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Model analysis of soil dust impacts on the boundary layer meteorology and air quality over East Asia in April 2015

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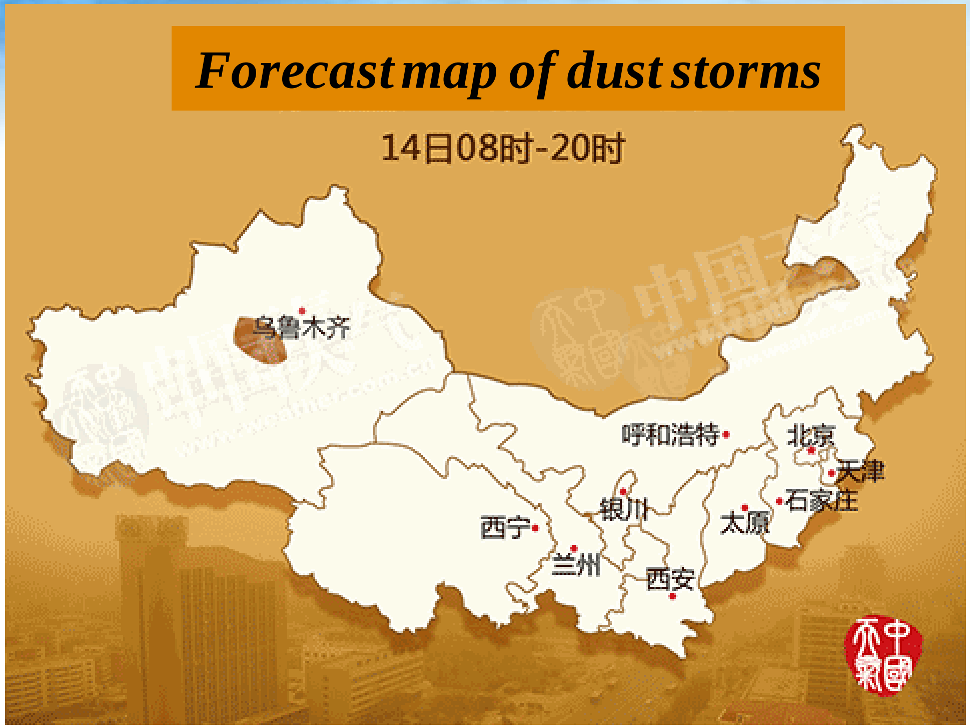
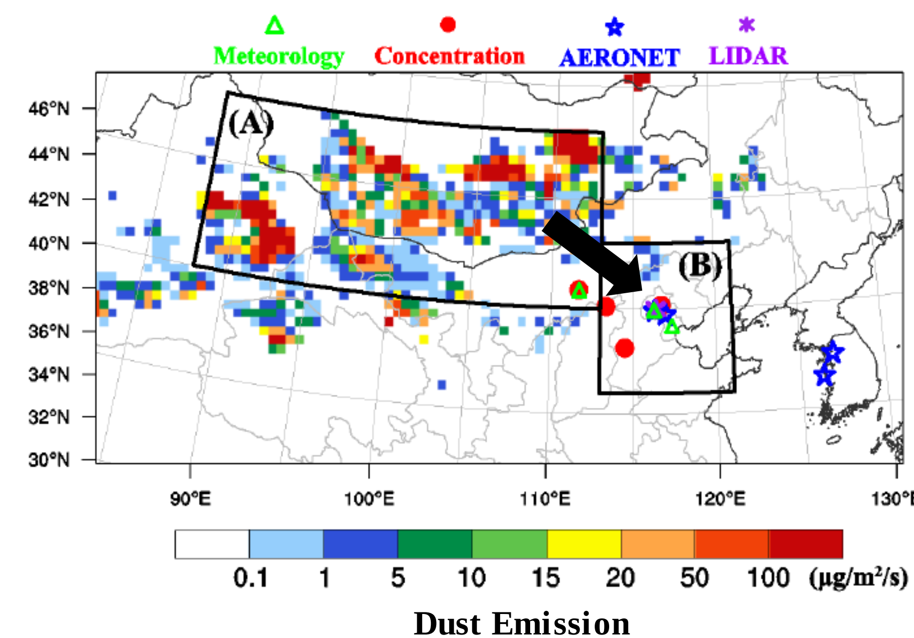
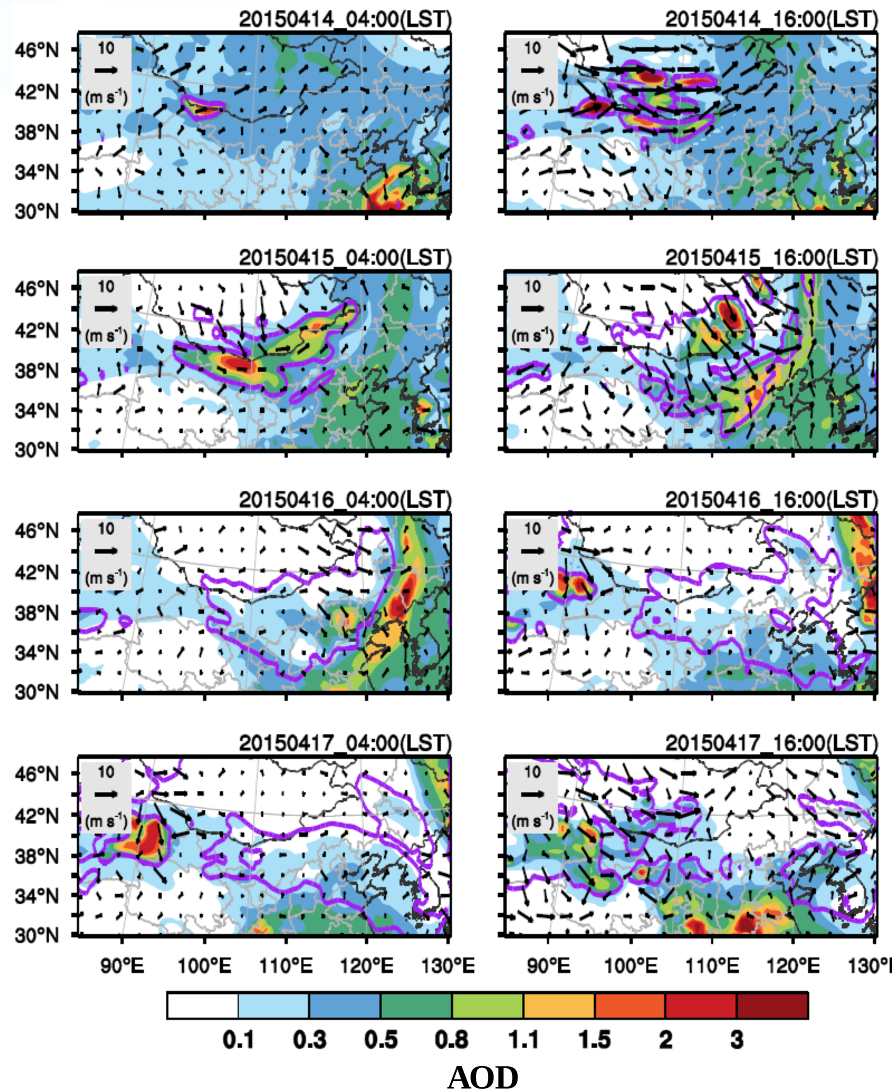
Outline

- **Background**
- **Objective**
- **Model description**
- **Model evaluation**
- **Results**
- **Conclusion**

Dust Evolution







Objective

- Estimate radiative perturbations caused by dust particles.
- Study the feedback between dust aerosols and boundary layer meteorology.
- Quantify the effects of dust-related heterogeneous chemical reactions on pollutant concentrations.

Model Description

WRF-Chem (v3.7)

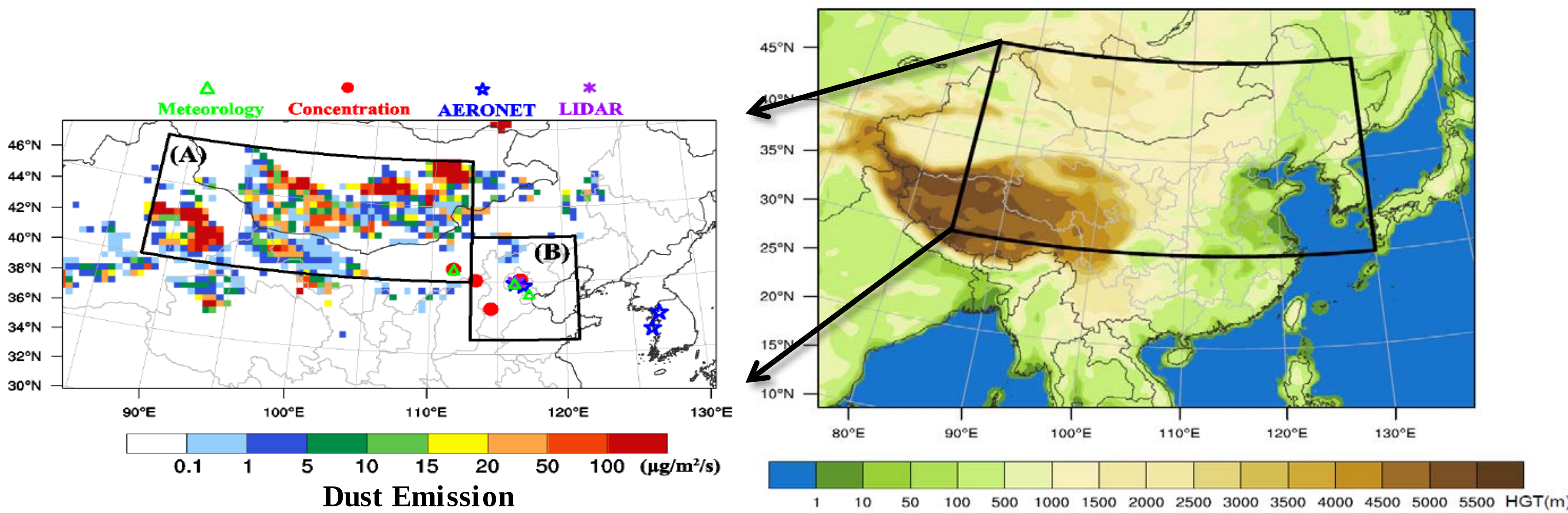
- A version of WRF which can simulate trace gases and aerosols simultaneously with meteorological field.

Time:

- Simulation is conducted for the period over 10 to 18 April 2015, but results during 14–17 April are analyzed.

Domain:

- The model computational domain covers Asia (15.4°S–58.3°N, 48.5°E–160.2°E) using 180×170 grid points at 45 km horizontal resolution, but the inner region (29.8°N–50.6°N, 79.2°E–133.3°E) are selected to analyze.



Data inputs

- Anthropogenic emissions are based on the MIX inventory for the year 2010.
- Biogenic emissions are calculated online using MEGANv2.04.
- Biomass burning emissions are taken from GFEDv3.1.
- NCEP Final reanalysis data is used as initial meteorological fields and boundary condition.
- MOZART output data is used as the chemical initial and boundary condition.

Parameterization schemes

Options	WRF–Chem
Microphysics option	Morrison two–moment microphysics scheme
Longwave radiation option	RRTMG scheme
Shortwave radiation option	RRTMG scheme
Surface layer option	MYNN surface layer
Land surface option	Unified Noah land–surface model
Urban canopy model	Single–layer UCM
Boundary layer option	MYNN 2.5 level TKE scheme
Cumulus option	Grell 3D ensemble scheme
Photolysis scheme	Fast–J
Dust scheme	Shao_2004
Chemistry option	CBMZ
Aerosol option	MOSAIC

Dust scheme

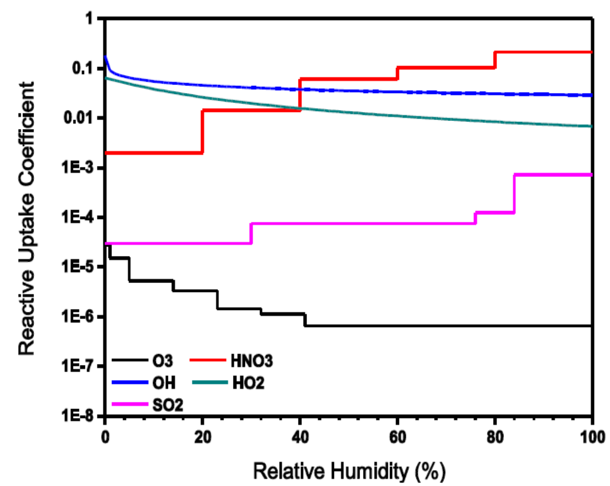
- Shao_2004 scheme is proposed by Shao (2004JGR) and is implemented in WRF–Chem by Kang et al. (2011JGR).
- Previous studies have reported that Shao_2004 dust scheme had a good performance in dust emission amount over source areas and spatial distribution of dust particles over the downwind regions over East Asia (Kang et al., 2014AE; Su and Fung, 2015JGR).

Dust-related heterogeneous reaction

- Nine heterogeneous reactions are assumed to occur on the surface of dust particles.
- Absorption and heterogeneous reactions of gases on dust aerosols are commonly parameterized using a pseudo–first–order rate constant (Zheng et al., 2015ACP), and they are assumed to be irreversible (Jacob, 2000AE).
- The RH-dependence of reactive uptake coefficients are included to calculate the change of pollutant concentrations according to Zhu et al., (2010ACP) and Kumar et al., (2014ACP).

Reactions and Uptake Coefficients

Reactions	Uptake coefficients	RH–dependence Ref	Reaction Ref
O_3 + Dust = Products	RH–dependence	Cwiertny et al. (2008)	Zhu et al. (2010)
HNO_3 + Dust = 0.5NO_x + Products	RH–dependence	Liu et al. (2008)	Kumar et al. (2014)
OH + Dust = 0.05H_2O_2 + Products	RH–dependence	Bedjanian et al. (2013a)	Kumar et al. (2014)
HO_2 + Dust = 0.1H_2O_2 + Products	RH–dependence	Bedjanian et al. (2013b)	Kumar et al. (2014)
H_2O_2 + Dust = Products	2.00E-03	-	Pradhan et al. (2010)
NO_2 + Dust = 0.5HONO + 0.5HNO_3	2.10E-06	-	Zhu et al. (2010)
NO_3 + Dust = HNO_3	0.1	-	Martin et al. (2003)
N_2O_5 + Dust = 2HNO_3	0.03	-	Zhu et al. (2010)
SO_2 + Dust = H_2SO_4	RH–dependence	Preszler Prince et al. (2007)	Zheng et al. (2015)



Numerical experiments

- **CTL:** The control simulation with both dust emissions and heterogeneous chemical reactions on dust surface.
- **NoD_NoH:** The simulation neither with dust emissions nor heterogeneous chemical reactions on dust surface.
- **D_NoH:** The simulation with dust emissions but without heterogeneous chemical reactions on dust surface.

Experiments	Description	Dust	Heterogeneous Chemical reactions on dust surfaces
CTL[1]	Dust_Hetrxn	On	On
NoD_NoH[2]	Nodust_Nohetrxn	Off	Off
D_NoH[3]	Dust_Nohetrxn	On	Off

NoD_NoH .vs. D_NoH: analyze the impacts of dust aerosols on radiative forcing and planetary boundary–layer meteorology.

D_NoH .vs. CTL: quantify the effects of dust–related heterogeneous chemical reactions on air quality.

Model evaluation

- Meteorological parameters:
  - Temperature
  - Relative Humidity
  - Wind
- Surface-layer concentrations:
  - SO_2
  - NO_2
  - Sulfate
  - Nitrate
  - $PM_{2.5}$
  - PM_{10}
- Aerosol optical depth (AOD)

Statistics of comparisons between Obs and Sim

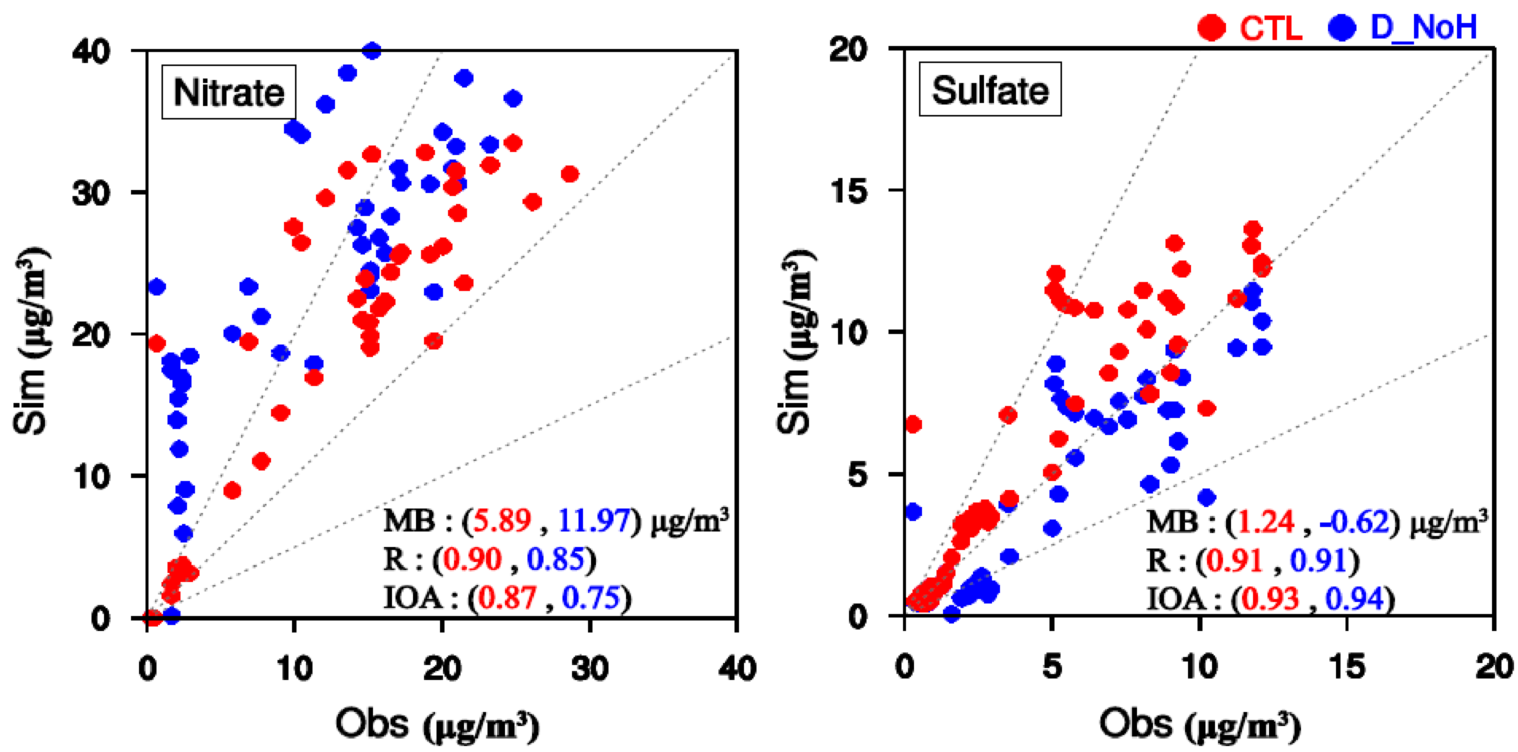
Mete_Vars	Stations	OBS[1]	SIM[2]	MB[3]	RMSE[4]	R[5]	IOA[6]
T_2 (°C)	Hohhot	8.57	7.35	-1.22	2.17	0.96	0.97
	Beijing	16.72	19.54	2.82	3.29	0.96	0.91
	Tianjin	17.49	16.96	-0.52	2.44	0.93	0.95
RH_2 (%)	Hohhot	28.04	30.18	2.14	6.61	0.92	0.94
	Beijing	35.36	29.53	-5.83	10.77	0.96	0.92
	Tianjin	33.66	35.75	2.09	7.85	0.95	0.96
WS_{10} ($m\ s^{-1}$)	Hohhot	3.70	3.52	-0.18	1.96	0.76	0.87
	Beijing	4.61	3.95	-0.66	2.51	0.84	0.76
	Tianjin	4.92	4.13	-0.79	1.48	0.91	0.92
$PM_{2.5}$ ($\mu g\ m^{-3}$)	Hohhot	55.81	49.53	-5.73	31.46	0.44	0.65
	Beijing	76.97	103.33	24.78	48.45	0.69	0.78
	Shijiazhuang	78.56	111.11	32.71	49.85	0.46	0.55
	Shanxi	42.37	64.04	21.39	33.31	0.63	0.70
PM_{10} ($\mu g\ m^{-3}$)	Hohhot	215.05	136.83	-79.69	217.47	0.63	0.63
	Beijing	165.56	168.79	6.35	136.37	0.75	0.77
	Shijiazhuang	211.33	206.24	-3.38	105.37	0.50	0.70
	Shanxi	145.19	140.88	-9.13	64.84	0.87	0.91
SO_2 ($ppbV$)	Hohhot	10.83	9.78	-0.95	8.11	0.57	0.75
	Beijing	3.96	11.64	7.56	10.45	0.45	0.46
	Shijiazhuang	15.21	21.19	5.62	11.02	0.54	0.68
	Shanxi	10.53	17.86	7.46	10.10	0.82	0.72
NO_2 ($ppbV$)	Hohhot	21.00	18.86	-2.05	6.67	0.86	0.91
	Beijing	25.04	17.80	-7.08	13.89	0.70	0.79
	Shijiazhuang	22.54	19.91	-3.49	16.26	0.46	0.60
	Shanxi	14.37	13.58	-0.68	9.05	0.53	0.73

R : [0.76 , 0.96]
IOA : [0.76 , 0.97]

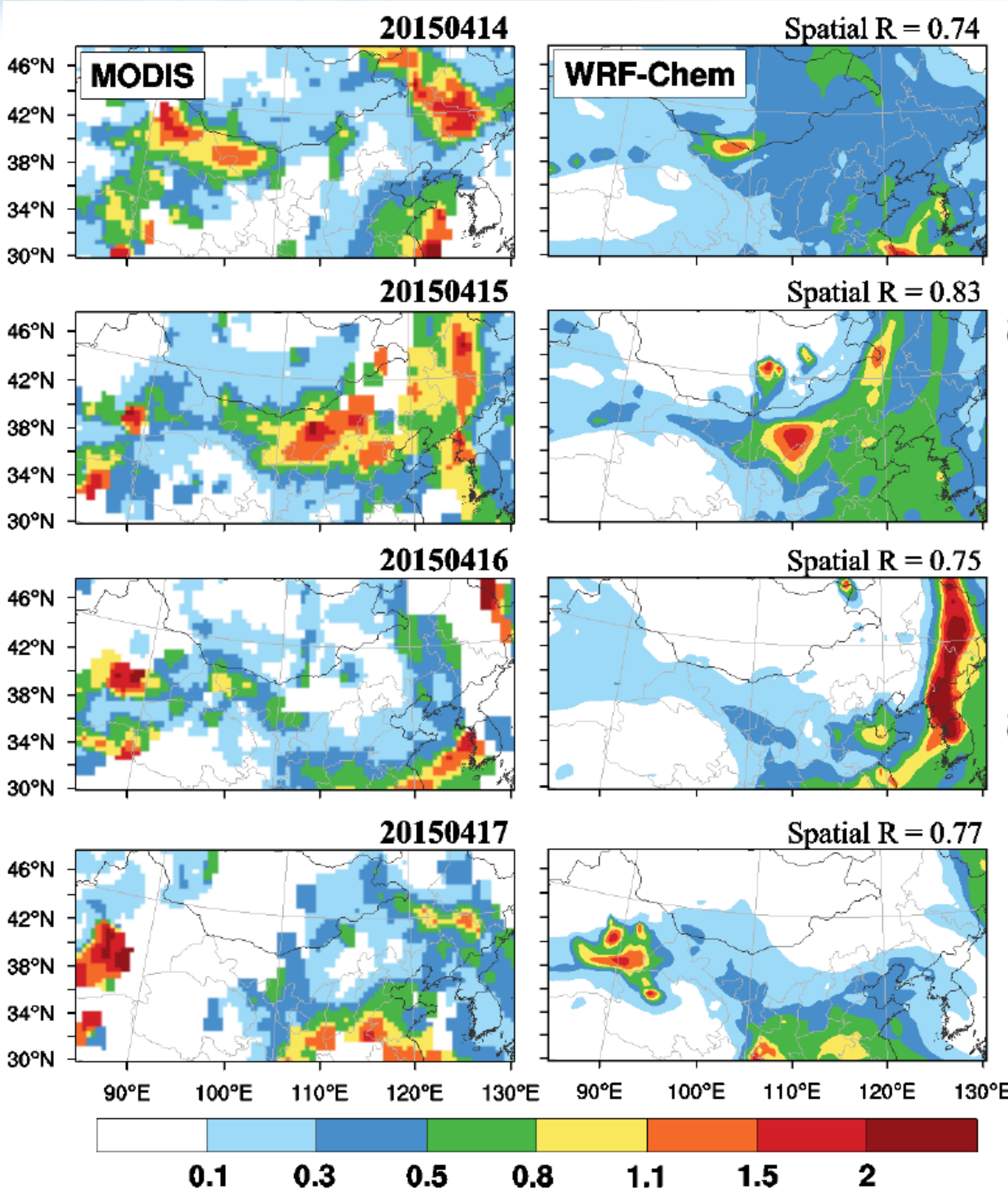
R : [0.44 , 0.87]
IOA : [0.55 , 0.91]

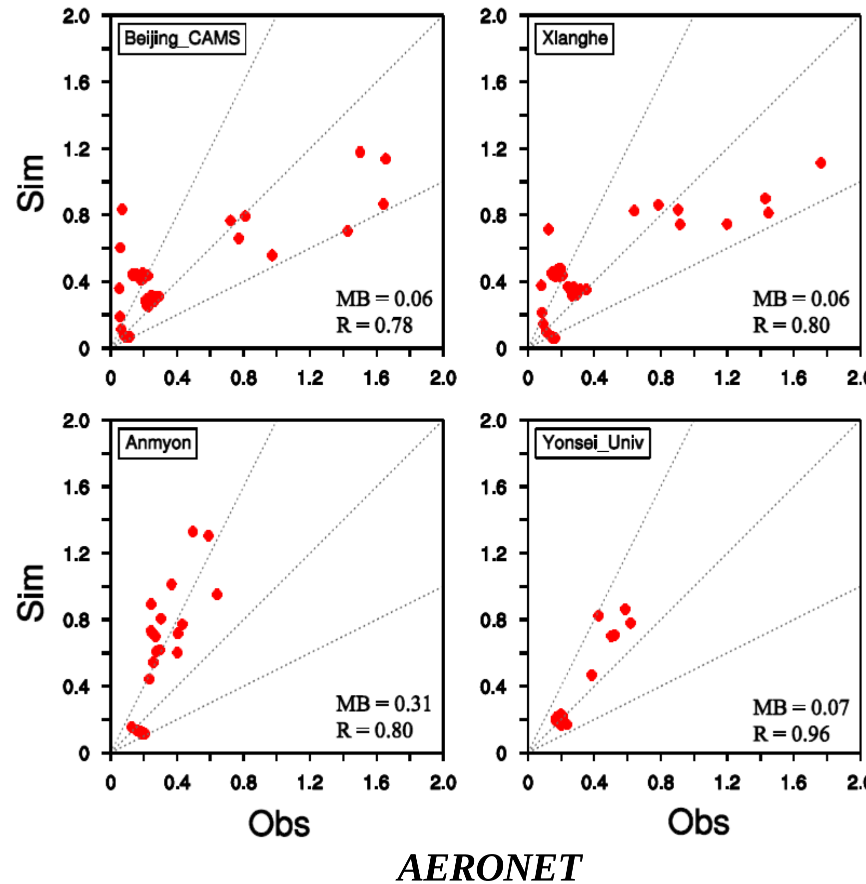
R : [0.45 , 0.86]
IOA : [0.46 , 0.91]

Scatter plots of hourly nitrate and sulfate concentrations



AOD at 550nm


20150414
Spatial R = 0.74
MODIS
WRF-Chem
20150415
Spatial R = 0.83
20150416
Spatial R = 0.75
20150417
Spatial R = 0.77
46°N
42°N
38°N
34°N
30°N
90°E
100°E
110°E
120°E
130°E
0.1
0.3
0.5
0.8
1.1
1.5
2

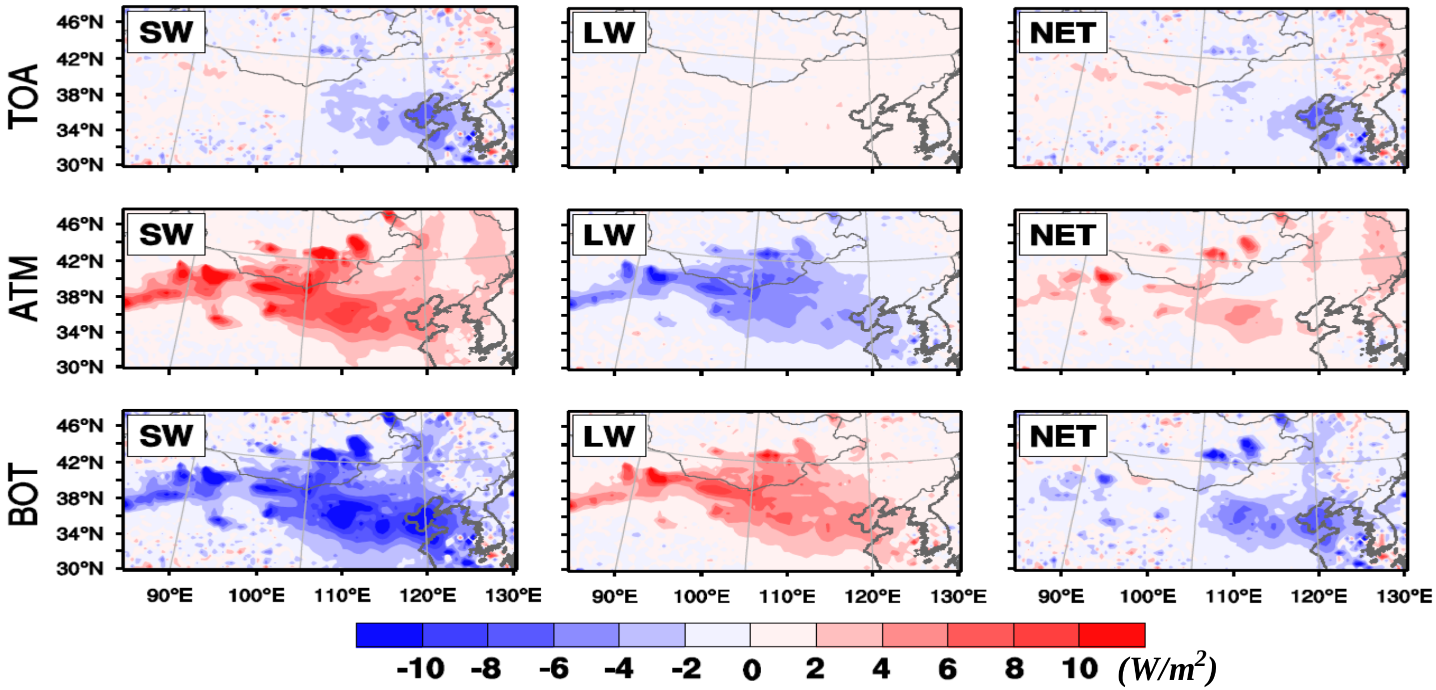

Beijing_CAMS
MB = 0.06
R = 0.78
Xianghe
MB = 0.06
R = 0.80
Anmyon
MB = 0.31
R = 0.80
Yonsei_Univ
MB = 0.07
R = 0.96
Sim
Obs
AERONET

Results

- Impacts of dust aerosols on radiative forcing.
- Impacts of dust aerosols on meteorological variables.
- Impacts of dust aerosols on pollutant concentrations.

Impacts of dust aerosols on radiative forcing

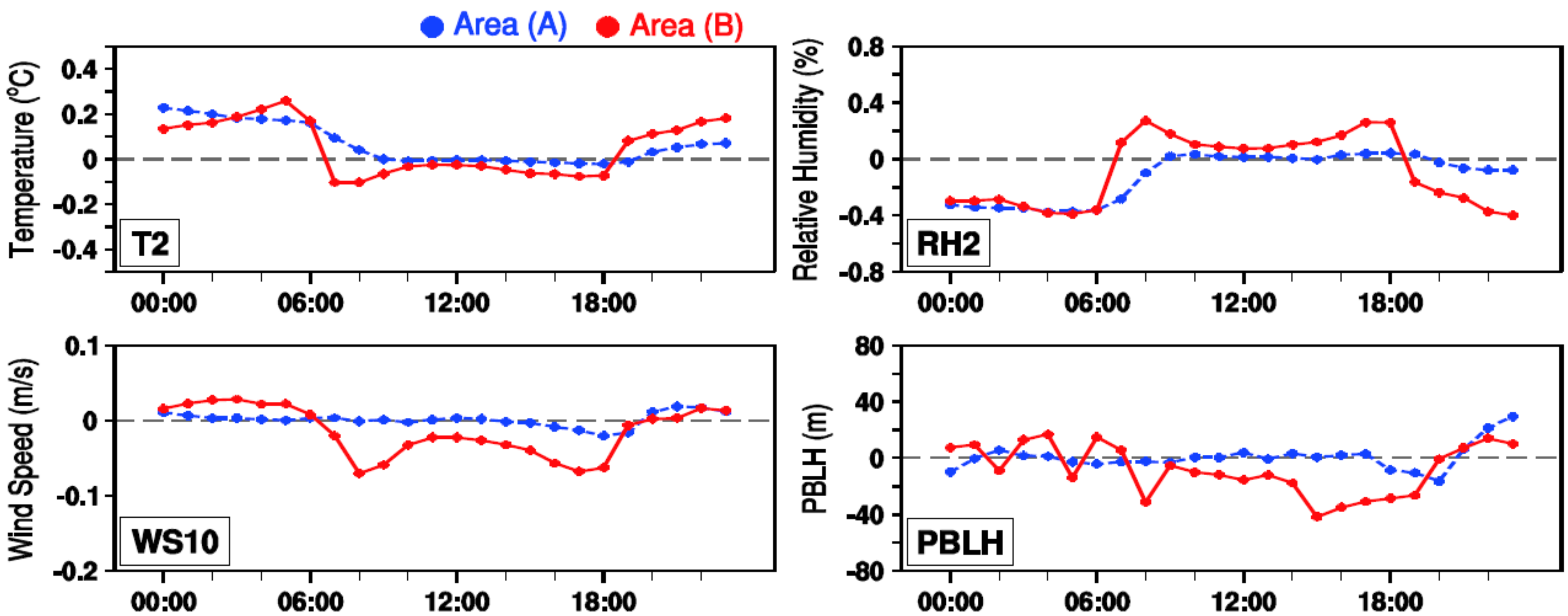
Results = D_NoH - NoD_NoH

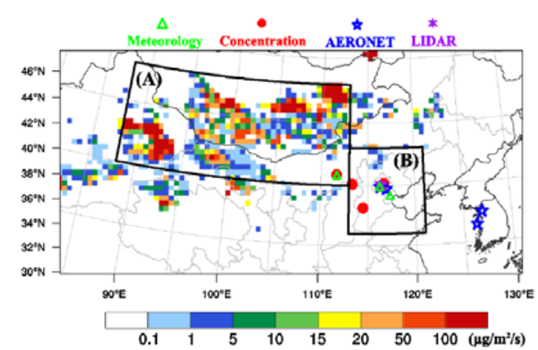


	SW	LW	NET
TOA	-0.54	0.25	-0.29
ATM	2.41	-1.50	0.90
BOT	-2.95	1.76	-1.19

Impacts of dust aerosols on meteorological variables

Results = D_NoH - NoD_NoH



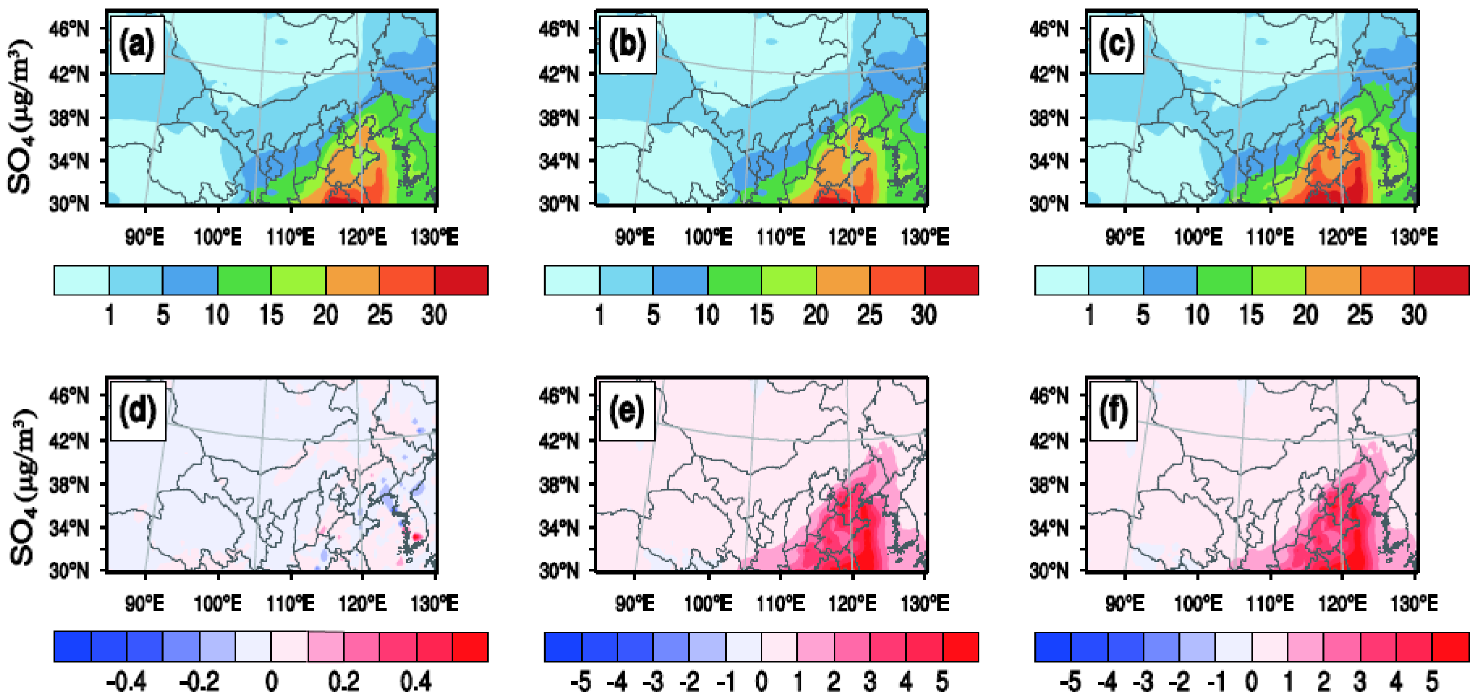


Impacts of dust aerosols on sulfate concentrations

NoD_NoH

D_NoH

CTL



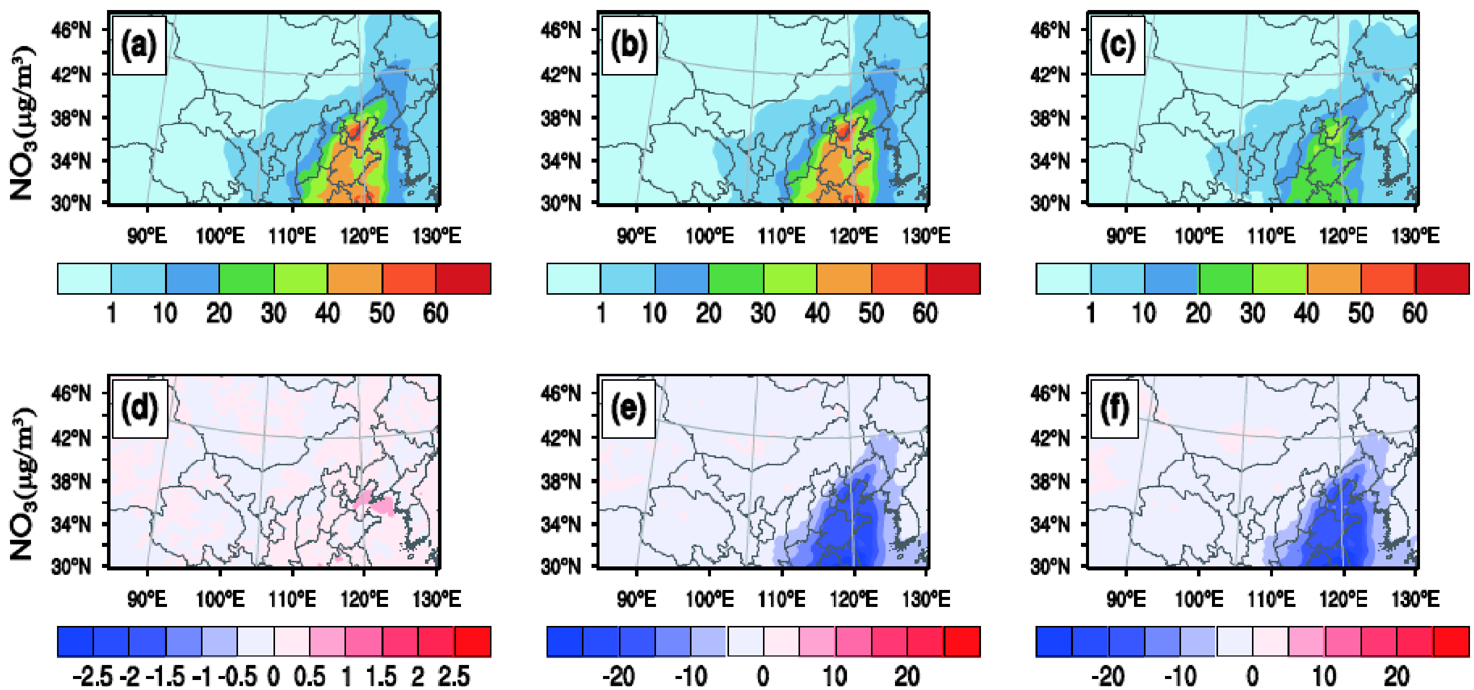
Results :
D_NoH - NoD_NoH

Results :
CTL - D_NoH

Results :
CTL - NoD_NoH

Impacts of dust aerosols on nitrate concentrations

NoD_NoH | **D_NoH** | **CTL**

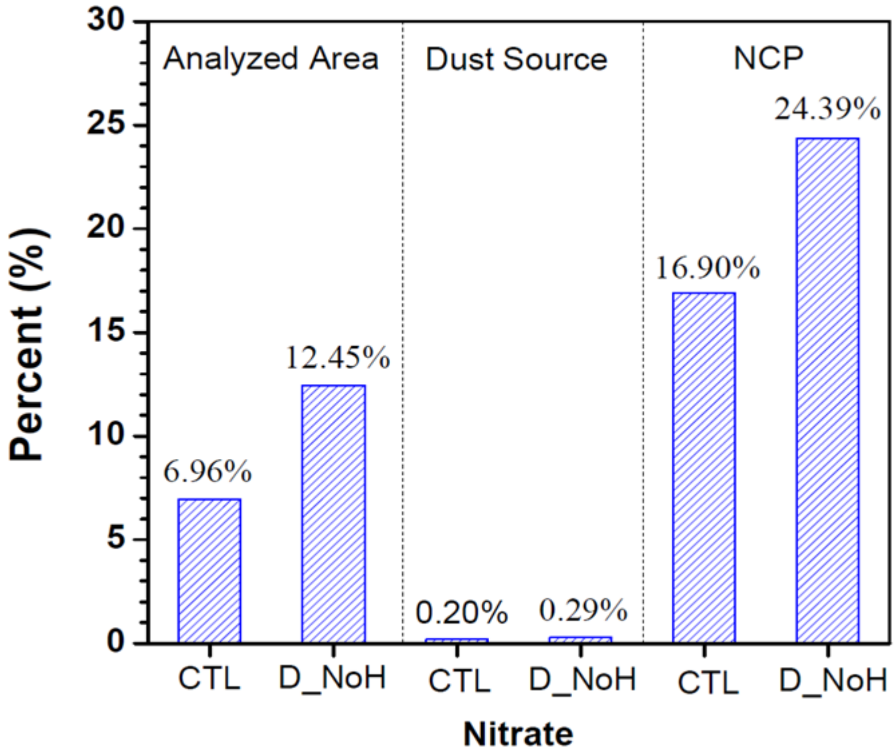


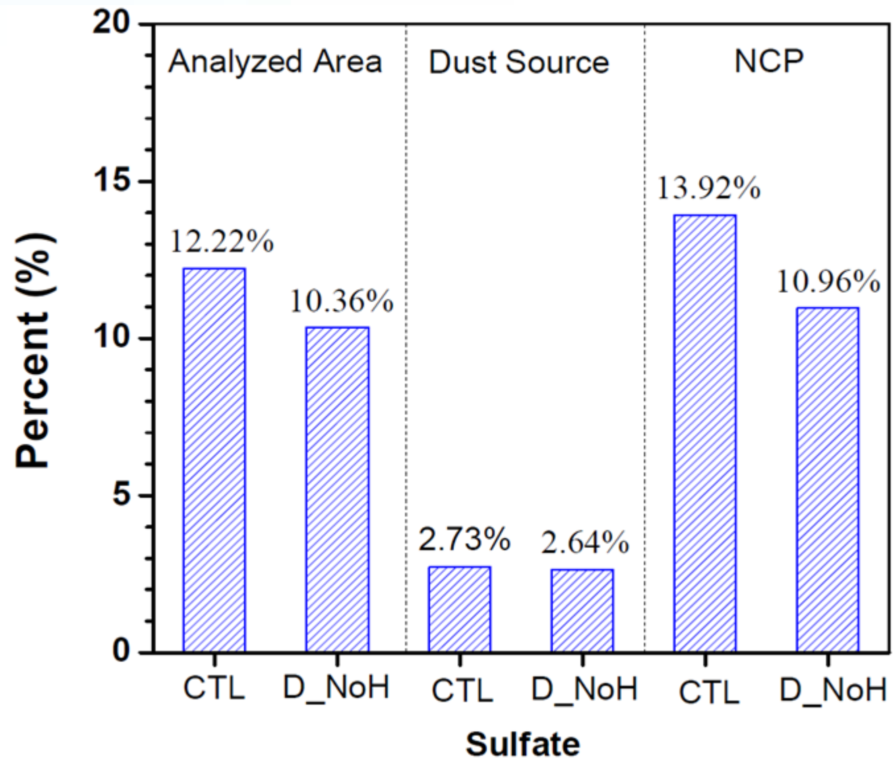
Results :
D_NoH - NoD_NoH

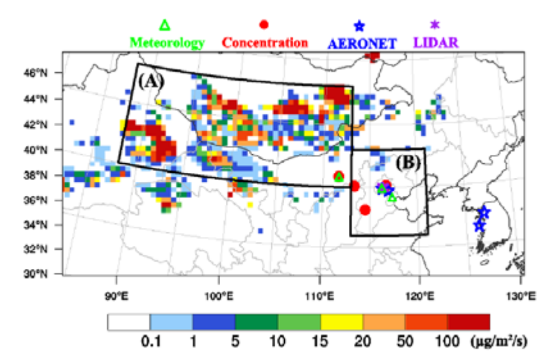
Results :
CTL - D_NoH

Results :
CTL - NoD_NoH

Mass percentage to $PM_{2.5}$







Conclusions

- Dust has a cooling effect (−1.19 W m^{-2}) at the surface, a warming effect (0.90 W m^{-2}) in the atmosphere and a small forcing (−0.29 W m^{-2}) at the top of the atmosphere averaged over East Asia.
- The near–surface air temperature is decreased by 0.01^{o}C and 0.06^{o}C in the daytime and increased by 0.13^{o}C and 0.14^{o}C at night averaged over dust sources and NCP. The changes in relative humidity are in the range of −0.38% to +0.04% for dust sources and −0.40% to +0.27% for NCP. The maximum decrease of wind speed is ~0.1 m s^{-1} over NCP. PBLH during the daytime exhibits maximum decreases of 16.34 m and 41.70 m over dust sources and NCP, respectively.
- Due to dust–related heterogeneous reactions, a maximum decrease of 35.04 μg m^{-3} for NO_3^- and a maximum increase of 9.47 μg m^{-3} for SO_4^{2-} are found over downwind areas.

Thank you