Chinese Academy of Meteorological Sciences, Beijing, China

Changes in Anthropogenic $PM_{2.5}$ and Resulting Global Climate Effects During 1850–2010

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AeroCom19, Barcelona, Spain, June 8-17, 2019

Content

- Ⅰ Background
- Ⅱ Experimental Design
- Ⅲ Results & Discussions
- Ⅳ Conclusions

Background

Beijing, China

PM$_{2.}$ distribution in China

Dec. 15, 2015

Background

● Environment

Reducing regional visibility.

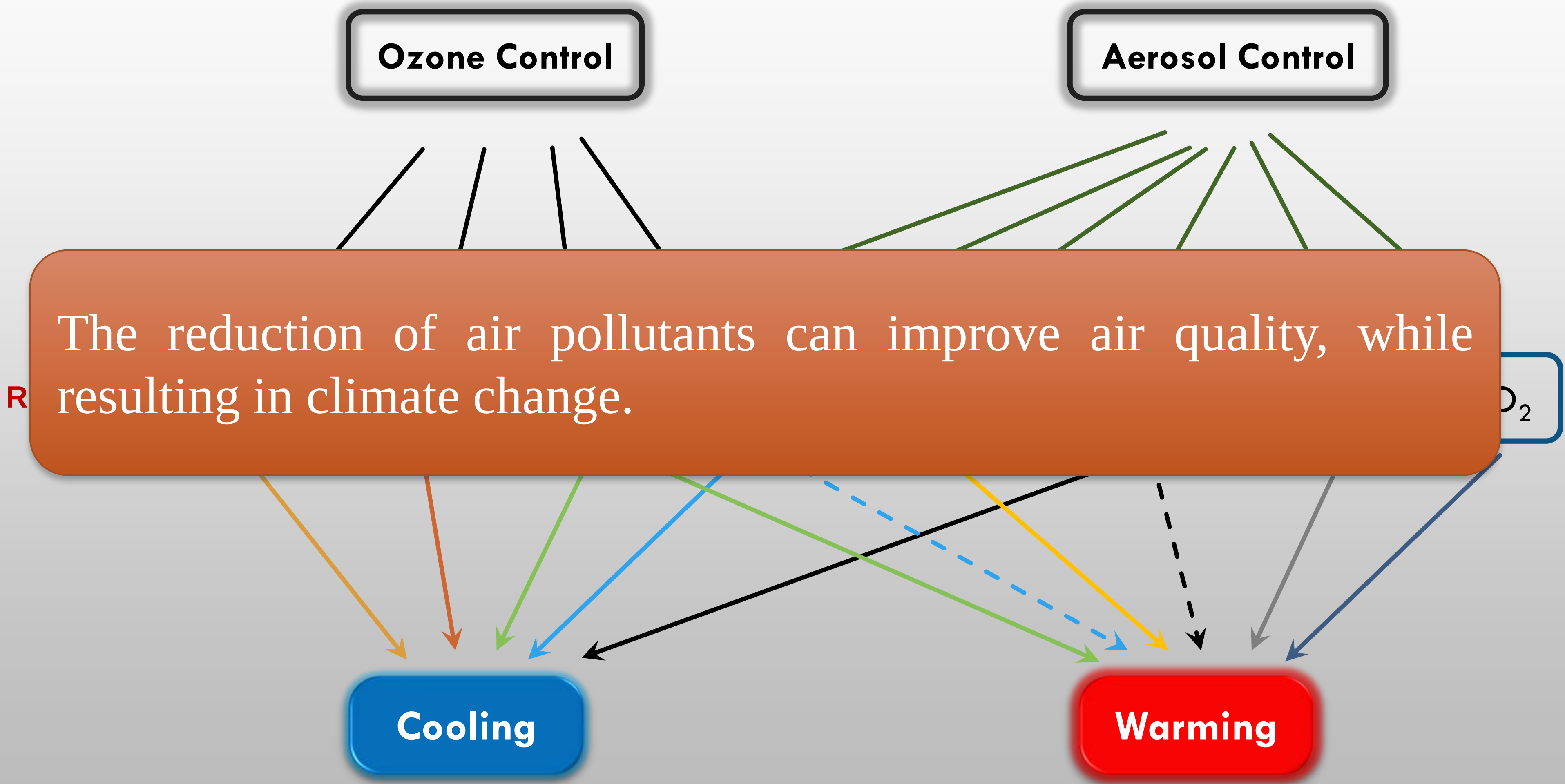
● Health

- Increasing mortality of patients with severe and chronic diseases;
- Aggravating respiratory and cardiac diseases;
- Increasing the incidence of cancer.

● Climate

- Direct effect: absorption and scattering of solar radiation;
- Indirect effect: change the microphysical and radiative properties of clouds as water or ice cloud nuclei;
- Semi-direct effect: by BC.

Effect of Reduction air pollutants



The reduction of air pollutants can improve air quality, while resulting in climate change.

Climatic Impacts of Reduction in Pollutant Emission

IPCC AR5

Research Progress

1 Fu et al., 2016. Impacts of historical climate and land cover changes on fine particulate matter (PM2.5) air quality in East Asia between 1980 and 2010. Atmospheric Chemistry & Physics.

2 Wang et al., 2013. Radiative forcing and climate response due to the presence of black carbon in cloud droplets. Journal of Geophysical Research Atmospheres. 118: 3662-3675.

- **How PM$_{2.5}$ affect climate change?**
- **What is the different impact played by PM$_{2.5}$ and non-PM$_{2.5}$ (NPM)? They has not been paid attention so far.**

Here NPM refers the particles with the radius larger than 2.5 micrometers.

7 Zhao et al., 2017. Simulating the Effects of Anthropogenic Aerosols on Terrestrial Aridity Using an Aerosol-Climate Coupled Model.

Research Contents

- Investigate the temporal and spatial distribution of changes in anthropogenic $PM_{2.5}$ and NPM from 1850 to 2010;

- Explore the effective radiative forcing due to the changes of $PM_{2.5}$, NPM, and contribution from three types of aerosols concentrations (sulfate, black carbon, and organic carbon);

- Study the different impacts of fine ($PM_{2.5}$) and coarse (NPM) particles on global climate.

Ⅱ Experimental design

Model Introduction

2.1

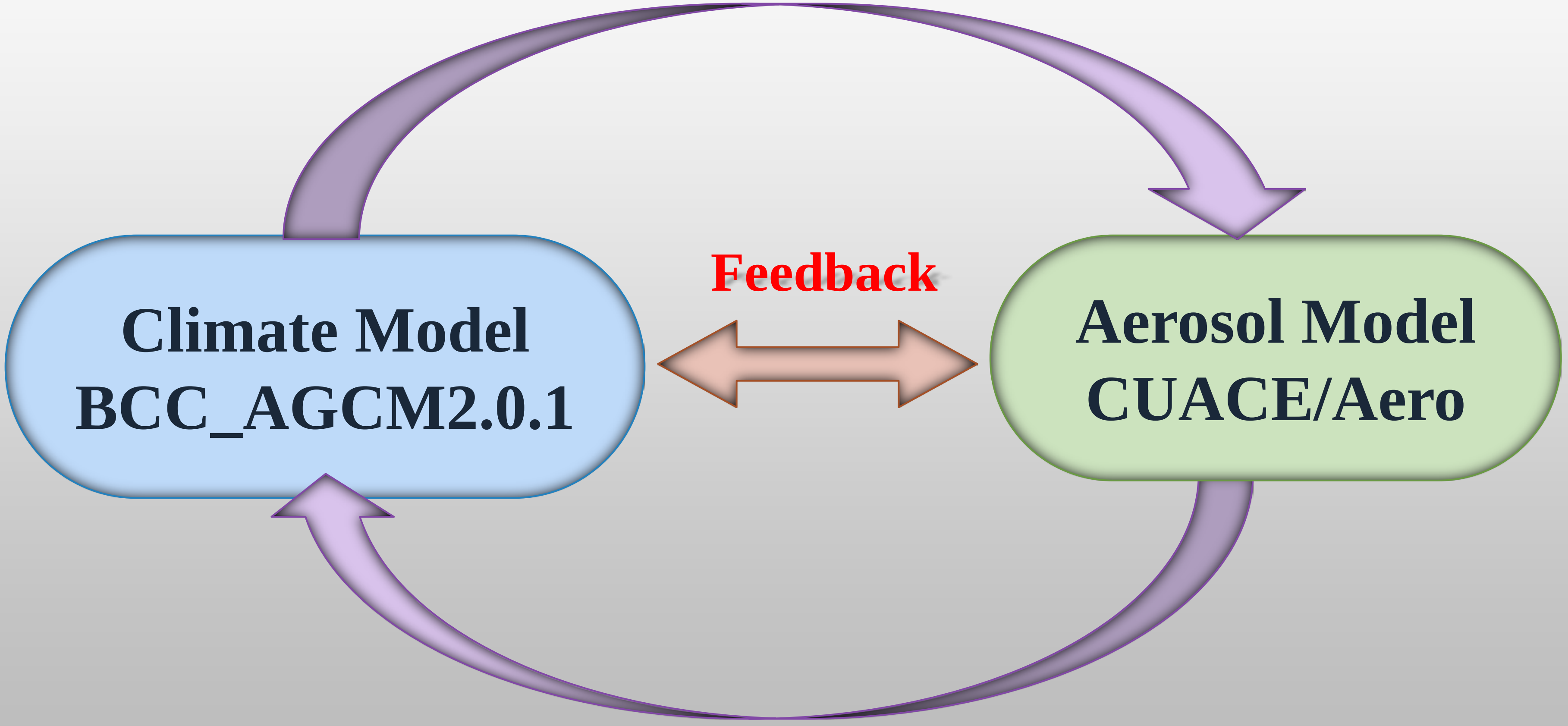
Aerosol Emission

2.2

Experimental Design

2.3

2.1 Model Introduction



Meteorological Conditions forcing
(Temperature, pressure, humidity, wind)

Climate Model
BCC_AGCM2.0.1

Feedback

Aerosol Model
CUACE/Aero

Aerosol column concentration
(sulfate, black carbon, organic carbon, dust, sea salt)

2.1 Model Introduction

Climate Model

BCC_AGCM2.0.1

Beijing Climate Center Atmospheric General Circulation Model 2.0

developed by the China Meteorological Administration

- **Dynamical Framework: Eulerian dynamical core.**
- **Horizontal Resolution: T42(~2.8°×2.8°)**
- **Vertical direction:26-layer hybrid sigma-pressure coordinate, top pressure ~2.9 hPa.**
- **Radiation Scheme: BCC_RAD (Zhang et al., 2016)**
- **Cloud Vertical Overlap Scheme : McICA (Zhang et al., 2014)**

2.1 Model Introduction

China Meteorological Administration Unified Atmospheric Chemistry Environment for Aerosols

Aerosol Model
CUACE/Aero

developed by the Chinese Academy of Meteorological Sciences.

- Five types of aerosols:
  Sulfate(**SF**), black carbon(**BC**), organic carbon(**OC**), dust(**SD**), sea salt(**SS**)

- Particles of each aerosol type are classified into **12 bins** with radii between **0.005 and 20.48 μm**.

1√	**2**√	**3**√	**4**√	**5**√	**6**√	**7**√	**8**√	**9**	**10**	**11**	**12**
0.005 ~0.01	0.01~ 0.02	0.02~ 0.04	0.04~ 0.08	0.08~ 0.16	0.16~ 0.32	0.32~ 0.64	0.64~ 1.28	1.28~ 2.56	2.56~ 5.12	5.12~ 10.24	10.24~ 20.28

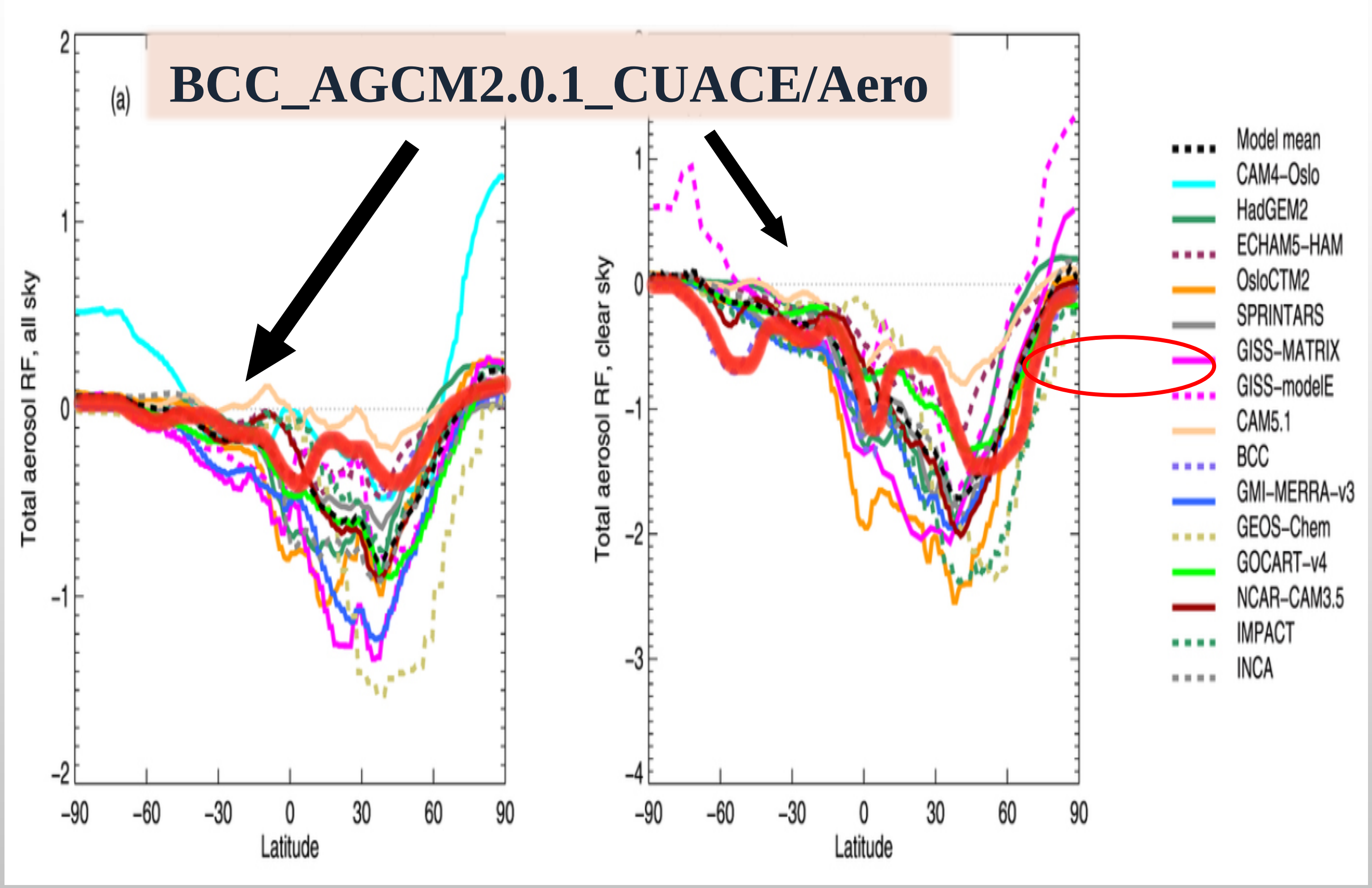
$PM_{2.5}$:1~8 bins
SF($PM_{2.5}$) BC($PM_{2.5}$) OC($PM_{2.5}$)

TPM:1~12 bins

NPM: 9~12 bins
SF(NPM) BC(NPM) OC(NPM)

- Transport, chemical transformation, cloud interaction, and aerosol removal processes are also included in the model.

2.1 Model Introduction



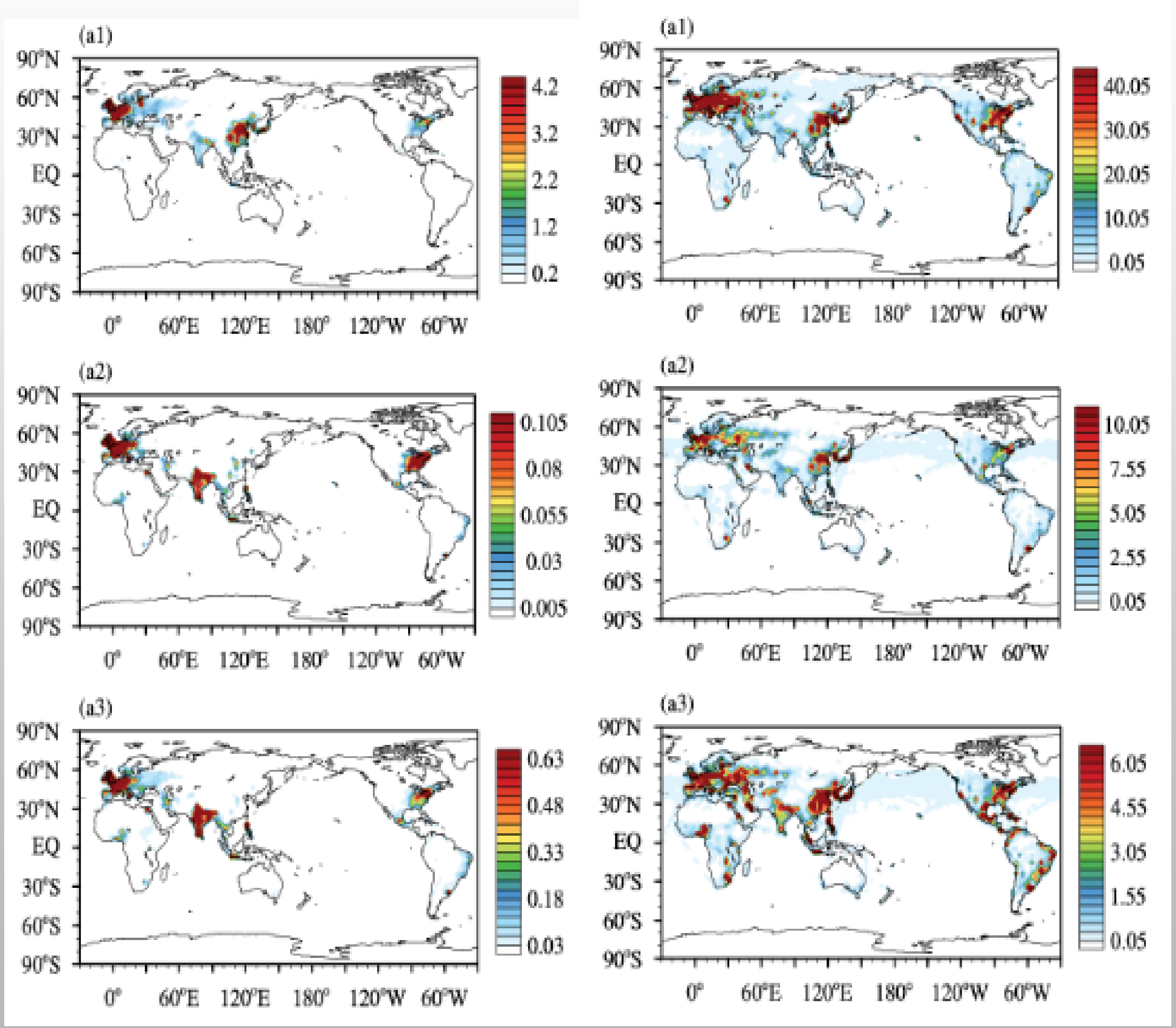
BCC_AGCM2.0.1_CUACE/Aero

The zonal mean direct radiation of simulated anthropogenic aerosols by AeroCom Phase II(W m^{-2})
(Myhre et al., *Atmos. Chem. Phys.*, 2013)

The simulated radiative forcing by our model is as above

2.2 Aerosol Emission

Anthropogenic aerosol particle emissions and their precursors were obtained from the Community Emissions Database System (CEDS; Hoesly et al., 2017).



2.3 Experimental Design

Exp. 1: Effective Radiative Forcing

Group	Test name	Time node	Emission data	Sea Temperature	Running Years
1	ERF_SF	2010	BC, OC of 1850 SF of 2010	Prescribed SST and SI	25
	ERF_BC	2010	SF, OC of 1850 BC of 2010	Prescribed SST and SI	25
	ERF_OC	2010	SF, BC of 1850 OC of 2010	Prescribed SST and SI	25
2	ERF_PM$_{2.5}$_1; ERF_TPM_1	1850	SF, BC, and OC of 1850	Prescribed SST and SI	25
	ERF_PM$_{2.5}$_2; ERF_TPM_2	2010	SF, BC, and OC of 2010	Prescribed SST and SI	25

- Group 1 was used to diagnose ERF caused by SF, BC, and OC. Group 2 was used to calculate ERF, caused by PM2.5, NPM, and TPM, respectively.
- Each test was run for 25 years with prescribed climatological monthly mean SST and sea ice data, and the results of the last 15 years were used for analysis

2.3 Experimental Design

Experiment. 2
climate impacts

Group	Test name	Time node	Emission data	Sea Temperature	Running Years
3	CLI_PM$_{2.5}$_1; CLI_TPM_1	1850	SF, BC, and OC of 1850	Coupled SOM	80
	CLI_PM$_{2.5}$_2; CLI_TPM_2	2010	SF, BC, and OC of 2010	Coupled SOM	80

- Group 3 was used to calculate the responses of climate variables to changes in PM2.5 and TPM.
- Each test was run for 80 years, coupling the model with a slab ocean model (Hansen et al., 1984) to calculate the responses of climate variables to changes in aerosols and PM2.5; the results for the last 40 years were used for analysis.

Ⅰ Research background

Ⅱ Experimental design

Ⅲ Results & Discussions

Ⅳ Conclusions

Ⅲ Results & Discussions

Change In $PM_{2.5}$

3.1

Radiative Effect

3.2

Climate Effect

3.3

3.1 Temporal and Spatial Changes in $PM_{2.5}$ and NPM

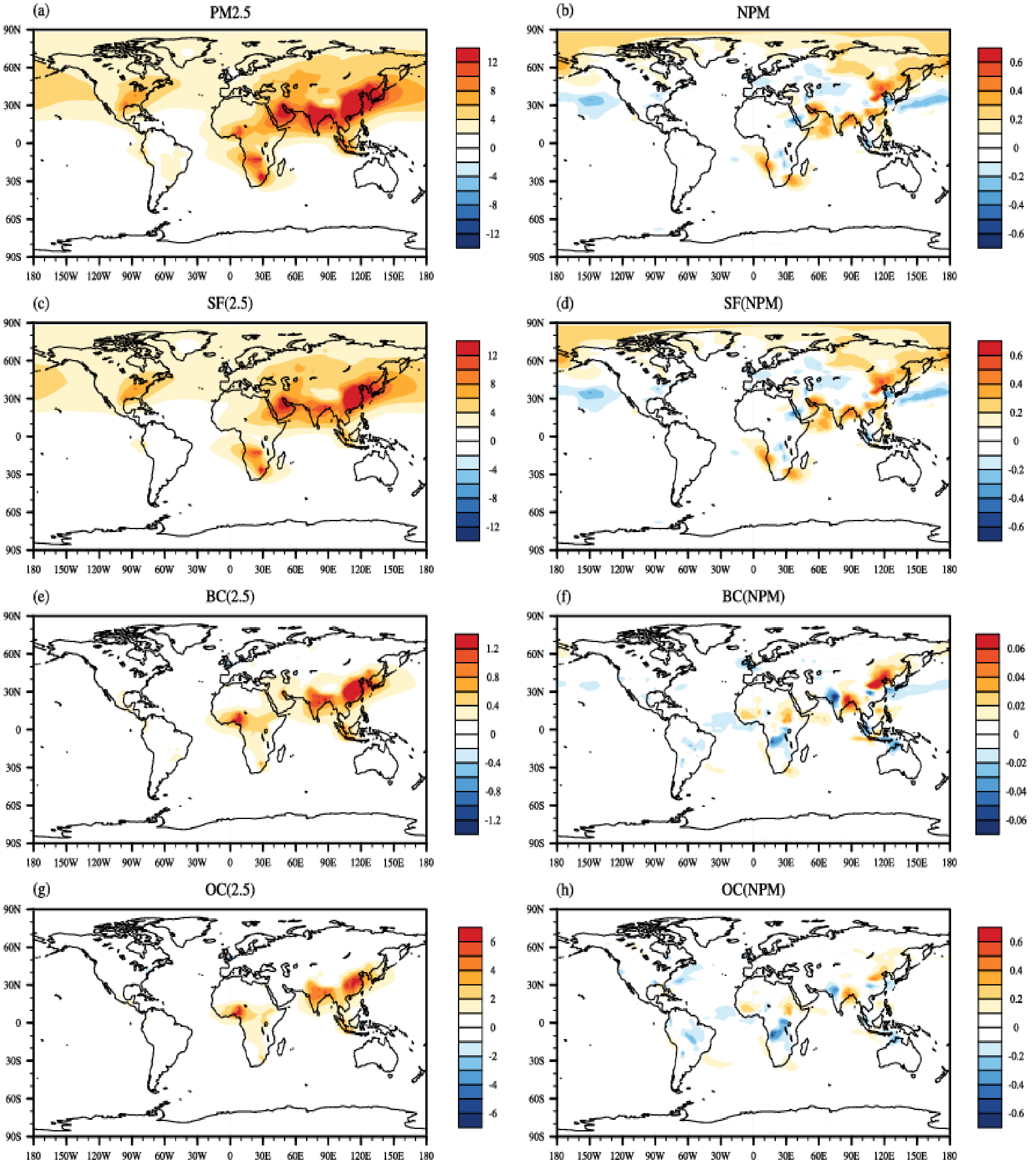
- The column burden of anthropogenic $PM_{2.5}$ has increased globally from 1850 to 2010

- Especially over South Africa and southern and eastern parts of Asia.

- Geographical distribution of changes in NPM were different from that of $PM_{2.5}$.

left： $PM_{2.5}$

right： NPM



Seasonal Change in SF($PM_{2.5}$), BC($PM_{2.5}$), and OC($PM_{2.5}$)

Table 2

Changes in three types of the fine $PM_{2.5}$ (SF, BC, and OC) over different regions from 1850 to 2010 (column concentrations, unit: mg m^{-2}). The percentages in brackets represent for the contribution of SF/BC/OC to the total $PM_{2.5}$.

Change(1850-2010)	DJF (winter)			JJA(summer)		
Regions	SF	BC	OC	SF	BC	OC
South Africa	5.1(80%)	0.3(4%)	1.0(16%)	6.0(83%)	0.2(3%)	1.0(14%)
Central Africa	2.1(45%)	0.5(12%)	2.0(43%)	4.2(57%)	0.6(8%)	2.6(35%)
North America	3.2(89%)	0.1(3%)	-0.3(8%)	9.0(94%)	0.2(2%)	0.3(4%)
West Europe	4.4(92%)	0.1(2%)	-0.3(6%)	8.2(94%)	0.2(2%)	0.3(4%)
Indian Peninsula	5.5(63%)	0.7(7%)	2.6(30%)	9.8(71%)	0.8(6%)	3.1(23%)
Arabian Peninsula	4.1(85%)	0.3(5%)	0.5(10%)	15.3(93%)	0.4(3%)	0.8(4%)
Southeast Asia	4.7(69%)	0.5(7%)	1.6(24%)	4.7(67%)	0.4(7%)	1.8(26%)
East Asia	12.0 (69%)	1.3(7%)	4.2(24%)	17.6(78%)	1.2(5%)	3.7(17%)
Global mean	1.7(80%)	0.1(5%)	0.3(15%)	2.8(85%)	0.1(4%)	0.4(11%)

SF/BC

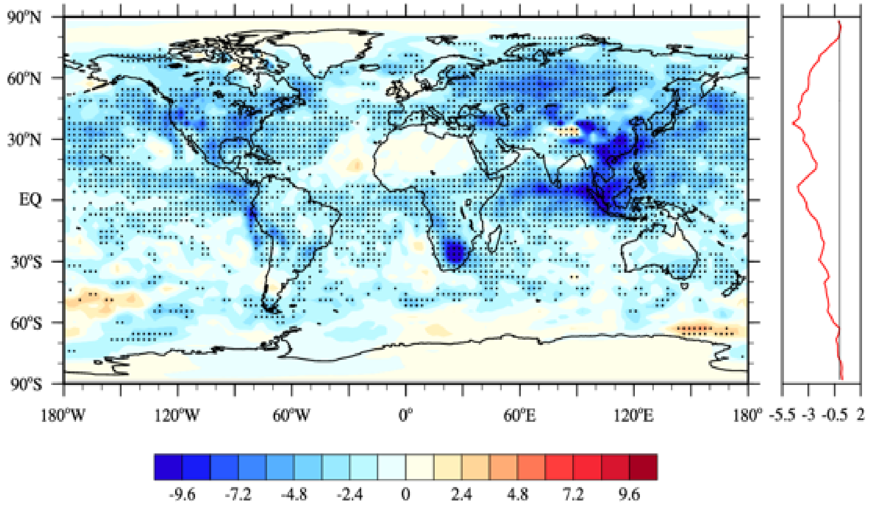
SF

SF/BC

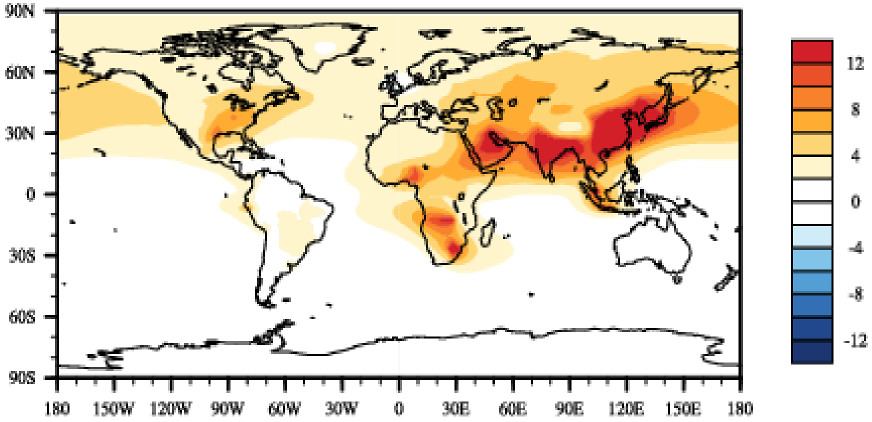
3.2 Effective Radiative Forcing due to $PM_{2.5}$ and NPM

Effect Radiative Forcing due to PM2.5

- **Global mean: -2.34 W m^{-2}**
- **The ERF due to PM$_{2.5}$ are found negative over the globe, mostly due to increasing in scattering particles;**
- **Main regions： East Asia, Southeast Asia and their nearby oceanic regions;**



ERF_PM$_{2.5}$



Changes in PM$_{2.5}$ burden

Effect Radiative Forcing due to NPM

- **Global mean: 0.01 W m^{-2}**

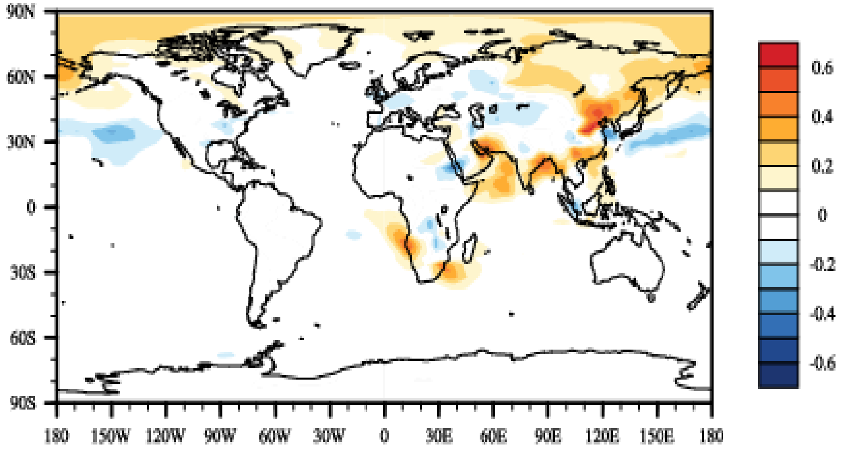
Positive ERFs:

- **North Asia, mainly due to the decreases in the local low cloud;**
- **North India, due to increases in the absorbing coarse BC particles;**

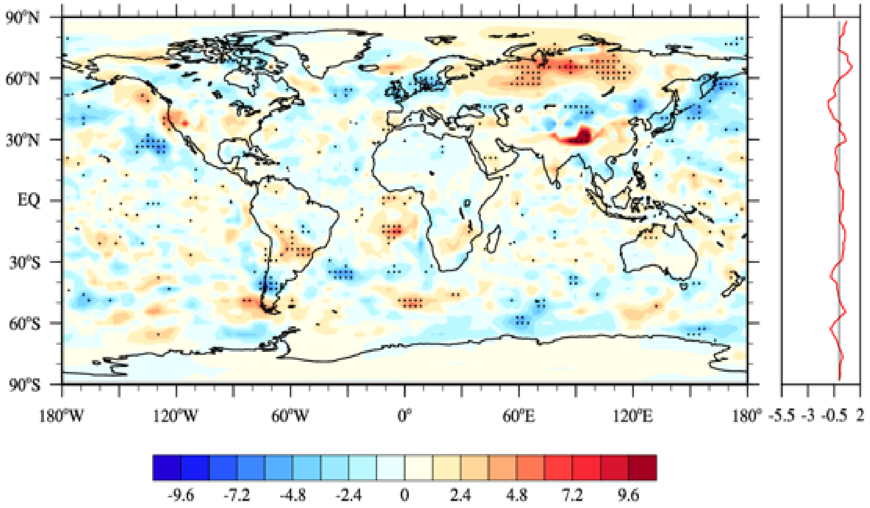
Negative ERFs:

- **Northern China: mainly due to increases in the scattering coarse SF particles; the local low cloud changes slightly.**

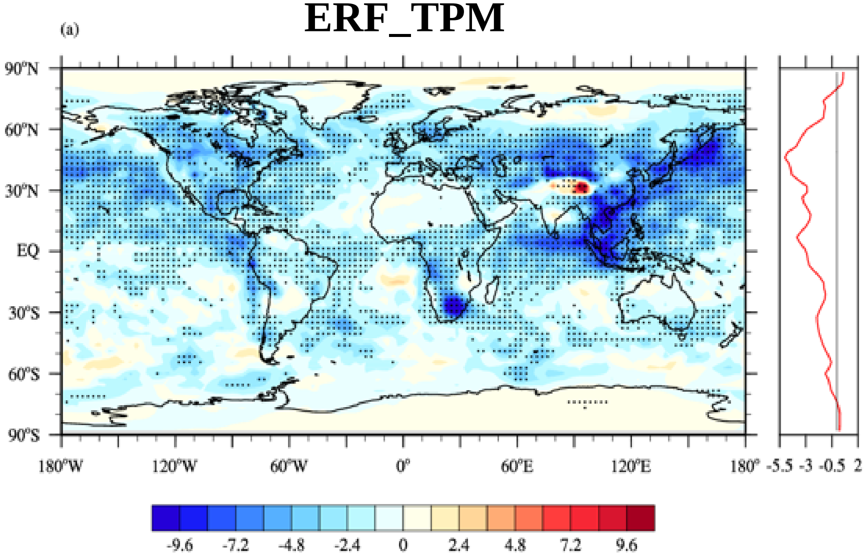
Changes in NPM burden



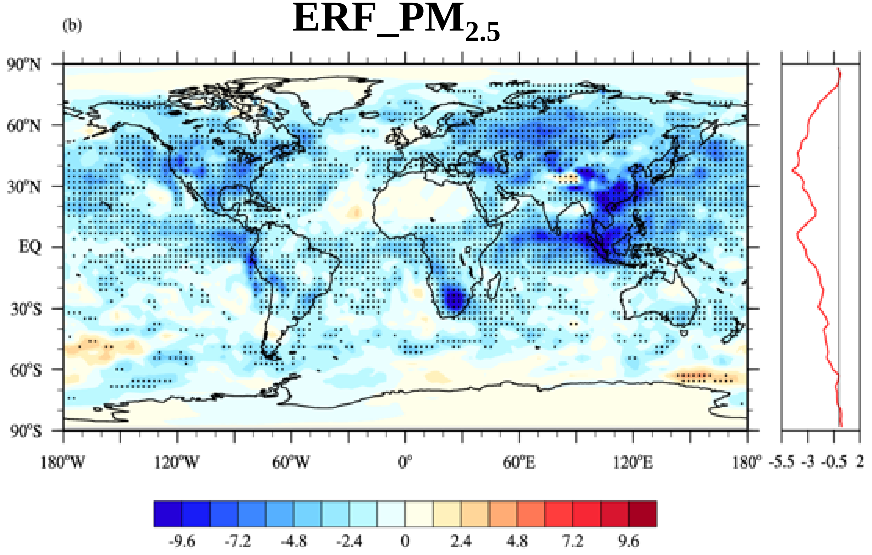
ERF_NPM



Effect Radiative Forcing due to TPM

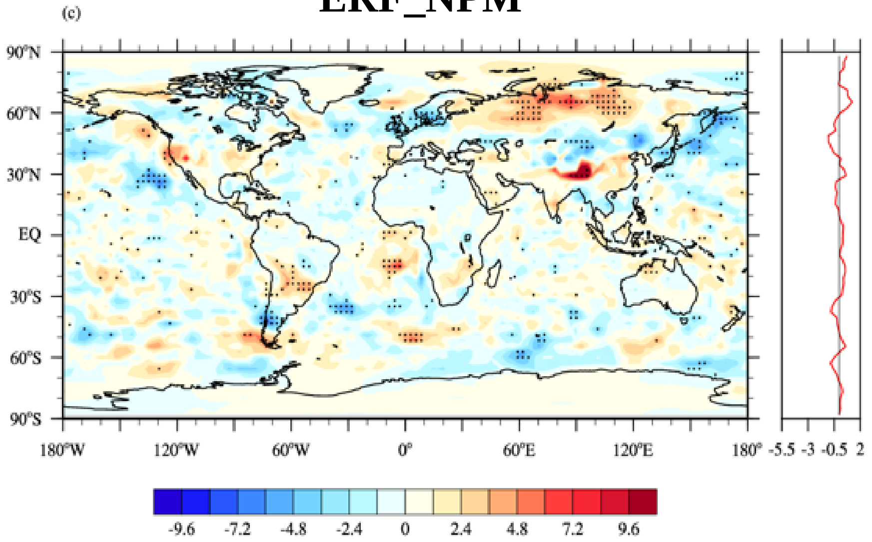


ERF_TPM



ERF_$PM_{2.5}$

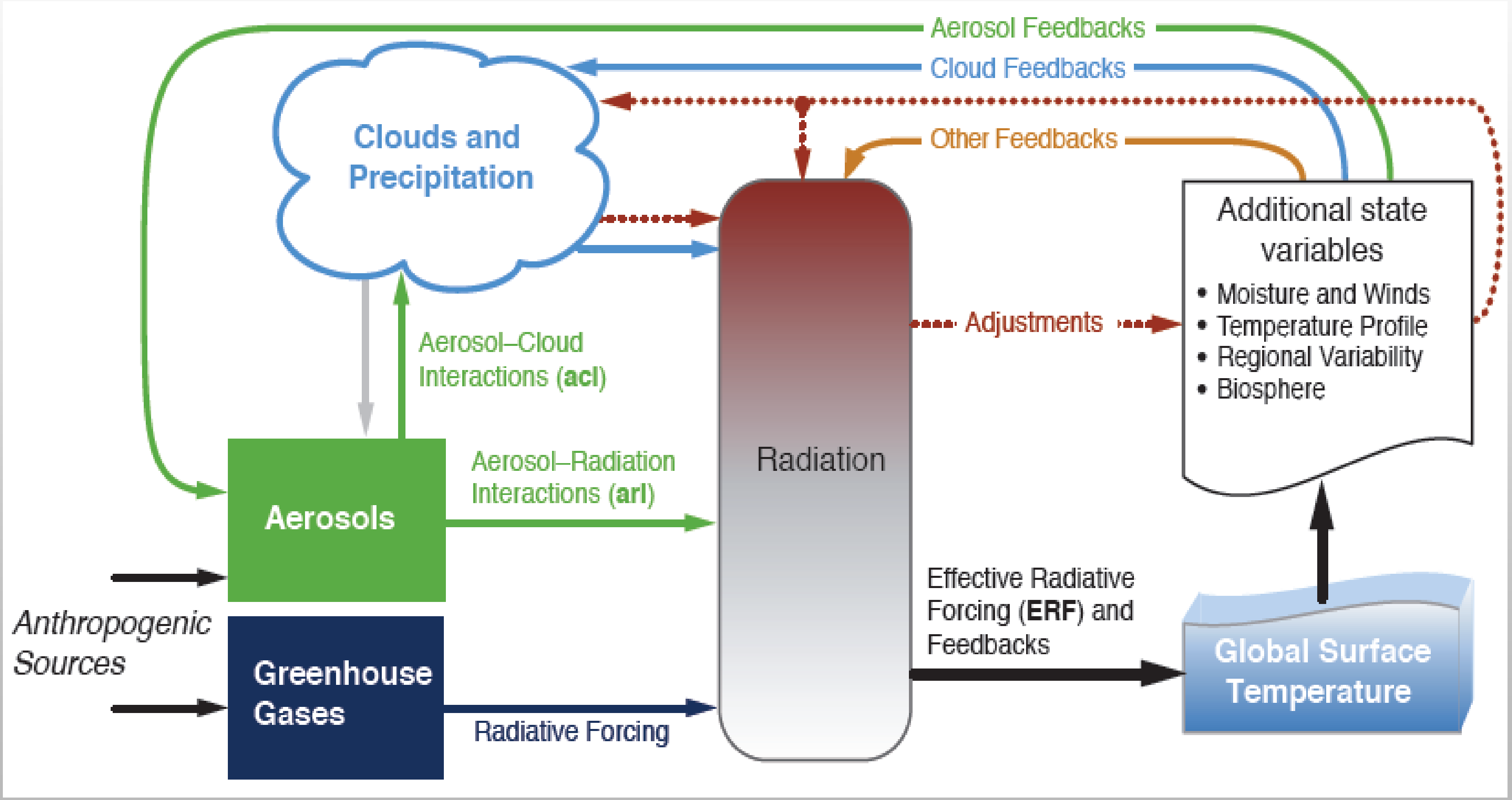
The ERF due to $PM_{2.5}$ contributed most to the total.



ERF_NPM

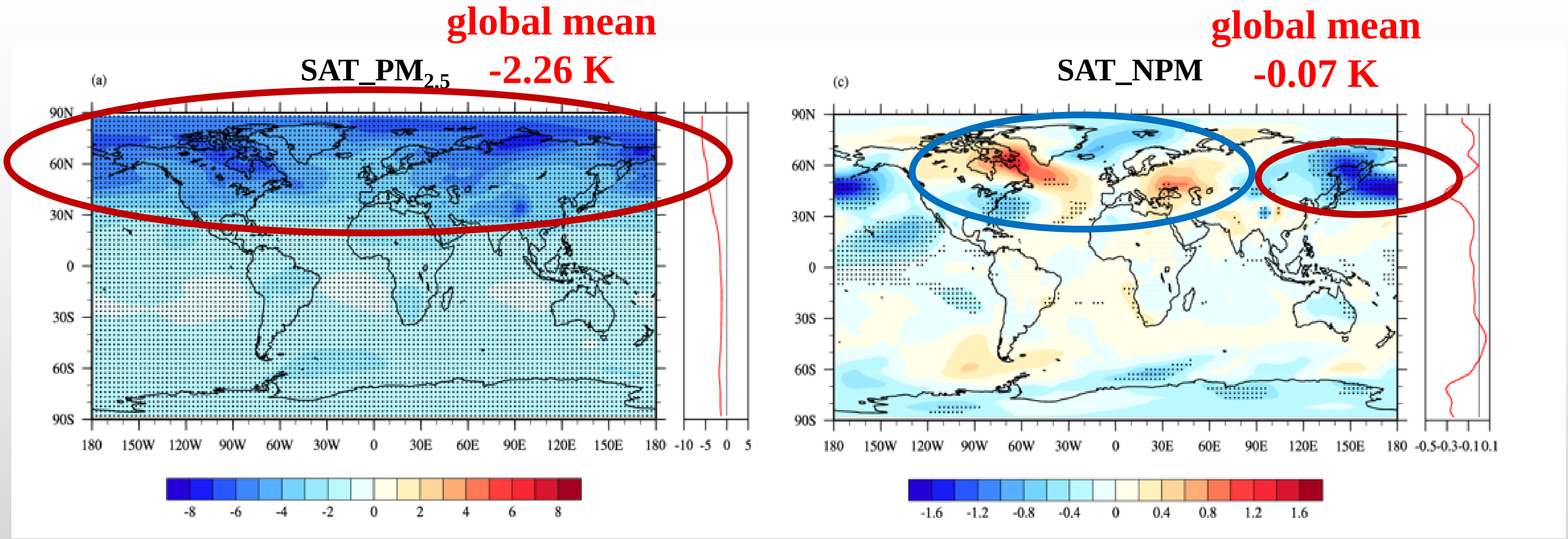
3.3 The effects $PM_{2.5}$ and NPM changes on Climate

Climate Impacts and Feedback Mechanisms of Aerosol and Greenhouse Gas Emissions



IPCC WGI AR5

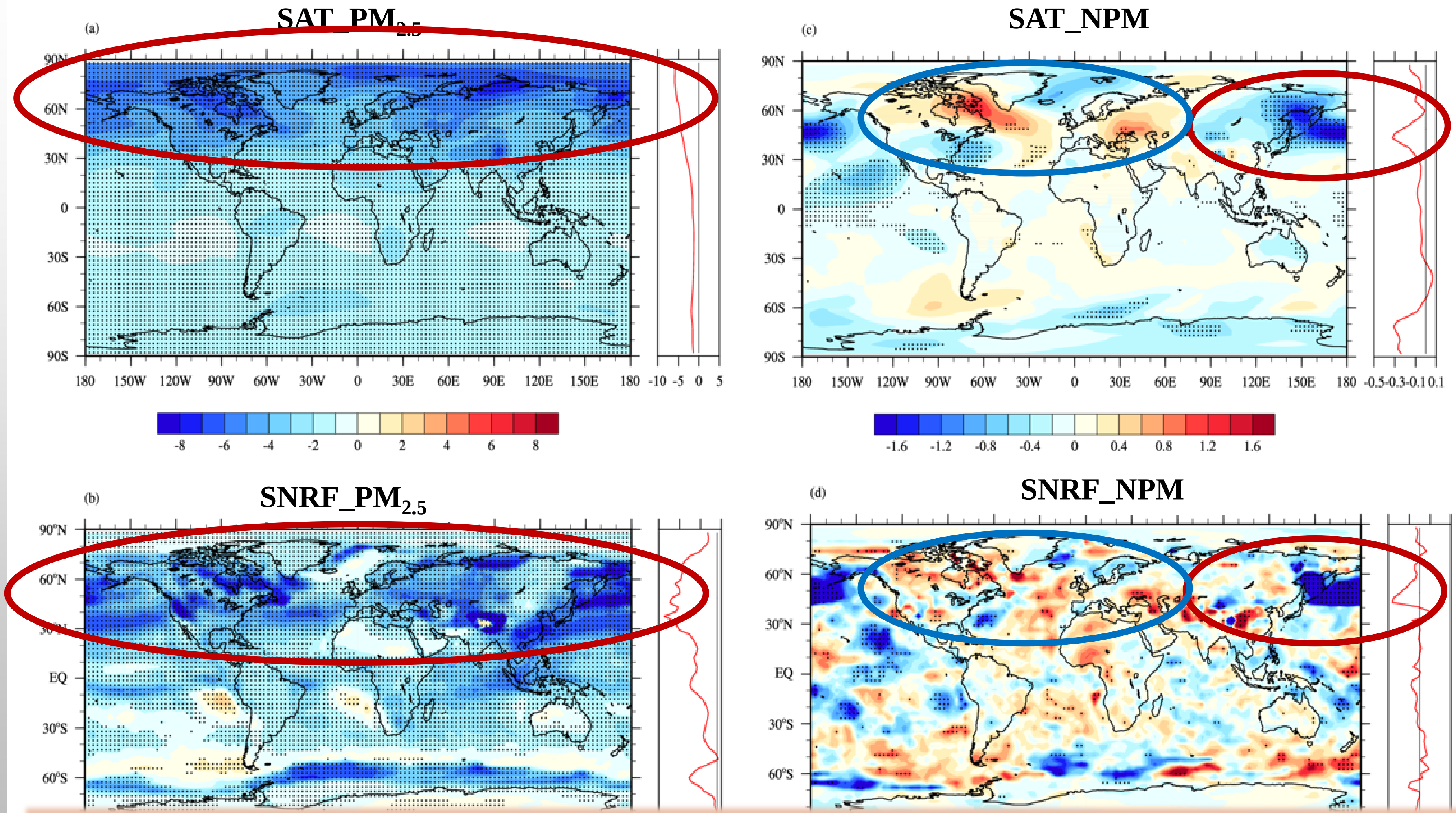
Surface Air Temperature(SAT) &Surface Net Radiation Flux(SNRF)



- Cooling due to increased PM$_{2.5}$ was obvious over NH land and ocean at mid- to high latitudes, where SF particles were highly concentrated

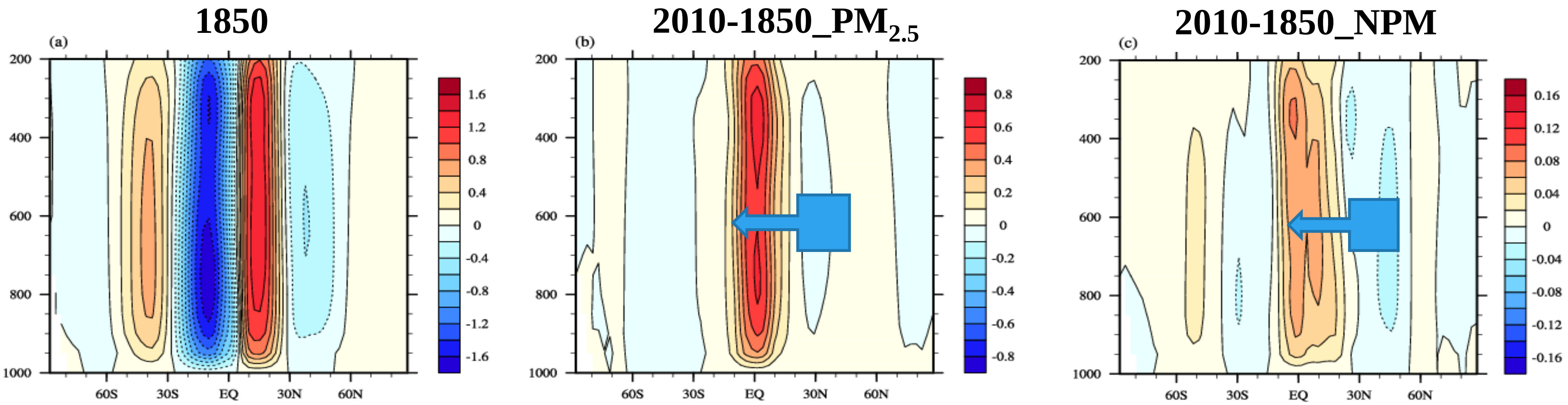
- SAT change caused by the NPM change was **positive** over North America, the Indian Peninsula, South Asia, and Europe.
- Maximum increase was located over North America(**1.32 K**).

Surface Air Temperature(SAT) &Surface Net Radiation Flux(SNRF)



SNRF, is one of the key factors affecting the SAT changes, which provides the leading source for energy balance at the surface.

Atmospheric Circulation



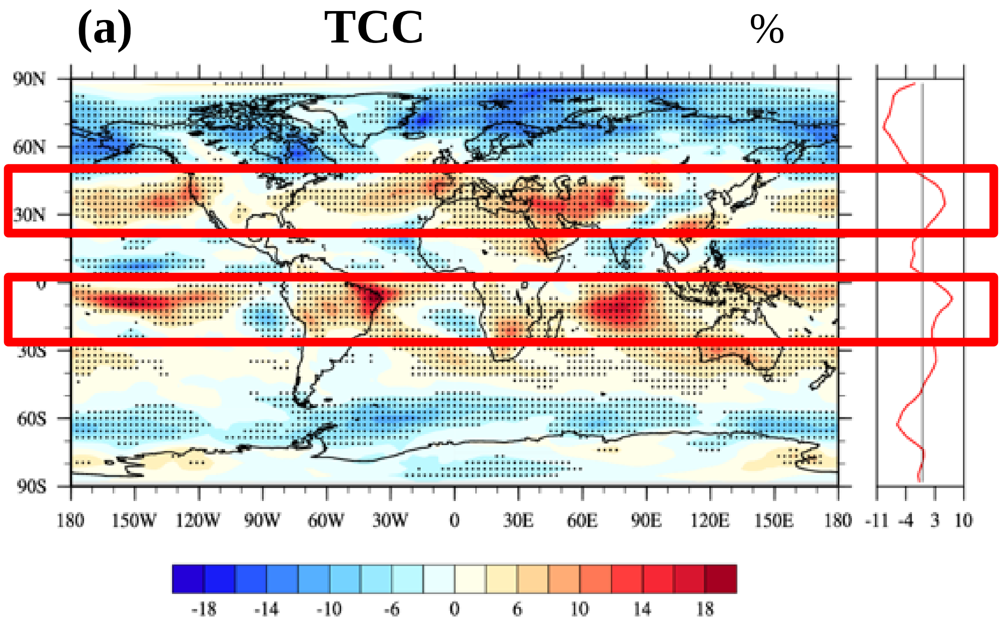
1850

2010-1850_PM$_{2.5}$

2010-1850_NPM

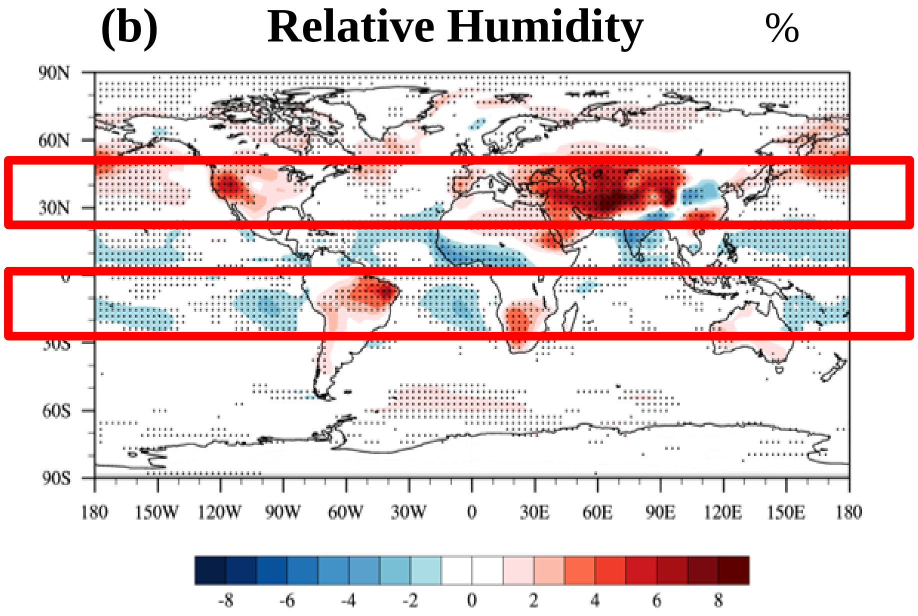
- The **same** signs in changes of meridional stream function were found, indicating that the patterns of change in Hadley circulation were similar due to PM$_{2.5}$ and NPM changes.
- ITCZ strengthened and shifted to the south.

Changes in Total Cloud Cover (TCC) and Precipitation

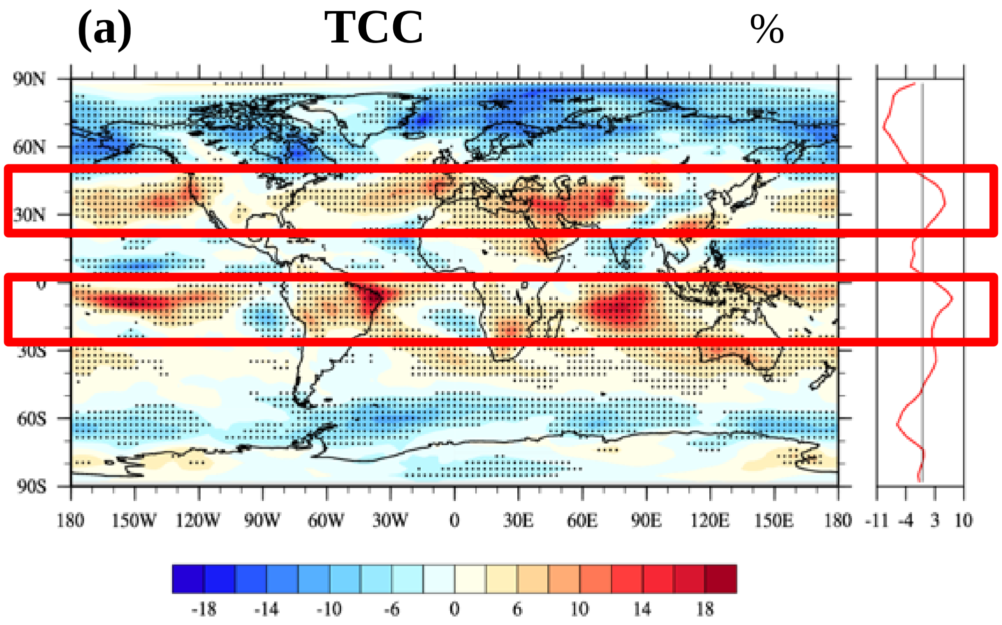


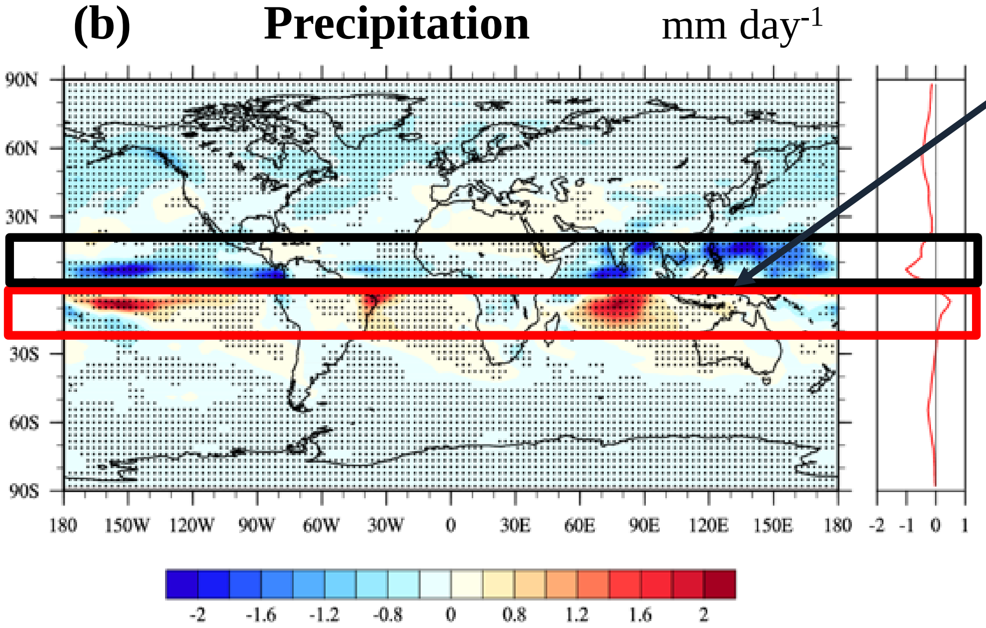
The TCC increased over the mid-latitudes in NH, and mid- and low latitudes in SH, whereas decreased over high latitudes in the two hemispheres and the tropics.

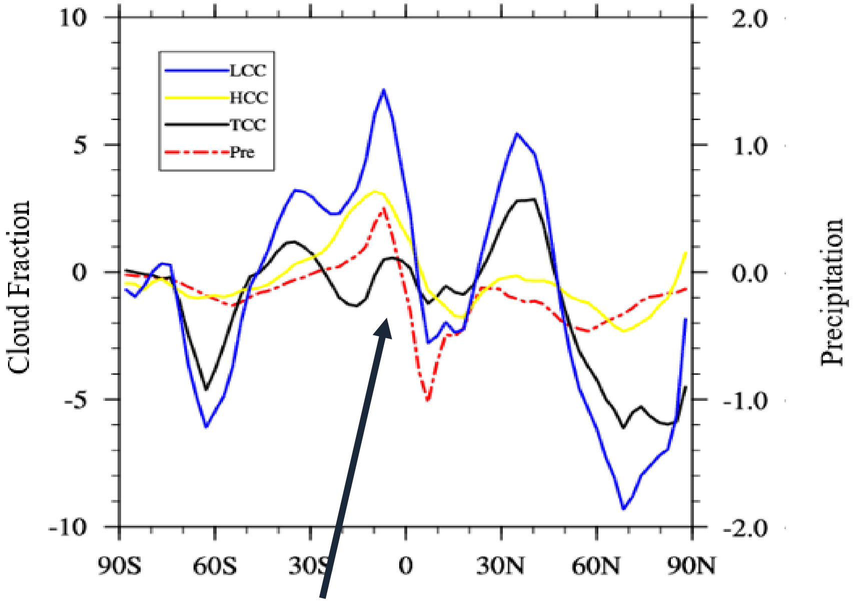
The changes in TCC caused by $PM_{2.5}$ were, to some extent, consistent with that of relative humidity.



Changes in Total Cloud Cover (TCC) and Precipitation







ITCZ shifting

10° S: increases of the surface relative humidity, TCC, and precipitation are found due to ITCZ strengthened and shifted to the south.

Ⅰ Background

Ⅱ Experimental design

Ⅲ Results & Discussions

Ⅳ Conclusions

Conclusions

- Increases in $PM_{2.5}$ column concentrations were found mainly over **East and South Asia, southeastern North America, and southeastern Europe since** 1850.
- The global annual mean ERF due to $PM_{2.5}$ was **-2.34 W m^{-2}**, resulted in significant **cooling effects** on the climate, of which **0.01W m^{-2}** was due to the change of NPM, produced **small and warming effects**.
- Increased $PM_{2.5}$ led to global mean SAT of **-2.26 K** since 1850. Decreases in SAT were greatest at mid- to high latitudes over land and ocean in the NH.
- The precipitation decreased by **0.18 mm day^{-1}**, accounting for **95%** of total changes in precipitation due to increased TPM.
- Hadley circulation in the NH **strengthened and shifted southward** and weakened in the SH due to the change of PM2.5 and NPM since 1850.

THANKS!