Soot2016_program

Impacts of meteorological parameters and emissions on decadal and interannual variations of black carbon in China for 1980-2010

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Outline

- Motivation
- Methods
- Simulated BC and Model Evaluation
- Simulated Decadal Trends of BC
- Simulated Interannual Variations of BC
- Direct Radiative Forcing of BC
- Summary and Conclusions

Environmental Effects of Black Carbon

Absorb solar radiation

Cloud processes

Snow and ice albedo

Contribute 25% of the global total emissions [Cook et al., 1999; Bond et al., 2004]

The largest BC emitter: China

Particulate matter

BC reduction may provide an efficient near-term solution to **mitigate global warming** and to **improve air quality** simultaneously.

Objectives of This work

- To quantify **the decadal and interannual variations** of **surface concentrations** and **tropospheric column burdens** of BC in China for 1980-2010

- To quantify the **roles** of variations in **meteorological parameters**, **anthropogenic and biomass burning emissions** in the variations.

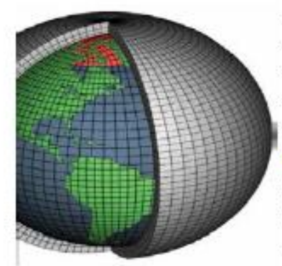
Methods

Assimilated MERRA meteorological fields

BC emissions

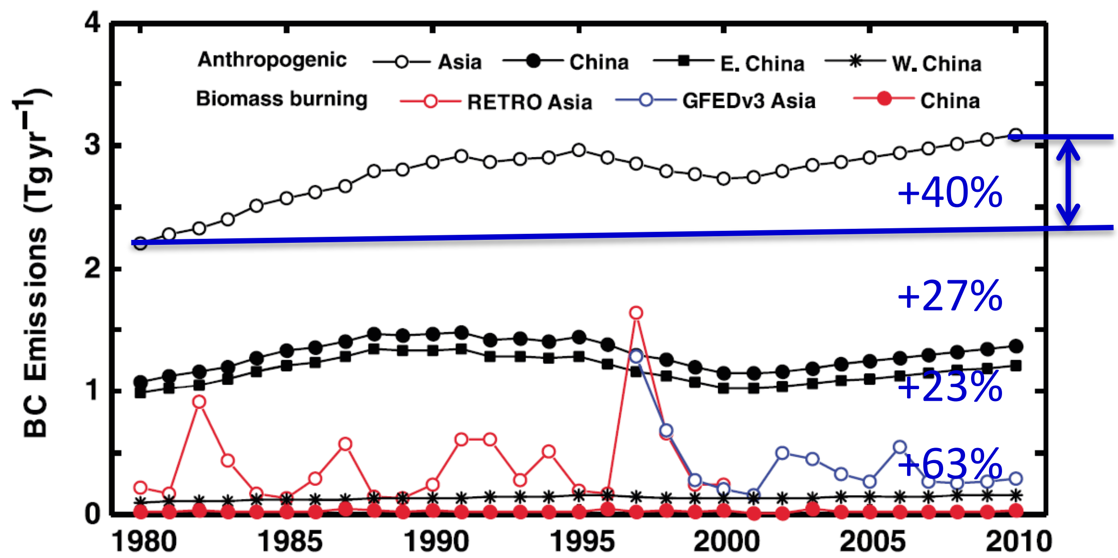
Global
- Bond et al. [2007] for 1980/1990/2000;
- Streets 2000+scaling factor for 2010

Asia
- The regional Emission inventory in Asia (REAS)



GEOS-Chem

To identify the relative roles of variations in meteorological parameters and emissions in the decadal and interannual variations of BC in China for 1980-2010



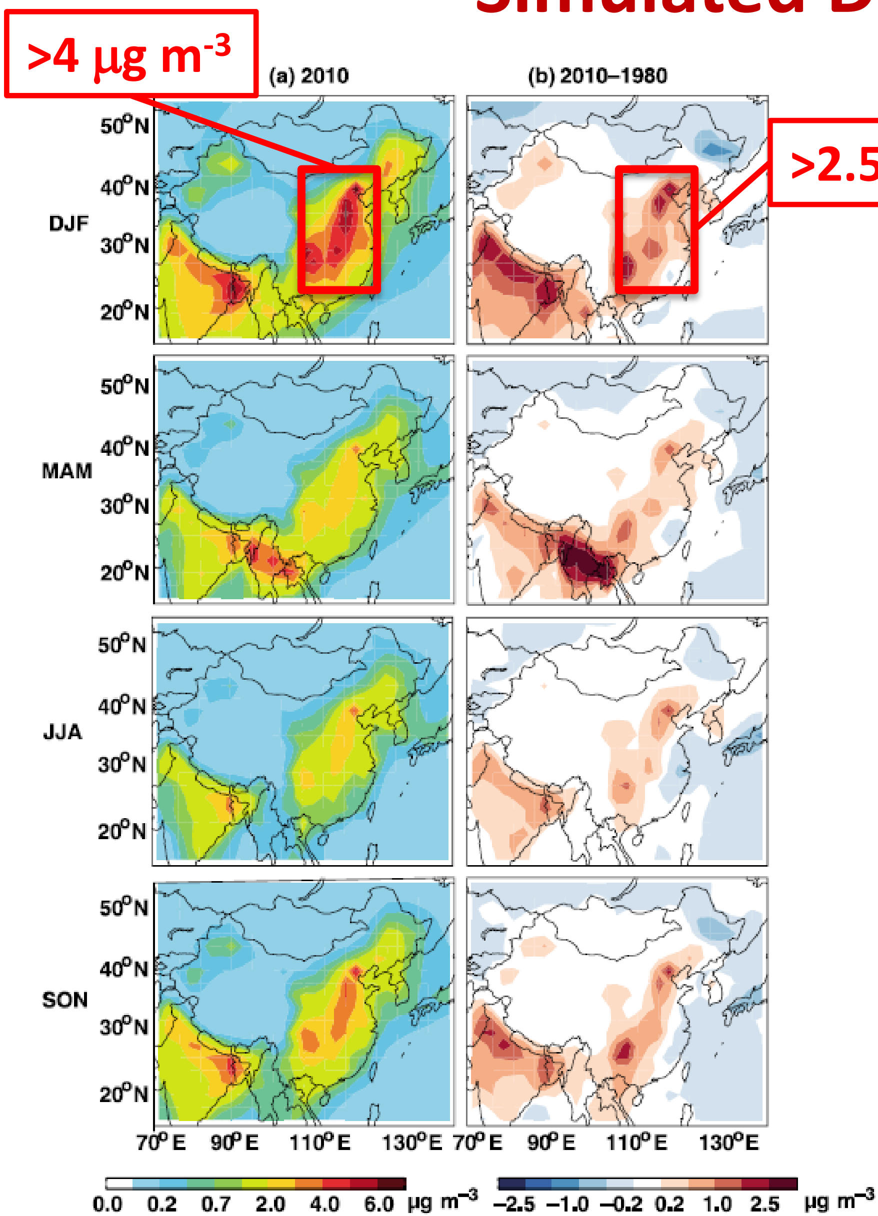
Simulations

GEOS-Chem Simulations of BC （1 year spin-up）

Model Experiments		Meteorological Parameters	Emissions	
			Anthropogenic	Biomass Burning
VALL	**Standard**	1980—2010	1980—2010	1980—2010
VMET	**met**	1980—2010	2010	2010
VEMIS	**Emission(an+bb)**	2010	1980—2010	1980—2010
VEMISAN	**Emission(an)**	2010	1980—2010	Not included
VEMISBB	**Emission(bb)**	2010	Not included	1980—2010
VNOC	**Emission(non-China)**	1980—2010	1980—2010	1980—2010
			Turn off emissions in China	
VAN2X		1980—2010	1980—2010	1980—2010
			Doubled in Asia	

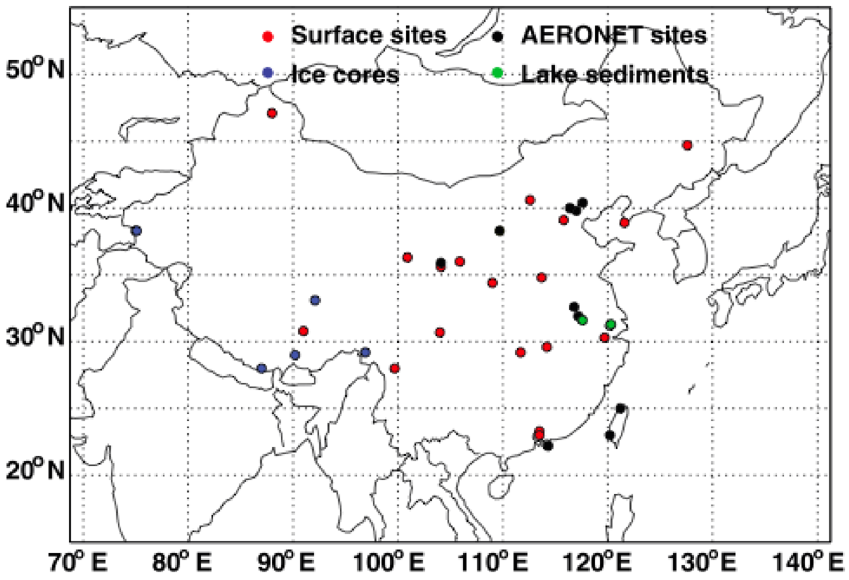
Compared to a recent top-down estimates of BC emissions in China [Fu et al., 2012], emissions in China from REAS (this study) are biased low by a factor of 2.

Simulated Distribution of BC



- **High concentration regions:**
  East China
- **Seasonal variation:**
  JJA: 0.67 μg m^{-3}/DJF: 1.77 μg m^{-3}
  (meteorological parameters
  and emissions from eg. heating)
- **Differences (2010-1980):**
  Eastern China : 0.29 μg m^{-3} (24%)
  Western China: 0.12 μg m^{-3} (66%)

Evaluation of Simulated BC Concentrations and AAOD

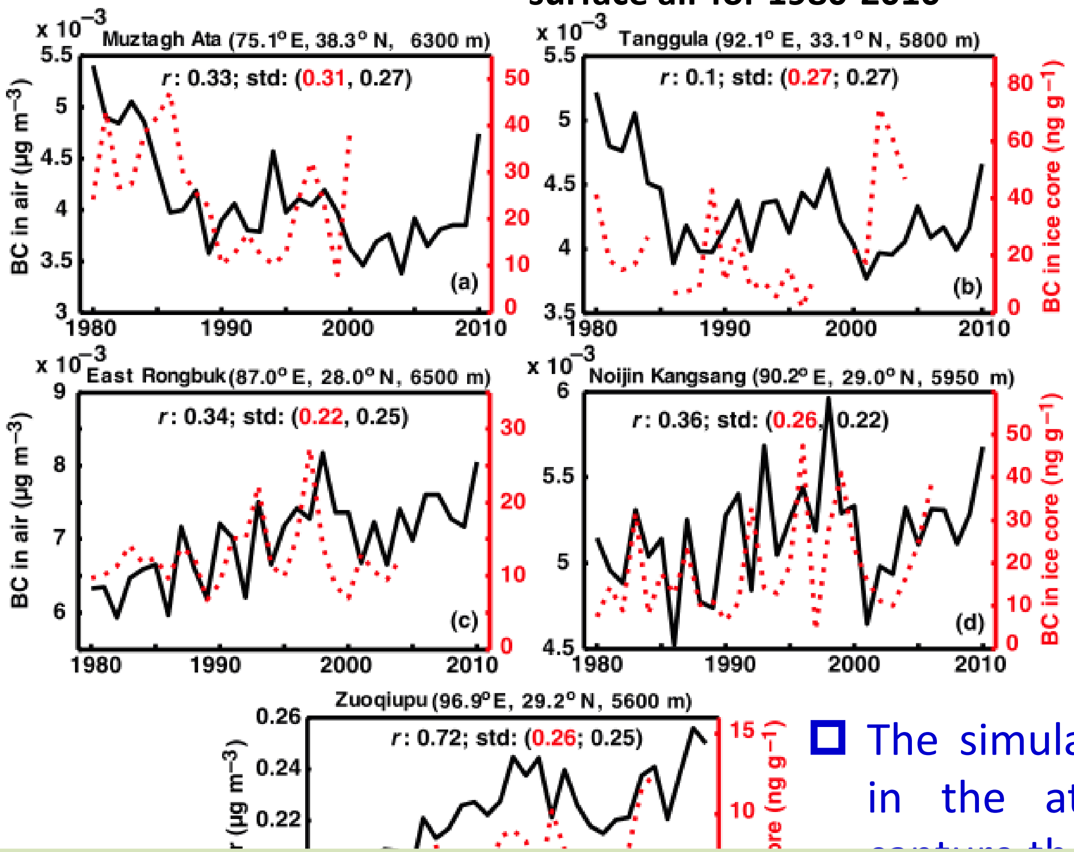


- **Ground-base measurements** of BC concentrations from literatures (20 sites)
- **AERONET AAOD** (12 sites)
- **BC concentrations in ice cores and lake sediments**

- **Simulated BC concentrations** show NMBs of —37% at remote sites, —49% at rural sites, and —79% at urban sites (VALL). Improved in VAN2X.
- **Simulated annual mean BC AAOD** in simulation VALL(VAN2X) show NMB values of —77% (—57%) at urban sites and —50% (—4%) at remote sites.

Comparisons With Measurements in Ice Cores

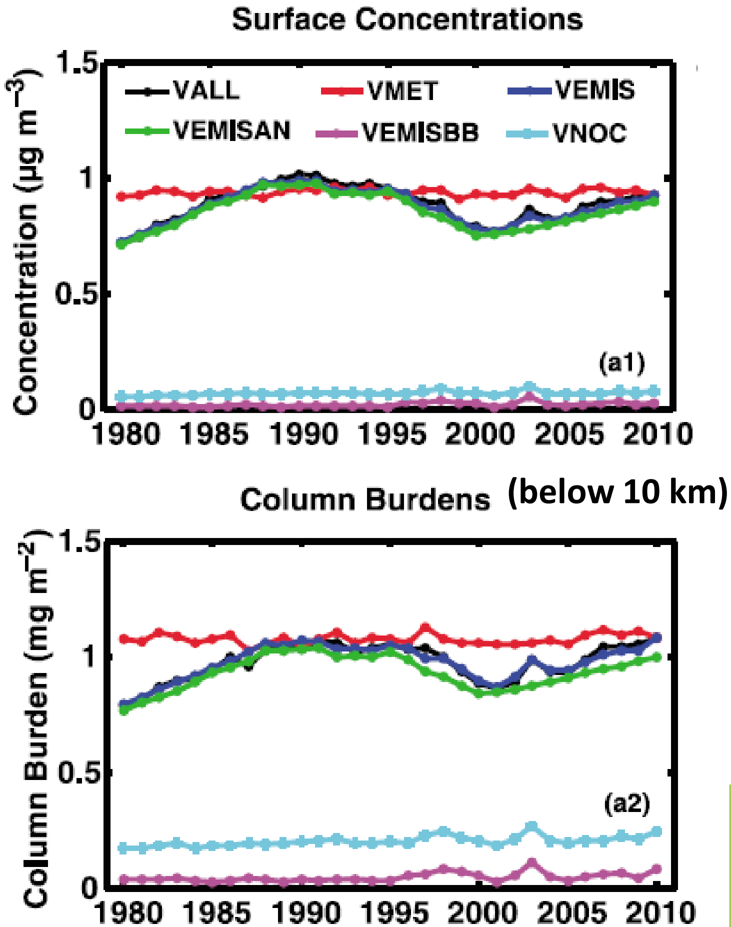
Observed annual BC concentrations (red) in ice cores in Tibetan Plateau [Xu et al., 2009] and simulated annual mean BC concentrations (black) in the atmosphere at 300 hPa and in surface air for 1980-2010



- The simulated BC concentrations in the atmosphere reasonably

The evaluations of model results prove the ability of the GEOS-Chem model to reasonably capture the decadal and interannual variations of BC in China.

Simulated Decadal Trends of BC

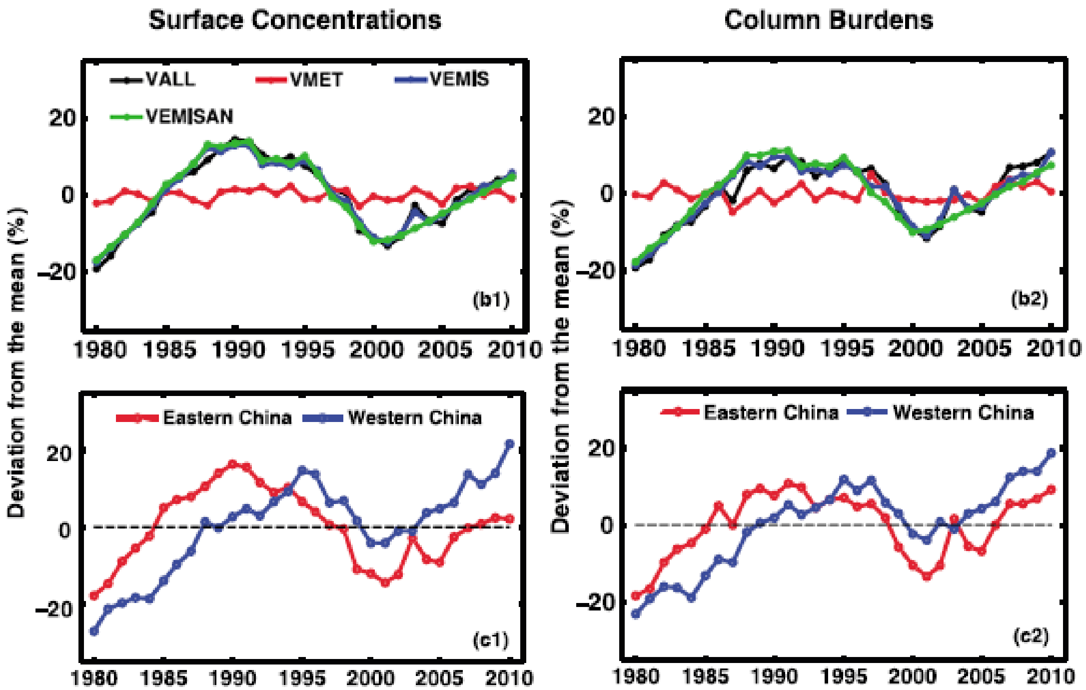


VALL

	Concentrations (μg m^{-3})	Column burdens (mg m^{-2})
annual mean	0.7–1.0	0.8–1.1
2010—1980	0.21 (29%)	0.29(37%)
	The decadal trend	
	Concentrations (μg m^{-3} decade^{-1})	**Column burdens** (mg m^{-2}decade^{-1})
1980s	0.31	0.29
1990s	–0.20	–0.10
2000s	0.16	0.21

- **VALL** VS. **VEMIS** : emissions
- **VEMIS** VS. **VEMISAN**: anthropogenic emissions (98/95%)
- **VALL** VS. **VMET**
- VNOC (8/21%) ~9% decade^{-1}

Simulated Decadal Trends of BC



The deviation from the mean (DM):

$$DM_i = \left(M_i - \frac{1}{n}\sum_{i=1}^{n} M_i \right) / \frac{1}{n}\sum_{i=1}^{n} M_i,$$

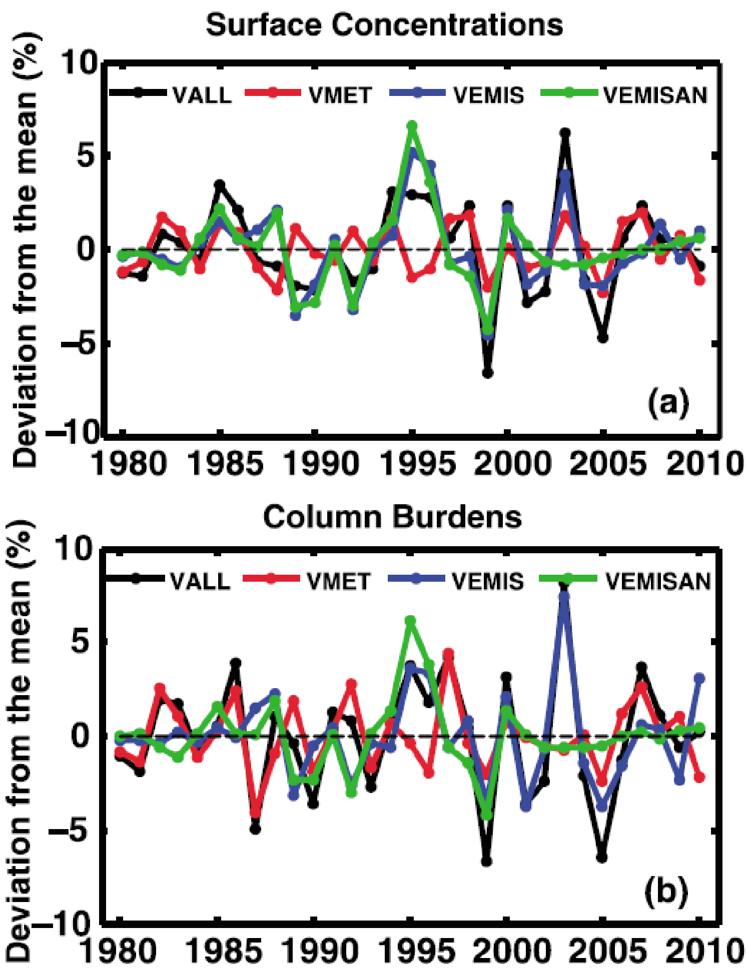
M_i: the simulated annual mean BC in China for year ***i***;

n: the number of years examined (n=31 for years 1980–2010).

[Mu and Liao, 2014; Yang et al., 2015]

- **VALL** VS. **VEMIS** VS. **VMET** : emissions
- **VEMIS** VS. **VEMISAN** : anthropogenic emissions
- **Eastern China :** 1980(0.52), 1990(-0.38), 2000(0.25) μg m^{-3} $decade^{-1}$
  Western China: 1980(0.07), 1990(-0.09), 2000(0.06) μg m^{-3} $decade^{-1}$

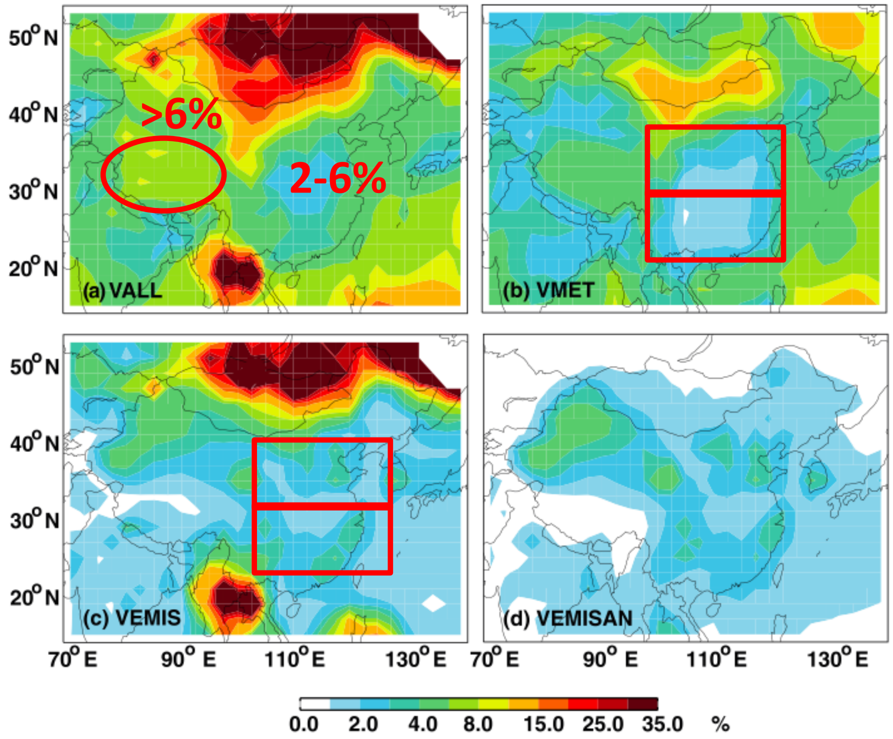
Simulated Interannual Variations of BC



- The peaks and troughs in deviations in **VALL** simulation are consistent with those in either **VMET** or **VEMIS**.
- The DM values in **VMET** are larger in column burdens of BC than in surface concentrations.
- The interannual variations of BC in **VEMISAN** are similar to those in **VEMIS** (except in 2003).

Simulated Interannual Variations of BC

The APDM values of detrended simulated annual mean surface BC concentrations in China for 1980–2010



The mean absolute deviation (MAD):

$$\mathrm{MAD} = \frac{1}{n}\sum_{i=1}^{n}\left|M_i - \frac{1}{n}\sum_{i=1}^{n}M_i\right|$$

The absolute percent departure from the mean (APDM):

$$\mathrm{APDM} = 100\% \times \mathrm{MAD} / \left(\frac{1}{n}\sum_{i=1}^{n}M_i\right)$$

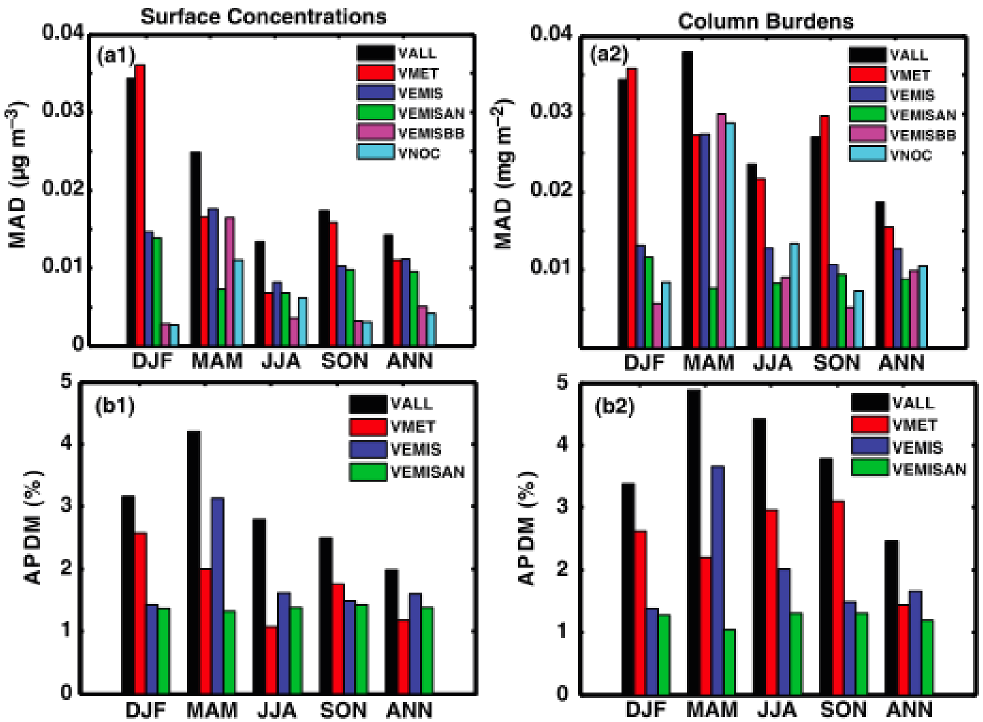
$\boldsymbol{M_i}$: the detrended simulated annual mean BC in China for year ***i***;

n: the number of years examined.

[Mu and Liao, 2014; Yang et al., 2015]

The **MAD** and **APDM** (or **DM**) represent the interannual variations of BC in terms of absolute value and percentage, respectively, averaged over the 31 years for 1980–2010 in the present study.

Simulated Interannual Variations of BC

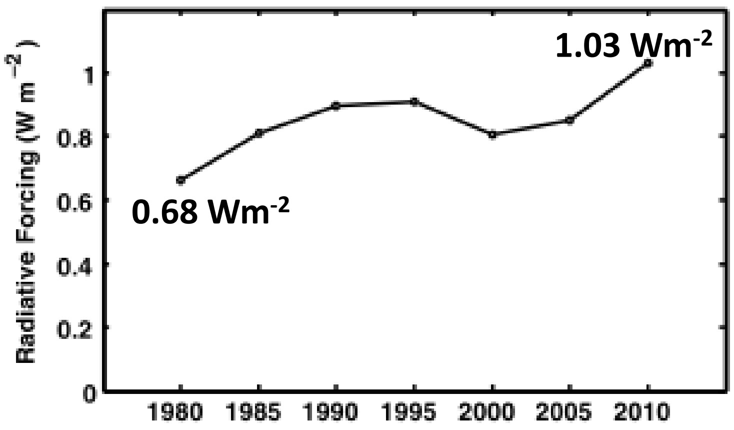


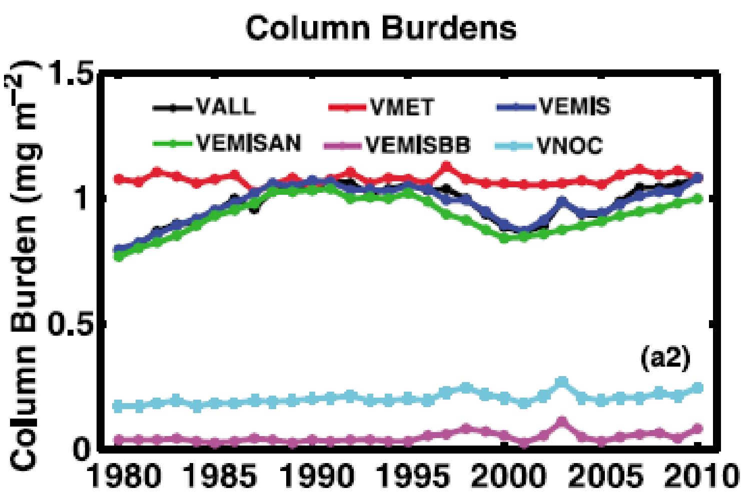
VALL	concentrations	column burden
MAD	0.013–0.034μg m^{-3}	0.024–0.038mg m^{-2}
APDM	2.5–4.2%	3.4–4.9%

- ☐ The MAD and APDM values in **VMET** and **VEMIS** are generally comparable.
- ☐ In DJF, both MAD and APDM values in **VMET** are 2 times of those in **VEMIS**.
- ☐ The MAD and APDM values of surface concentrations (column burdens) of BC in **VEMISAN** are 90% (70%) of those due to variations in **VEMIS**.
- ☐ The influences of biomass burning and **non-China** emissions on BC are largest in MAM.

Direct Radiative Forcing of BC

The annual mean all-sky TOA DRF of BC

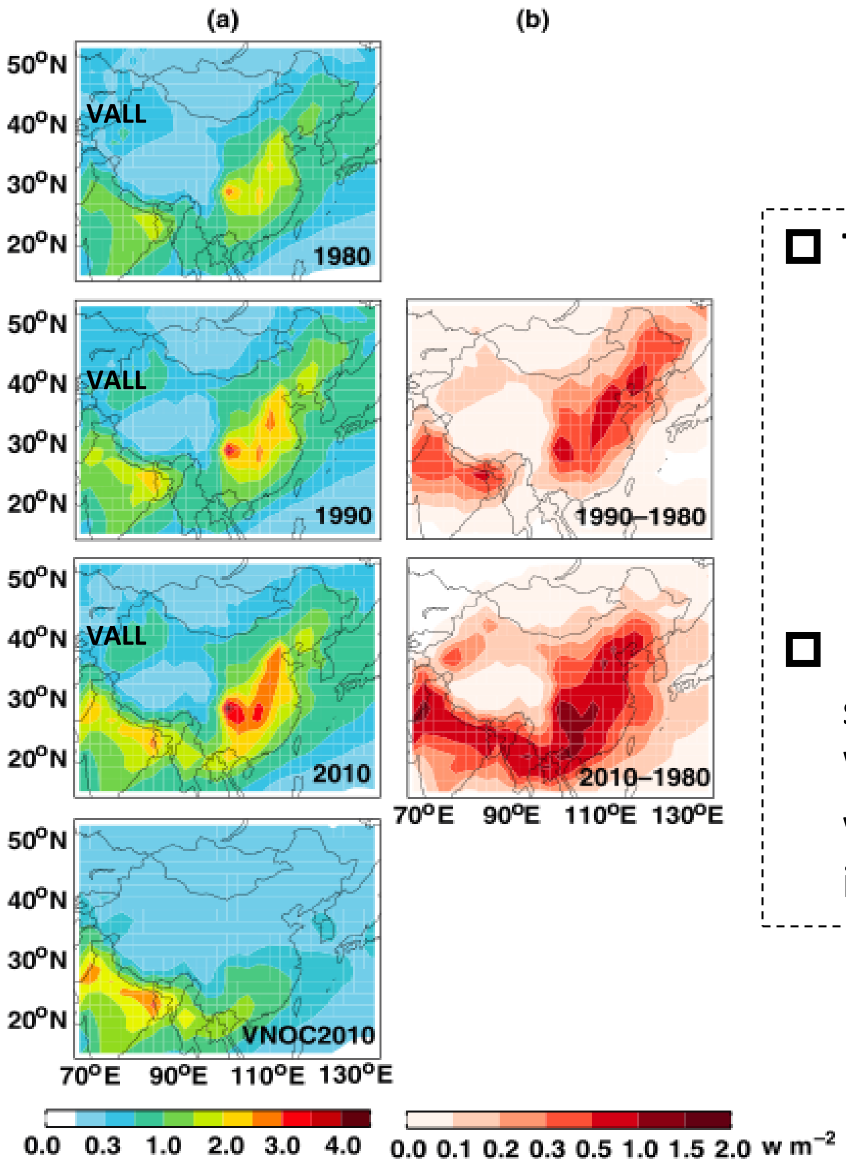




- The variations of **DRF** are similar to the changes in **tropospheric column burden**.

- The increases of **BC DRF** in China from 1980 to 2010 (0.35 Wm^{-2}) are significant comparing to the **global annual mean DRF values of BC** (0.4 Wm^{-2}), **tropospheric ozone** (0.4 Wm^{-2}), and **carbon dioxide** (1.82 Wm^{-2}) reported by IPCC [2013].

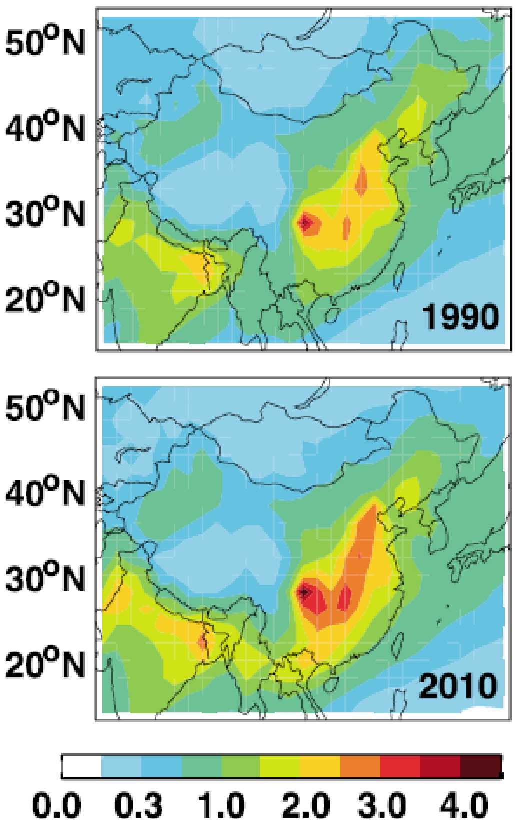
Direct Radiative Forcing of BC



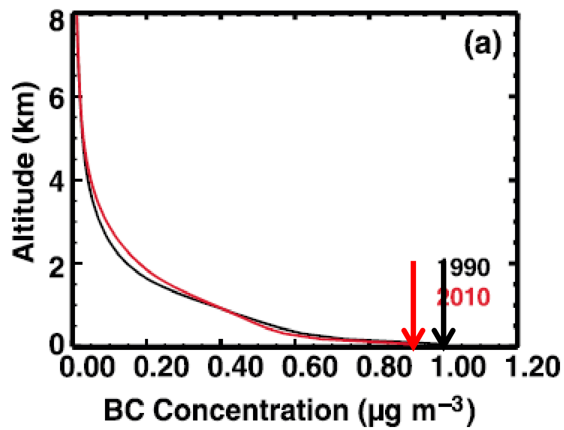
- □ **The TOA DRF of BC (Wm^{-2}) in:**
  - 1980: the lowest concentrations and tropospheric column burdens
  - 1990: the highest concentrations
  - 2010: the highest tropospheric column burdens
- □ From 1980 to 1990 (2010), the DRF shows a significant **increase** of >0.3 (>0.5) Wm^{-2} in the most region of **eastern China**, with the **largest value** of 1.1 (1.4) Wm^{-2} in the **Sichuan Basin**.

Direct Radiative Forcing of BC

TOA DRF



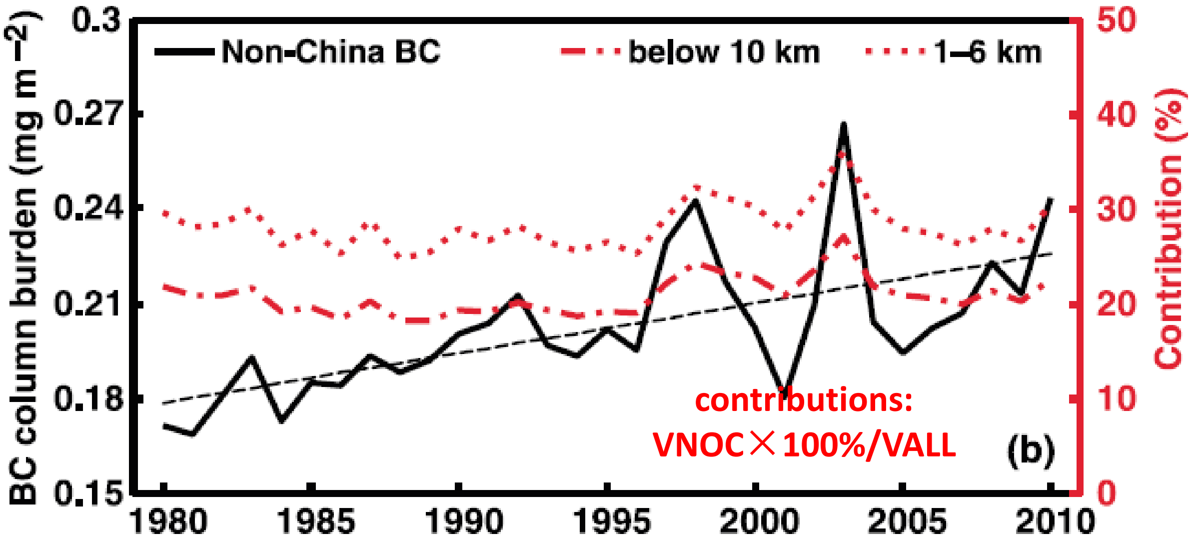
Vertical concentrations



- **High column burdens lead to high DRF in 2010.**
- **The influence of meteorological parameters:**
  - Column burdens of BC are higher in 2010 than in 1990 by 0.03 mgm^{-2} in **VMET** and by 0.01 mgm^{-2} in **VEMIS**.

Direct Radiative Forcing of BC

Contributions of non-China emissions to tropospheric column burdens of BC averaged over China for 1980–2010 from model simulation VNOC



The influence of non-China emissions:

- **Contributions to column burden:** 18–27% below 10 km and 25–36% at 1–6 km.
- **Account for** 0.32 Wm^{-2} (31%) of simulated all-sky TOA DRF of BC averaged over China in 2010
- **From 1990 to 2010**, the contributions to column burden of **increase** by 0.04 mgm^{-2} below 10 km and by 0.03mgm^{-2} at 1–6 km.

Summary and Conclusions

☐ The decadal variations:

- The **decadal variations** of simulated annual mean surface concentrations (column burdens) of BC averaged over China were 0.31 $\mu gm^{-3}decade^{-1}$ ($0.29mgm^{-2}decade^{-1}$) in the 1980s, 0.20 (0.10) in the 1990s, and 0.16 (0.21) in the 2000s.

- The changes in **emissions** were the major driver of the decadal trends of BC.

☐ The interannual variations:

- The **interannual variations** were 20% to 15% (20% to 11%) for DM, 0.068 μgm^{-3} (0.069 mgm^{-2}) for MAD, and 7.7% (7.1%) for APDM.

- The interannual variations were dependent on variations of **both emissions and the meteorological parameters** such as the transport.

More details about this work:

Mao, Y.-H., H. Liao, Y. Han, and J. Cao (2016), Impacts of meteorological parameters and emissions on decadal and interannual variations of black carbon in China for 1980–2010, J. Geophys. Res. Atmos., 121, 1822–1843, doi:10.1002/2015JD024019.

Thanks very much for your attention!

Evaluation of Simulated BC concentrations and AAOD

Table 2. Observed and Simulated Annual Mean Surface BC Concentrations ($\mu g\ m^{-3}$) at 20 Sites in China[a]

Site	Latitude (°N)	Longitude (°E)	Altitude (m)	Observation Period	BC Concentrations: Observation	Model	NMB[e] (%)	Reference[d]
Remote								
Akdala	47.1	88.0	562	2004.8–2005.3	0.35	0.23[b] (0.43[c])	−34 (23)	[1]
Zhuzhang	28.0	99.7	3583	2004.8–2005.2	0.34	0.19 (0.38)	−44 (12)	
Muztagh Ata	38.3	75.0	4500	2005	0.055	0.078 (0.15)	42 (173)	[2]
Nam Co	30.8	91.0	4730	2006.7–2007.1	0.082	0.064 (0.12)	−22 (46)	[3]
Waliguan	36.3	100.9	3616	2000–2010	0.30	0.15 (0.29)	−50 (−3)	[4]
Rural								
Wusumu	40.6	112.6	1221	2005.9; 2006.12006.7; 2007.5	3.10	1.22 (2.41)	−61 (−22)	[5]
Gaolanshan	36.0	105.9	2075	2006–2007	3.77	0.98 (1.95)	−74 (−48)	[6]
Jinsha	29.6	114.2	424	2006–2007	2.98	2.00 (3.97)	−33 (33)	
Linan	30.3	119.7	149	2006–2007	4.24	1.73 (3.44)	−59 (−19)	
Longfengshan	44.7	127.6	337	2006–2007	2.25	1.48 (2.92)	−34 (30)	
Taiyangshan	29.2	111.7	571	2006–2007	2.61	2.00 (3.99)	−23 (53)	
Lanzhou	35.6	104.1	1966	2007.1–2009.8	1.59	1.10 (2.19)	−31 (38)	[7]
Maofengshan	23.3	113.5	550	2009	2.43	1.12 (2.19)	−54 (−10)	[8]
Urban								
Chengdu	30.7	104.0	496	2006–2007	10.8	2.12 (4.22)	−80 (−61)	[6]
Dalian	38.9	121.6	92	2006–2007	5.3	1.48 (2.93)	−72 (−45)	
Gucheng	39.1	115.8	15	2006–2007	10.6	2.04 (4.06)	−81 (−62)	
Panyu	22.9	113.3	5	2006–2007	7.5	0.98 (1.92)	−87 (−74)	
Zhengzhou	34.8	113.7	99	2006–2007	9.4	2.70 (6.93)	−71 (−26)	
Xian	34.4	109.0	363	2006–2007	12.1	2.04 (4.07)	−83 (−66)	
Dongguan	23.0	113.5	30	2009	5.3	1.42 (2.79)	−73 (−47)	[7]

[a]Model results are from simulations VALL and VAN2X. See text and Table 1 for the definitions of model simulations.
[b]Results are from model simulation VALL.
[c]Results are from model simulation VAN2X.
[d]Sources are the following: [1] *Qu et al.* [2008]; [2] *Cao et al.* [2009]; [3] *Ming et al.* [2010]; [4] *Zhao et al.* [2014]; [5] *Han et al.* [2008]; [6] *Zhang et al.* [2012]; [7] *Zhang et al.* [2011]; and [8] *Chen et al.* [2013].
[e]Normalized mean biases (NMB) = 100% × (Model − Observation)/Observation, where Model and Observation are the simulated and observed BC concentrations, respectively.

Evaluation of Simulated BC concentrations and AAOD

Table 3. AERONET-Derived and GEOS-Chem-Simulated Annual Mean BC Absorption Aerosol Optical Depth (AAOD) at 12 AERONET Sites in China[a]

					BC AAOD		
Site	Latitude(°N)	Longitude(°E)	Altitude(m)	Time	Observation	Model	NMB[d] (%)
				Rural			
Taihu	31.2	120.2	20	2006–2010	0.054	0.021[b] (0.041[c])	−61 (−24)
SACOL	35.9	104.1	1965	2006–2010	0.031	0.010 (0.019)	−68 (−39)
Xinglong	40.4	117.6	970	2006–2010	0.037	0.027 (0.053)	−27 (43)
Shouxian	32.6	116.8	22	2008	0.038	0.021 (0.040)	−45 (5)
Hefei	31.9	117.2	36	2008	0.047	0.026 (0.050)	−45 (6)
Xianghe	39.8	117.0	36	2005–2010	0.058	0.027 (0.052)	−53 (−10)
				Urban			
Beijing	40.0	116.4	92	2002–2010	0.065	0.026 (0.050)	−60 (−23)
Yulin	38.3	109.7	1080	2002	0.061	0.010 (0.019)	−84 (−69)
HK_PolyU	22.3	114.2	30	2006–2010	0.062	0.008 (0.017)	−87 (−73)
HK_Hok_Tsui	22.2	114.3	80	2008–2010	0.045	0.010 (0.018)	−78 (−60)
Chen-kung	23.0	120.2	50	2004–2010	0.025	0.006 (0.010)	−76 (−60)
NCU	25.0	121.2	171	2002–2010	0.030	0.005 (0.009)	−83 (−70)

[a]Model results are from simulations VALL and VAN2X. See text and Table 1 for the definitions of model simulations.
[b]Results are from model simulation VALL.
[c]Results are from model simulation VAN2X.
[d]Normalized mean biases (NMB) = 100% × (Model − Observation)/Observation, where Model and Observation are the simulated and derived BC AAOD, respectively.