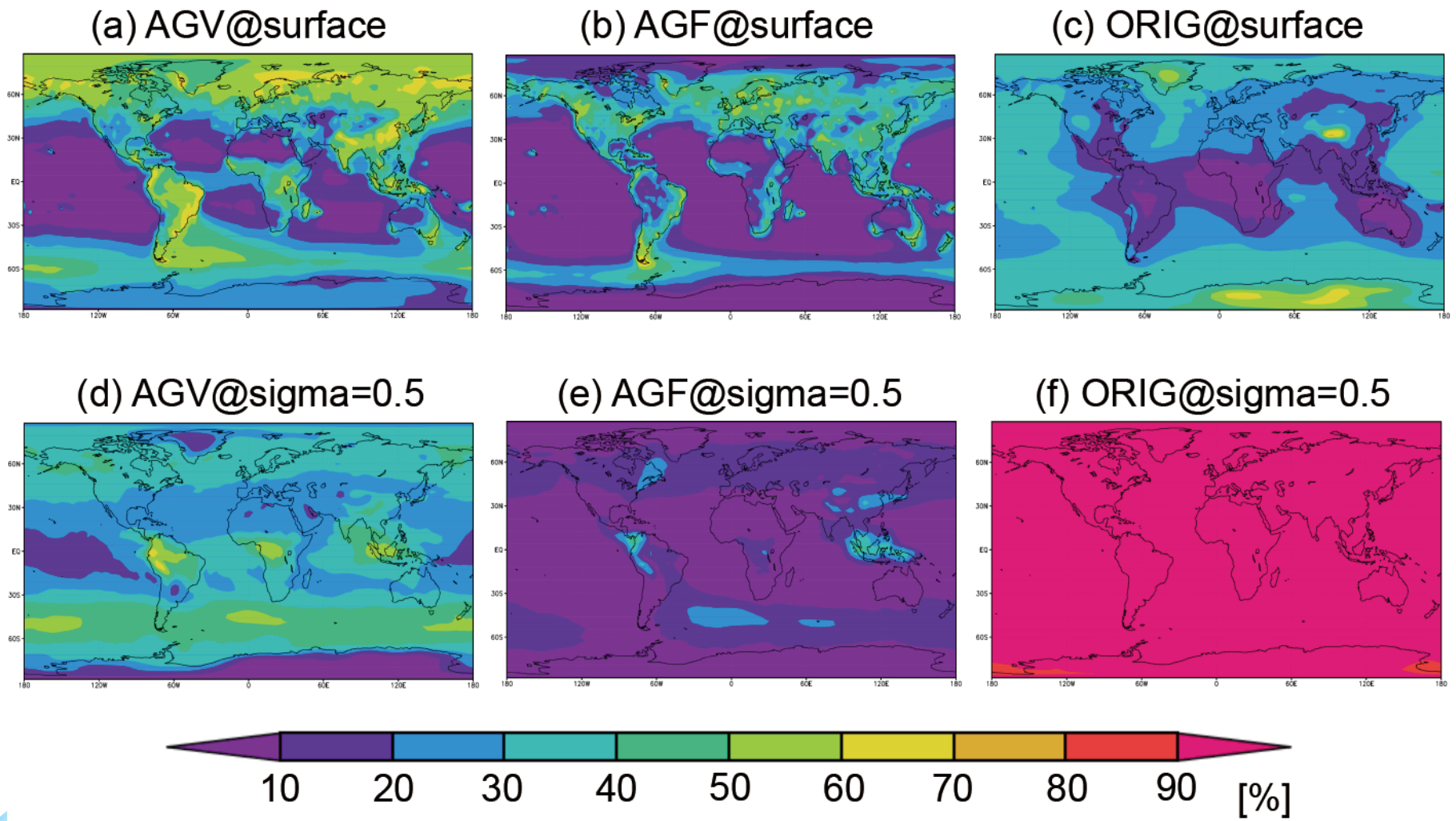


(b) Relative difference: (AGF-AGV)/AGV

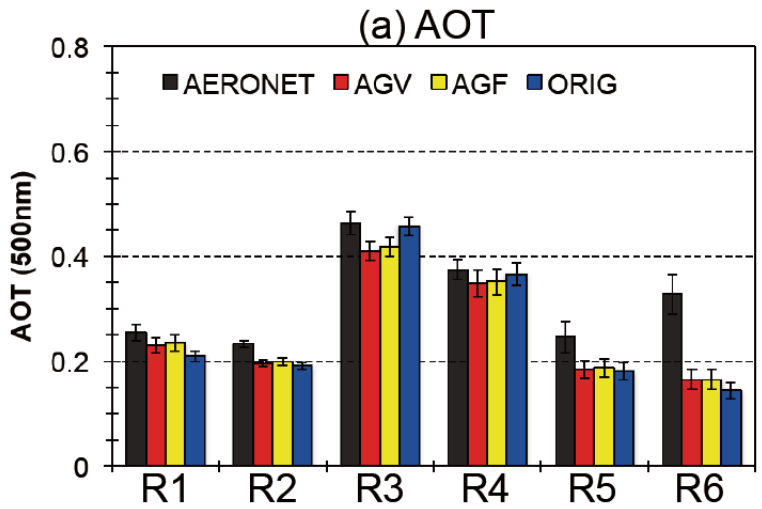
(c) Relative difference: (ORIG-AGV)/AGV

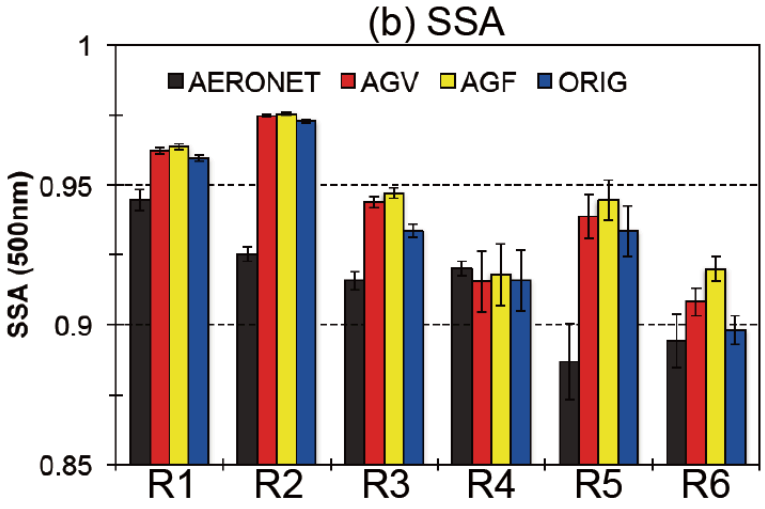


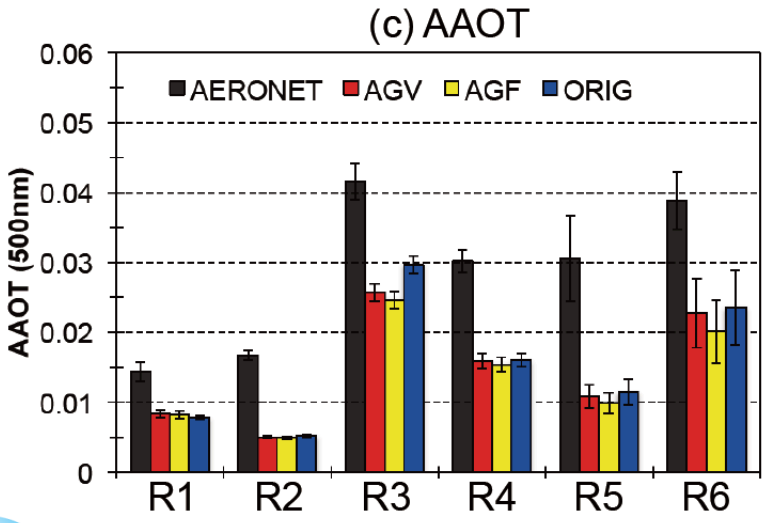
Ratio: WIBC/BC



AOT, SSA, AAOT under clear-sky conditions



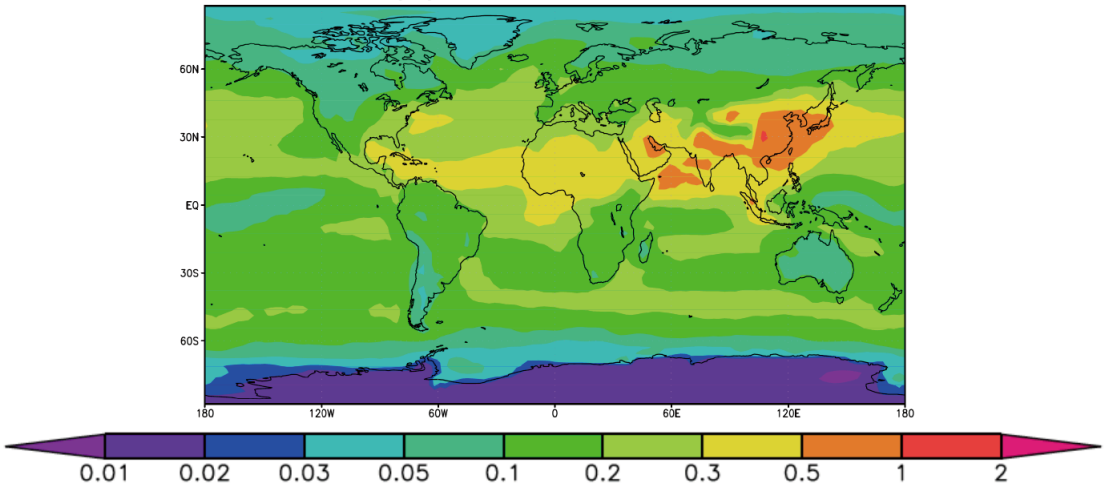




Regions
R1: N. America
R2: Europe
R3: Asia
R4: N. Africa
R5: S. Africa
R6: S. America

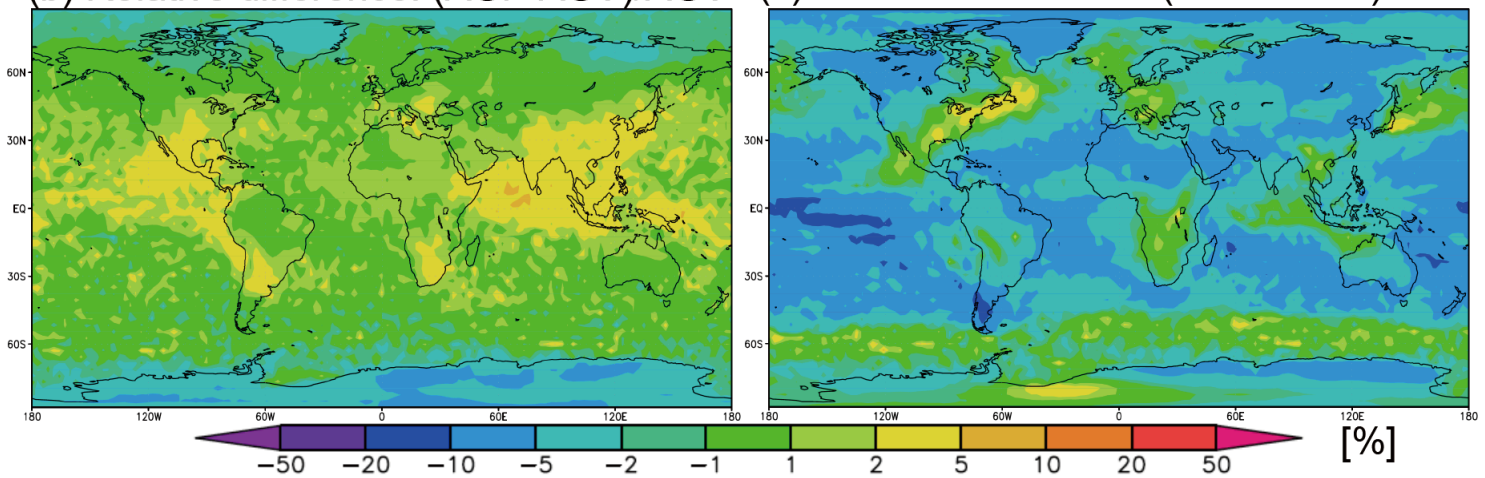
Annual averaged AOT

(a) Result in AGV



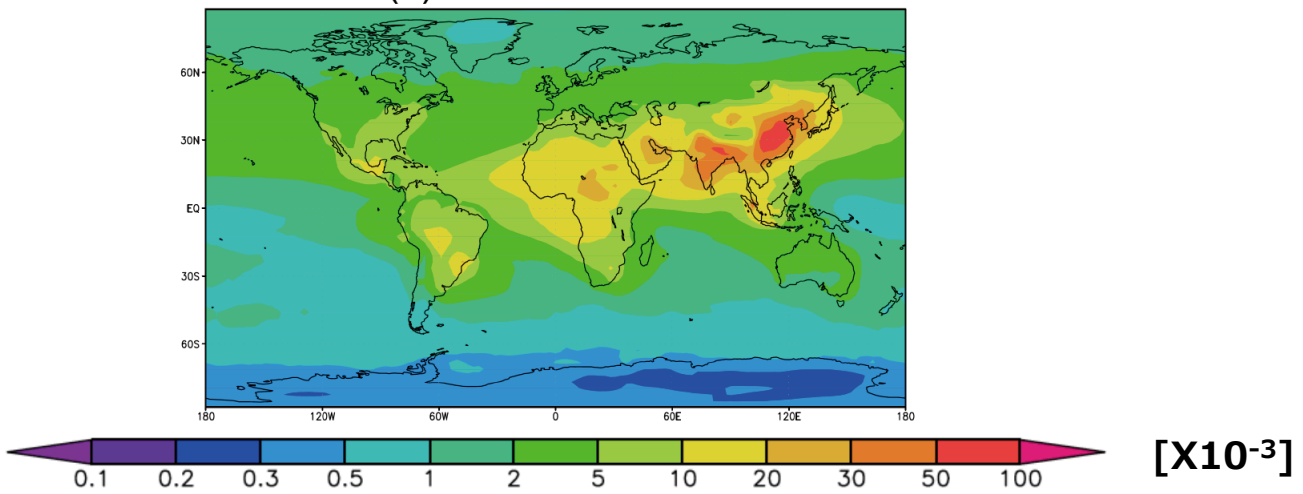
(b) Relative difference: (AGF-AGV)/AGV

(c) Relative difference: (ORIG-AGV)/AGV



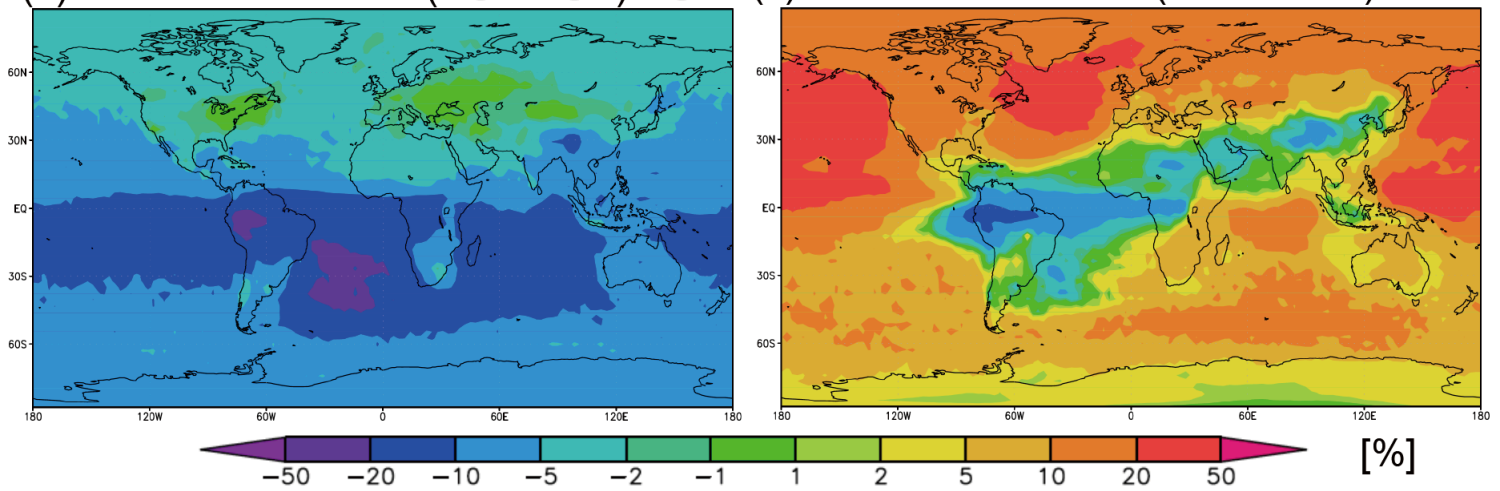
Annual averaged Absorption AOT

(a) Result in AGV

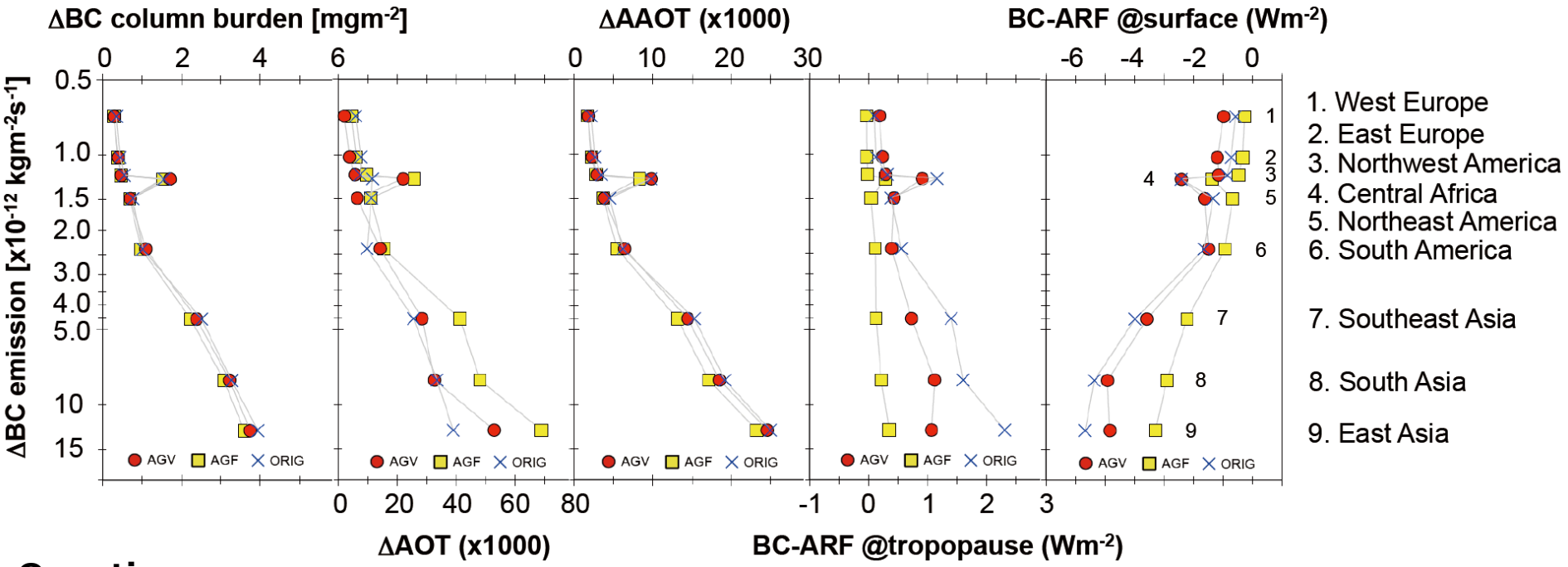


(b) Relative difference: (AGF-AGV)/AGV

(c) Relative difference: (ORIG-AGV)/AGV



Relationship between d-BC emission and d-others



Question :

What's the aerosol direct radiative forcing caused by different methods?

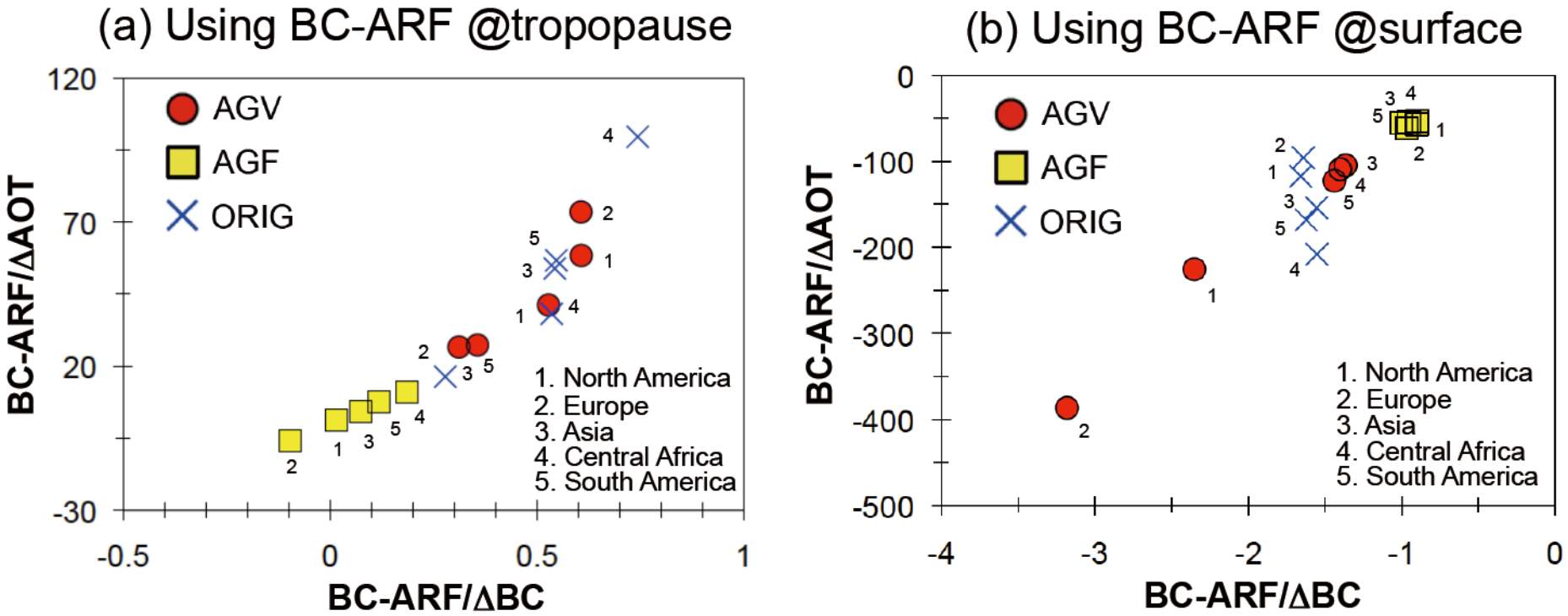
Answer :

Global annual mean BC-ARF: +0.30 Wm^{-2} (AGV), +0.05 Wm^{-2} (AGF), and +0.36 Wm^{-2} (ORIG)

→0.31W/m^2 (anthro.aerosol @tropopause, under whole-sky)

- Uncertainty of the BC-RF
  - ~0.3 W/m^2 (IPCC-AR4, 2007), +0.28 W/m^2 (Schulz et al., 2006)

Relationship between BCARF/BC and BCARF/AOT



These results reflect on the difference in the mixing states of BC particle (WSBC) AGF method with ignoring attached compounds in the WSBC particle causes a small impact on the ARF compared to the other two methods with taking into account attached compounds (OC or sulfate).

The ORIG method with treating BC-OC mixed particle causes large values of the b_1 and b_2 over biomass burning areas (South America and Central Africa), whereas AGV method with treating BC-sulfate mixed particle cause large values in the industrial areas (North America and Europe).

→ The mixing rule of BC has a great impact of the normalized ARF depending on regions (biomass burning and industrial regions).

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Thank you for your attention