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

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Environmental Effects of Black Carbon

Absorb solar radiation

Cloud processes

Snow and ice albedo

Particulate matter

BC is the third most important human emissions in terms of its climate forcing in the present atmosphere after CO_2 and CH_4.

~0.64 W m^{-2} **(IPCC2013)**

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

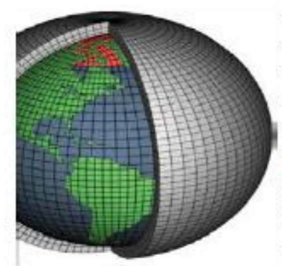
Methods

Assimilated MERRA meteorological fields

BC emissions

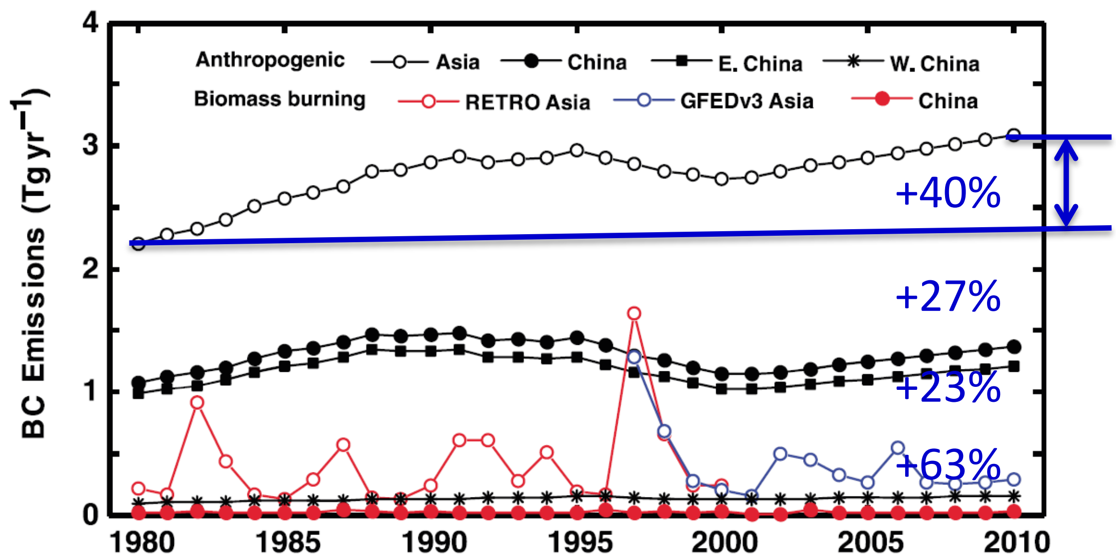
Global
- Bond et al. [2007] for 1980/1990/2000;
- Streets 2000+scaling factor for 2010

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



Mao et al., JGR, ACCR, 2016

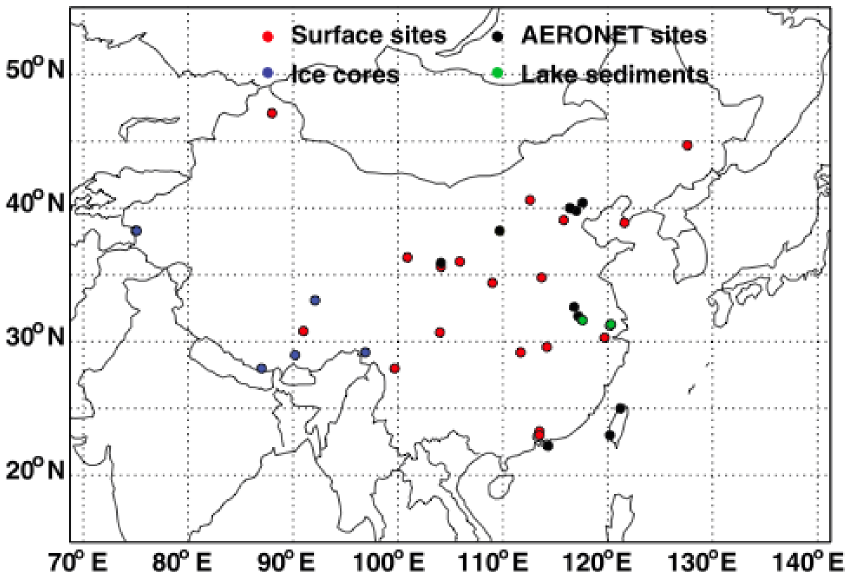
Simulations

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 Turn off emissions in China	1980—2010
VAN2X		1980—2010	1980—2010 Doubled in Asia	1980—2010

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.

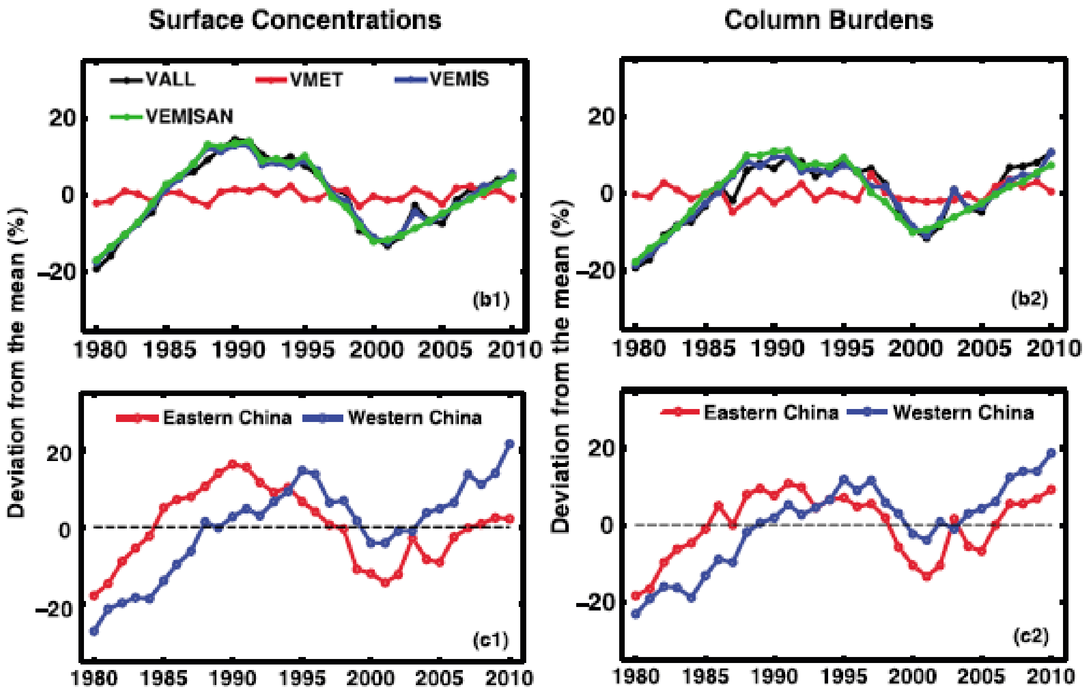
Evaluation of Simulated BC Concentrations and AAOD



- **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);1% at remote and rural sites 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.
- The simulated BC concentrations in the atmosphere reasonably capture the interannual variations of observed BC concentrations in **ice cores**.

Simulated Decadal Trends of BC



The deviation from the mean (DM):

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

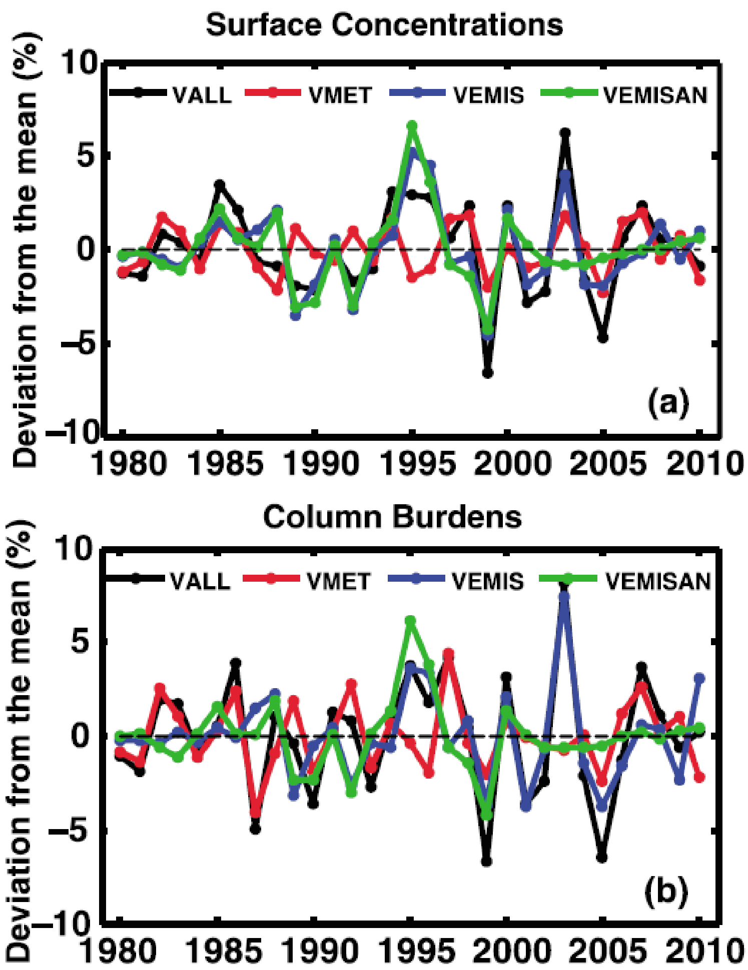
$\boldsymbol{M_i}$: the simulated annual mean BC in China for year $\boldsymbol{i}$;

$\boldsymbol{n}$: the number of years examined (n=31 for years 1980–2010).

- **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} $decade^{-1}$

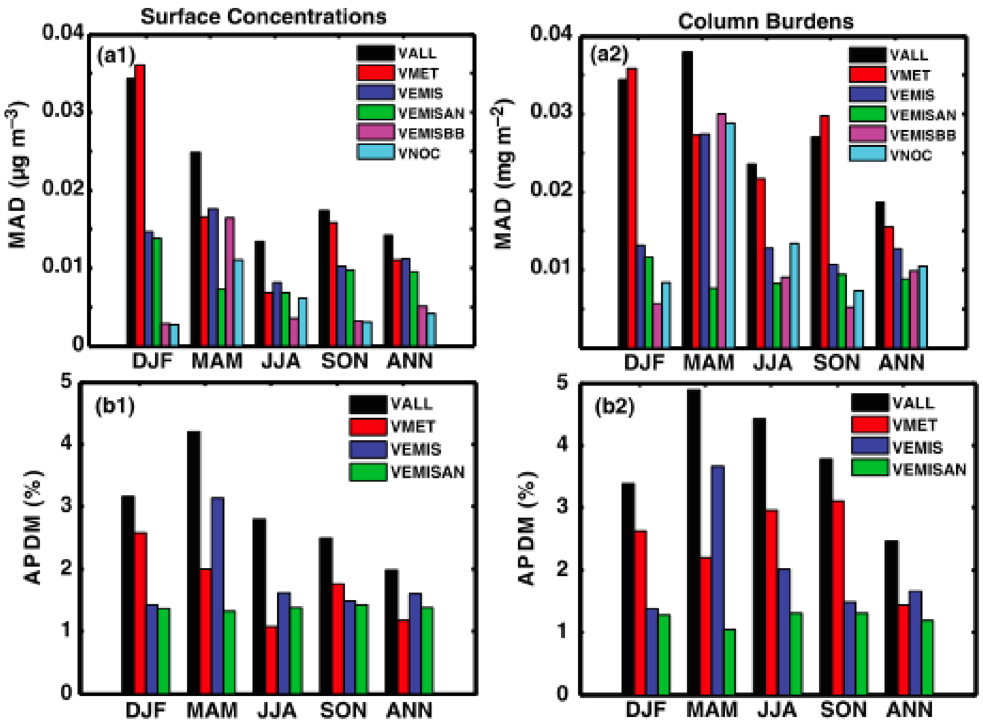
  Western China: 1980(0.07), 1990(-0.09), 2000(0.06) μg m^{-3} $decade^{-1}$

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 mean absolute deviation (MAD):

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

The absolute percent departure from the mean (APDM):

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

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

$\boldsymbol{n}$: the number of years examined.

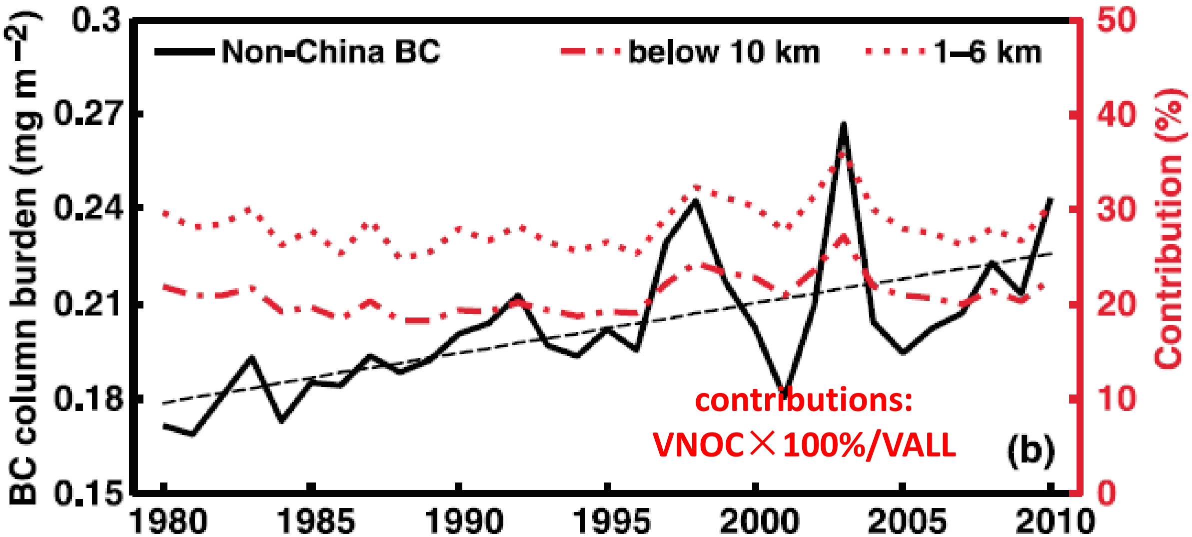
[Mu and Liao, 2014; Yang et al., 2015]

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** (or **DM**) represent the interannual variations of BC in terms of absolute value and percentage, respectively.

Contributions of non-China emissions to BC

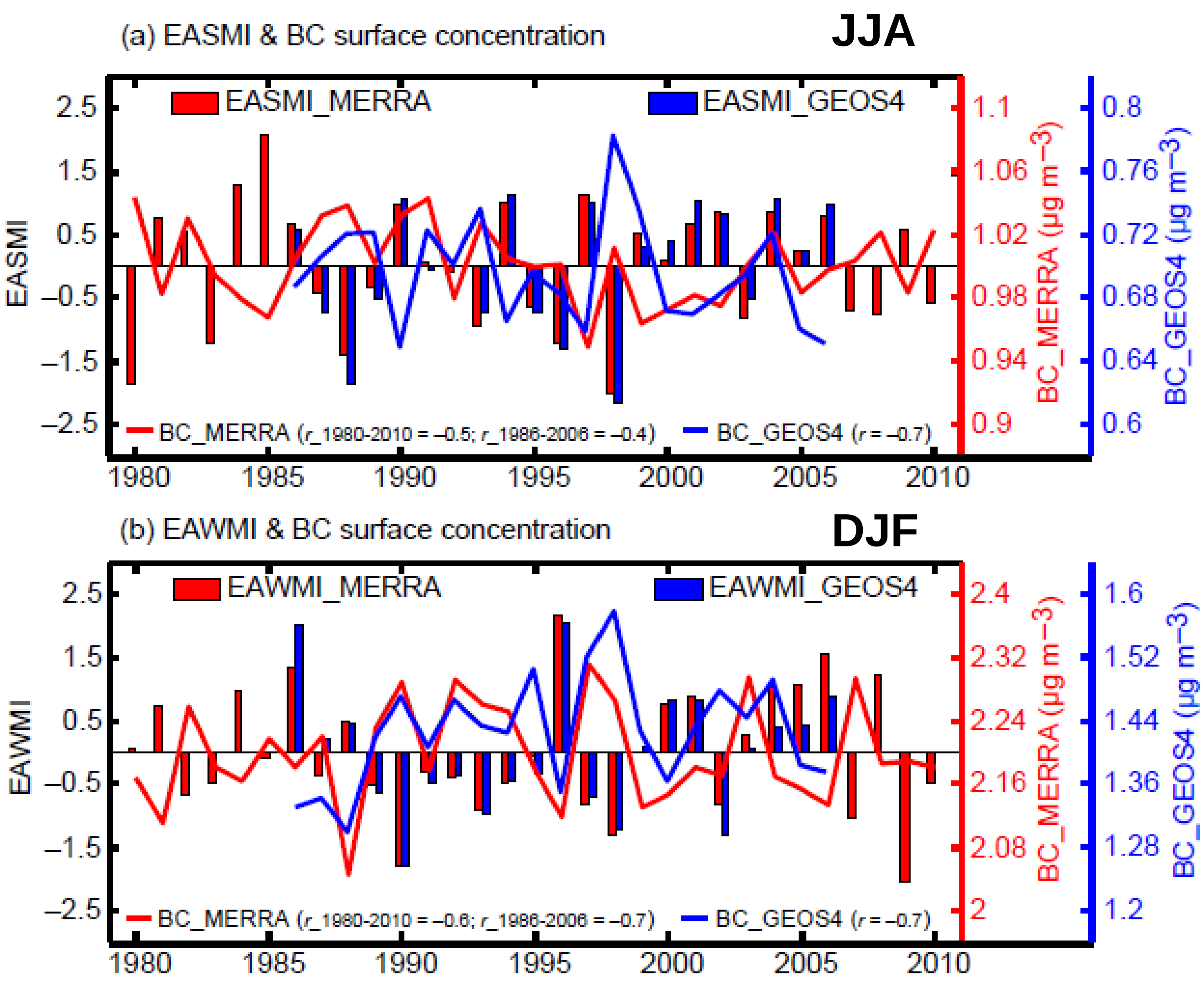
Contributions of non-China emissions to tropospheric column burdens of BC averaged over China for 1980–2010 from model simulation VNOC



The influence of non-China emissions:

- **Contributions to surface Concentrations**： 8%
- **Contributions to column burden:** 21%； increase by ~9% decade^{-1}
- **Account for** 0.32 W m^{-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 mg m^{-2} below 10 km and by 0.03mg m^{-2} at 1–6 km.

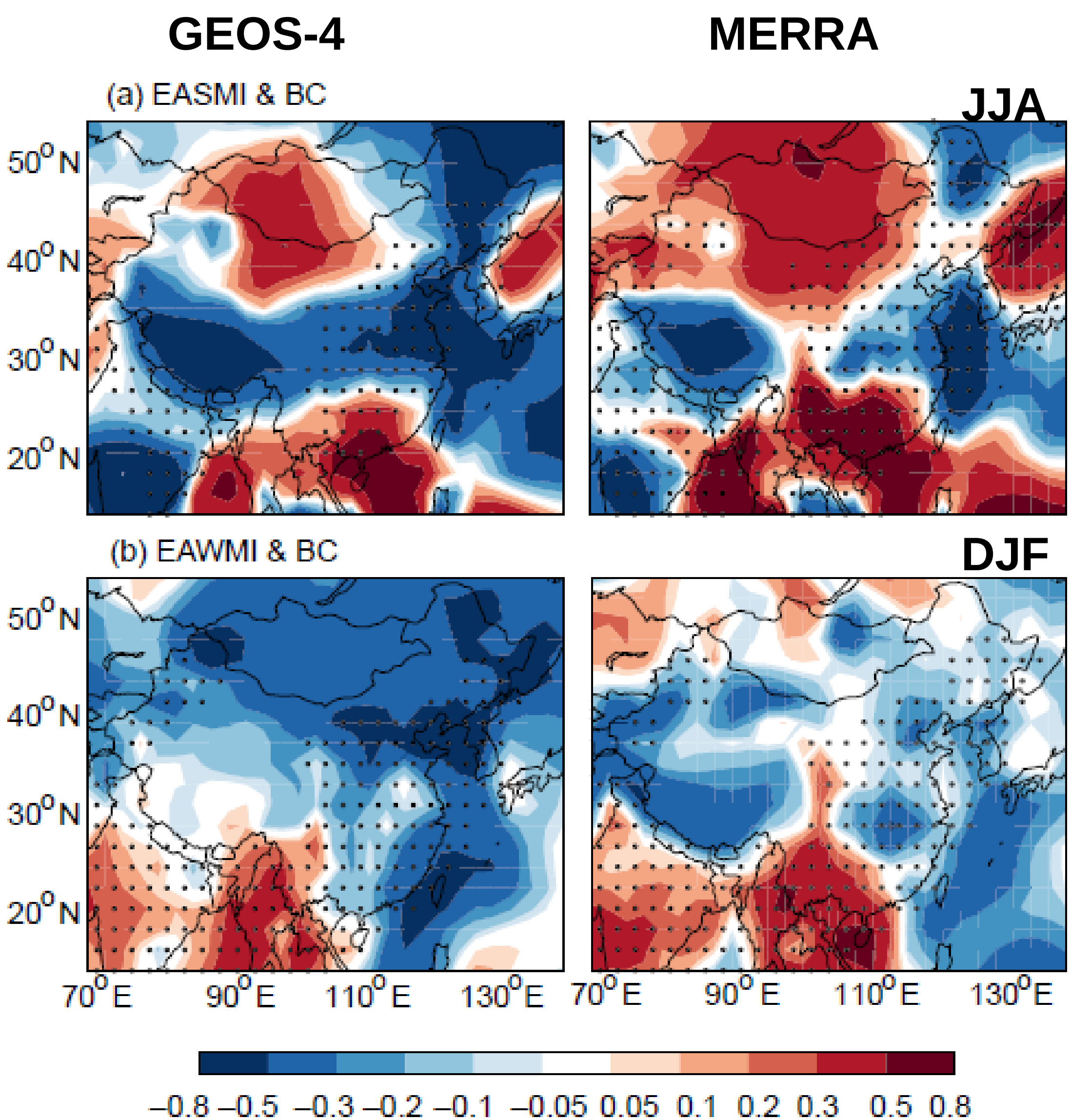
Negative Correlations between BC and EAMI



Mao et al., ACP, 2017

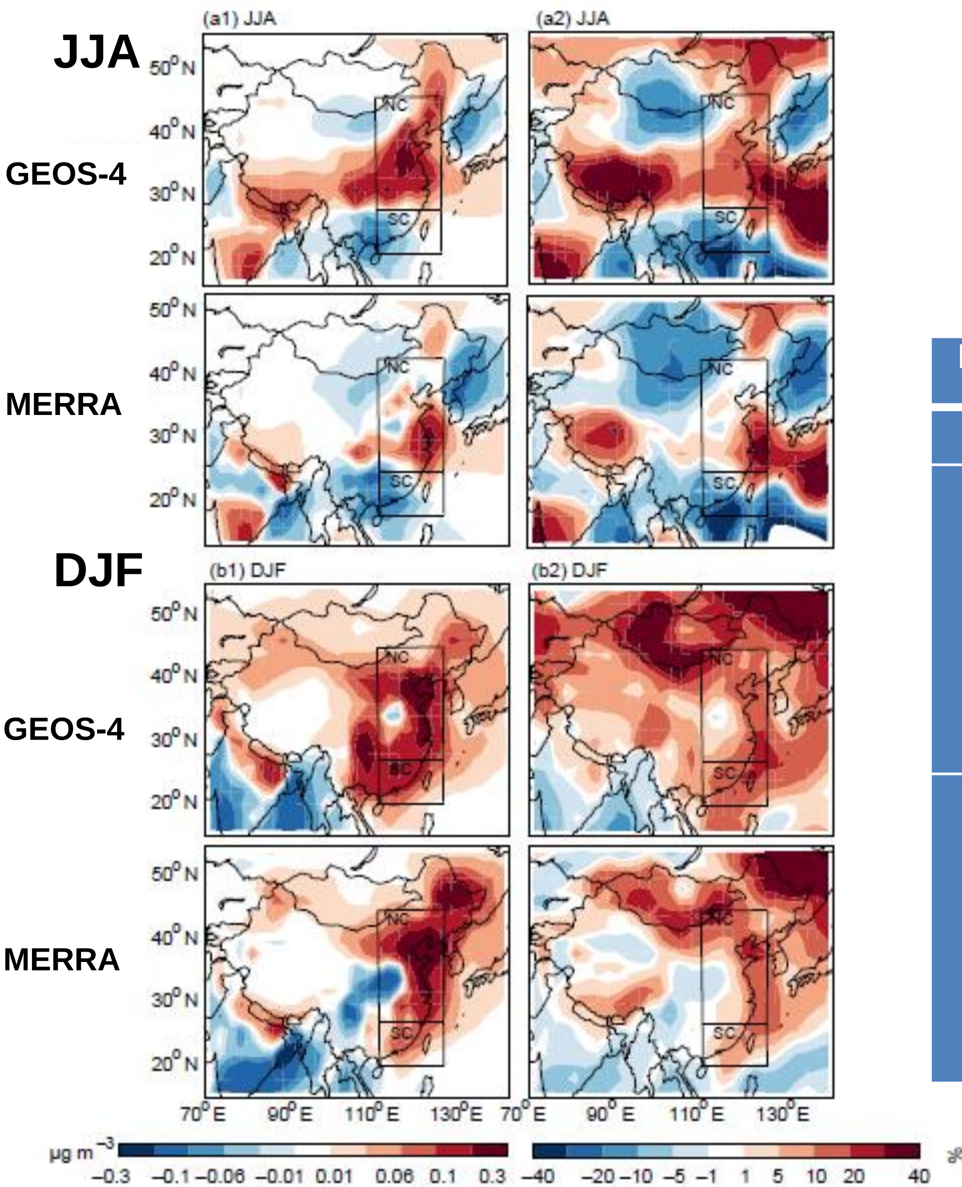
- The strength of the EASM (EAWM) negatively correlated with simulated JJA (DJF) sfc. BC conc. over EC (110–125°E, 20–45°N).
- Relative to the 5 strongest EAM years, simulated sfc. BC conc. in the 5 weakest monsoon years were higher by ~10%.

Correlation Coefficients between BC and EAMI



- **Summer:** Negative correlations are found in central and NEC, while positive correlations are over SC and NWC.
- **Winter:** negative correlations are found in most of China, while positive correlations are over SWC.

Differences in Simulated Surface BC concentrations



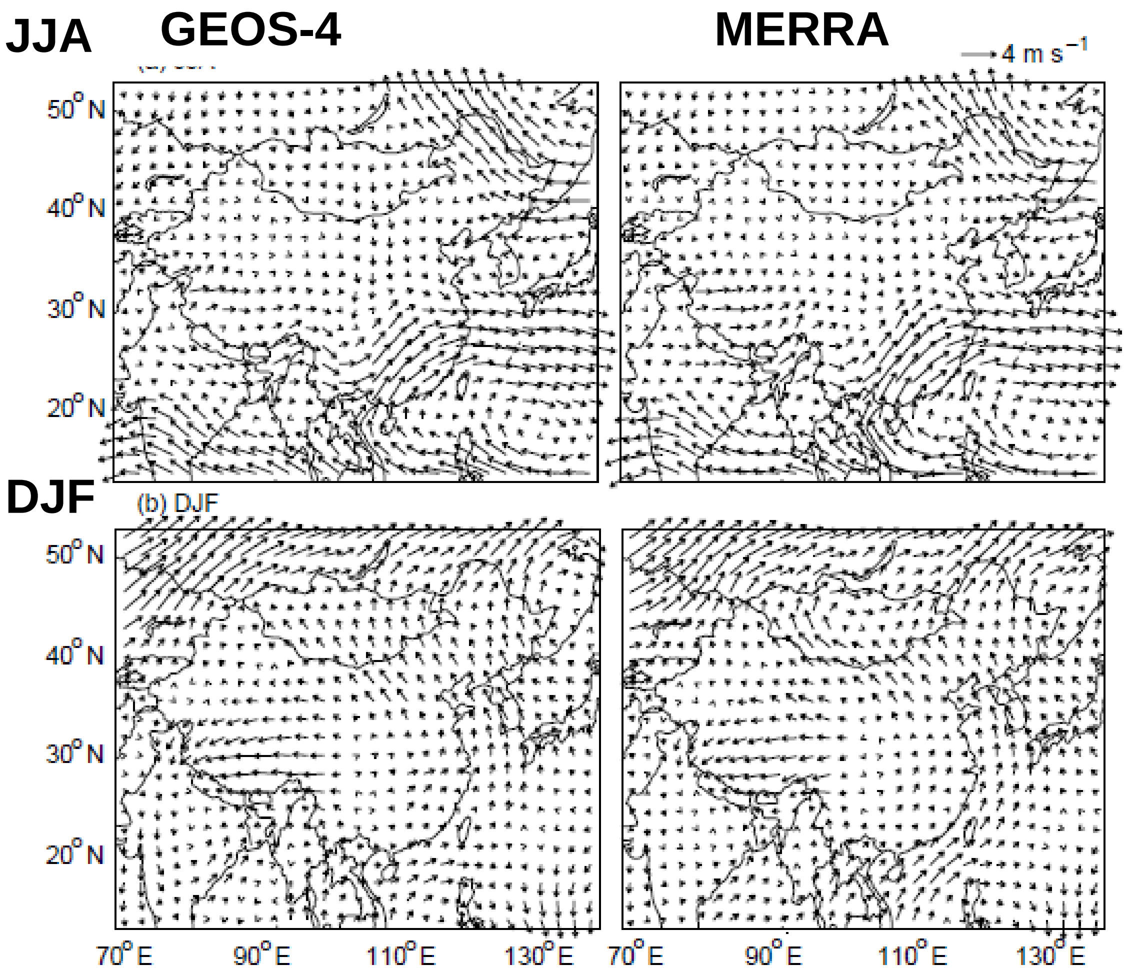
(Five Weakest – Five Strongest) EAM years for 1986–2006

GEOS-4

Month	Region	Surface Concentrations of BC (μg m^{-3})			
		Weak	Strong	Diff.[a]	Std.[c]
JJA	SC	0.24	0.27	–0.03 (–11%)	0.02
	NC	0.94	0.85	0.09 (11%)	0.05
	EC	0.72	0.67	0.05 (9%)	0.03
DJF	SC	0.90	0.80	0.10 (12%)	0.06
	NC	1.76	1.63	0.13 (8%)	0.08
	EC	1.37	1.50	0.12 (9%)	0.07

Differences in Wind Vector @ 850 hPa

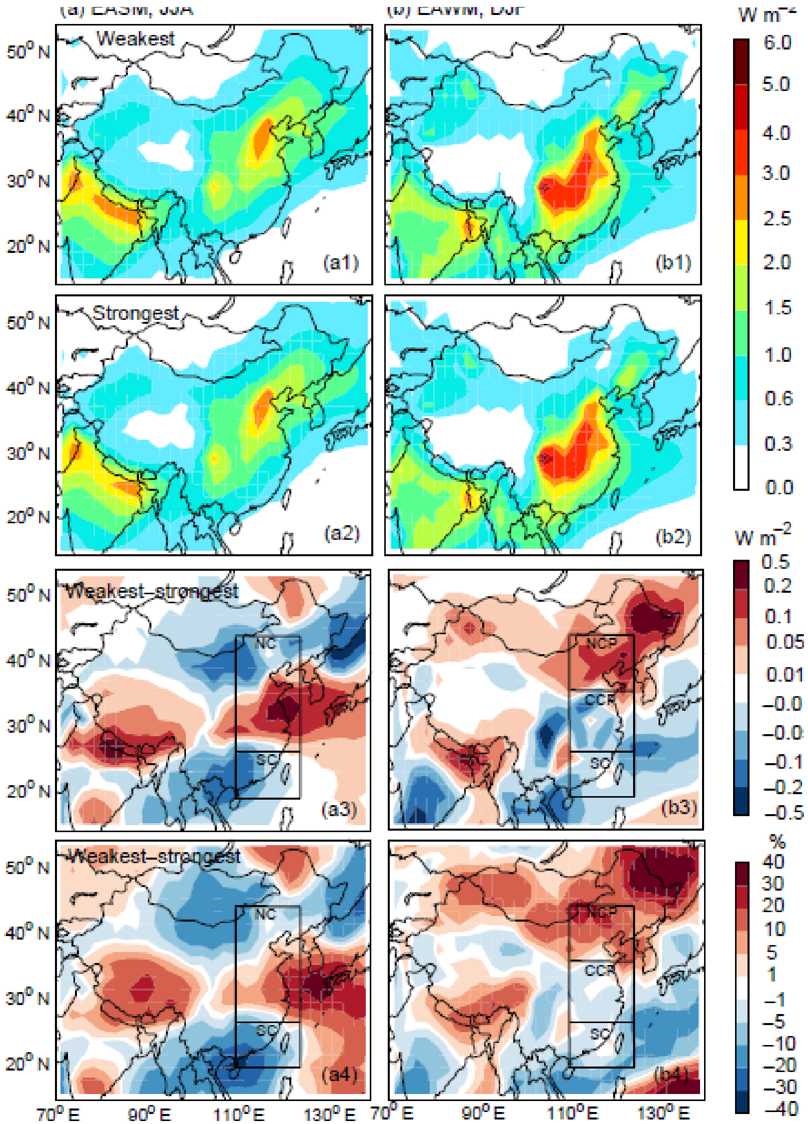
(Five Weakest – Five Strongest) EAM years for 1986–2006



- Impacts of the EAM on BC conc. in EC are mainly due to the changes in atmospheric circulation.
- **Summer:** an anomalous convergence in NC in the weak EASM years, while an anomalous anticyclone in the south of the middle and lower reaches of the Yangtze River and nearby oceans.
- **Winter:** anomalous southerlies in the weak monsoon years did not favor the outflow of pollutants.

Differences in All-Sky DRF of BC @TOA

MERRA **EASM, JJA** **EAWM, DJF**

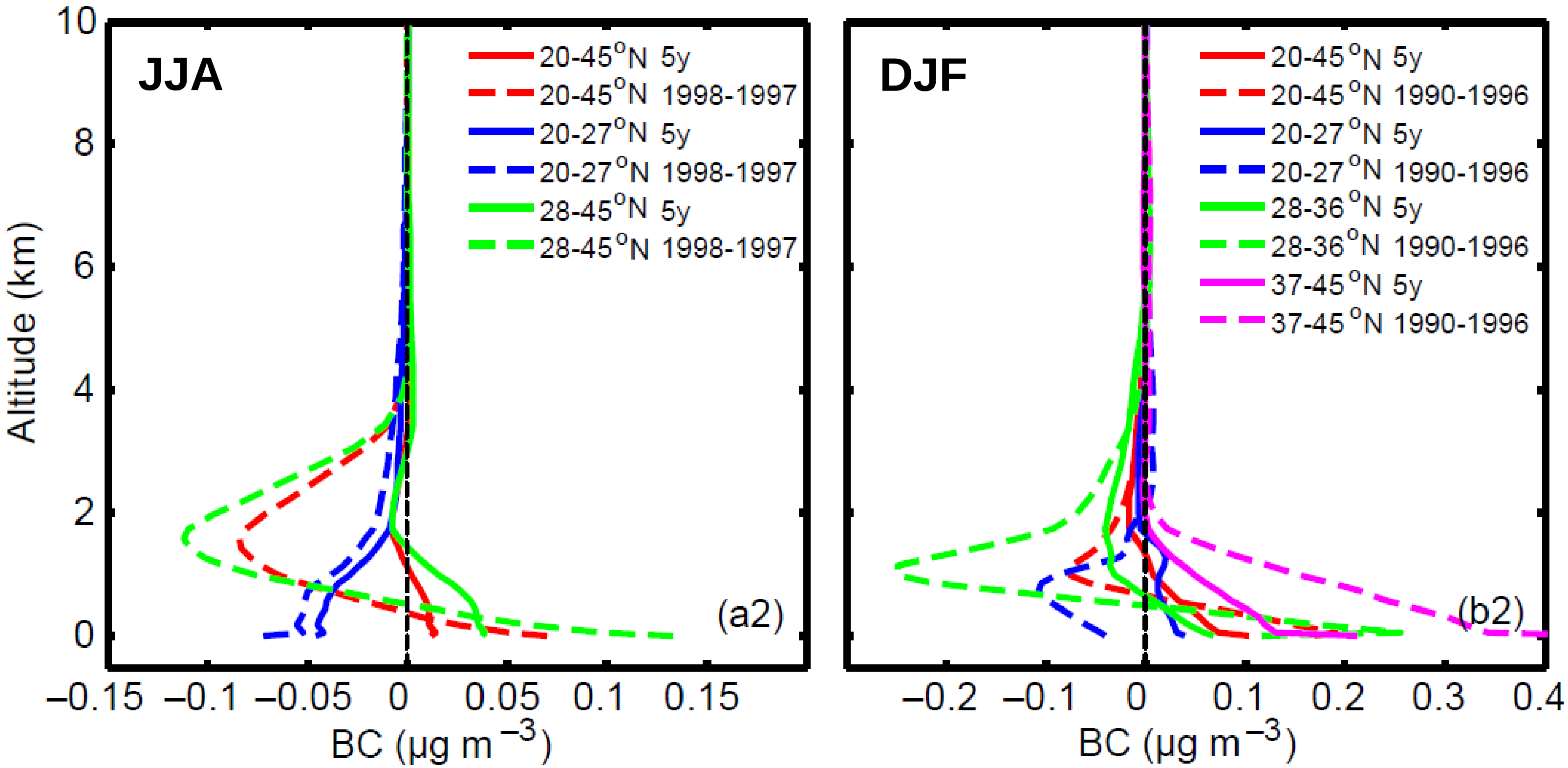


(Five Weakest – Five Strongest) EAM Years for 1986–2006

Month	Region	TOA DRF of BC, MERRA (W m^{-2})		
		Weak	Strong	Diff.[a]
JJA	SC	0.34	0.40	–0.06 (14%)
	NC	1.41	1.38	0.04 (3%)
	EC	1.08	1.07	0.01 (1%)
DJF	SC	1.04	1.07	–0.03 (3%)
	NC	1.65	1.62	0.03 (2%)
	CCP	2.11	2.14	–0.03 (1%)
	NCP	1.08	0.97	0.11 (11%)
	EC	1.46	1.45	0.01 (1%)

Differences in Simulated Vertical Profiles of BC

(Five Weakest – Five Strongest) EAM Years for 1986–2006



- In the weakest monsoon years, the weaker vertical convection at the elevated altitudes led to the lower BC conc. above 1–2 km in SC, and therefore the lower BC DRF in the region.
- The differences in vertical profiles of BC between the weakest and strongest EASM years (1998–1997) and EAWM years (1990–1996) reached up to 0.09 μg m^{-3} (46 %) and 0.08 μg m^{-3} (11 %) at 1–2 km in EC.

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.

☐ the influence of East Asian summer monsoon on BC

- The strength of the EASM (EAWM) negatively correlated with simulated JJA (DJF) sfc BC conc. over EC (110–125° E, 20–45° N). mainly by the changes in atmospheric circulation.

Thanks!

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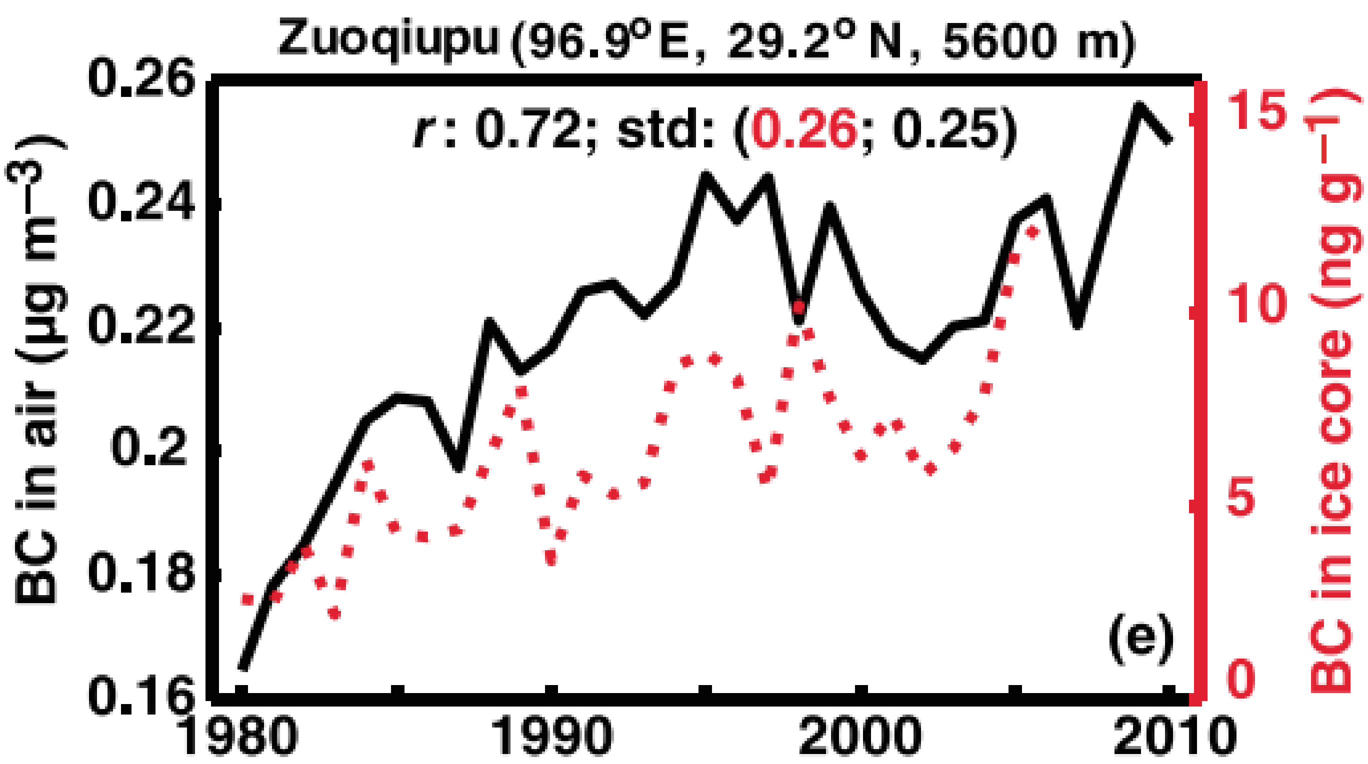
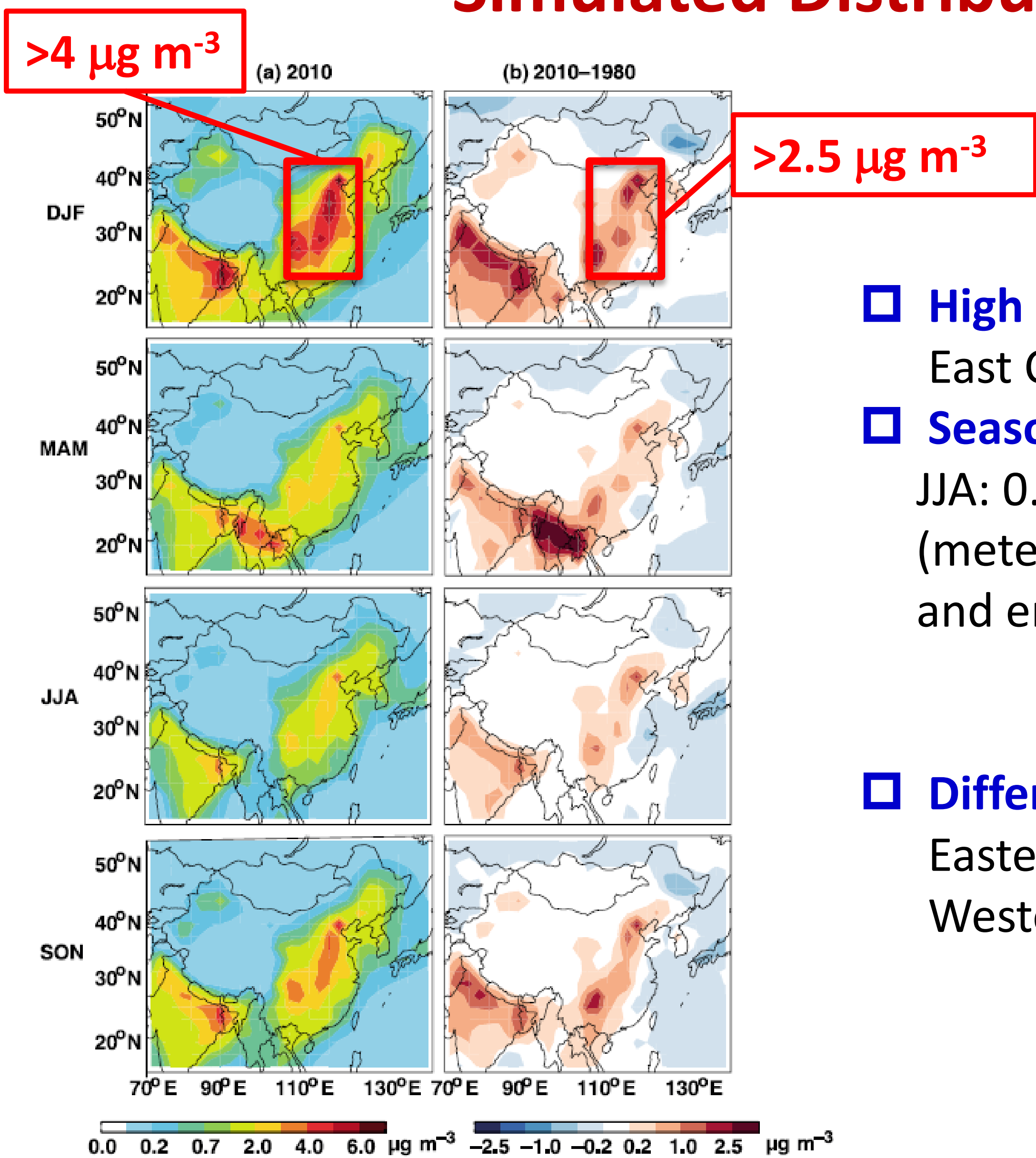
Backup Slides



Zuoqiupu (96.9° E, 29.2° N, 5600 m)
r: 0.72; std: (0.26; 0.25)
BC in air (μg m⁻³)
BC in ice core (ng g⁻¹)
0.26
0.24
0.22
0.2
0.18
0.16
15
10
5
0
1980
1990
2000
2010
(e)

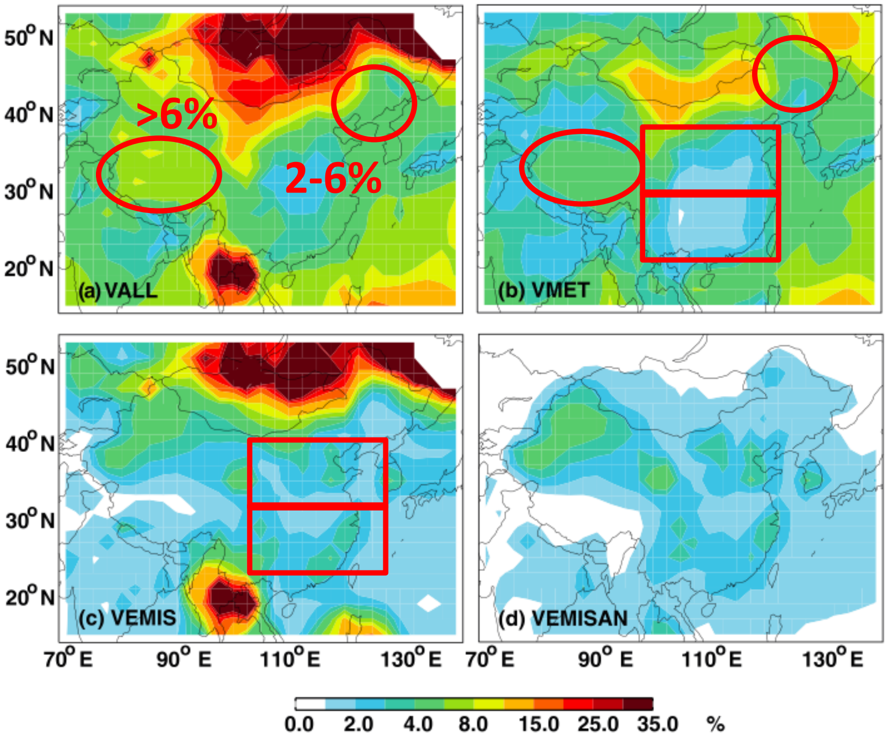
Simulated Distribution of BC



- **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%)

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):

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

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

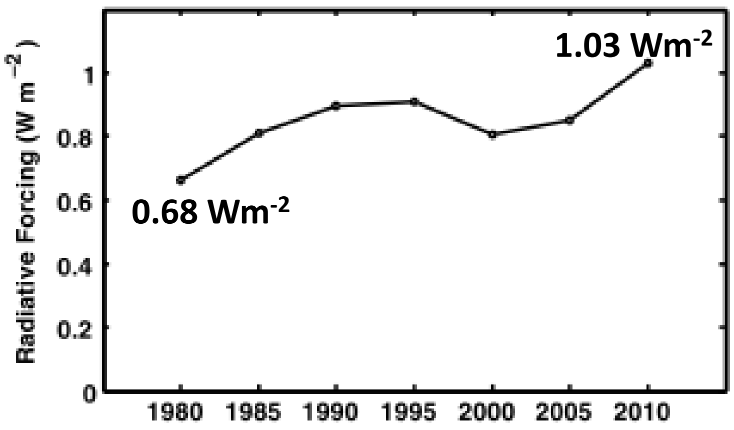
n: the number of years examined.

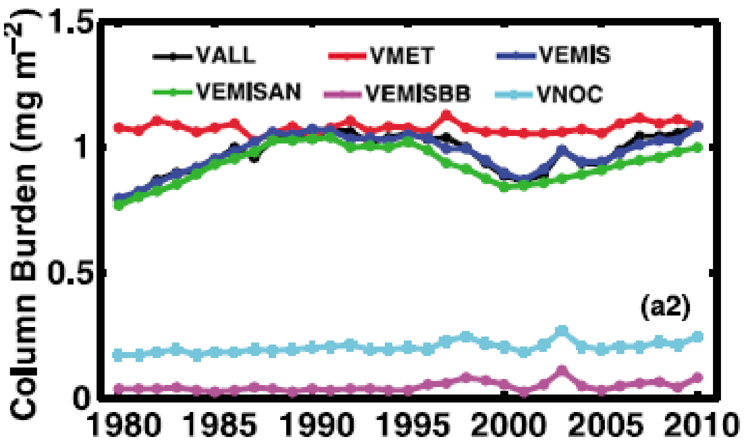
[Mu and Liao, 2014; Yang et al., 2015]

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.

Direct Radiative Forcing of BC

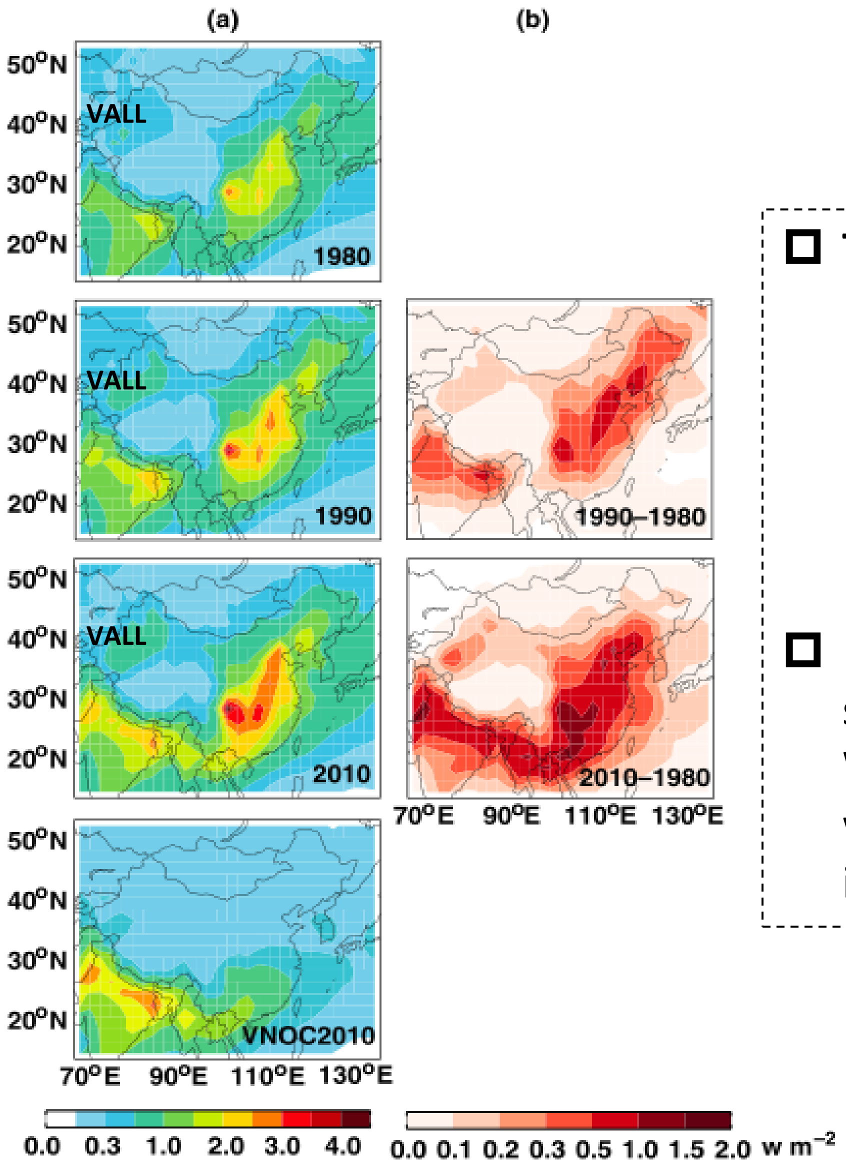
The annual mean all-sky TOA DRF of BC





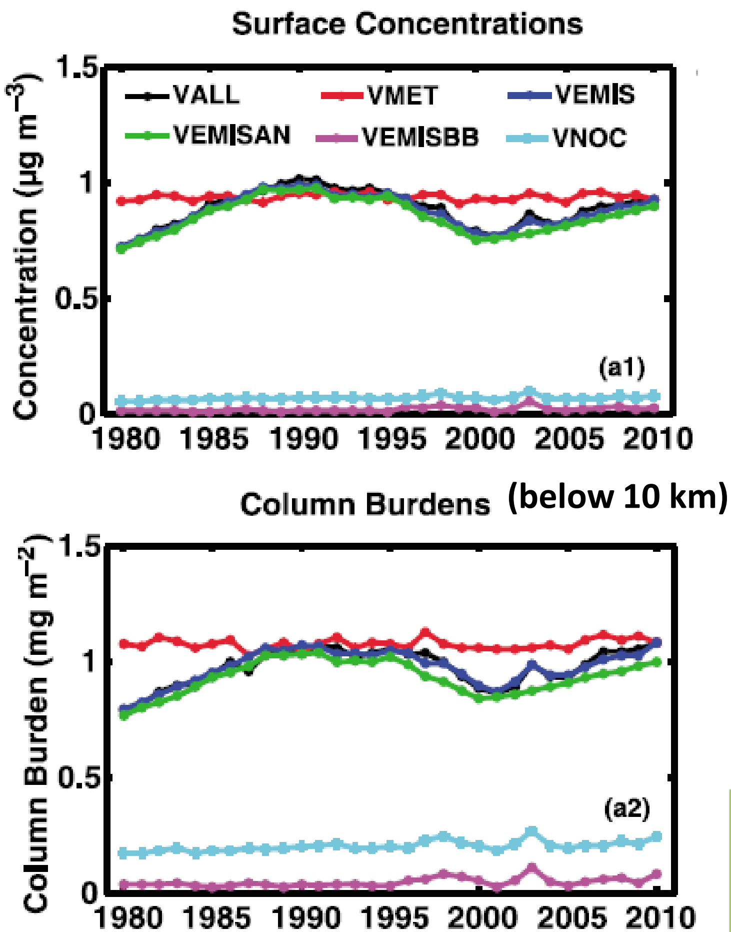
- The variations of **DRF** are similar to the changes in **tropospheric column burden**.
- The increases of **BC DRF** in China from 1980 to 2010 (0.35 W m^{-2}) are significant comparing to the **global annual mean DRF values of BC** (0.4 W m^{-2}), **tropospheric ozone** (0.4 W m^{-2}), and **carbon dioxide** (1.82 W m^{-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**.

Simulated Decadal Trends of BC



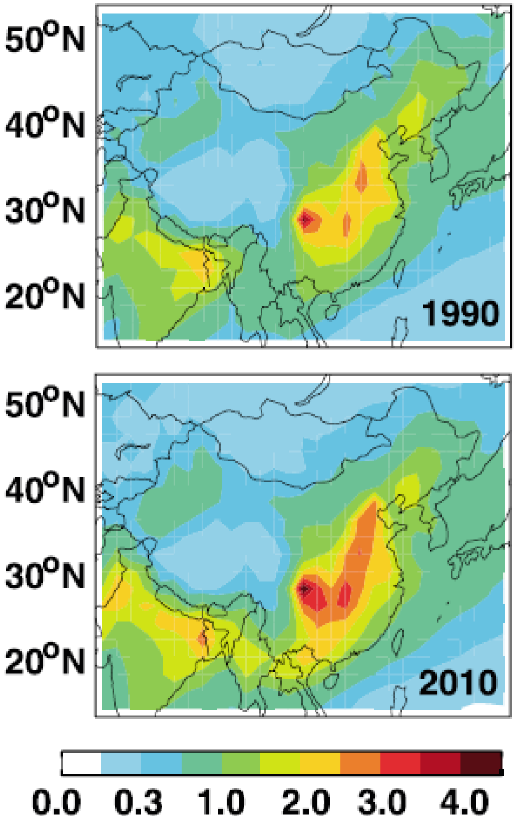
VALL

	Concentrations ($\mu g\ m^{-3}$)	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 ($\mu g\ m^{-3}$ decade^{-1})	**Column burdens** ($mg\ m^{-2}$decade^{-1})
1980s	0.31	0.29
1990s	–0.20	–0.10
2000s	0.16	0.21

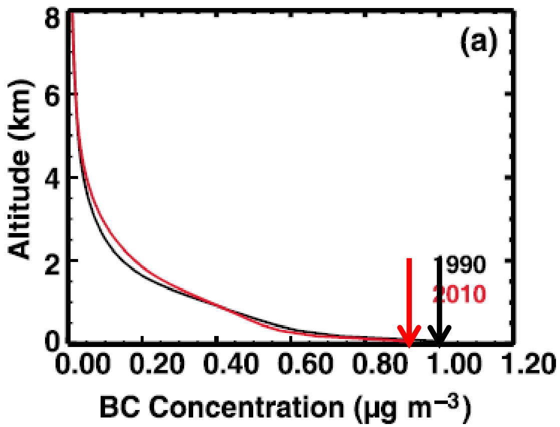
- **VALL** VS. **VEMIS** : emissions
- **VEMIS** VS. **VEMISAN**: anthropogenic emissions (98/95%)
- **VALL** VS. **VMET**
- VNOC (8/21%) ~9% decade^{-1}

Direct Radiative Forcing of BC

TOA DDRF

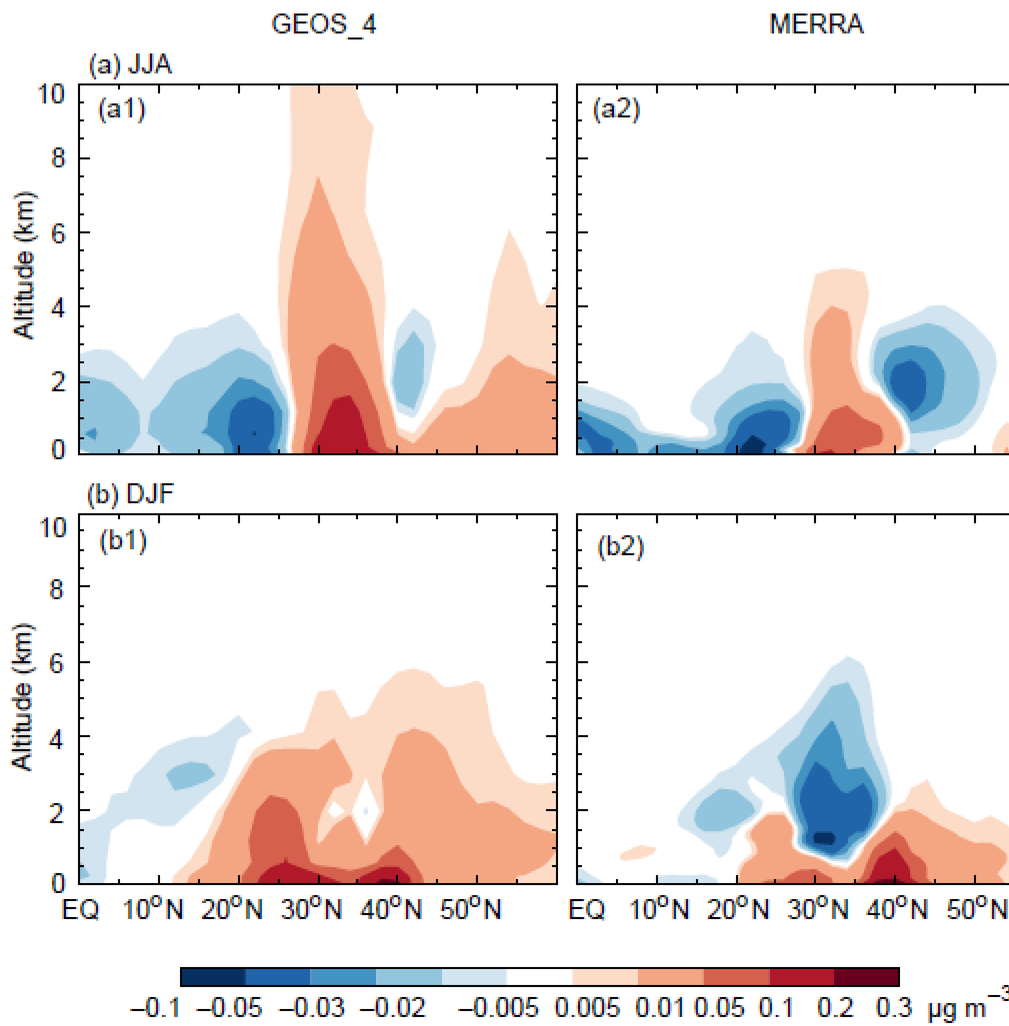


Vertical concentrations

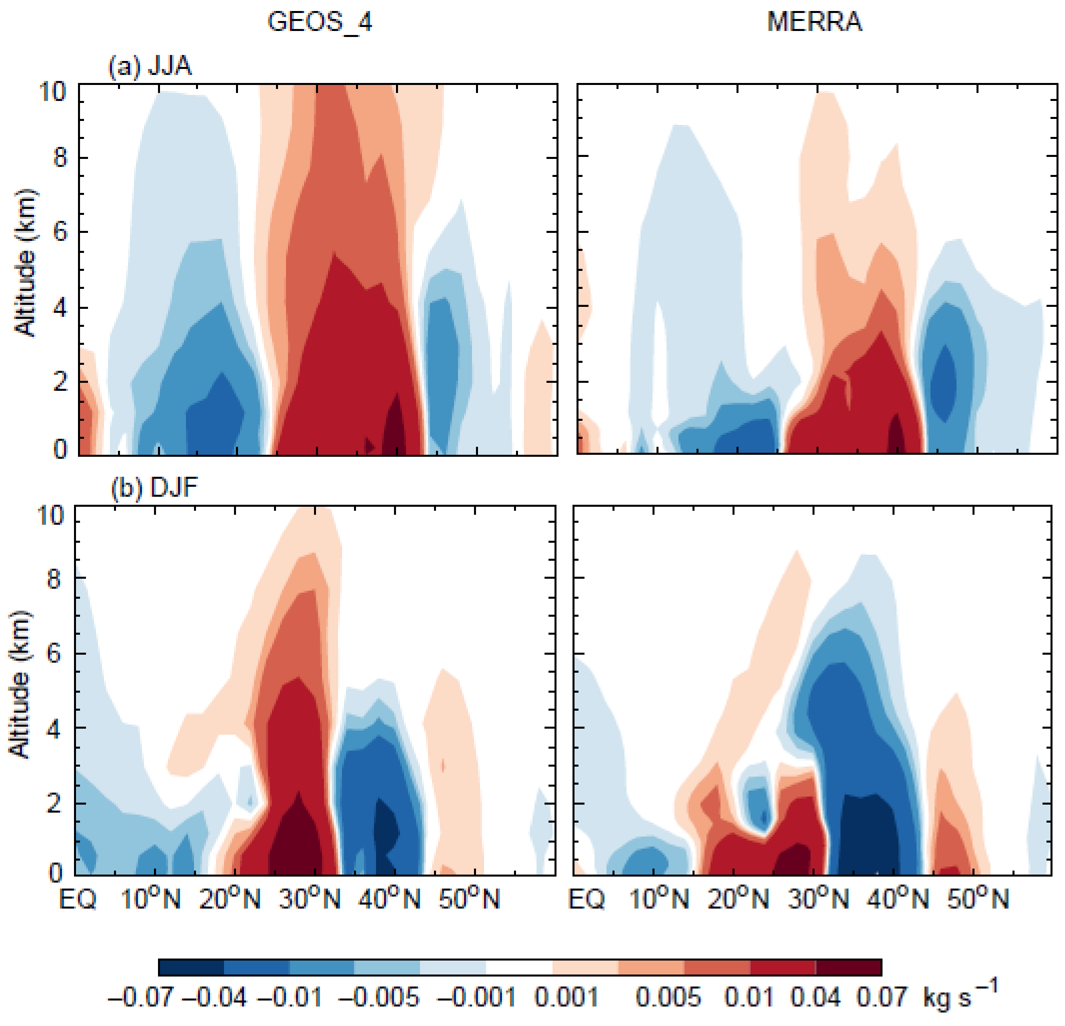


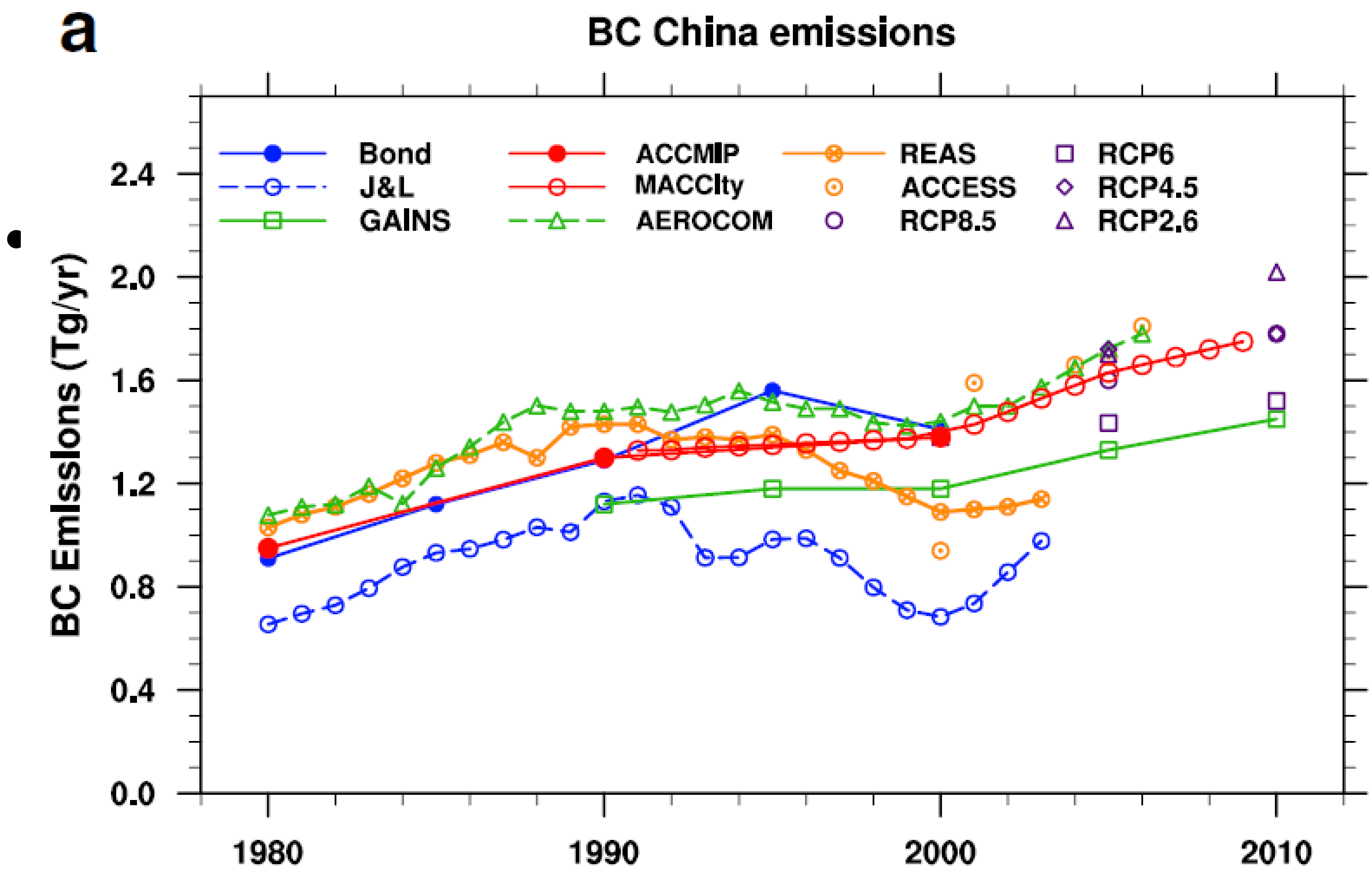
- **High column burdens lead to high DRF in 2010.**
- **The influence of meteorological parameters:**
  - Column burdens of BC are higher in 2010 than in 1990 by 0.03 mgm^{-2} in **VMET** and by 0.01 mgm^{-2} in **VEMIS**.

黑碳垂直浓度（弱季风年—强季风年）



向上输送通量（弱季风年—强季风年）





Granier et al., 2011