Impacts of the East Asian monsoon on seasonal, interannual, and decadal variations of tropospheric ozone and aerosols in China

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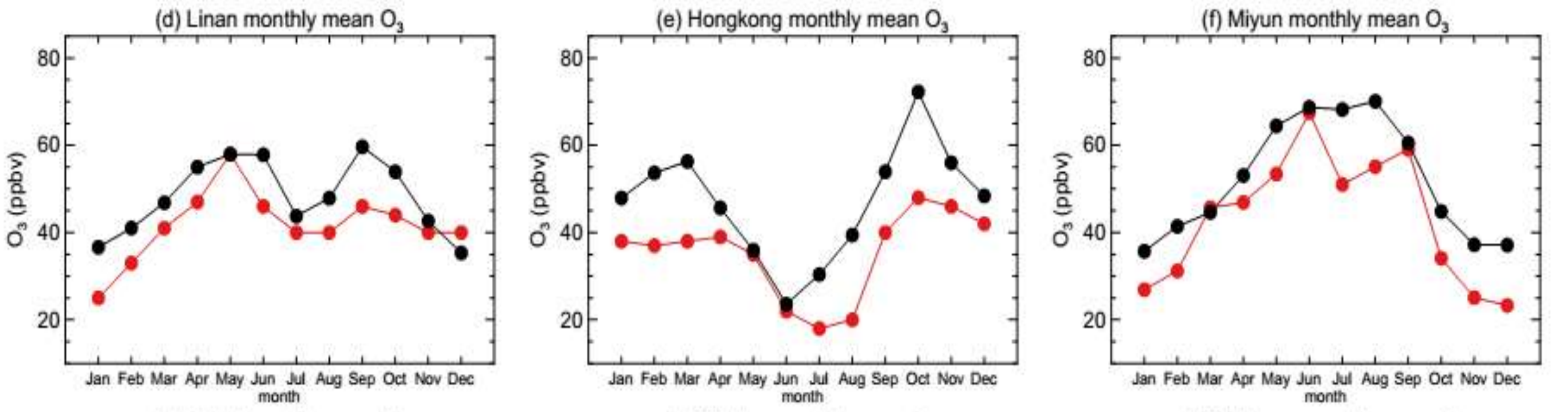
Observed Seasonal Variations of Surface-Layer O_3

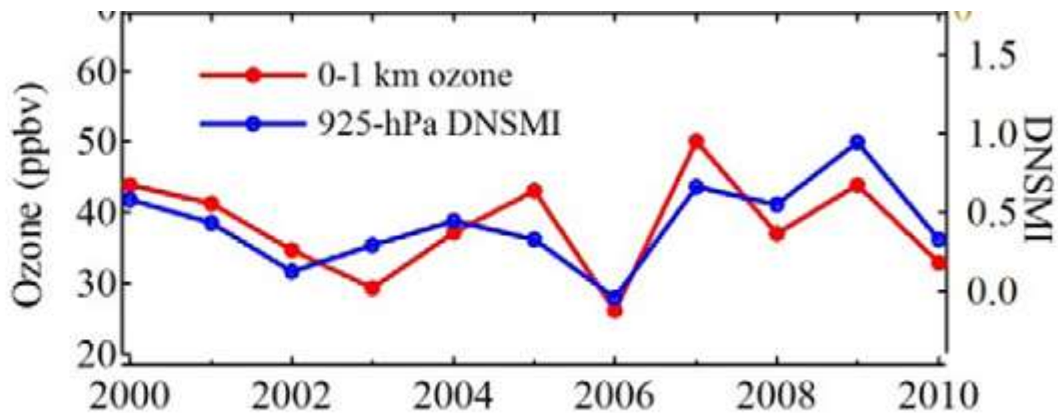
Linan Hongkong Miyun



Clouds associated with precipitation during summer monsoon suppress photochemistry

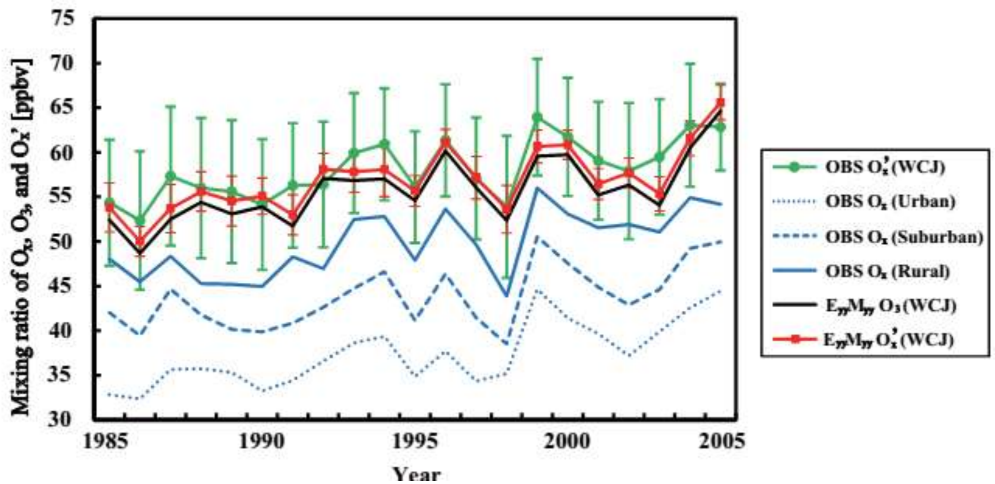
Wang et al., 2008; Lin et al., 2009; Zhao et al., 2010

Observed interannual and decadal variations of O_3



Hong Kong

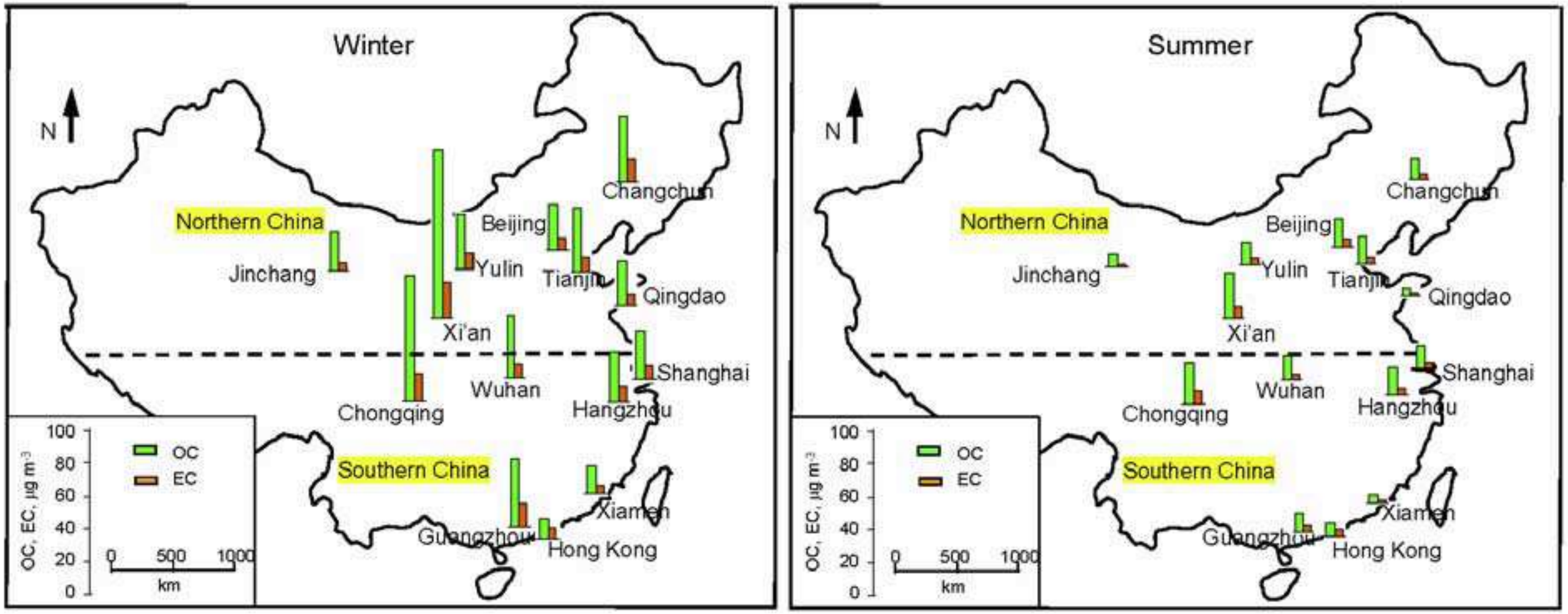
Zhou et al., ERL, 2013



Western central Japan

Kurokawa et al., ACP, 2009

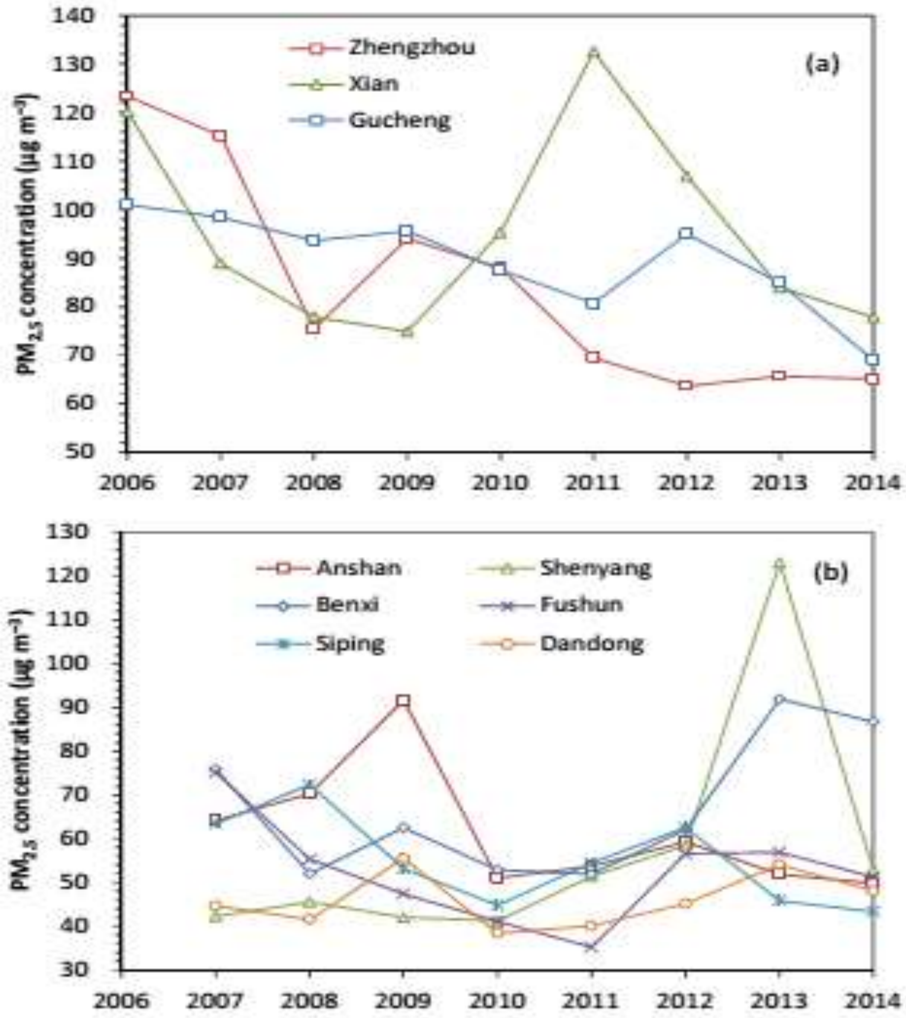
Observed Seasonal Variations of Aerosols



Cao et al., 2007

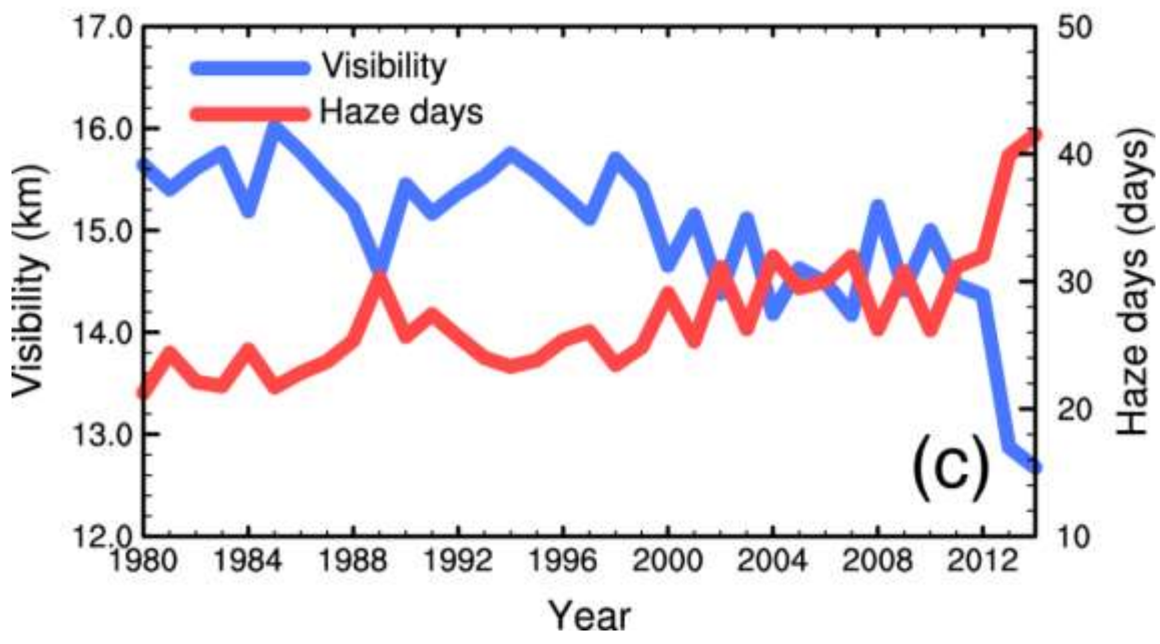
Concentrations OC and BC are high in winter and low in summer

Observed Interannual Variations of $PM_{2.5}$



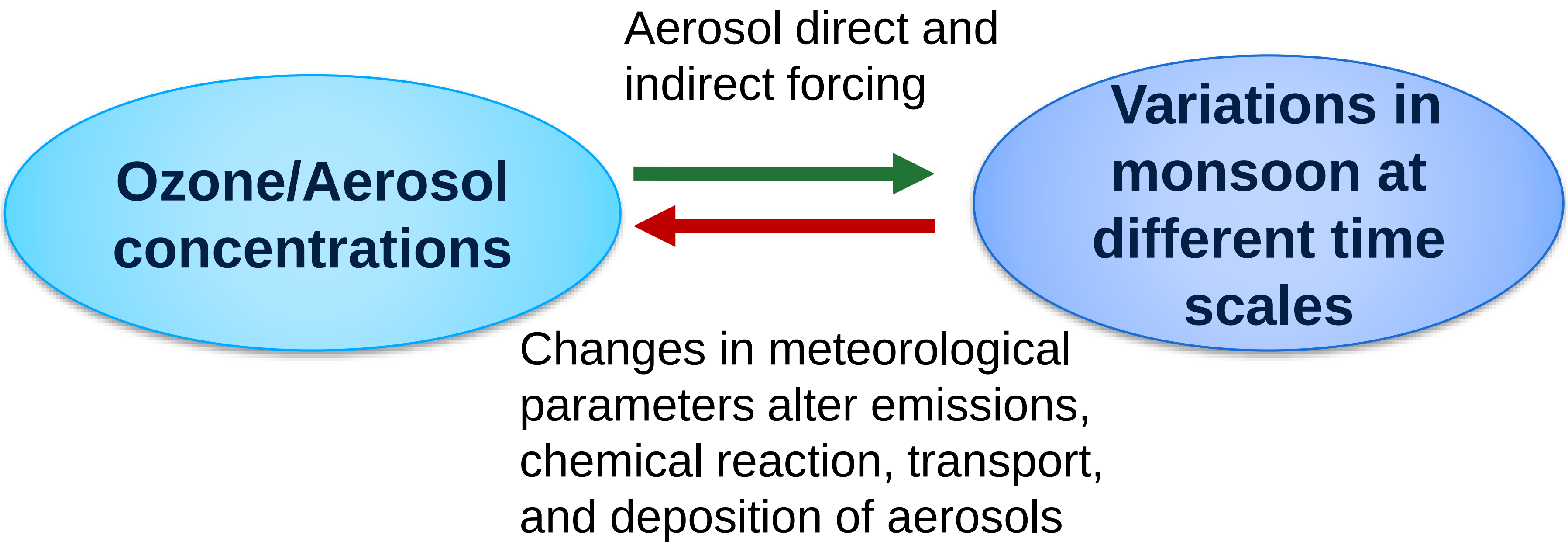
Wang YQ et al., ACP, 2015

Decadal Changes in Observed DJF Atmospheric Visibility and Haze Days over 1980-2014 (averaged over eastern China)



Yang et al., JGR, 2016

Ozone/Aerosols and Monsoon Variability



GEOS-Chem Model Simulations

Assimilated meteorology
GEOS-4, GEOS-5, MERRA

GEOS-Chem

Impacts of monsoon on atmospheric chemistry on seasonal to decadal time scales.

Chemistry scheme:
O_3-NO_x-CO-CH_4-NMHC

Aerosols:
Sulafte, nitrate, ammonium, OC, BC, sea salt and mineral dust

Anthropogenic emissions:
Fixed at year 2006 levels

OUTLINE

- Impacts of the EASM on seasonal variations of aerosols
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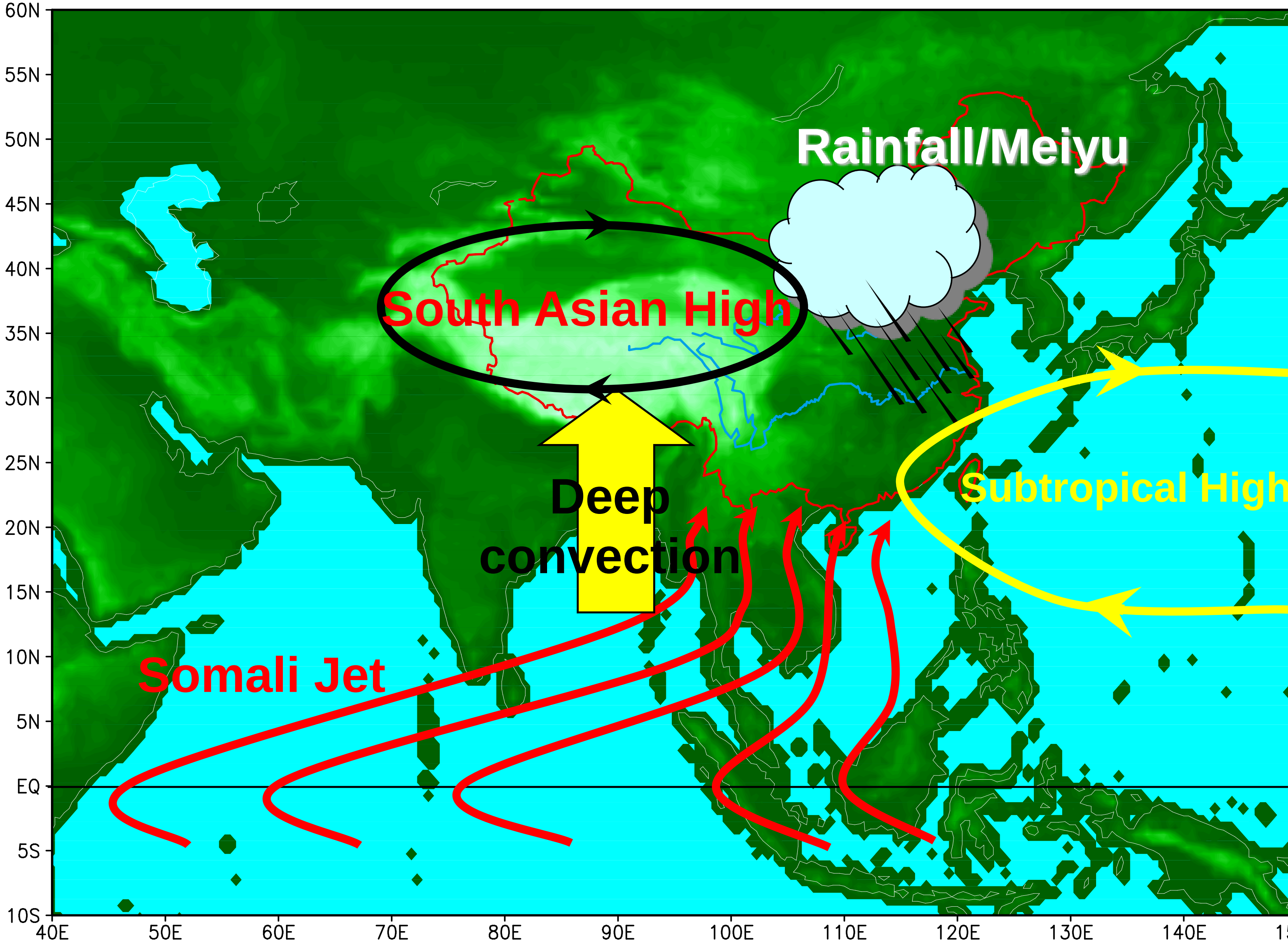
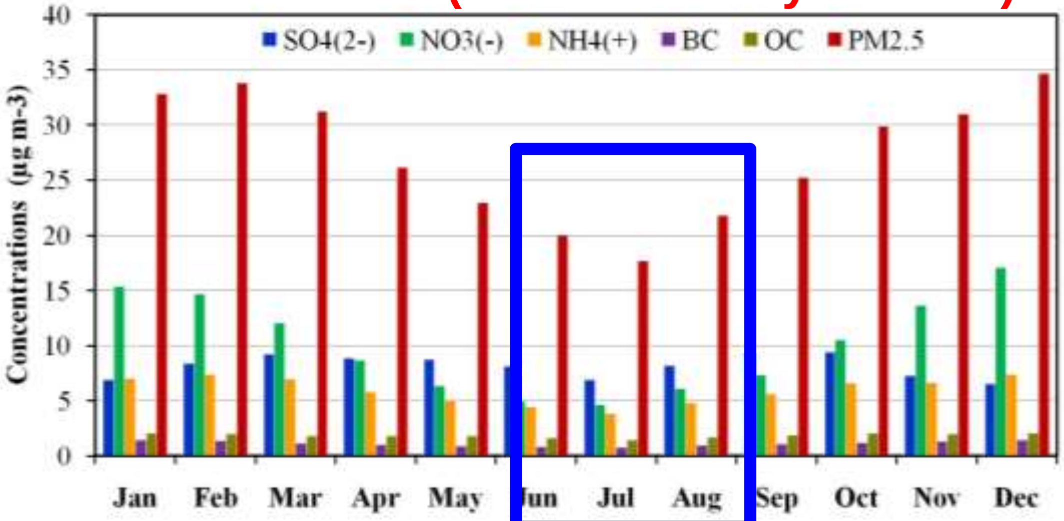
Asian Summer Monsoon



Eastern China (Simulated for year 2001)



Simulated seasonal variation agrees with measurements

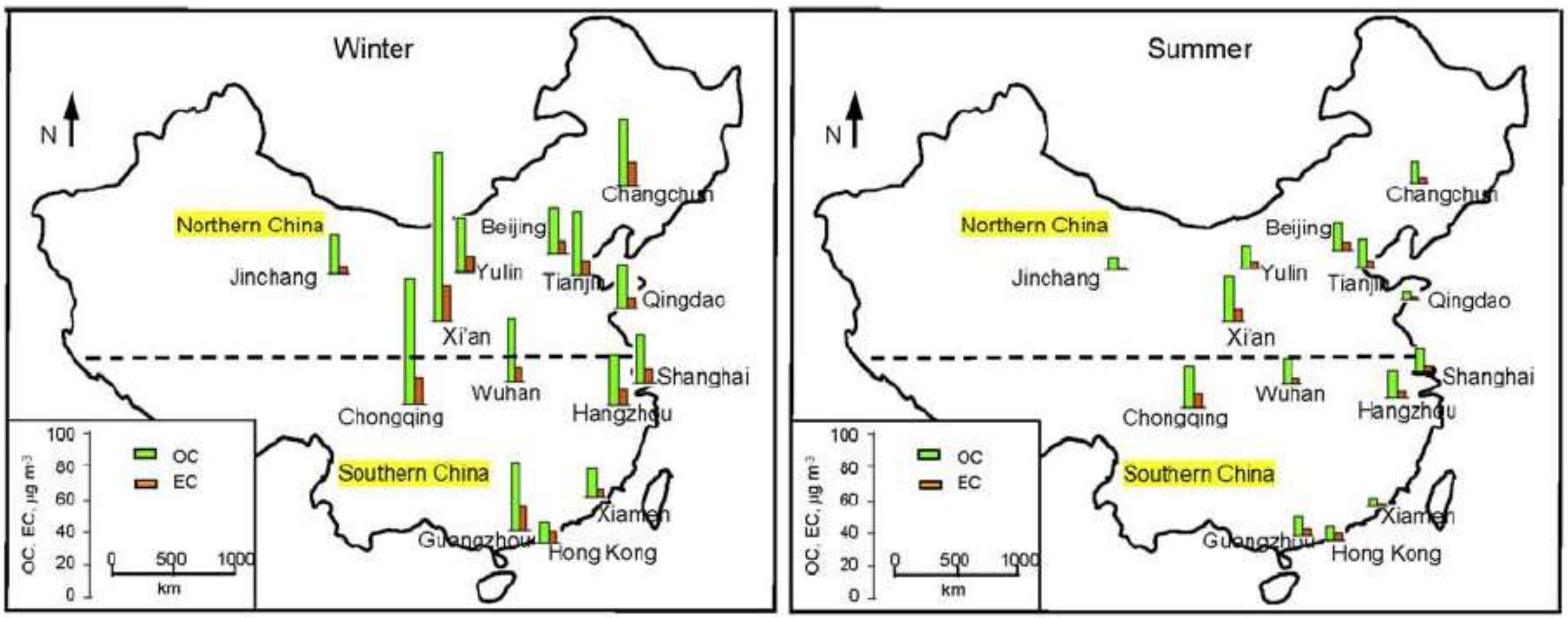
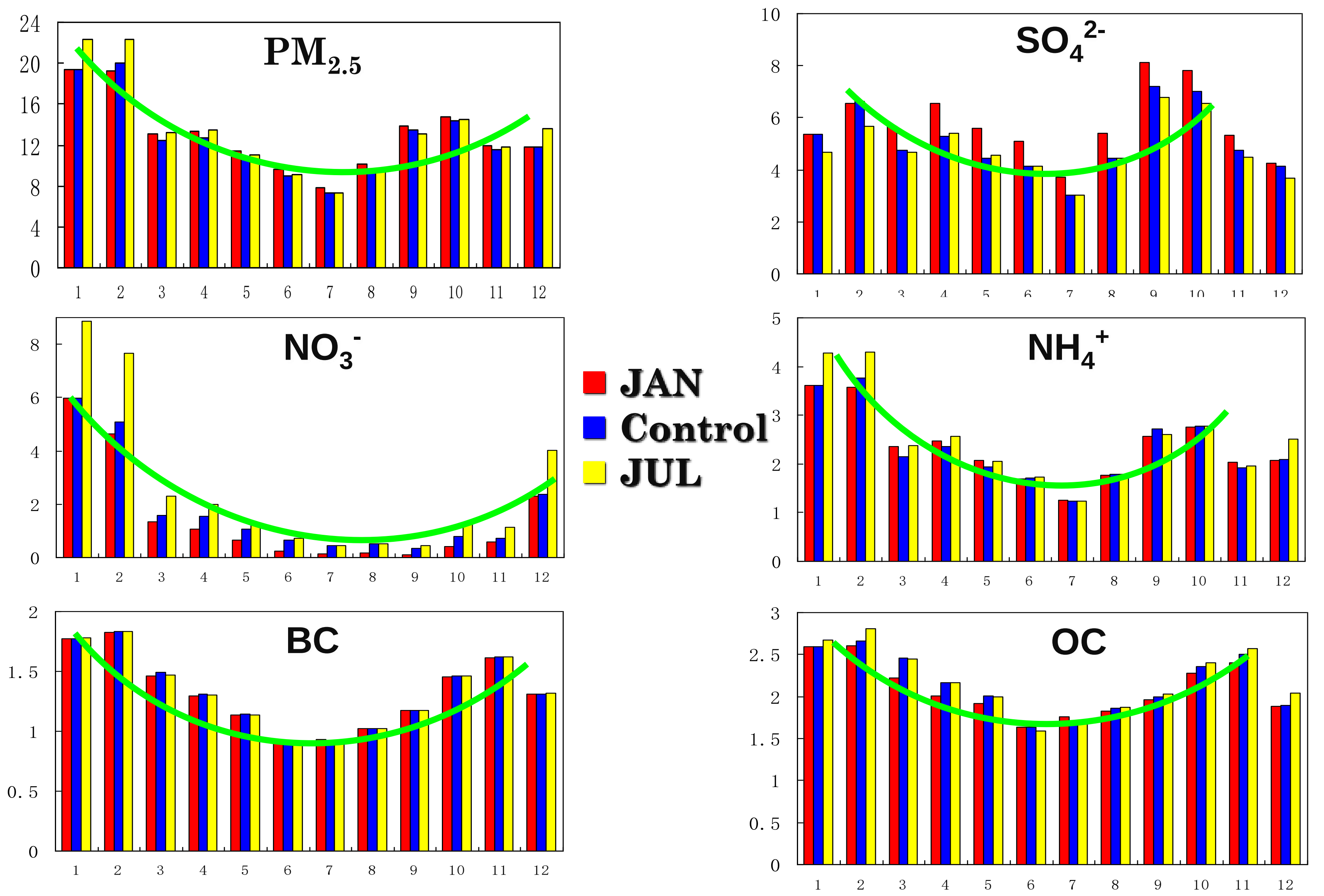


Figure 1. Location of 14 Chinese cities with summer and winter averages of $PM_{2.5}$ OC and EC indicated by bar height.

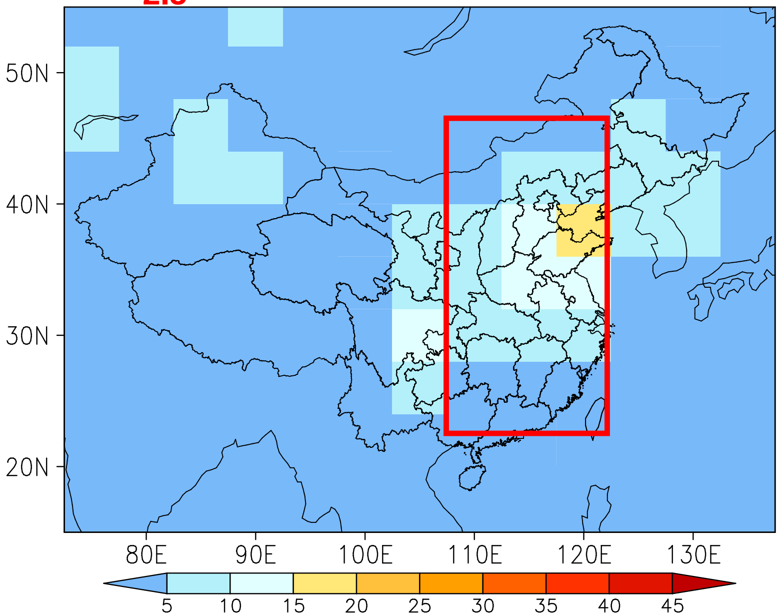
Cao et al., 2007

Two Sensitivity Studies: (1) Fix emissions in all 12 months at January values
(2) Fix emissions in all 12 months at July values



Reduction in Surface $PM_{2.5}$ over Eastern China by Monsoon

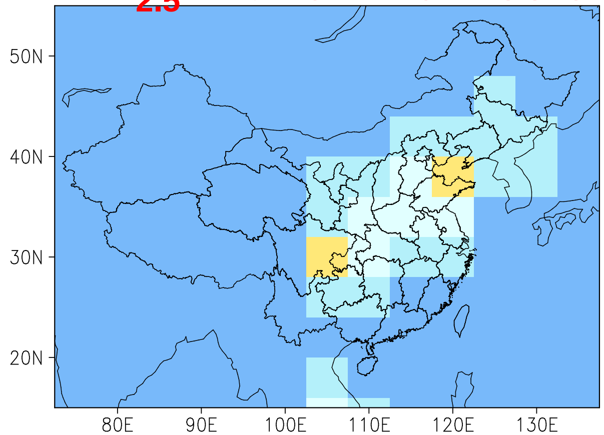
$PM_{2.5}$ in Control run



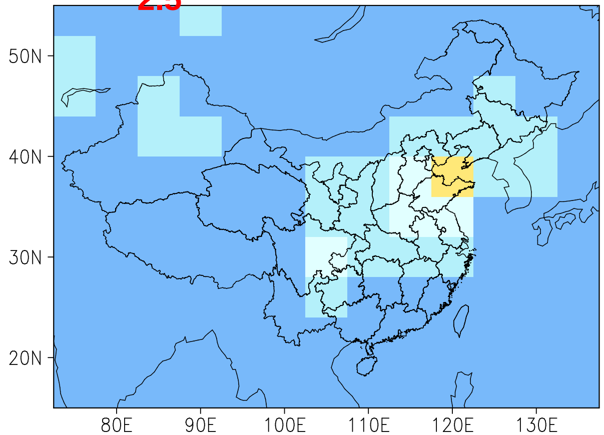
$$\frac{PM_{2.5}(JUL) - PM_{2.5}(JAN)}{PM_{2.5}(JAN)}$$

Control run:	**-62.2%**
JAN Emission:	**-59.7%**
JUL Emission:	**-67.2%**

$PM_{2.5}$ with JAN emission

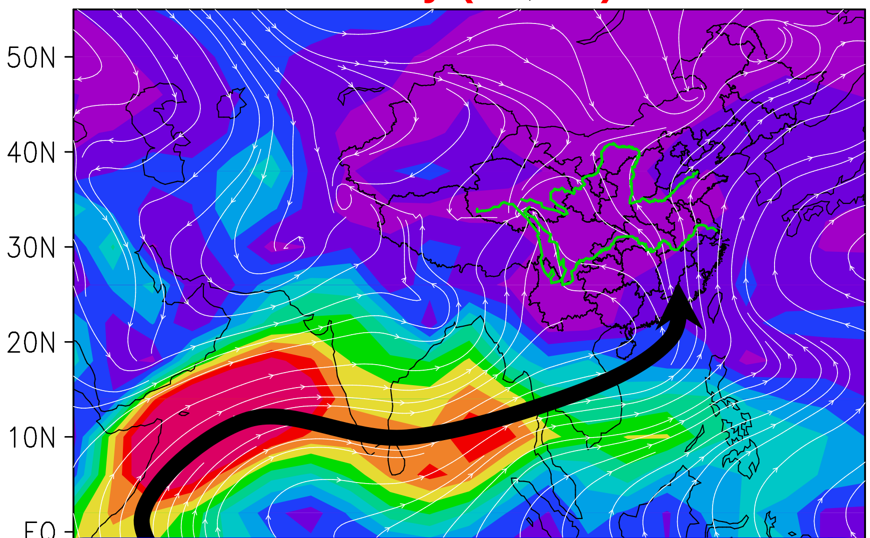


$PM_{2.5}$ with JULY emission

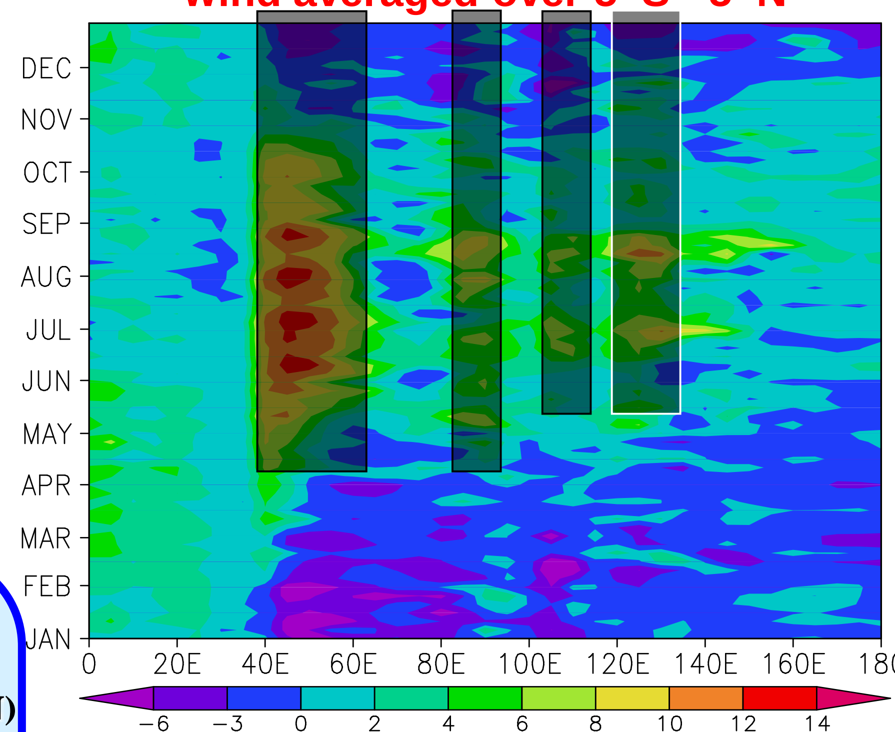


Cross Equatorial Flows That Influence Aerosols in China

JJA stream lines
and wind velocity (colors) at 925 mb

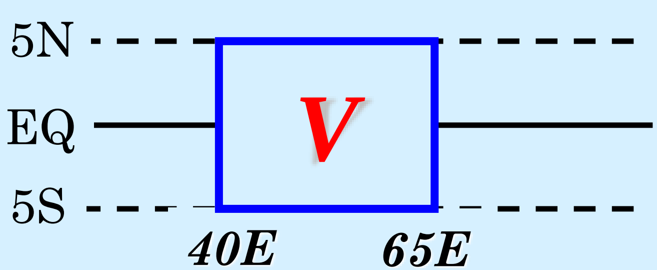


Time-longitude distribution of meridional wind averaged over 5˚S - 5˚N



Cross-equatorial flow index

$I_c = V_{average}$ (over channel width and 5˚S - 5˚N)



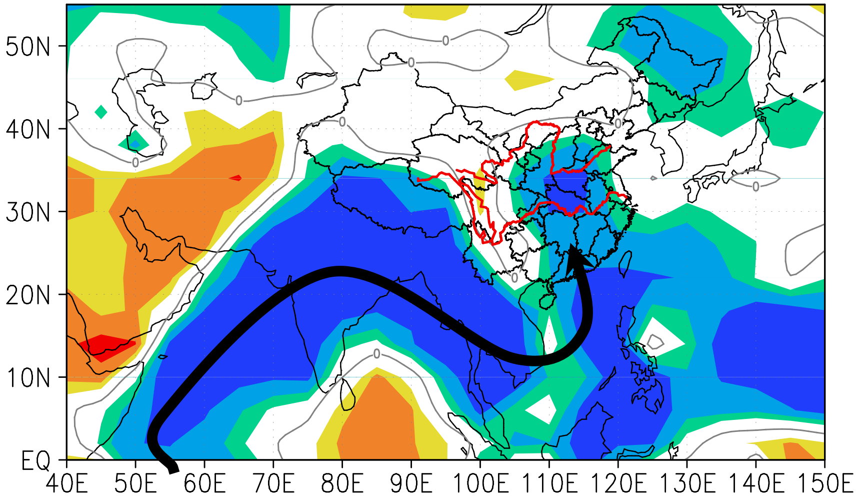
Four channels of strong meridional wind located in the ranges of

40°-65°E 85°-95°E
105°-115°E 120°-135°E

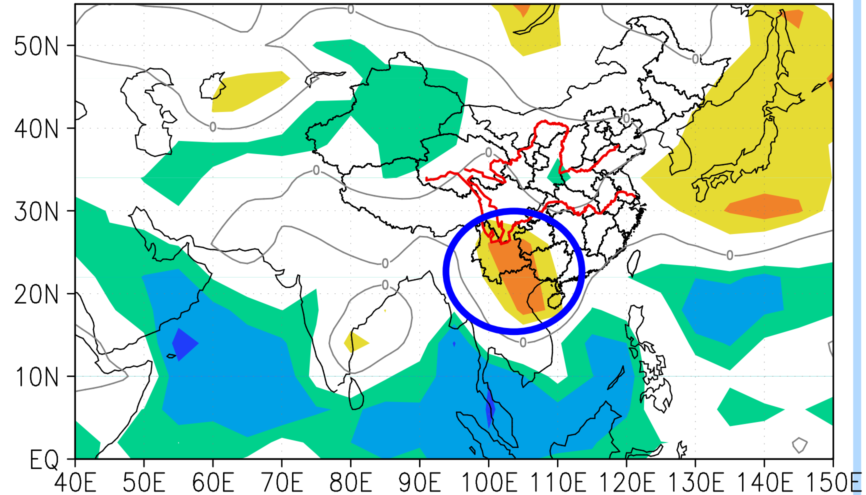
Zhang et al., JGR, 2010

Correlation between *Ic* of Each Channel and $PM_{2.5}$

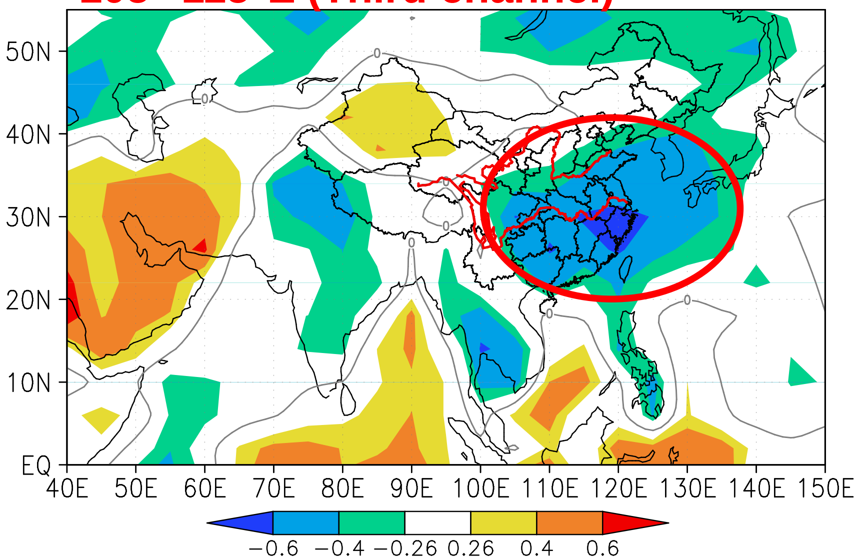
40°-65°E (First channel, Somali jet)



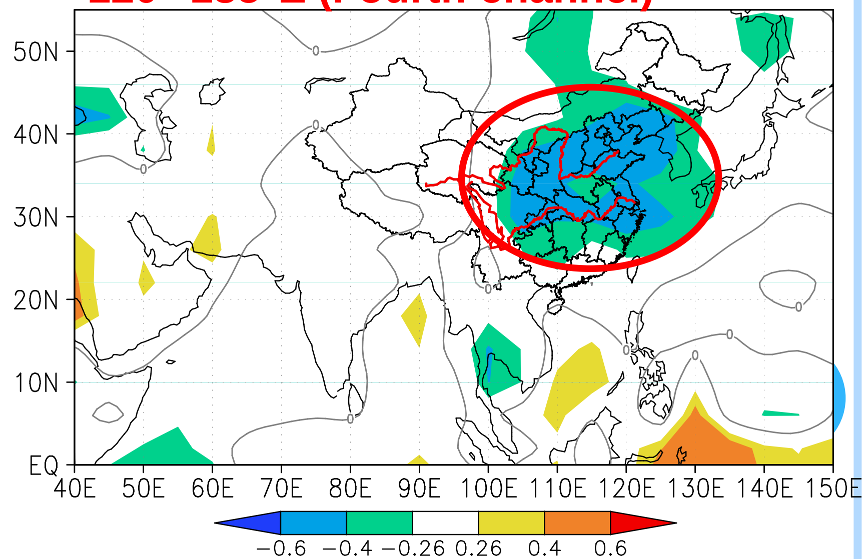
85°-95°E (Second channel)



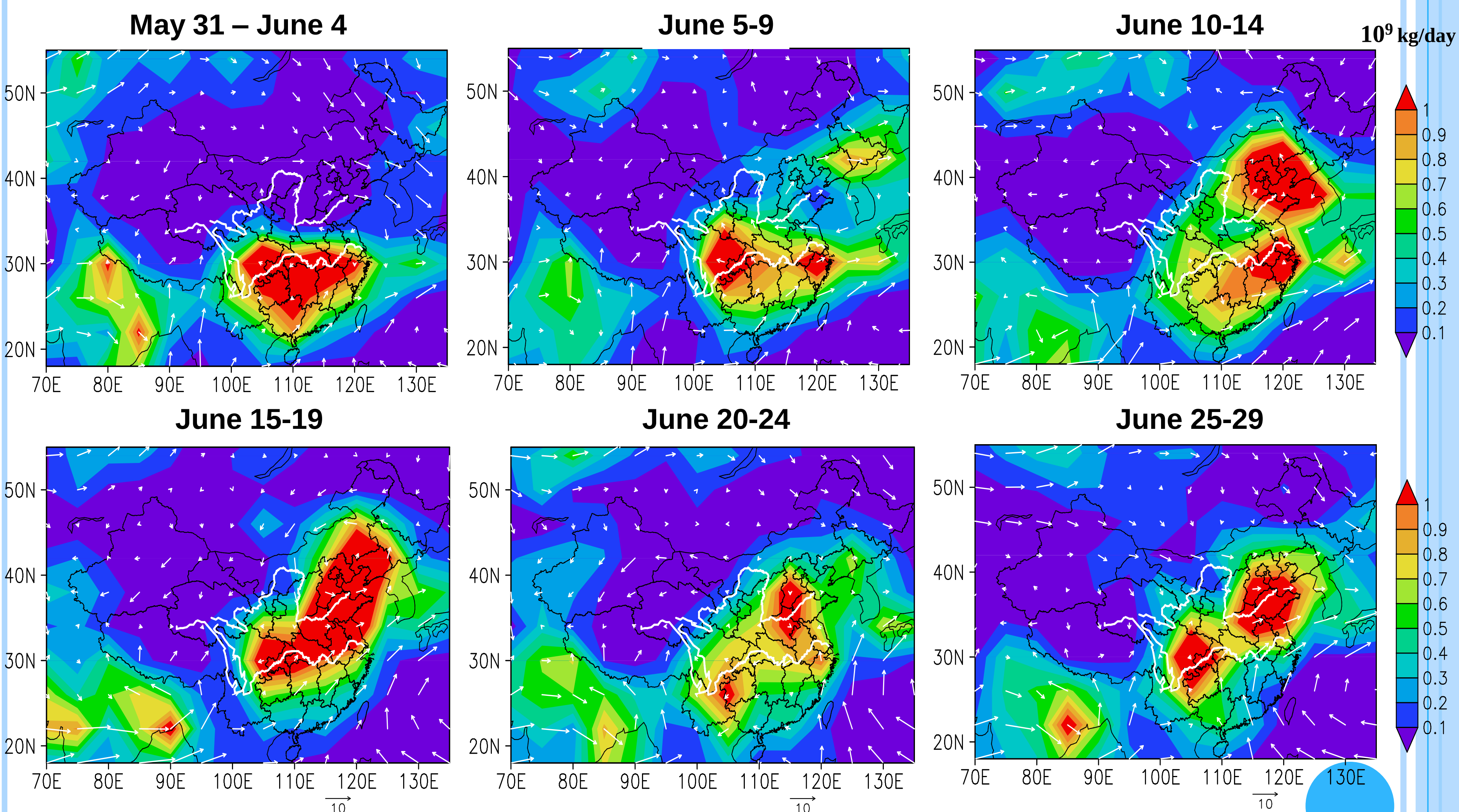
105°-115°E (Third channel)



120°-135°E (Fourth channel)



Wet Deposition of $PM_{2.5}$ Associated with Monsoon



Zhang et al., JGR, 2010

Summary

(1) Impacts of EASM on seasonal variations of aerosols

--- Asian summer monsoon (cross cross-equatorial flows, rainfall, etc.) is predicted to reduce $PM_{2.5}$ concentrations over eastern China by 60-70% as concentrations in July are compared with those in January.

OUTLINE

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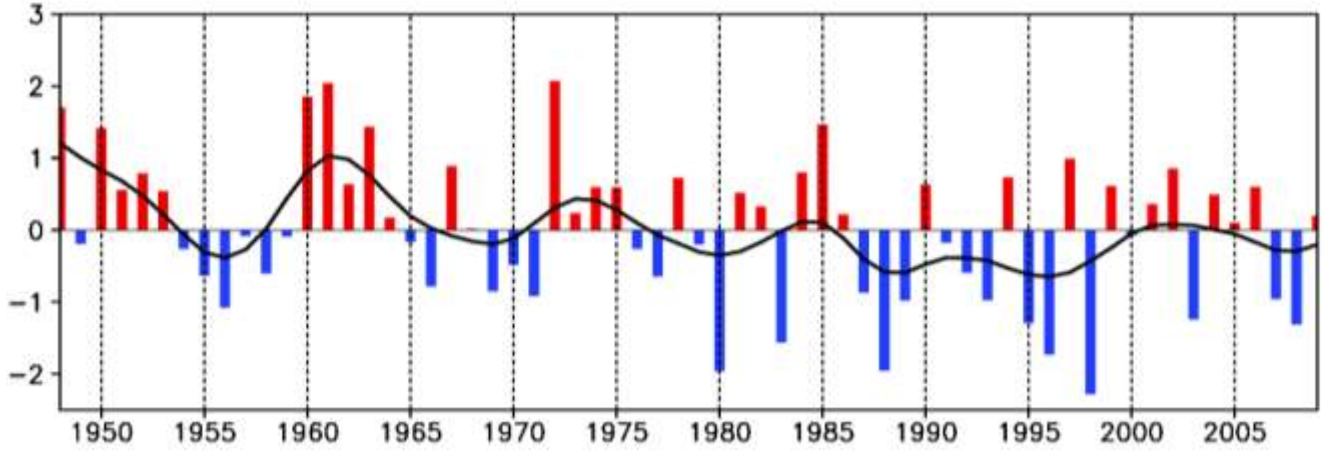
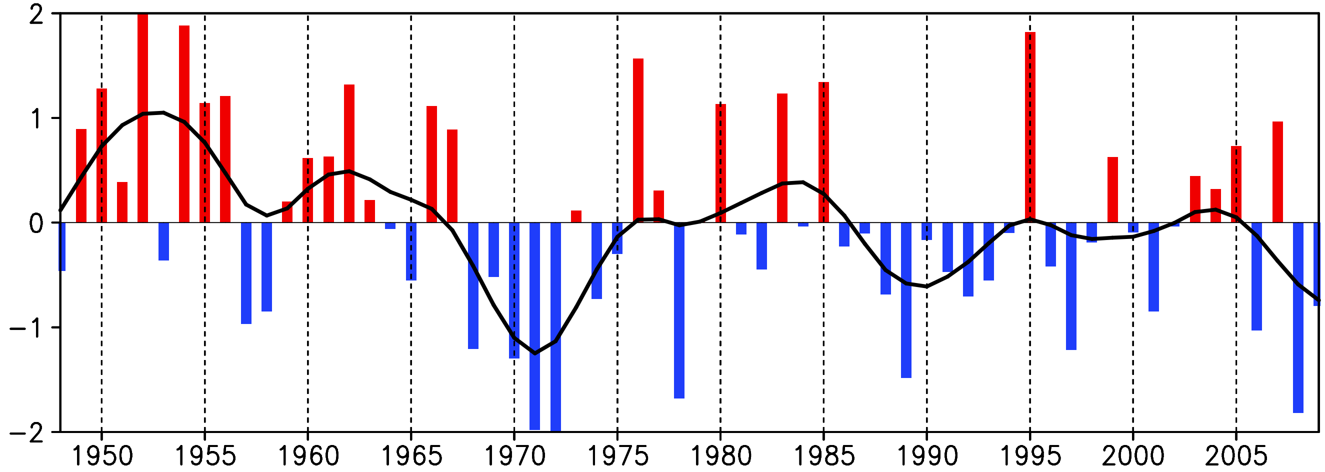
Interannual Variations of the East Asian Monsoon

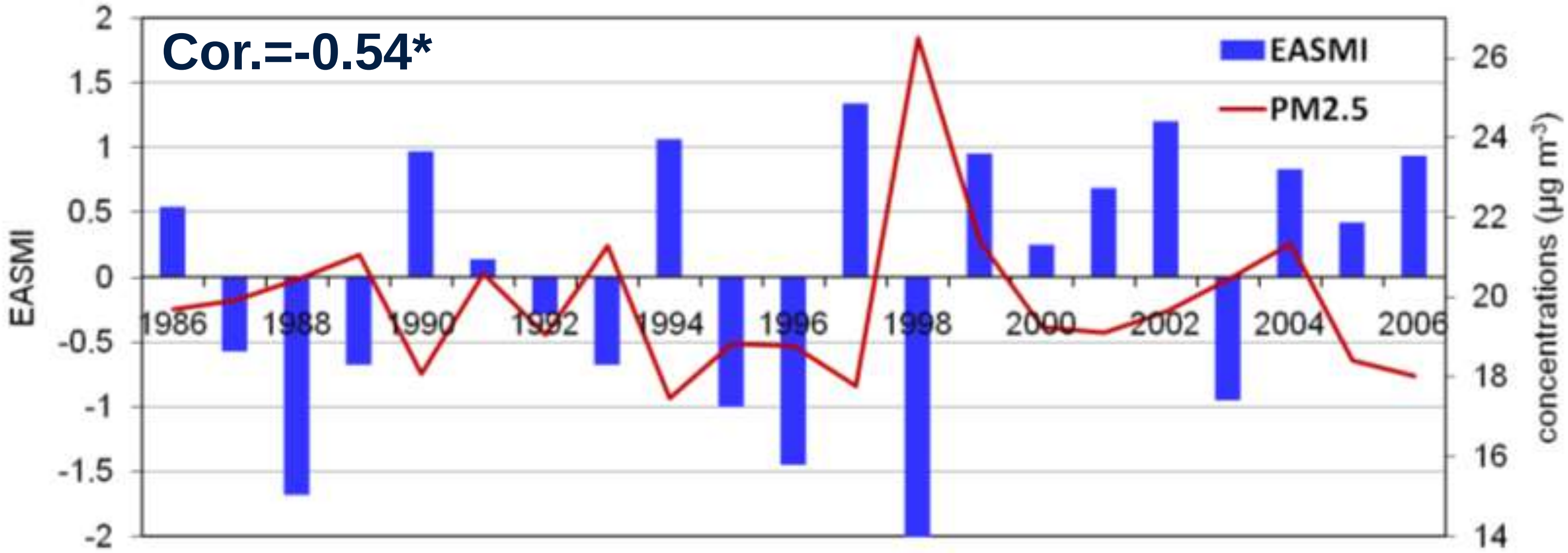
East Asian Summer Monsoon Index（Li and Zeng, 2002, 2003）



East Asian Winter Monsoon Index（Wu and Wang, 2002）



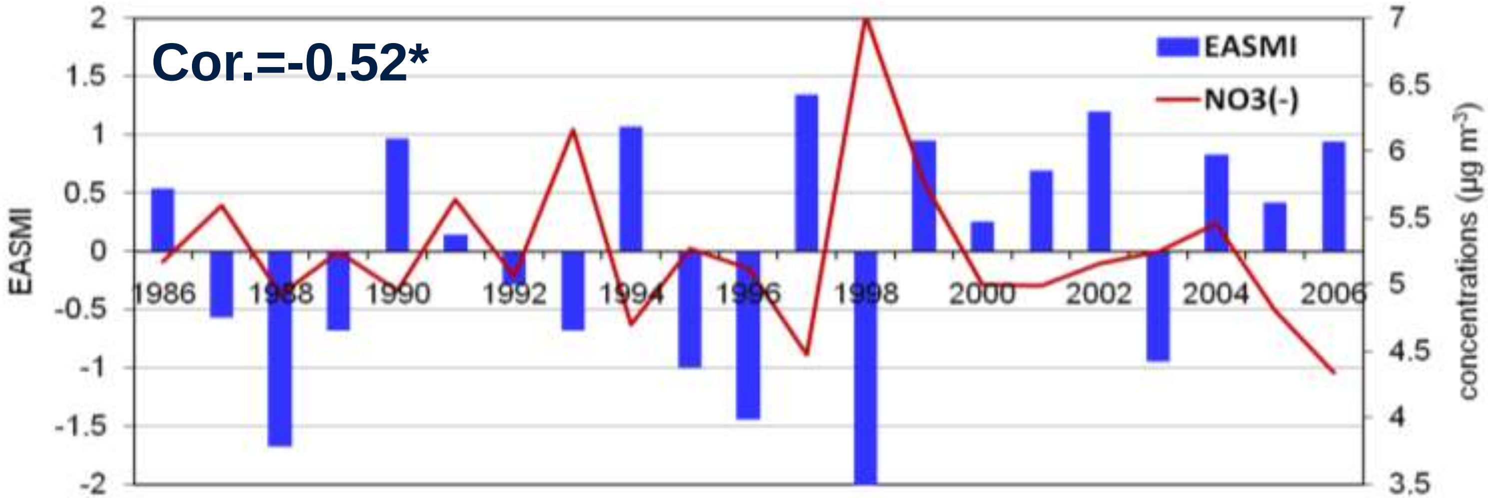
Negative Correlations are Found between JJA Aerosol Concentrations and EASMI

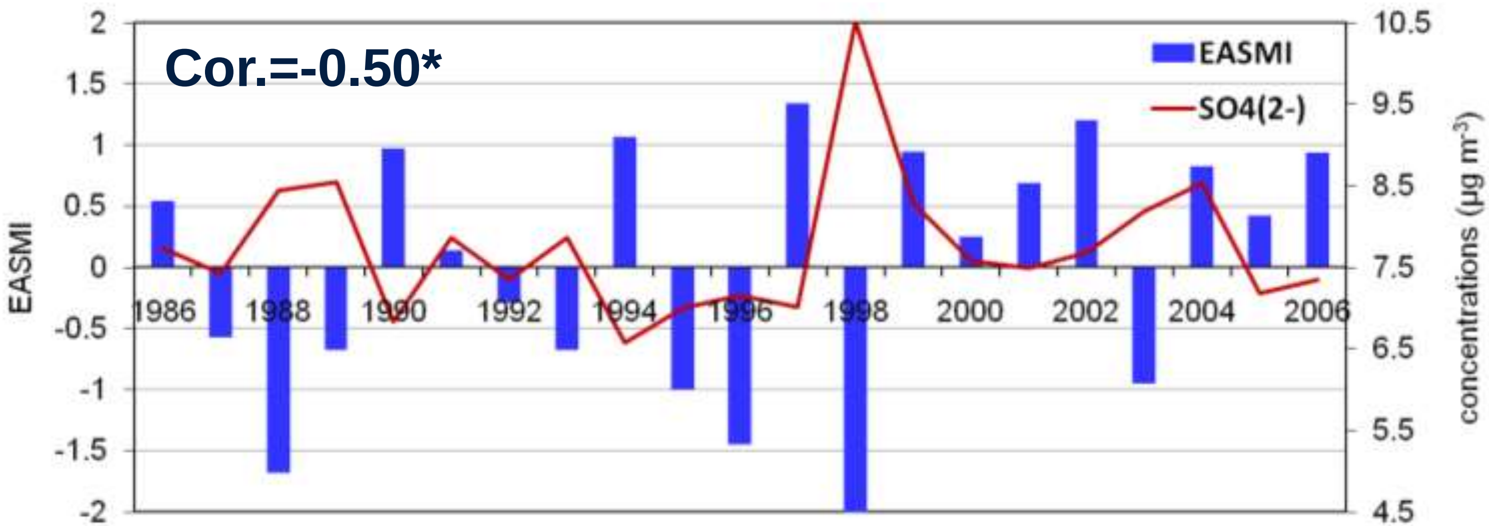


***Significant at the 0.05 level.**
Concentrations averaged over Eastern China (110°-120°E, 20°-45°N)

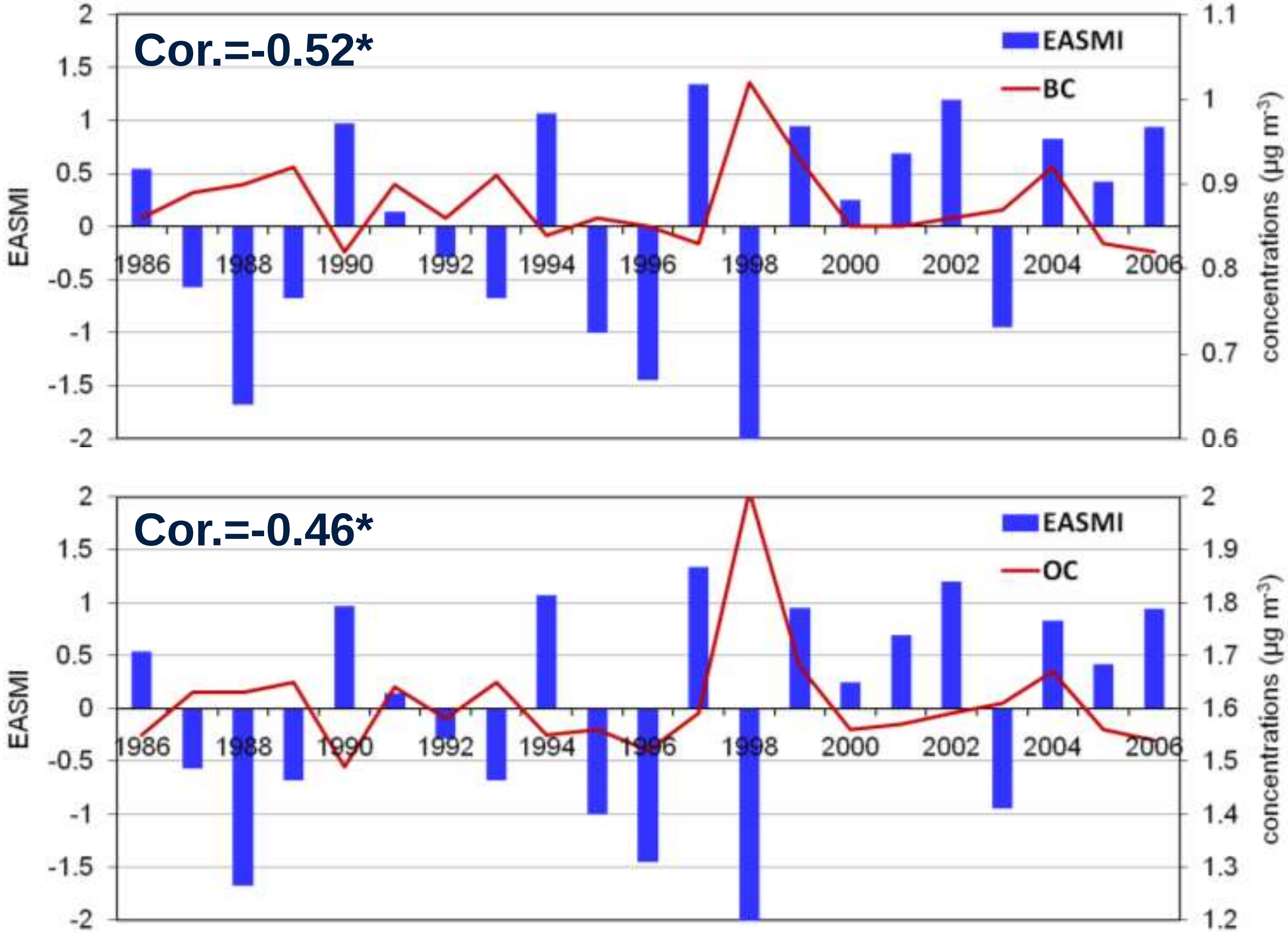
Zhu et al., GRL, 2012

Negative Correlations are Found for All Aerosol Species

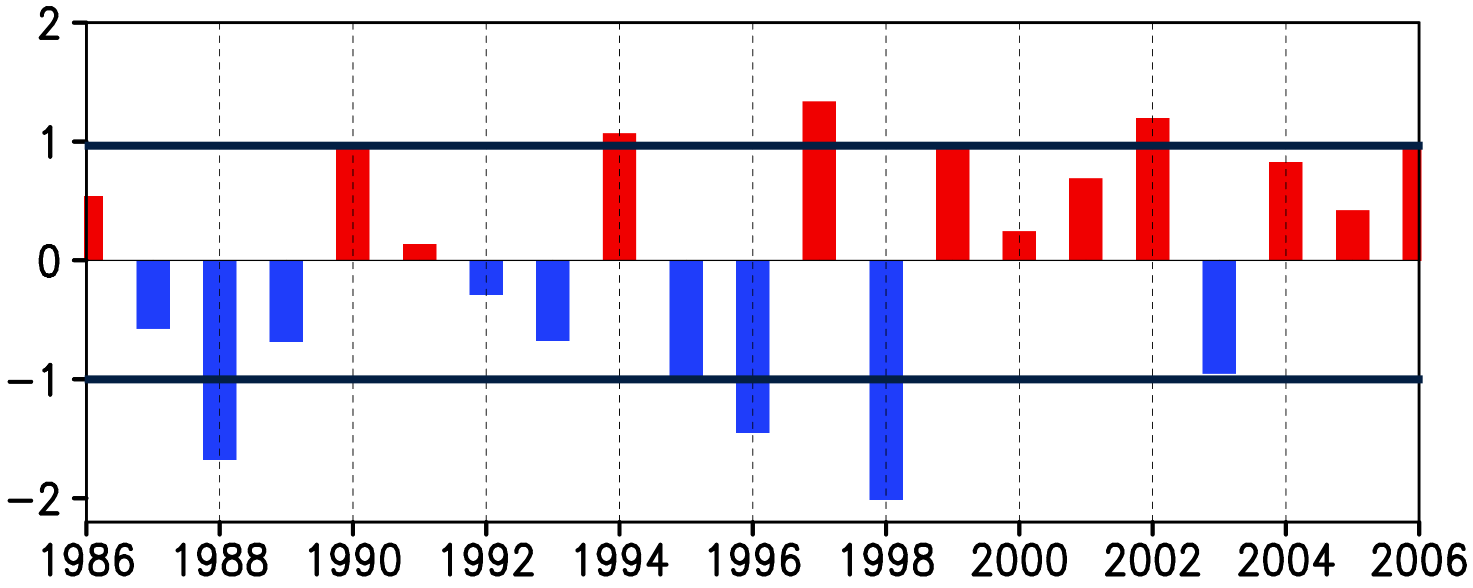




Negative Correlations are Found for All Aerosol Species



Strongest vs. Weakest Monsoon Years



Ten samples:

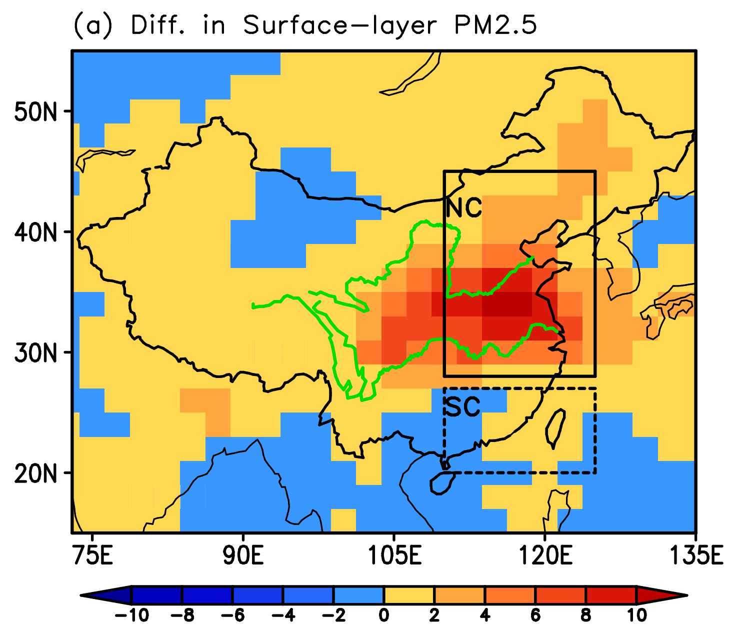
Five strongest monsoon years: 1990, 1994, 1997, 1999, 2002

Five weakest monsoon years : 1988, 1995, 1996, 1998, 2003

East Asian Summer Monsoon Index（Li and Zeng, 2002, 2003）

Differences in JJA surface layer $PM_{2.5}$ concentrations between the weakest and the strongest monsoon years

($[PM2.5]_{weakest}$ - $[PM2.5]_{strongest}$)



In the weakest monsoon years:

- Higher concentrations by about 10 μg m^{-3} over northeastern China;
- Lower concentrations of about 2-4 μg m^{-3} in southeastern China.

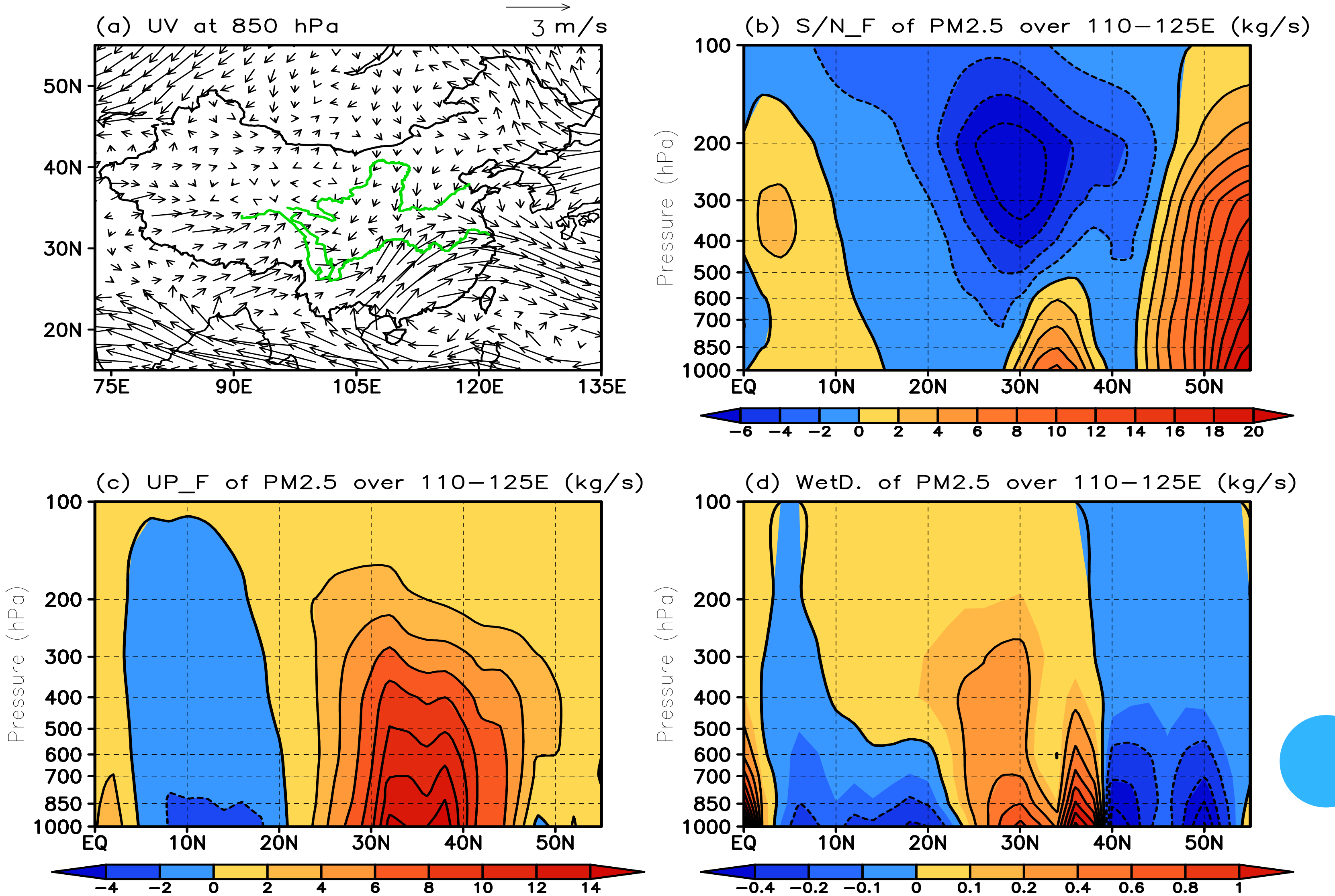
Zhu et al., GRL, 2012

JJA Aerosol Concentrations in the Weakest vs. Strongest Monsoon Years

Northeastern China (110°-120°E,30°-45°N)

Species	Weakest ($\mu g\ m^{-3}$)	Strongest ($\mu g\ m^{-3}$)	Difference ($\mu g\ m^{-3}$)	Percent (%)
SO_4^{2-}	10.93	9.15	1.78	19.44
NO_3^-	7.66	6.64	1.02	15.38
NH_4^+	6.25	5.31	0.94	17.70
BC	1.20	1.10	0.09	8.12
OC	2.06	1.90	0.16	8.58
$PM_{2.5}$	28.12	24.11	4.01	16.62

Differences in JJA Parameters between the Weakest and Strongest EASM Years (weakest - strongest)



Correlation Coefficients between Different EAWMI and $PM_{2.5}$

EAWMI / Corr. / $PM_{2.5}$	Defined by Near-surface Winds		Defined by Sea-level Pressure			
	I_{JLR}	I_{CW}	I_{GDY}	$I_{WBY\text{--}SH}$	$I_{WBY\text{--}EAWM}$	I_{SN}
EChina	-0.75*	-0.76*	-0.50*	-0.53*	-0.61*	-0.46*
NEChina	-0.75*	-0.77*	-0.49*	-0.51*	-0.68*	-0.61*
SNChina	-0.41	-0.41	-0.29	-0.32	-0.21	0.01

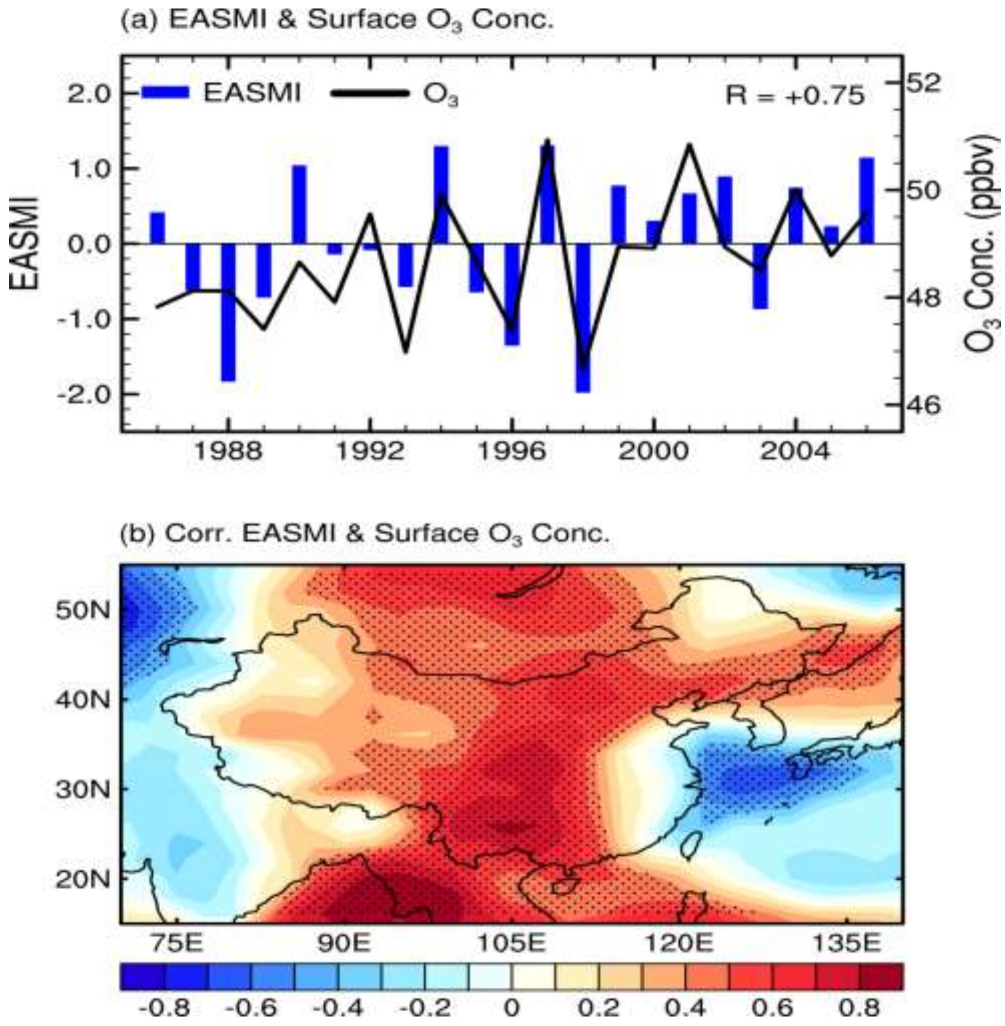
***Significant at the 0.05 level.**

EChina: Eastern China (110°-125°E, 20°-45°N)

NEChina: Northeastern China(110°-125°E, 28°-45°N)

SEChina: Southeastern China (110°-125°E, 20°-27°N)

Positive Correlation is Found between JJA O_3 Concentrations and EASMI

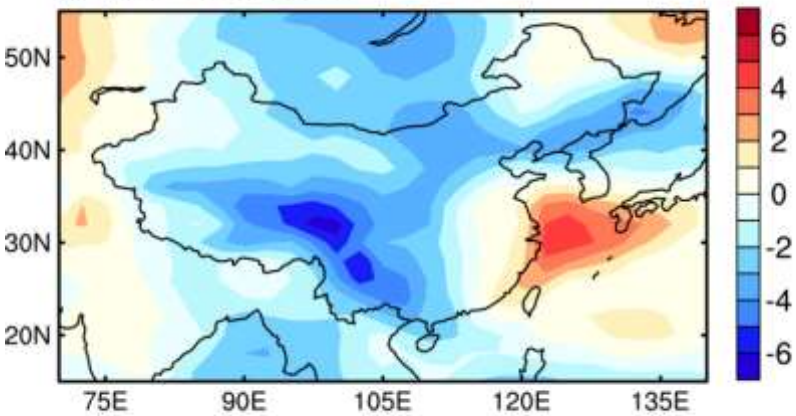


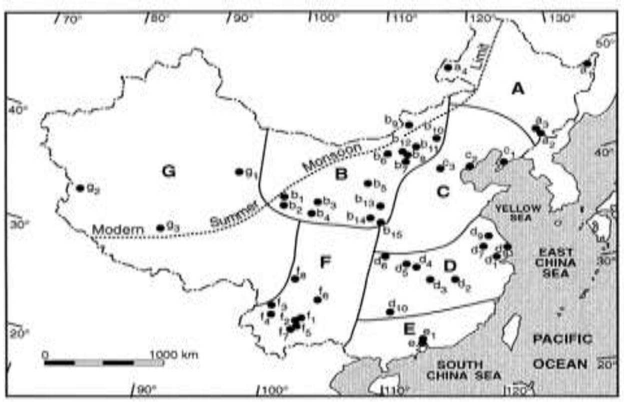
Yang et al., ACP, 2014

Differences in JJA surface layer O_3 concentrations between the weakest and the strongest monsoon years

($[O_3]_{weakest}$ - $[O_3]_{strongest}$)

(a) Diff. in O_3 Conc. (ppbv)

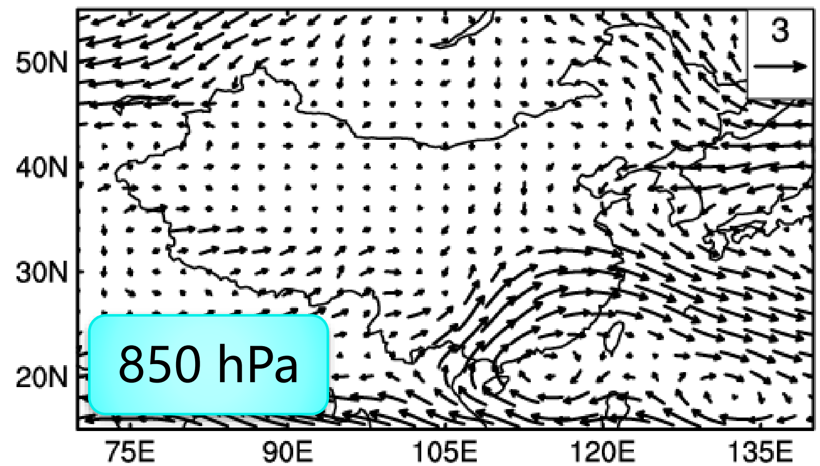




An et al. (2000)

Winds (weakest – strongest)

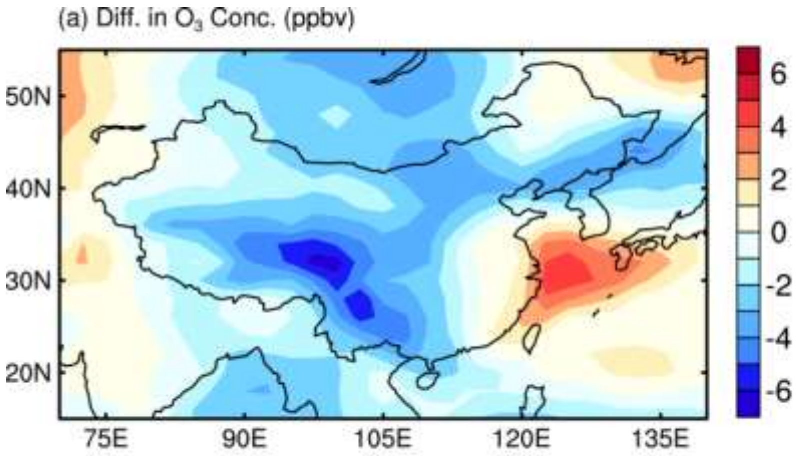
(c) Diff. in UV at 850 hPa ($m\ s^{-1}$)



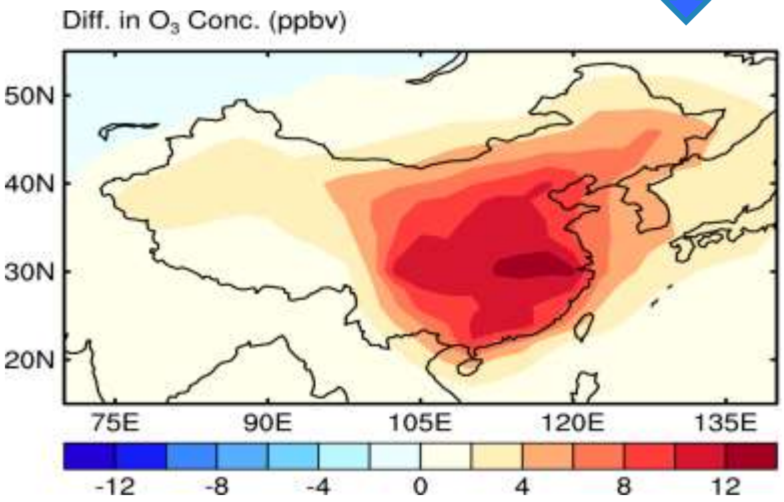
Yang et al., ACP, 2014

Impact of Monsoon vs. That of Anthropogenic Emissions

($[O_3]_{weakest}$ - $[O_3]_{strongest}$)



Changes in simulated JJA surface-layer O_3 concentrations (ppbv) owing to the changes in anthropogenic emissions of O_3 precursors over 1986–2006



Yang et al., ACP, 2014

Summary

(1) Impacts of EASM on seasonal variations of aerosols

--- Asian summer monsoon (cross cross-equatorial flows, rainfall, etc.) is predicted to reduce $PM_{2.5}$ concentrations over eastern China by 60-70% as concentrations in July are compared with those in January.

(2) Impacts of EASM on Interannual variations of aerosols and tropospheric O_3

--- Negative correlation is found between JJA aerosol concentrations in eastern China and EASMI, whereas positive correlation is found between JJA O_3 concentrations in China and EASMI;

--- With anthropogenic emissions fixed at year 2005 levels, aerosol concentration averaged over northeastern China is higher by about 17% and O_3 concentration averaged over whole China is lower by 2.0 ppbv (or 4%), as the concentrations in the weakest monsoon years are compared with those in the strongest monsoon years.

OUTLINE

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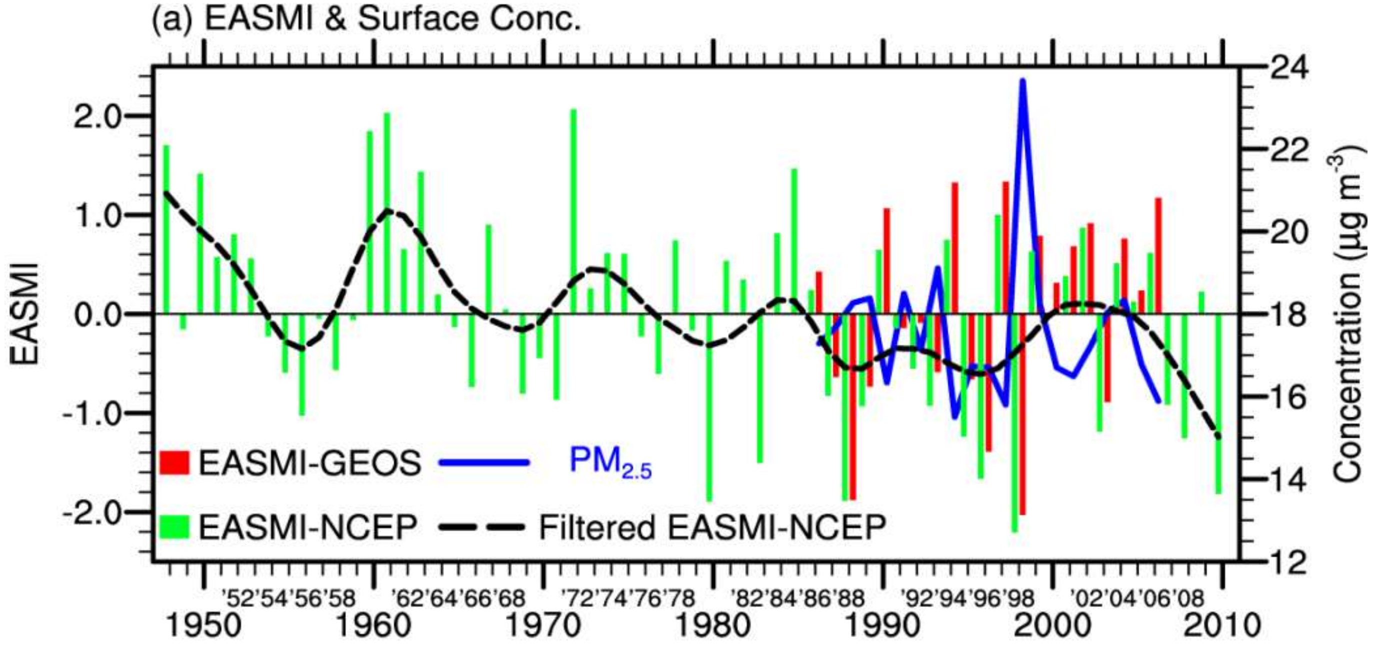
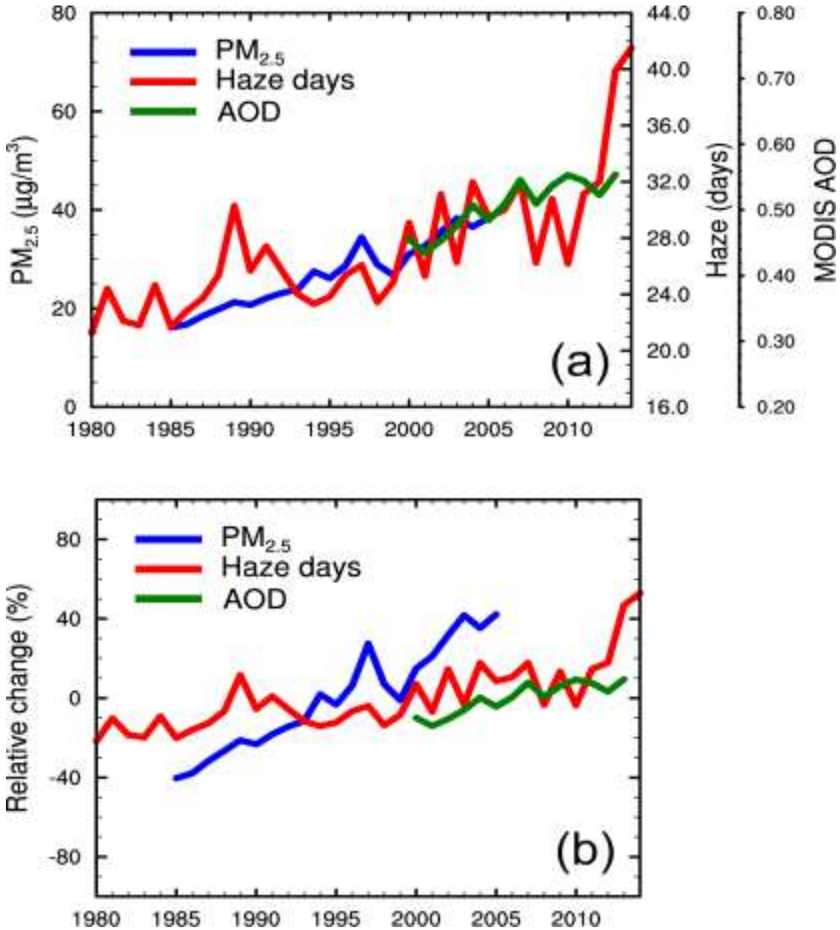
Decadal-scale Weakening of the EASM



Simulated vs. observed decadal trend in eastern China

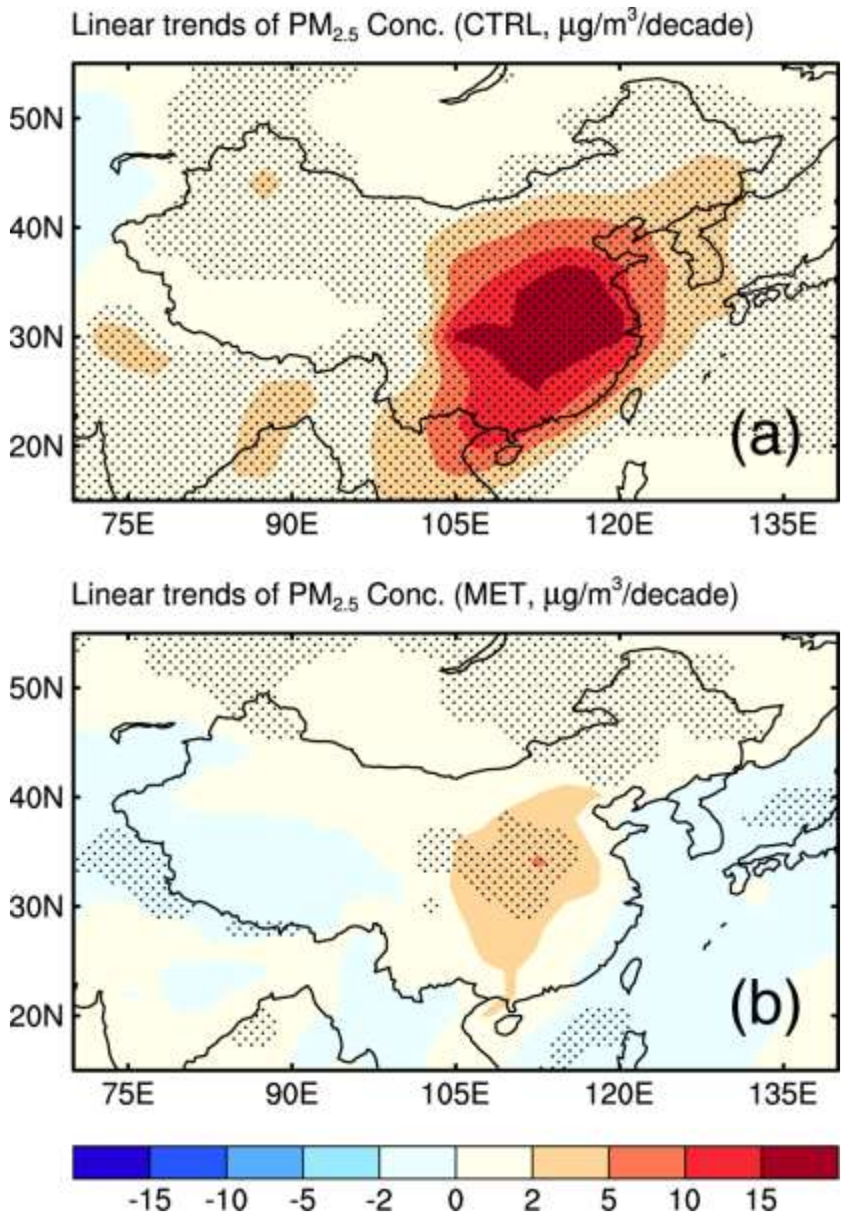


- Simulated $PM_{2.5}$ concentrations increased from 16.1 μg/m^3 in 1986 to 38.4 μg/m^3 in 2006, while observed winter haze days increased from 21.7 days in 1986 to 29.5 days in 2006;
- AOD had an increasing trend, from 0.45 in 2000 to 0.55 in 2013;
- $PM_{2.5}$ concentrations, haze days and AOD increased by 80%, 70% and 20% over years of 1986–2006, 1980–2014, and 2000–2013, respectively.
- Decadal trend were driven by emissions and interannual variations were driven by meteorology.

Linear trends in simulated surface-layer $PM_{2.5}$ for 1986–2006

CTRL

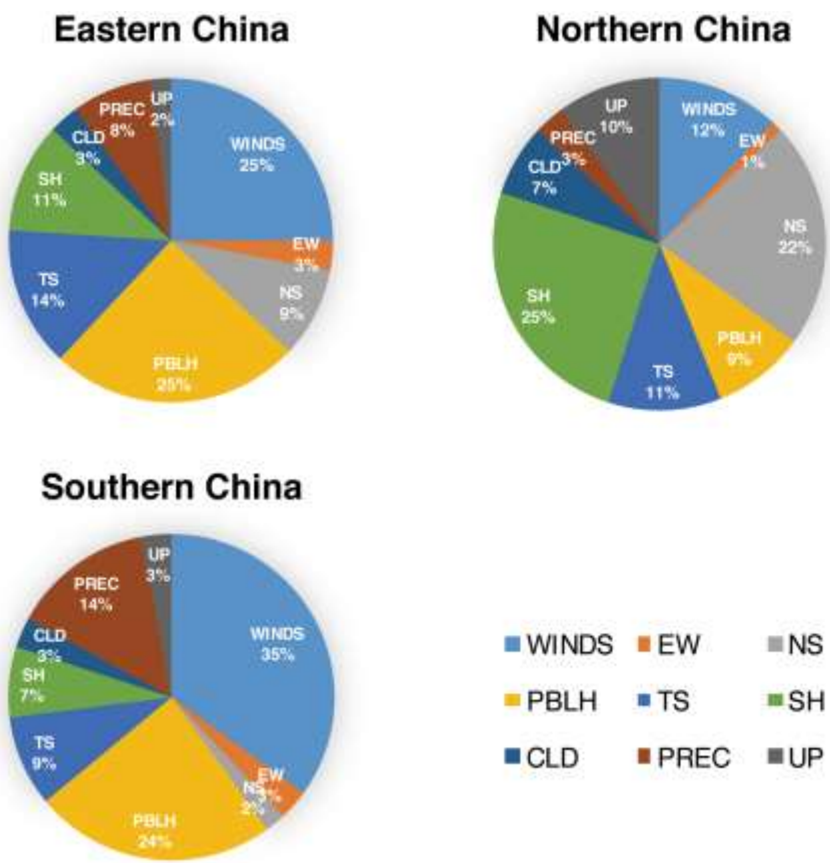
MET



- $PM_{2.5}$ concentrations increased significantly over eastern China, with linear trends of up to 15 μg/m³/decade ;
- Variations in meteorological parameters alone led to increases in wintertime $PM_{2.5}$, which explained 17 (±14) % of the increases in the CTRL simulation.

Yang et al., JGR, 2016

Contribution of each meteorological parameter to the decadal increase in DJF $PM_{2.5}$ concentration



Estimated by using MET simulation and the LMG (Lindeman, Merenda, and Gold) method (Lindeman et al., 1980; Grömping, 2006)

- Horizontal wind (WINDS+EW+NS) was the most dominant factor；
- Planetary boundary layer height was the second important factor；
- Over northern China, 25% of the variance was also driven by variations in specific humidity

Summary

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--- Negative correlation is found between JJA aerosol concentrations in eastern China and EASMI, whereas positive correlation is found between JJA O_3 concentrations in China and EASMI;

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(3) Decadal changes in seasonal variations of aerosols

--- For DJF, $PM_{2.5}$ concentrations, haze days and AOD in eastern China increased by 80%, 70% and 20% over years of 1986–2006, 1980–2014, and 2000–2013, respectively. Variations in meteorological parameters alone led to increases in wintertime $PM_{2.5}$, which explained 17 ($\pm$14) % of the increases in $PM_{2.5}$ concentrations in eastern China.