The 1st Regional GEOS-Chem Asia Meeting (GCA1)

Simulation of severe winter haze in Beijing-Tianjin-Hebei (BTH) region over 1985-2015 and the roles played by anthropogenic emissions and meteorological parameters

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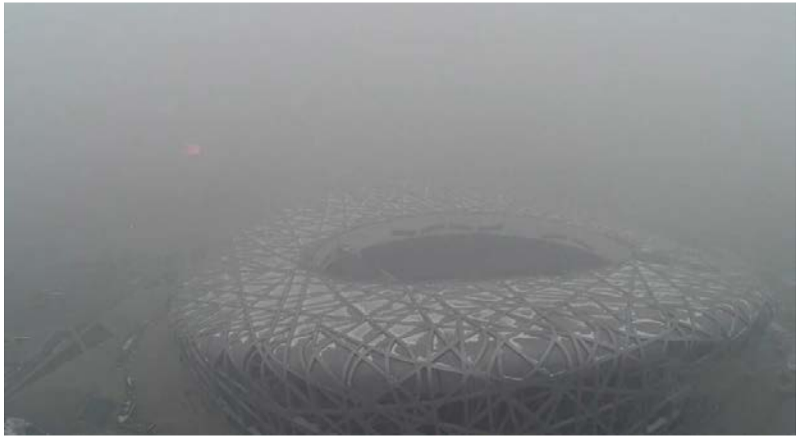
Current situation of Severe Winter Haze (SWH) in BTH



During SWH events, detected daily mean $PM_{2.5}$ concentration: **300-600μg/m³ >> WHO standard**

- Deteriorates ambient visibility
- Endangers traffic
- Detrimentally affects human health
- Brings impact on global air quality and contributes to climate change

How SWH frequency and intensity changed in history?

Severe Winter Haze: **observed daily mean $PM_{2.5}$ concentration > 150 μg/m³**
SWH frequency: **total days SWH occurred in one DJF**
SWH intensity: **mean $PM_{2.5}$ concentration of SWH days**

Model description and numerical experiments

Version : v11.01

MET : MERRA-2

Resolution : 2x2.5 (global)
0.5x0.625 (Asia)

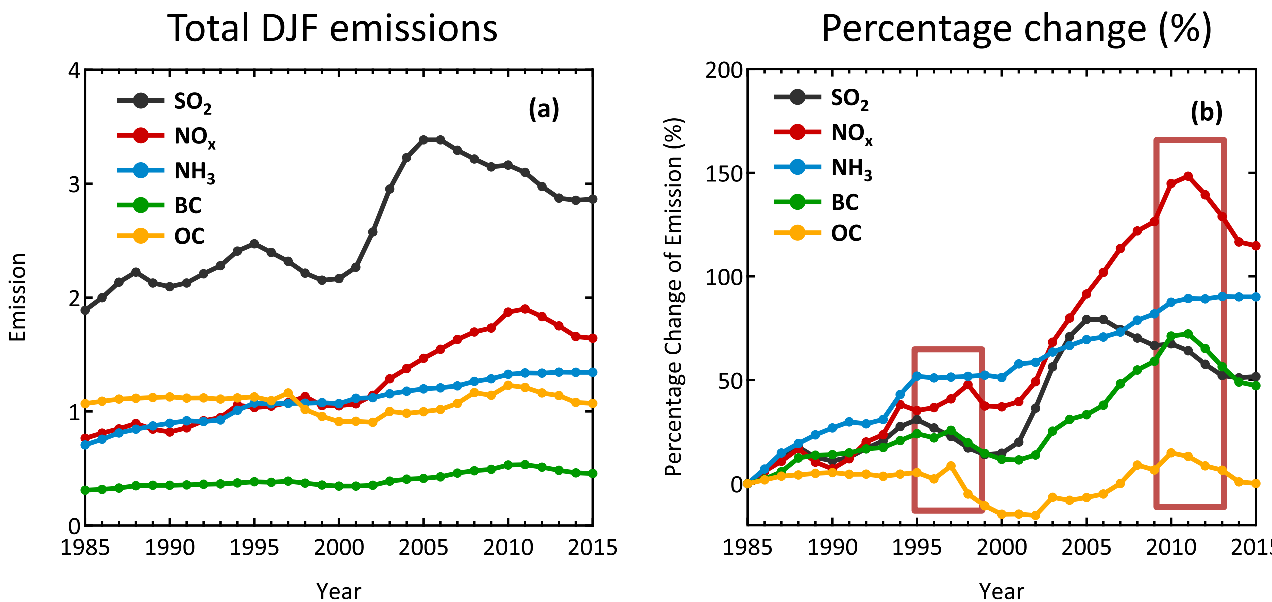
Emissions :

$PM_{2.5}$ components : Sulfate, Nitrate, Ammonium
Black carbon, Organic aerosols

Time : 31 DJFs, 1985-2015

<table>
<tr><th></th><th>Global</th><th colspan="3">Nested Domain (East Asia)</th></tr>
<tr><th></th><th>Emission inventories</th><th>Scale factors 1985-2009</th><th>Base year 2010</th><th>Scale factors 2011-2015</th></tr>
<tr><td>SO_2</td><td rowspan="4">EDGAR v4.2</td><td>96-09: Lu et al.</td><td rowspan="8">MIX</td><td rowspan="2">MEP</td></tr>
<tr><td>NO_x</td><td rowspan="7">EDGAR v4.3</td></tr>
<tr><td>NH_3</td><td>Kept constant</td></tr>
<tr><td>CO</td><td rowspan="5">Followed NO_x</td></tr>
<tr><td>BC</td><td rowspan="2">BOND</td></tr>
<tr><td>OC</td></tr>
<tr><td>NMVOCs except a, b</td><td>RETRO</td></tr>
<tr><td>[a] C_2H_6 and [b] C_3H_8</td><td>XIAO</td></tr>
</table>

Model description and numerical experiments



Emissions have increased 52, 115, 47, 90, 0.1% for SO_2, NO_x, NH_3, BC, OC respectively over Eastern China in the past three decades.

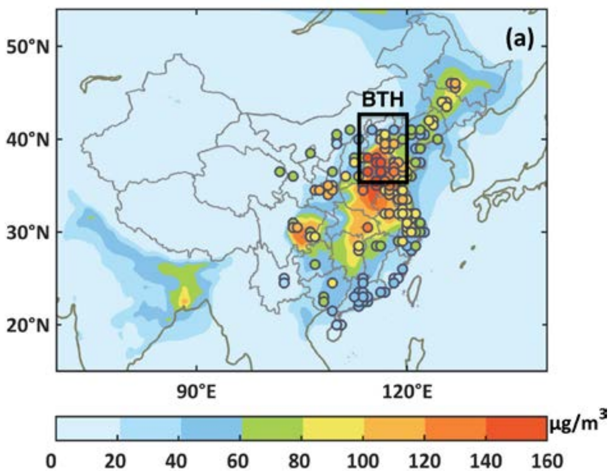
	Anthropogenic Emissions	Meteorological parameters
CTRL	1985-2015	1985-2015
EMIS	1985-2015	**Fixed at 1985**
MET	**Fixed at 2010**	1985-2015

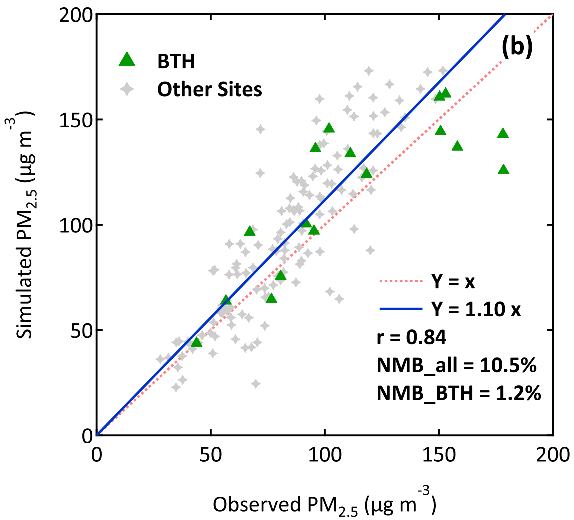
EMIS → **varied emission** → **varied SWH**

MET → **varied MET** → **varied SWH**

Model evaluation: $PM_{2.5}$ concentrations

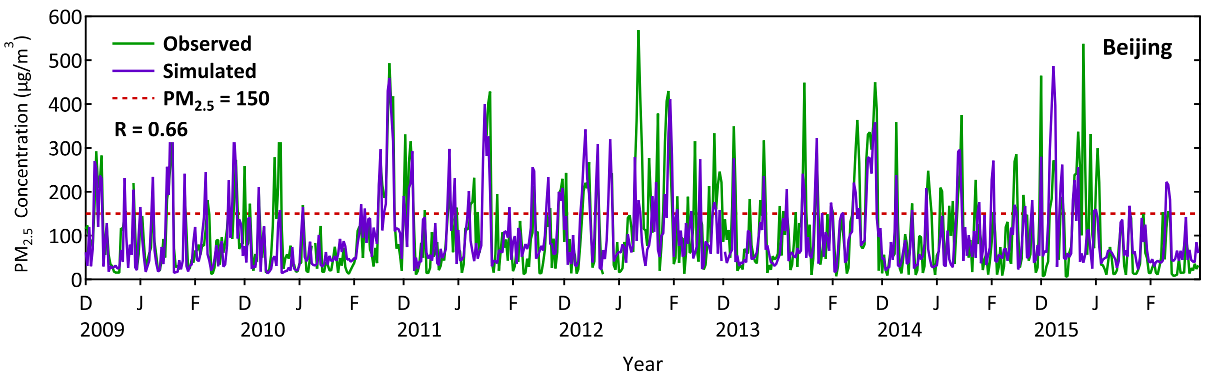
- DJF mean surface-layer $PM_{2.5}$ concentrations:





Well performed **spatial distribution** of DJF mean $PM_{2.5}$ with R of 0.84 and NMB as 1.2% in BTH.

- Time series of daily mean surface-layer $PM_{2.5}$ concentrations:

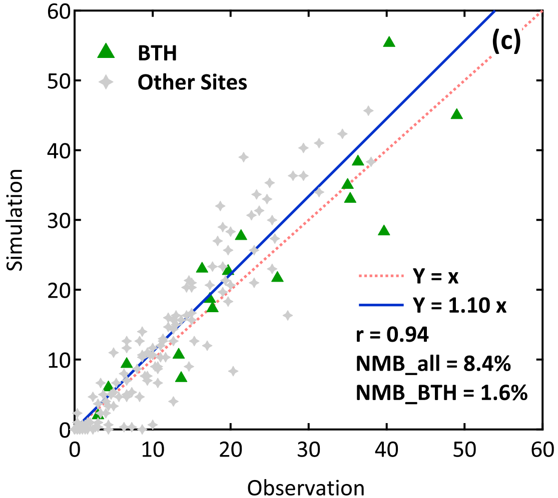


Well performed **day-to-day variation** with R being 0.51-0.66 in BTH

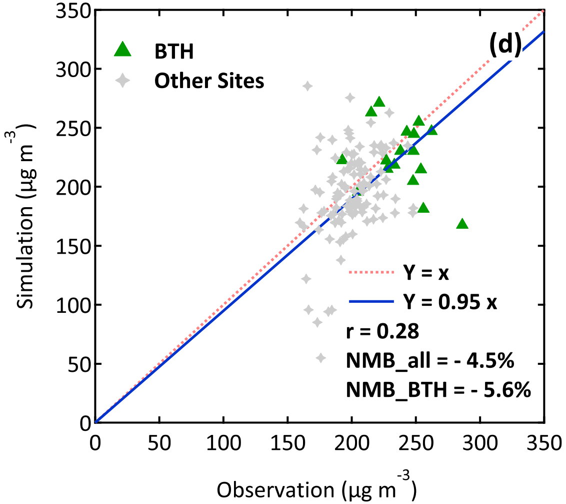
Underestimate maximum values

Model evaluation: **SWH frequency and intensity**

SWH Frequency

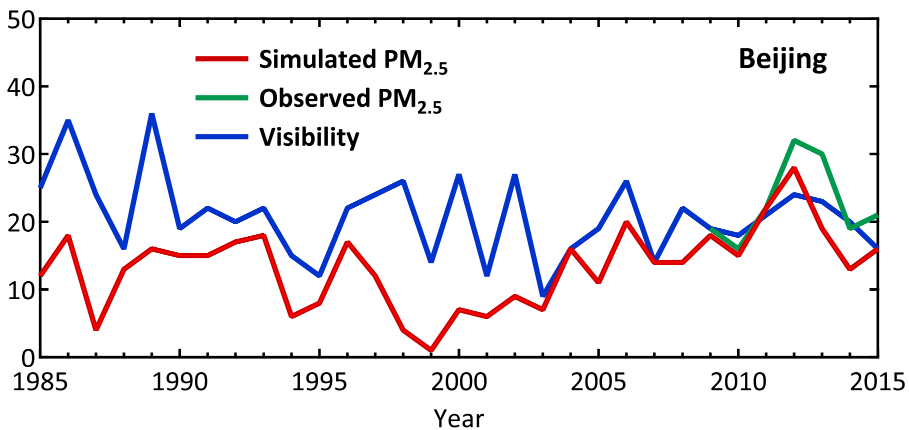


SWH Intensity



Well performed **SWH frequency and intensity** with high spatial R of 0.94/0.28 and NMB of 1.6%/-5.6% in BTH.

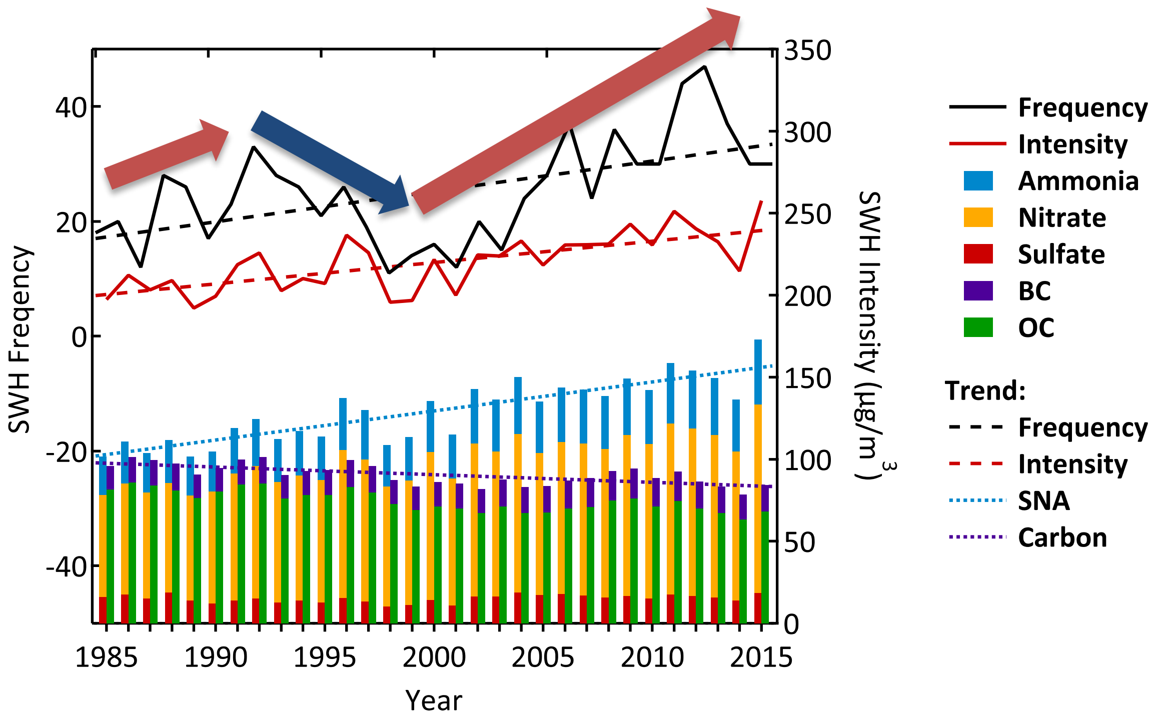
Long-term evaluation of frequency

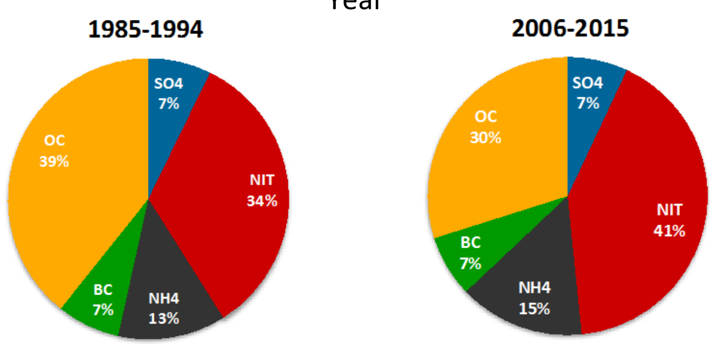


Partly reproduce **long term variation** with R of 0.30

Inconsistency problem in visibility dataset

Results: Decadal changes in SWH over BTH region





Regional SWH:

- >1/3 grids

SWH Frequency (black):

- 15 days (1985) to 30 days (2015)
- Increasing trend: 5.6 days/decade
- Three stages

SWH Intensity (red):

- Total $PM_{2.5}$ grew gradually: 13.5 $\mu g/m^3$/decade
- Nitrate contributed most
- SNA became increasingly important (54% to 63%)

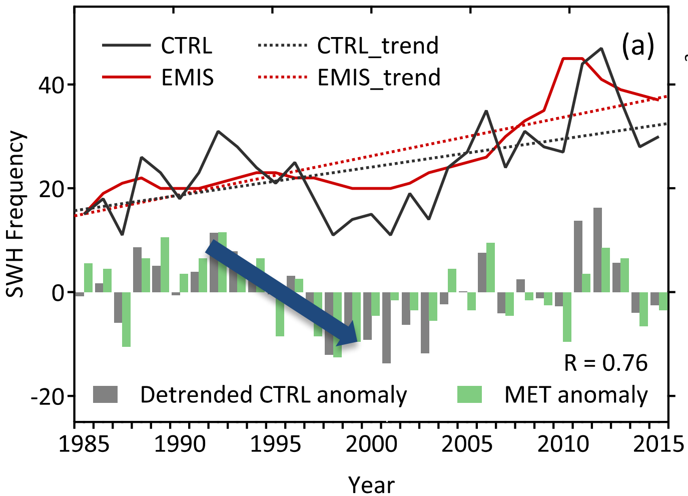
	FRE	*$PM_{2.5}$*	*NIT*	*NH4*	*BC*	*SO4*	*OA*
Trend	**5.6^a**	**13.5^a**	**13.4^a**	**4.2^a**	**0.7^a**	—	**-5.5^a**

Unit: **days/decade** for frequency trend; **$\mu g/m^3$/decade** for intensity trend

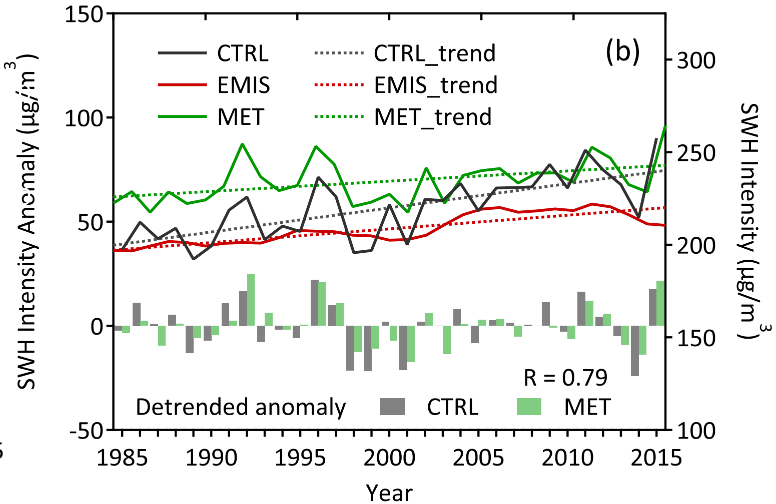
^{a} means p value < 0.01

Results: CTRL vs. EMIS vs. MET

SWH Frequency



SWH Intensity



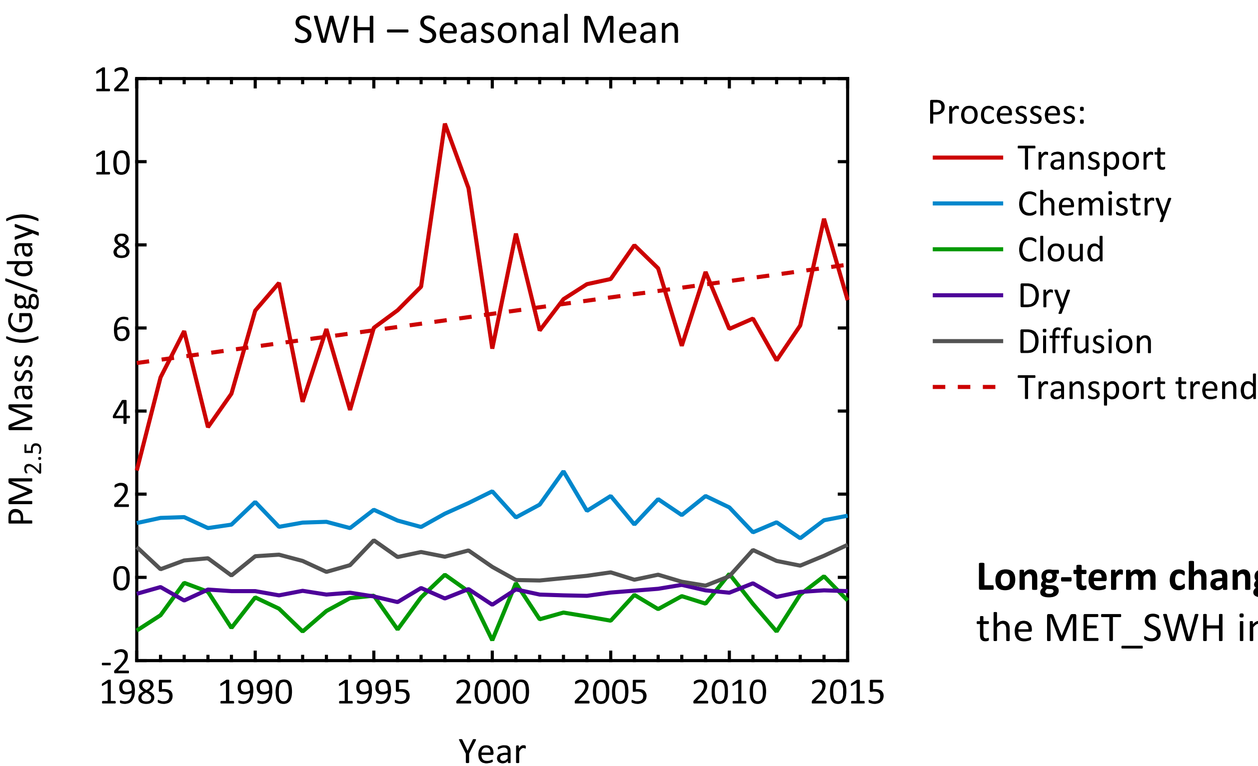
Trend	*FRE*	*INT*
CTRL	**5.6[a]**	**13.5[a]**
EMIS	**7.7[a]**	7.6[a]
MET	—	**5.7[a]**

Unit: **days/decade** for frequency trend; **μg/m^3/decade** for intensity trend
[a] means p value < 0.01

- **Anthropogenic emissions** changes dominated the increasing trend;
- **Meteorological parameters** explained the inter-annual variation, especially the sudden drop in 1990s.
- **Meteorological parameters** also contributed to the SWH intensity growth **up to 42%**

Results: Who intrigued the MET_SWH intensity increase

$$\Delta Concentration = Emission + Transport + Chemistry + Diffusion + Cloud\ processes + Dry\ deposition$$



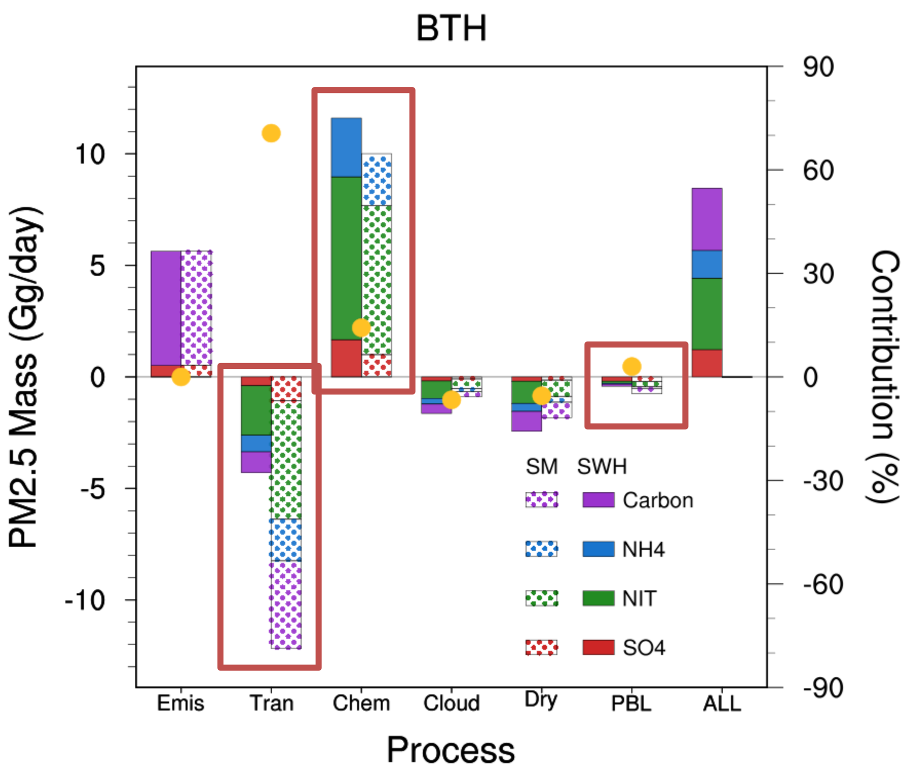
Long-term change of transport process led to the MET_SWH intensity increase

Results: Key process for SWH formation

$$\%PC_i = \frac{PC_{SWH\_i} - PC_{SM\_i}}{\sum_i^n abs(PC_{SWH\_i} - PC_{SM\_i})} * 100$$

(SWH: PC_{SWH_i}; DJF mean: PC_{SM_i})

$\%PC_i$: Relative contribution of each process



During SWH events (solid bars), **transport was the key process for $PM_{2.5}$ enhancement during SWH events over BTH.**

	$\%PC_i$
Transport	**70.6%**
Chemistry	**14.2%**
Diffusion	**3.0%**
Cloud processes	**-6.6%**
Dry deposition	**-5.5%**

Summary:

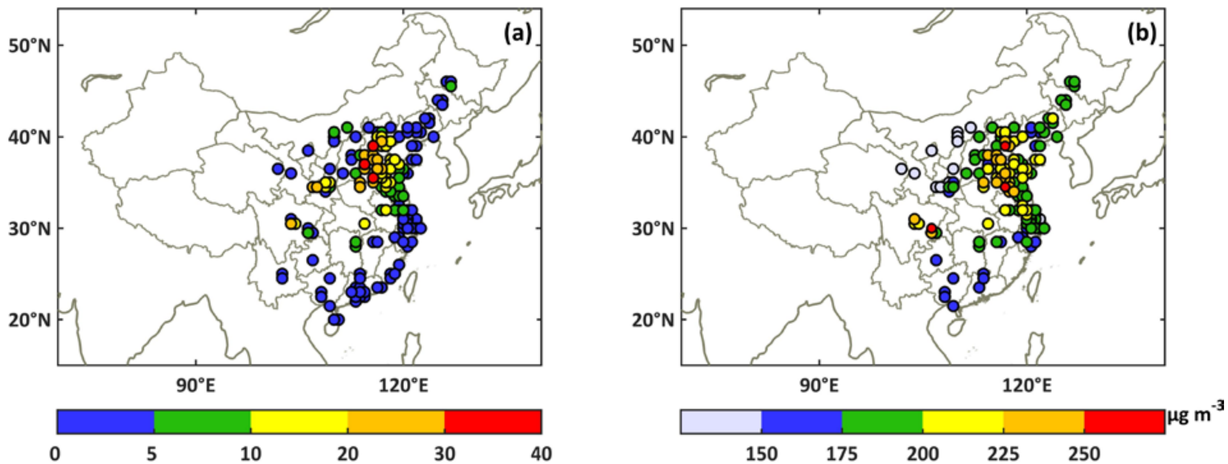
- The GEOS-Chem model could generally reproduce the severe winter haze and its historical change over China.
- **SWH events have occurred more frequently and more intense in BTH region over the past 3 decades.**

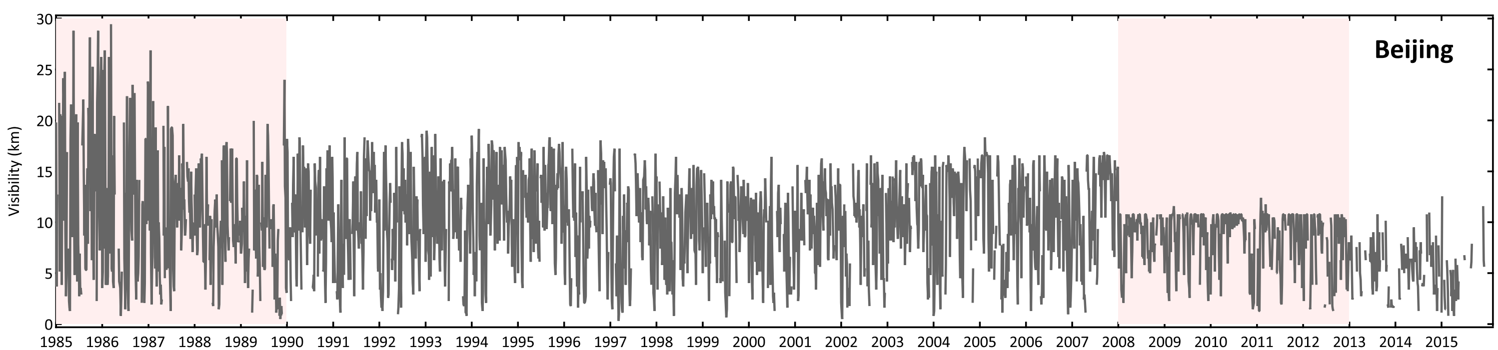
- Anthropogenic emissions changes led the increasing trends of both SWH frequency and intensity.
- **Meteorological parameters illustrated the inter-annual variations and contributed up to 42% of the SWH intensity growth due to the transport process.**

- Transport was the key process for the SWH formation over BTH with a contribution of 70.6%.

THANKS FOR YOUR ATTENTION!

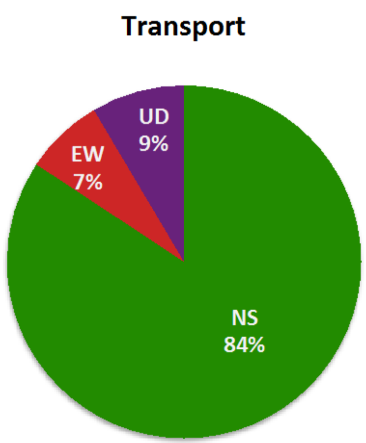
Backup material





Backup material

	Transport	Chemistry	Cloud	Dry	PBL Mixing
$PM_{2.5}$	70.6	14.2	-6.6	-5.5	3.0
Sulfate	44.5	44.6	-6.0	-3.4	1.5
Nitrate	69.4	14.0	-8.0	-6.0	2.6
Ammonium	67.4	17.8	-6.7	-5.7	2.5
Carbon	84.8	0	-5.2	-5.6	4.4



- (no significant trend in seasonal mean MET_$PM_{2.5}$)