4th ACAM workshop, June 26-28, 2019, Kuala Lumpur, Malaysia

Impact of current emission reduction of air pollutants over BTH region in China on ambient concentrations; Preliminary results of modelling approach

June 26, 2019

Korea-China Joint Air Quality Research Project
Modeling Team Members
and
Chang-Keun Song (Project P. I.) / UNIST

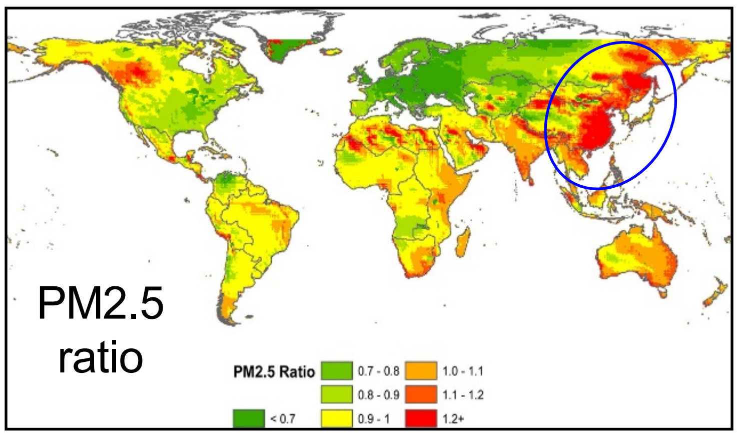
Contents

ULSAN NATIONAL INSTITUTE OF SCIENCE AND TECHNOLOGY

I-1. Background

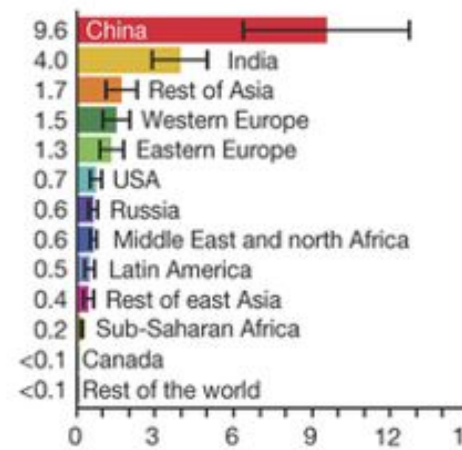
- Previous studies have reported serious air pollution problems over East Asia

Ratio of 2005:1990



(Brauer et al., ESNT, 2012)

air pollution-related deaths



(Zhang et al., Nature, 2017)

- China and Korea have been made huge efforts to reduce air pollution through implementing air quality (AQ) management and control policies, e.g., 2013 Clean Air Action in China, the SMA AQ Improvement Plan in Korea, and so on
- Korea and China have strengthened international research cooperation to examine the cause of air pollution via AQ monitoring and modeling

- In 2017, Korea-China Joint AQ research team was established in Beijing

I-2. Research goals

Korea-China Joint Air Quality Research Project; Modeling Part

- To assess the impact of recent Chinese air pollution mitigation efforts on air quality(AQ) changes, especially ambient concentration over Chinese and Korean regions, through AQ modeling approach

- To improve the AQ modeling performance of Korea and China

II. Methods and Results

ULSAN NATIONAL INSTITUTE OF SCIENCE AND TECHNOLOGY

II-1. Overview of modeling study in the project

- Implementation and evaluation of the high resolution(9km * 9km) different two chemical transportation models (CMAQ, CAMx) in the Asia domain
- Test model sensitivity to the different emission input datasets (i.e., w and w/o pollution controls in the Jing-Jin-Ji area in China

ULSAN NATIONAL INSTITUTE OF SCIENCE AND TECHNOLOGY

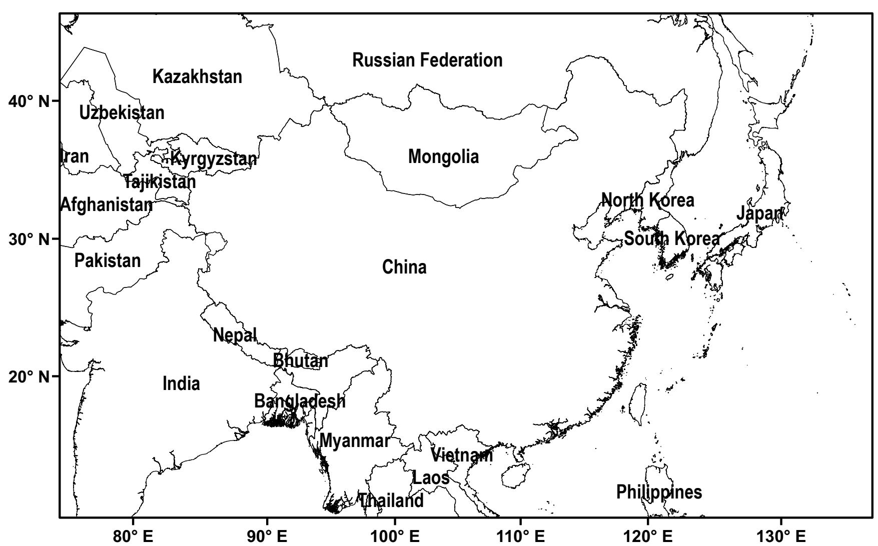
II-2. Overall procedure of AQ simulations and analyses

1. Establish high resolution modeling systems for the Asian region including China and Korea Peninsula: grid system of 9 km X 9km
   - CMAQ (Korea team) and CAMx (China team)

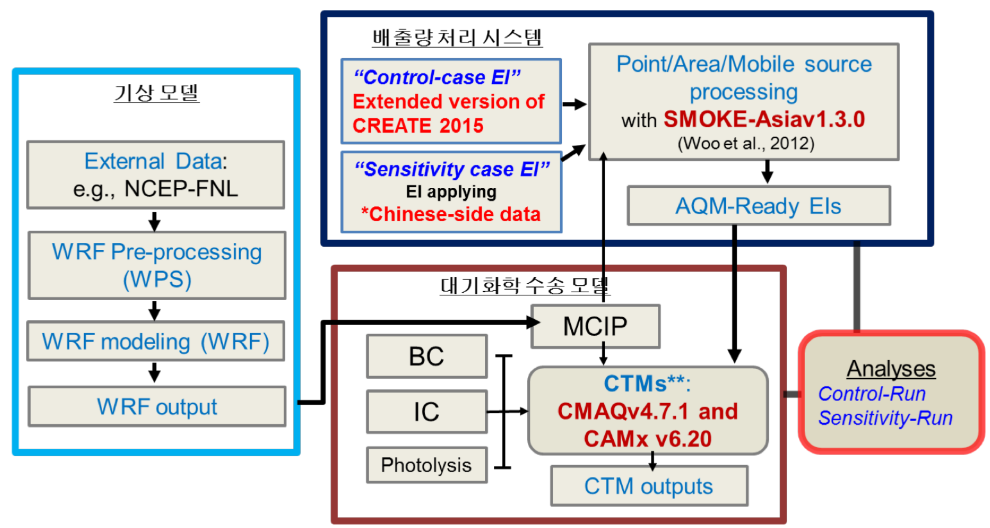
2. Develop modeling emission inventory (EI) data sets for two cases
   - Control-case (CON-EI): EI without emission reductions over JJJ
   - Sensitivity-case (SENS-EI): EI with consideration of emission reductions

3. Implement the modeling systems for three months: Oct. and Dec. in 2017, and Feb. 2018

4. Assess the effects of emission reductions over JJJ on the air quality in JJJ itself and Seoul Metropolitan Area (SMA) in Korea



Model domain for the fine grid modeling system (840 x 520 = 436,800 grids)

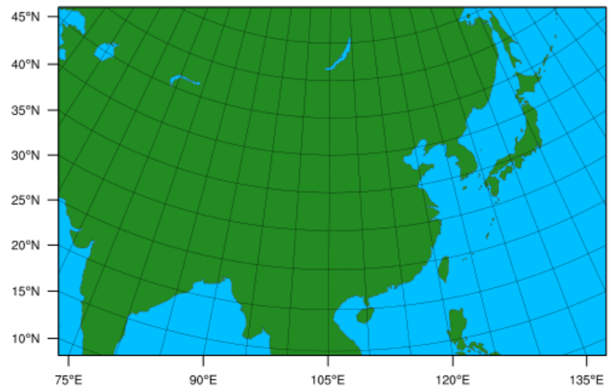


Modeling Framework (Emission scenarios and Inputs…)

III-3. Meteorological Model Configuration

Model	**WRFv3.9.1.1**
Basic equation	Compressible, Non-hydrostatic
Horizontal resolution	9km (880×560 grids)
Horizontal grid	Arakawa-C
Domain structure	Non-Nested grid
Vertical coordinate	Terrain following height
Vertical layers	43
Data assimilation	On
Cumulus parameterization	Kain-Fritsch (new Eta) scheme
TKE closer	horizontal Smagorinsky first order closure
PBL scheme	YSU scheme
Microphysics	WSM3
Radiation	RRTM scheme/ Dudhia scheme
Soil layer	Noah land-surface model
Land use type	USGS EROS (13 categories)

WPS Domain Configuration



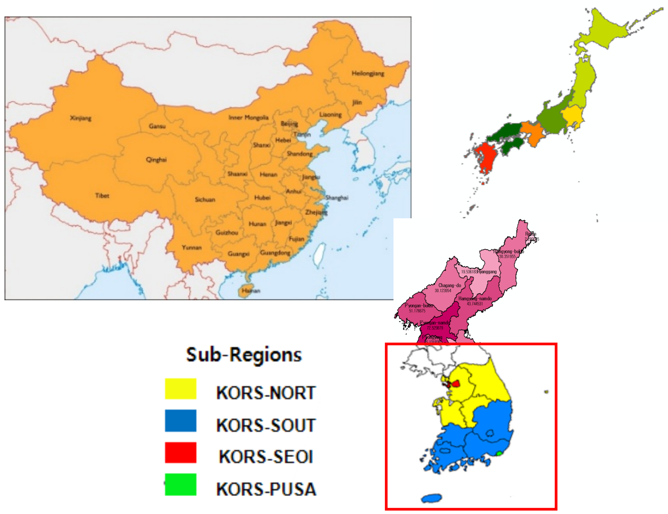
NCEP FNL

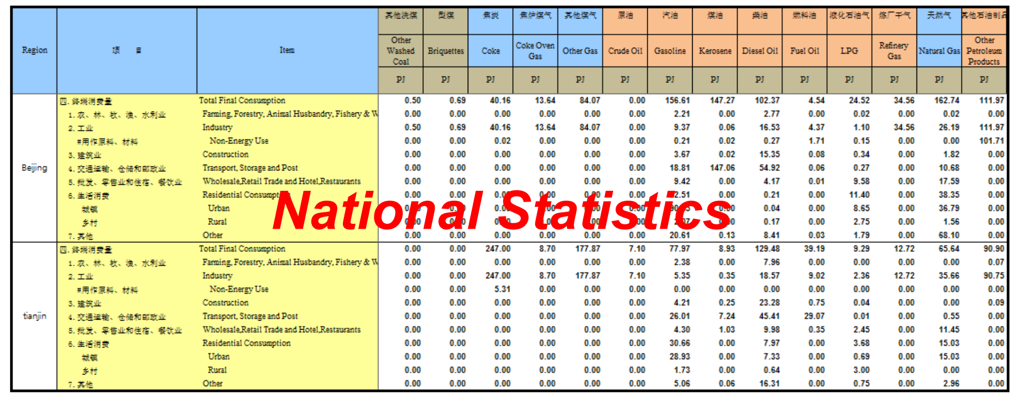
Data Format	WMO_GRIB2
Product	analysis
Resolution	1° x 1°
N of vertical levels/layers	62
Total N of fields	353

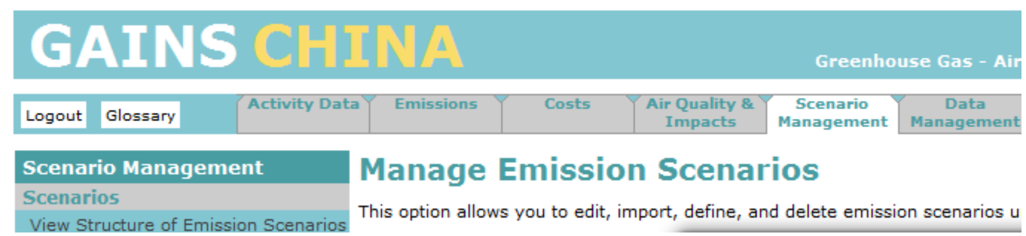
– Performed FDDA(four-dimensional data assimilation) during WRF simulation (analysis nudging)

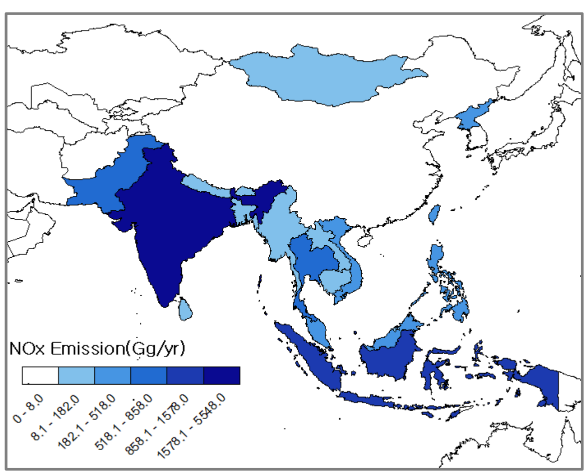
III-4. Configuration of Base Emission Inventory

Comprehensive **R**egional **E**missions inventory for **A**tmospheric **T**ransport **E**xperiments (CREATE)









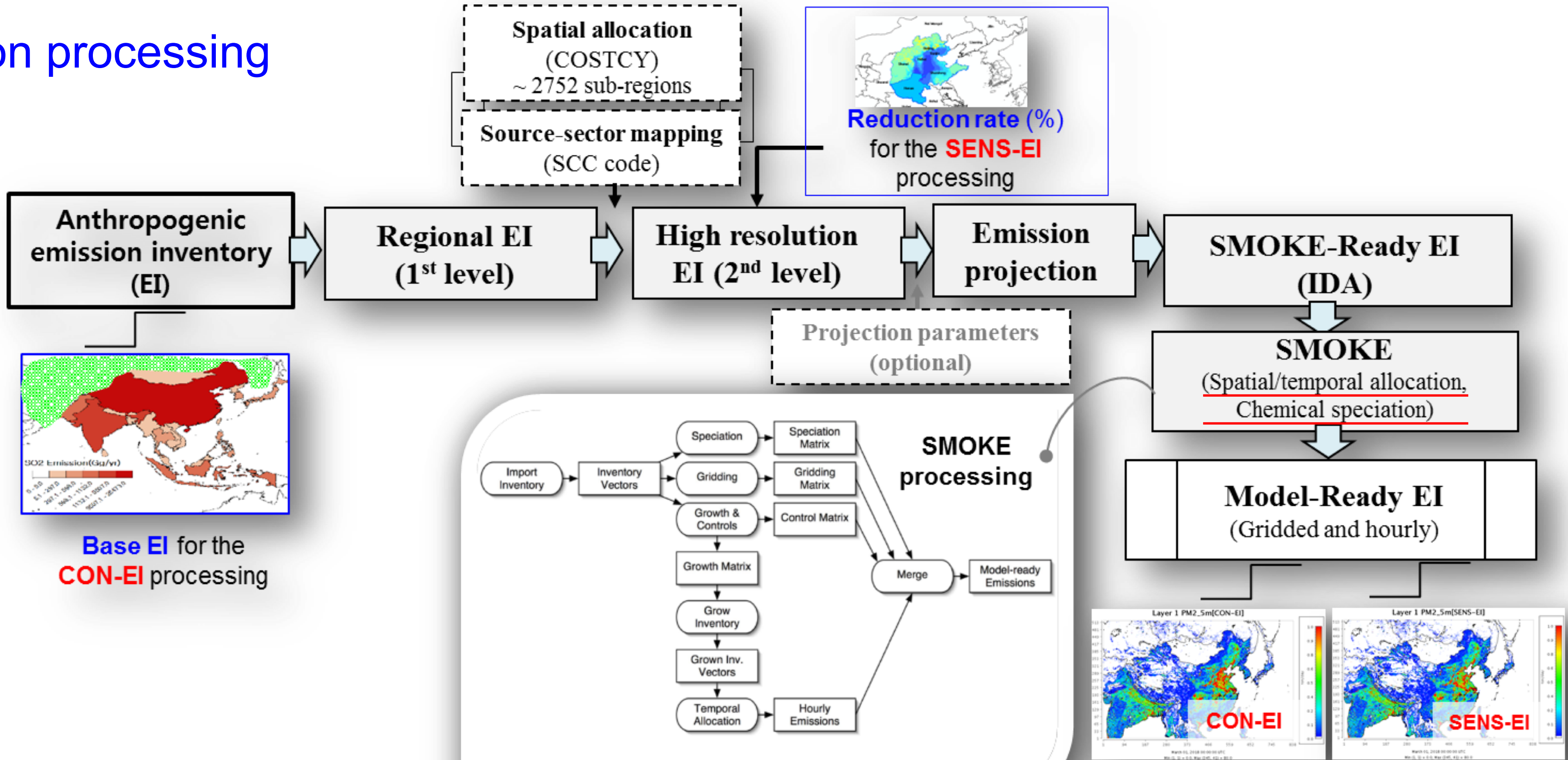
1. Year 2015

2. Regionally classifiable emission sources: ~180 of primarily sectors and 300-500 combination of sectors-fuels

3. Pollutants: PM_{10}, $PM_{2.5}$, NO_x, SO_2, VOC, NH_3, CO, BC, OC, CO_2, CH_4, N_2O, Mercury

II-5. Development of Model-Ready Emissions

Emission processing

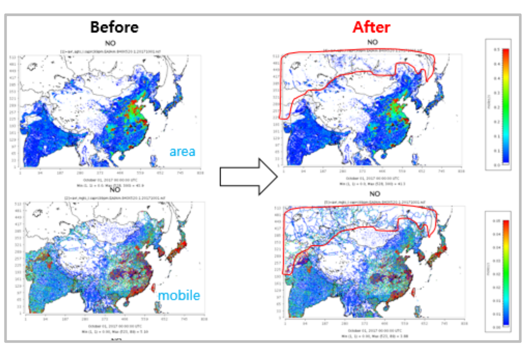


CON-EI: Without emission reductions (CREATE2015_ Extended)

SENS-EI: With emission reduction rates in JJJ China in 2017

CON-EI By **CREATE 2015**

CON-EI By **CREATE 2015_Extented**



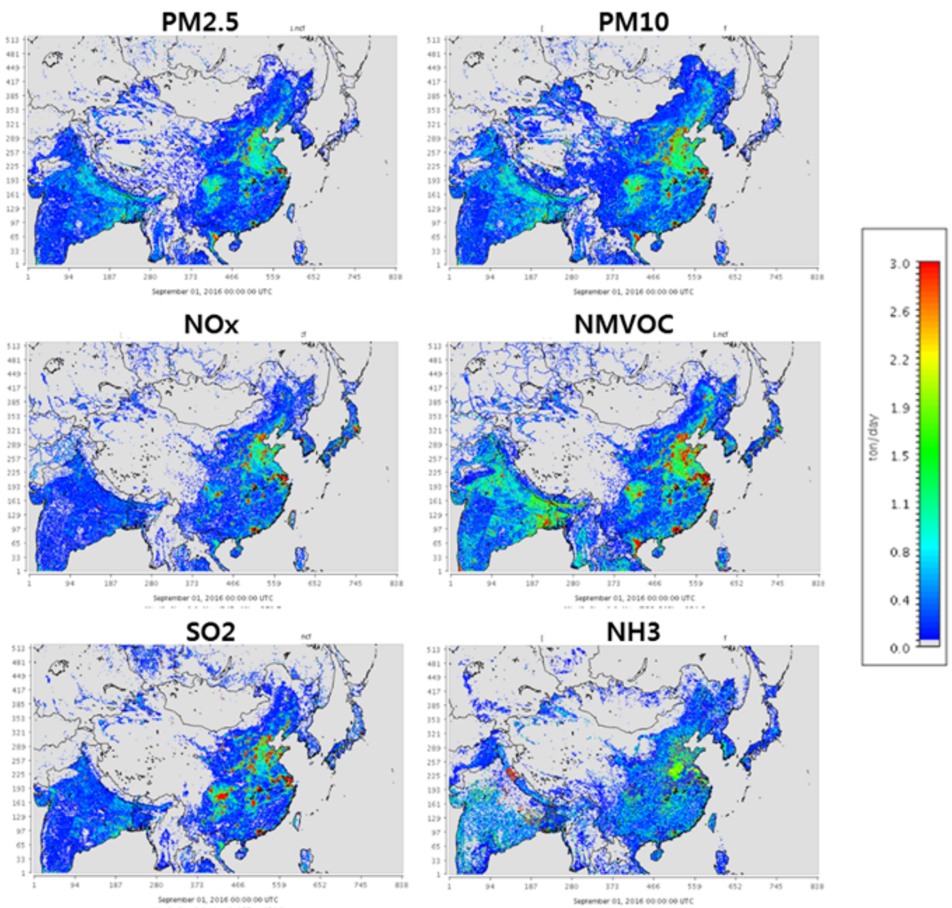
CREATE 2015_Extended: CREATE 2015 + emissions in Asian Russia, STAN countries (Afghanistan, Uzbekistan, etc.) and Iran

ULSAN NATIONAL INSTITUTE OF SCIENCE AND TECHNOLOGY

II-5. Development of Model-Ready Emissions (continued)

- **CON-EI**

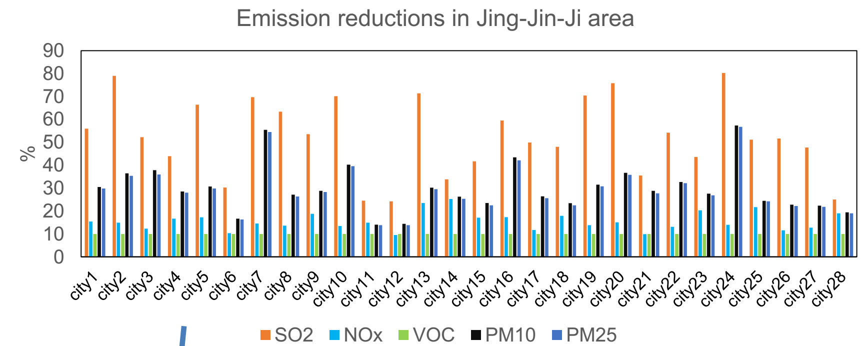
Developed by CREATE 2015_Extented emissions / produced by UNIST

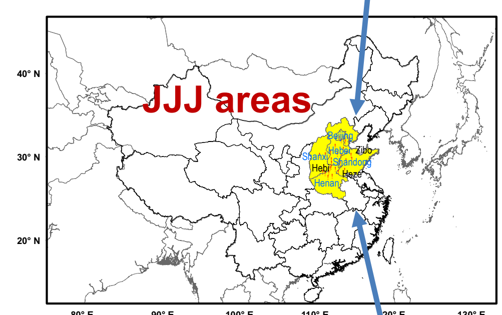


Mean emission flux (tons/day/grid) for 14 months (2016.09 – 2017.03 & 2017.09 – 2018.03)

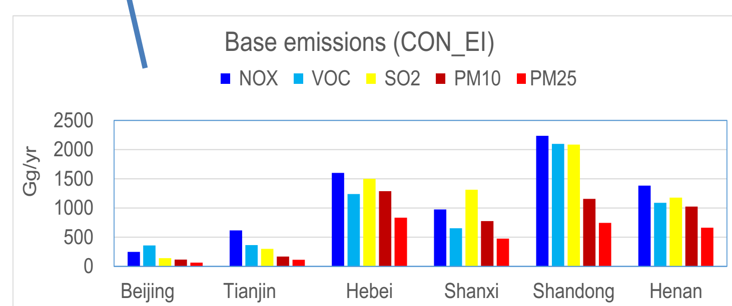
- **SENS-EI**

Developed by applying the reduction information in 2017 against 2016 in JJJ / provided by CRAES





NOx -16%, VOC -10 %, SO2 -53%, PM10 -30%, PM2.5 -29%



Total emissions in 2016

III-6. Configuration of Chemical Transport Model

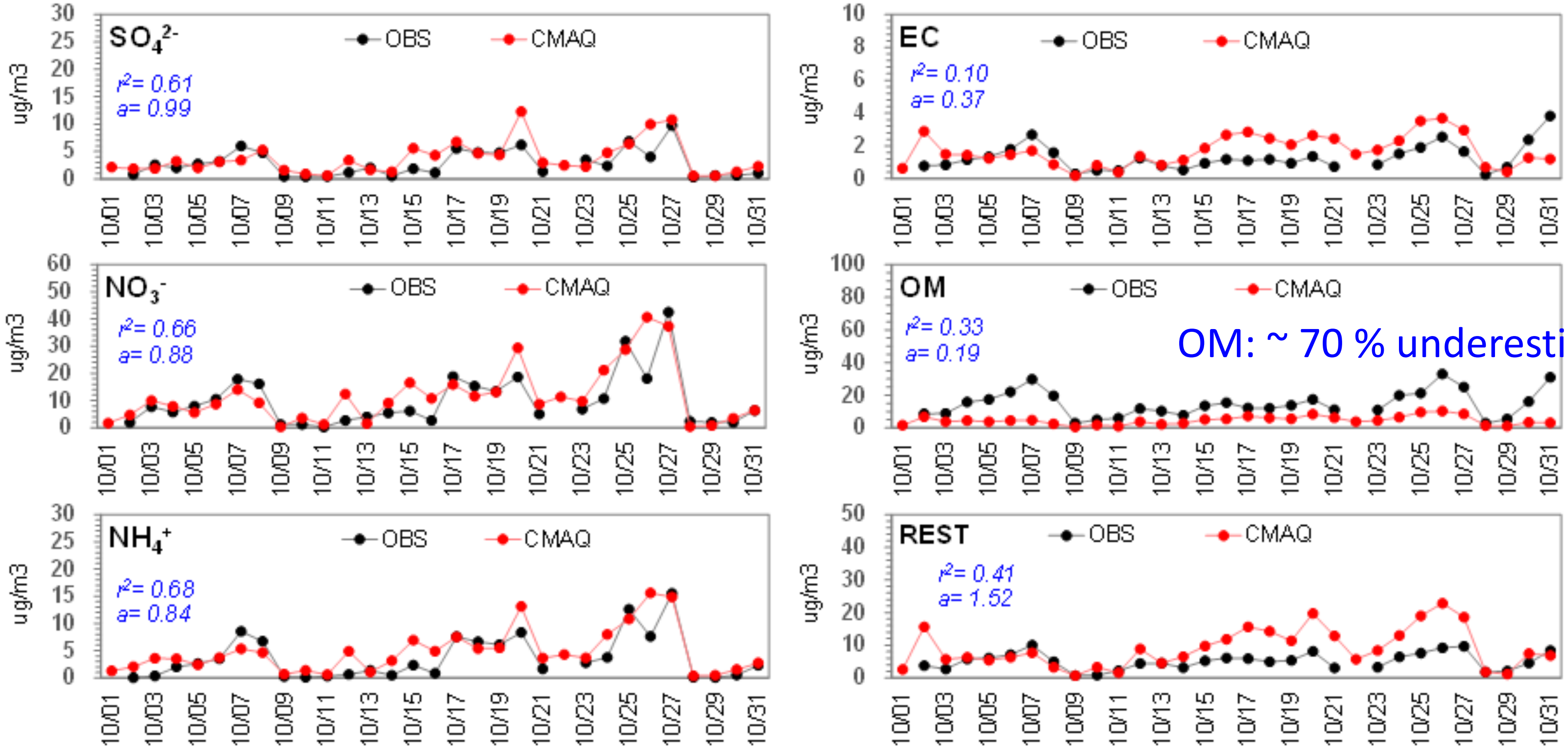
	Korea	**China**
Air quality model	**CMAQv4.7.1**	**CAMx v6.20**
Map projection	LCC	LCC
Model run type	Off-line	Off-line
Vertical coordinate	Terrain following	Terrain following
Horizontal resolution	9km x 9 km (840 x 520 grids)	9km x 9 km (840 x 520 grids)
Vertical layers	24	20
Gas phase chemistry	SAPRC 99 mechanism	SAPRC 99 mechanism
Aqueous chemistry	RADM2 Chemistry	RADM2 Chemistry
Aqueous phase species	17 rxns, 9 components	17 rxns, 9 components
Dry deposition	RADM2 module	WESELY89
Wet deposition	RADM2 module	RADM2 module
Aerosol thermodynamics	AERO5	CF
Anthropogenic emissions	1) CON-EI: CREATE15'_Ext 2) SENS-EI: Adjusted CREATE15'_Ext with reduction info.	1) CON-EI: CREATE15'_Ext 2) SENS-EI: Adjusted CREATE15'_Ext with reduction info.
Vertical Diffusivity	ACM2	ACM2

ULSAN NATIONAL INSTITUTE OF SCIENCE AND TECHNOLOGY

II-7. Evaluation of the AQ simulation results

- **CMAQ** (Korea team) **predictions** *vs.* **Beijing In-situ measurements** (October 2017)

Inorganic / overall good performance *vs.* **Organic** / under-predictions



OM: ~ 70 % underestimation

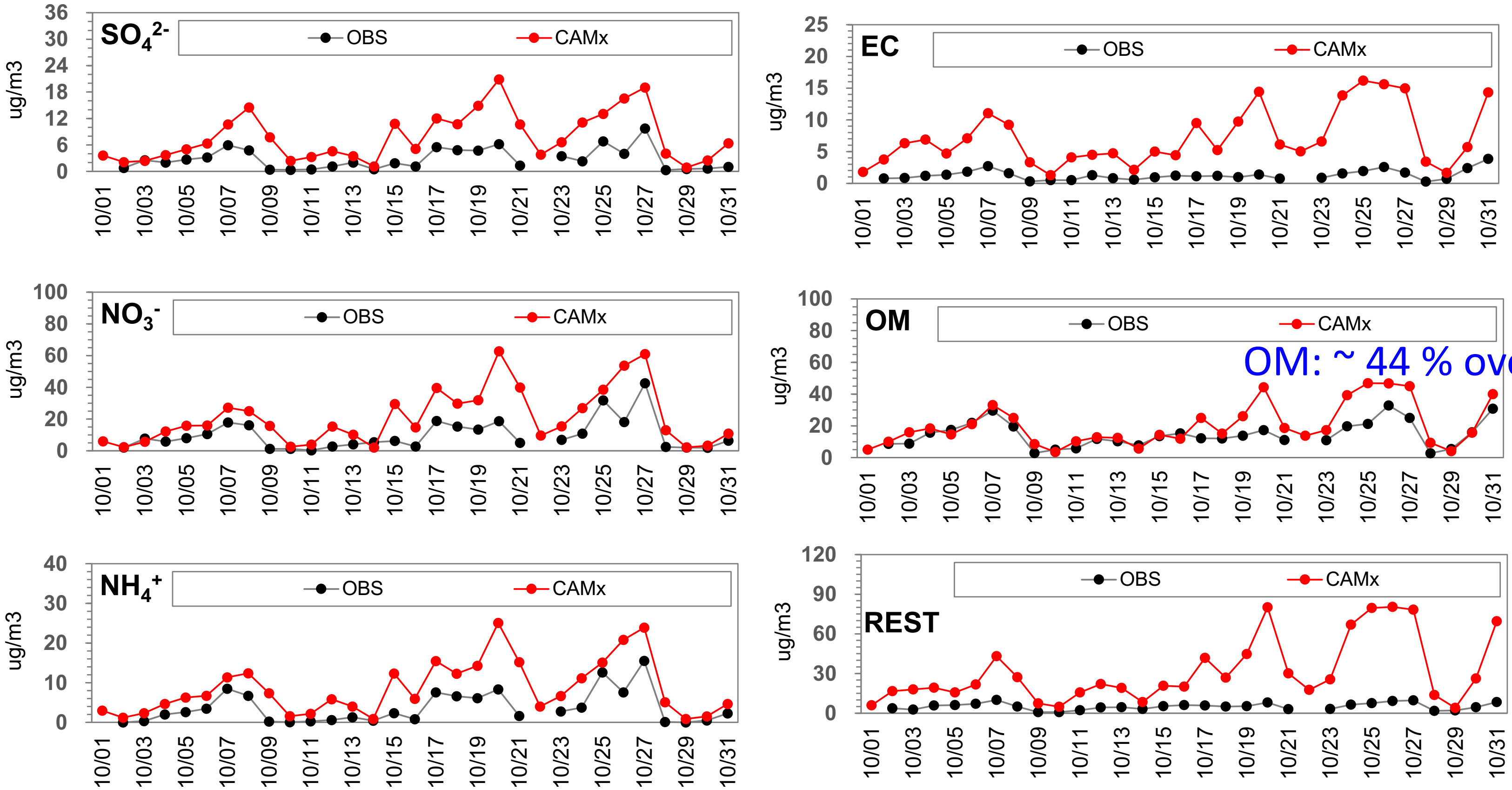
Inorganic species (SO4, NO3 and NH4):
about 20-35% overestimation

ULSAN NATIONAL INSTITUTE OF SCIENCE AND TECHNOLOGY

II-7. Evaluation of the AQ simulation results (continued)

- **CAMx** (China team) **predictions** *vs.* **Beijing In-situ measurements** (October 2017)

Inorganic / over-predictions *vs.* **Organic** / good performance



OM: ~ 44 % overestimation

Inorganic species (SO4, NO3 and NH4):
about 120 – 190 % overestimation

ULSAN NATIONAL INSTITUTE OF SCIENCE AND TECHNOLOGY

II-7. Evaluation of the AQ simulation results (continued)

- **CMAQ** (Korea team) **predictions** vs. **In-situ measurements @ Beijing, Baengnyung, and Seoul** (Oct. & Dec. in 2017, and Feb. 2018) → Large bias errors in OM

  * OM fractions in $PM_{2.5}$ mass: ~33% in Beijing, ~20% in Baengnyung, and ~27% in Seoul

Need to improve OM simulation capability !!

Beijing

Month	Variable (㎍/㎥)	OBS mean	OBS n	MODEL mean	MODEL n	MB (㎍/㎥)	NMB (%)	r
2017.10	$PM_{2.5}$	61.66	29	35.17	31	-26.49	-41.2	0.80
	SO4	2.81	29	3.68	31	0.88	34.6	0.78
	NO3	9.84	29	11.50	31	1.65	20.3	0.81
	NH4	3.63	29	4.75	31	1.12	34.5	0.82
	EC	1.28	29	1.71	31	0.42	36.5	0.31
	OM	**14.64**	**29**	**4.47**	**31**	**-10.17**	**-68.6**	**0.58**
	REST	5.06	29	8.96	31	3.90	83.6	0.64
	SEASALT	0.38	26	0.09	31	-0.29	-71.6	0.08
2017.12	$PM_{2.5}$	41.08	30	28.04	31	-13.03	-30.9	0.60
	SO4	1.73	30	1.36	31	-0.38	-20.5	0.55
	NO3	3.44	29	6.75	31	3.31	102.6	0.80
	NH4	1.61	30	2.47	31	0.86	55.9	0.80
	EC	1.31	30	1.81	31	0.50	39.6	0.21
	OM	**15.95**	**30**	**7.73**	**31**	**-8.22**	**-51.3**	**0.36**
	REST	4.92	30	7.89	31	2.96	62.5	0.36
	SEASALT	2.31	30	0.05	31	-2.27	-98.0	0.36
2018.02	$PM_{2.5}$	52.67	27	28.46	28	-24.21	-45.6	0.80
	SO4	6.02	26	1.31	28	-4.71	-77.7	0.87
	NO3	8.71	26	5.99	28	-2.72	-28.3	0.82
	NH4	4.36	27	2.23	29	-2.13	-46.8	0.88
	EC	1.14	27	2.04	28	0.90	81.0	0.44
	OM	**18.65**	**27**	**8.71**	**28**	**-9.94**	**-53.0**	**0.68**
	REST	9.13	27	7.93	28	-1.19	-13.0	0.23
	SEASALT	2.71	27	0.18	28	-2.52	-93.0	0.39

Baengnyung

Month	Variable (㎍/㎥)	OBS mean	OBS n	MODEL mean	MODEL n	MB (㎍/㎥)	NMB (%)	r
2017.10	$PM_{2.5}$	15.43	741	4.05	744	-11.38	-73.7	0.66
	SO4	1.67	688	1.47	744	-0.20	-8.6	0.76
	NO3	1.12	688	0.11	744	-1.00	-89.5	0.46
	NH4	0.81	688	0.50	744	-0.31	-36.2	0.68
	EC	0.63	710	0.19	744	-0.44	-70.2	0.53
	OM	**3.37**	**710**	**0.65**	**744**	**-2.72**	**-80.7**	**0.51**
	REST	0.56	657	1.03	744	0.47	84.5	0.52
	SEASALT	0.63	688	0.10	744	-0.53	-83.2	0.11
2017.12	$PM_{2.5}$	22.17	742	4.63	744	-17.54	-79.1	0.57
	SO4	1.66	688	0.98	744	-0.67	-40.5	0.36
	NO3	2.66	688	1.10	744	-1.56	-59.4	0.59
	NH4	1.27	688	0.65	744	-0.62	-49.5	0.63
	EC	0.90	700	0.15	744	-0.75	-83.6	0.61
	OM	**4.99**	**700**	**0.80**	**744**	**-4.19**	**-83.8**	**0.62**
	REST	0.78	646	0.89	744	0.11	13.6	0.64
	SEASALT	0.54	688	0.07	744	-0.47	-86.7	0.31
2018.02	$PM_{2.5}$	24.20	660	7.01	672	-17.19	-71.9	0.76
	SO4	3.08	601	1.41	672	-1.67	-62.9	0.82
	NO3	3.56	601	1.35	672	-2.22	-66.4	0.41
	NH4	1.83	601	0.89	672	-0.94	-58.7	0.75
	EC	0.55	393	0.27	672	-0.29	-64.0	0.58
	OM	**3.77**	**393**	**1.39**	**672**	**-2.37**	**-71.0**	**0.64**
	REST	0.99	577	1.48	672	0.48	30.2	0.35
	SEASALT	1.09	601	0.22	672	-0.87	-79.7	0.36

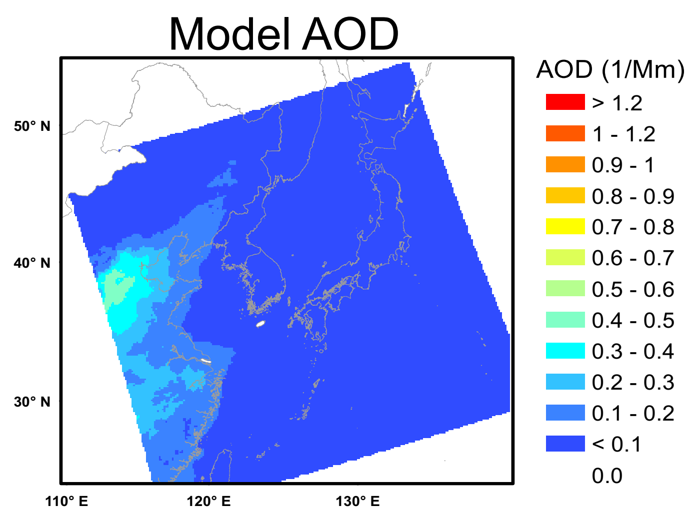
Seoul

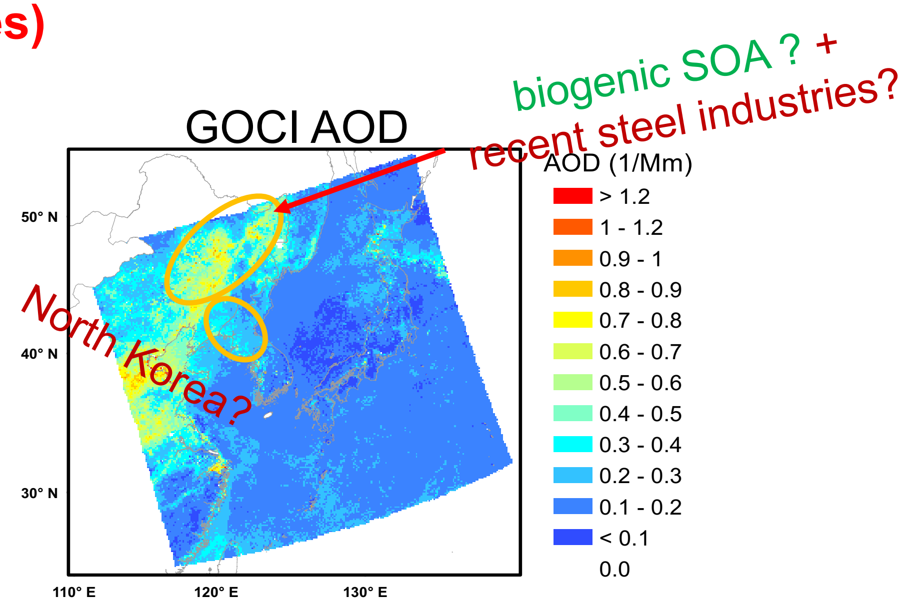
Month	Variable (㎍/㎥)	OBS mean	OBS n	MODEL mean	MODEL n	MB (㎍/㎥)	NMB (%)	r
2017.10	$PM_{2.5}$	17.74	742	5.20	744	-12.54	-70.7	0.44
	SO4	2.94	576	1.11	744	-1.82	-62.4	0.34
	NO3	2.06	576	0.94	744	-1.12	-62.8	0.31
	NH4	1.94	576	0.66	744	-1.28	-68.7	0.32
	EC	1.37	113	0.46	744	-0.91	-64.3	-0.01
	OM	**9.08**	**113**	**0.78**	**744**	**-8.31**	**-88.9**	**-0.36**
	REST	0.55	331	1.14	744	0.59	32.6	0.40
	SEASALT	ND	0	0.10	744	ND	ND	ND
2017.12	$PM_{2.5}$	30.59	744	12.11	744	-18.48	-60.4	0.32
	SO4	3.43	686	1.03	744	-2.40	-69.4	0.48
	NO3	8.77	686	4.59	744	-4.18	-48.5	0.33
	NH4	4.50	686	1.78	744	-2.72	-60.6	0.44
	EC	1.13	648	0.91	744	-0.22	-17.9	-0.10
	OM	**7.68**	**648**	**1.60**	**744**	**-6.08**	**-78.7**	**0.07**
	REST	0.98	664	1.97	744	0.99	103.7	0.03
	SEASALT	0.93	686	0.22	744	-0.70	-75.4	0.34
2018.02	$PM_{2.5}$	27.57	672	12.77	672	-14.80	-53.7	0.60
	SO4	3.26	644	1.43	672	-1.83	-56.1	0.86
	NO3	5.57	644	4.10	672	-1.47	-26.4	0.38
	NH4	3.23	644	1.75	672	-1.48	-45.7	0.64
	EC	0.89	469	0.88	672	-0.01	-3.7	0.27
	OM	**7.87**	**469**	**2.03**	**672**	**-5.84**	**-74.5**	**0.49**
	REST	0.97	615	2.34	672	1.38	143.1	0.44
	SEASALT	0.75	644	0.23	672	-0.52	-68.9	0.68

II-7. Evaluation of the AQ simulation results (continued)

● **CMAQ** (Korea team) **AOD** vs. **GOCI AOD** (Oct 2017 case)

Need to consider other emission sources (BVOCs and unidentified sources)





- Lower CMAQ AOD than GOCI AOD, especially over the north eastern China regions → the possibility of underestimation in PM sources in EI and missed new emission sources
- Need to include new **organic aerosol sources** (BVOC emissions) into EI and to cooperate with Chinese researchers to **update EI information** over the northeastern part of China

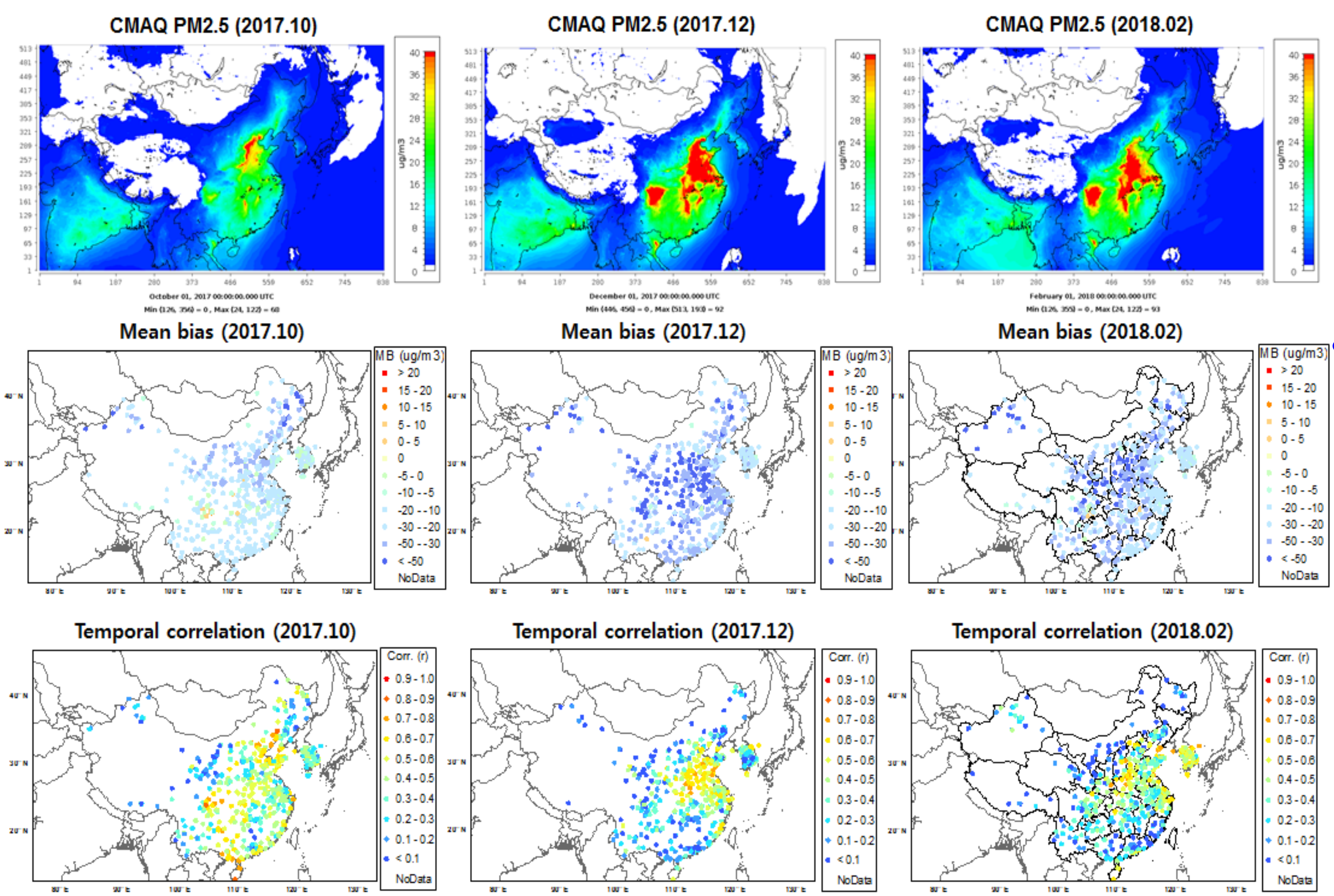
**For CMAQ AOD, IMPROVE 2007 algorithm (Hand et al., 2011) was adopted.*
**GOCI: The Geostationary Ocean Color Imager*

ULSAN NATIONAL INSTITUTE OF SCIENCE AND TECHNOLOGY

II-7. Evaluation of the AQ simulation results (continued)

- **CMAQ** (Korea team) **$PM_{2.5}$ mass conc. @ more than 1500 monitoring sites** in China and Korea (Oct. & Dec. in 2017, and Feb. 2018)

Need to improve meteorology over Korean Peninsula



- BTH, Shandong and Shanghai areas in China: overall good performance
- Overall better predictions of PM2.5 in China than the Korean peninsula
  - lower biases and higher temporal correlations over BTH, Shandong and Shanghai areas in China
- Lower temporal correlations in Korea in Oct and Dec 2017
  - meteorological(met.) variables are important factors (e.g., wind speed)
  - not easy to improve met. predictions in the Korean peninsula with complex geomorphology (e.g., West Sea and complex terrain)

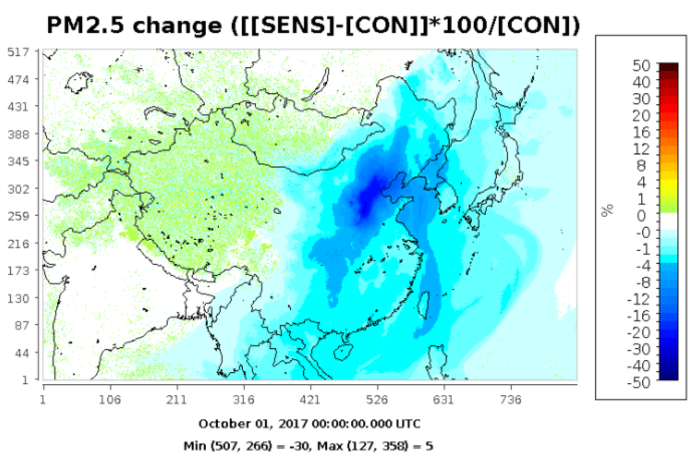
II-8. China emission reduction effects

- **Impact of emission reductions in JJJ on $PM_{2.5}$** in China and surrounding countries: **monthly mean** and **high episode mean**

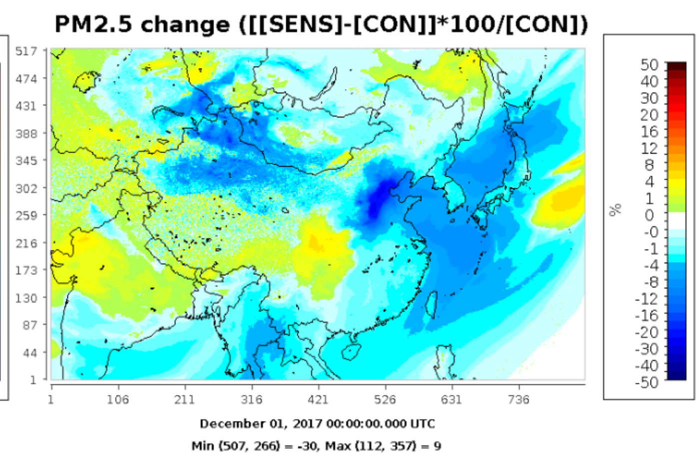
Monthly averaged effects (PM2.5)
: about 5%-30% decrease over JJJ, China and **only 1-5% over Korea**

The long-term averaged effects are mainly on China.

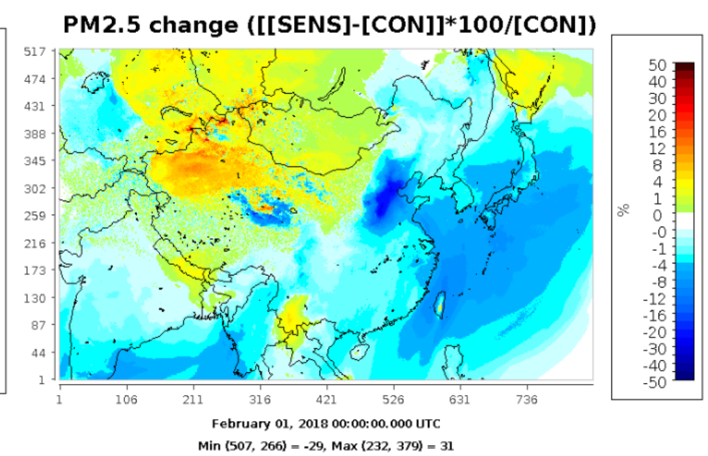
Oct 2017



Dec 2017



Feb 2018



II-8. China emission reduction effects (continued)

- **Effects of emission reductions in JJJ on $PM_{2.5}$** in **China and Korea**:

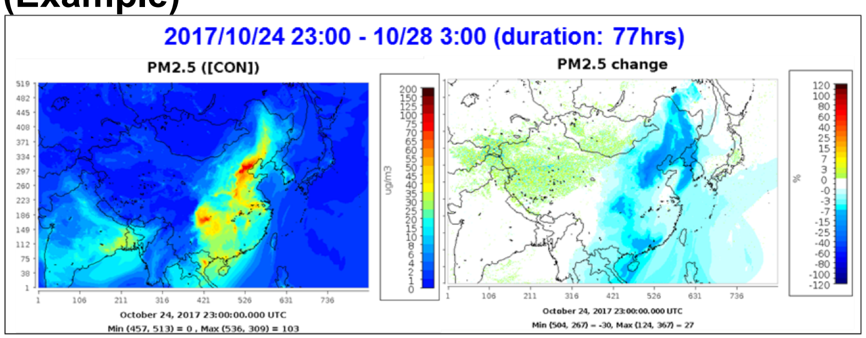
High concentration episodes: only JJJ vs. JJJ and SMA Korea

* high episode: the case that PM2.5 mass conc. 75 ㎍/㎥ or more lasts more than 4 hours

The effects during high concentration events are significant on both China(~50%) and Korea(~25%).

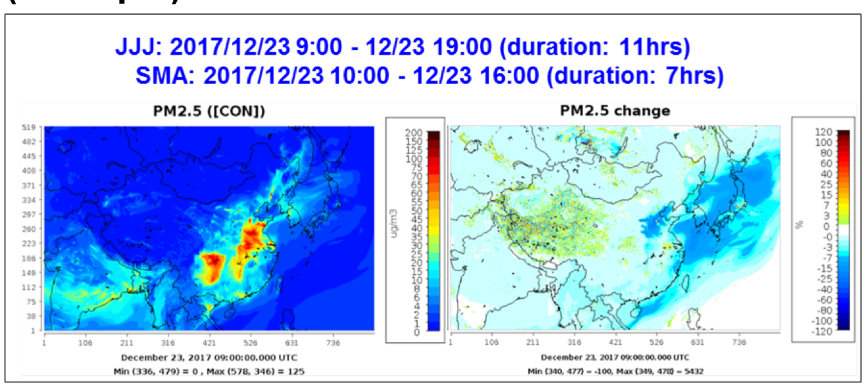
High episodes **only in JJJ** (20 cases)	… **both in JJJ & SMA Korea** (3 cases)
• Oct 2017 (9 cases): **about 3-50% decrease over JJJ, ~17% over South-Korea**, 3-17% over North-Korea • Dec 2017 (4 cases): **7-40% over JJJ, up-to 20% over South-Korea** • Feb 2018 (7 cases): **7-50% over JJJ, up-to 25% over South-Korea**	• Dec 2017 (2 cases): **about 7-40% decrease over JJJ, upto 20% over South-Korea** • Feb 2018 (1case): **10-90% over JJJ, 1-7% in South-Korea**

(Example)



7-40% reductions over JJJ (maximum ~ 21 ㎍/㎥ reduction), 1-15% reductions in South-Korea

(Example)



5-50% reductions across Hebei-Tianjin (maximum ~ 25 ㎍/㎥ reduction) (whereas, 3-15% increases in some locations), 1-20% reductions over South-Korea

III. Future Works

1) Improving model performance

- do model simulation for the

- Conduct multiple experiments by considering the lessons from previous works

+ To improve OM simulation

1) adding biogenic emissions and other new emission sources
2) including **GEOS-Chem modeling in addition to CMAQ and CAMx**
3) applying the latest version of CMAQ (v5.x with up-to-date SOA science module)

+ To improve meteorology

1) Use various sets of re-analysis data (e.g., **ECMWF**) for IC and FDDA

2) Expanding modeling period

- new time period : Oct. & Dec. in 2018, and Feb. 2019

3) Continuing to assess the impacts of the recent emission controls in China(JJJ) on the AQ over China and Korea

- quantify the effects (%) of the recent Chinese emission control policy (e.g., Air Pollution Prevention Action Plan)

Thank you for your attention!

Additional slides for ‘III. Future Works’

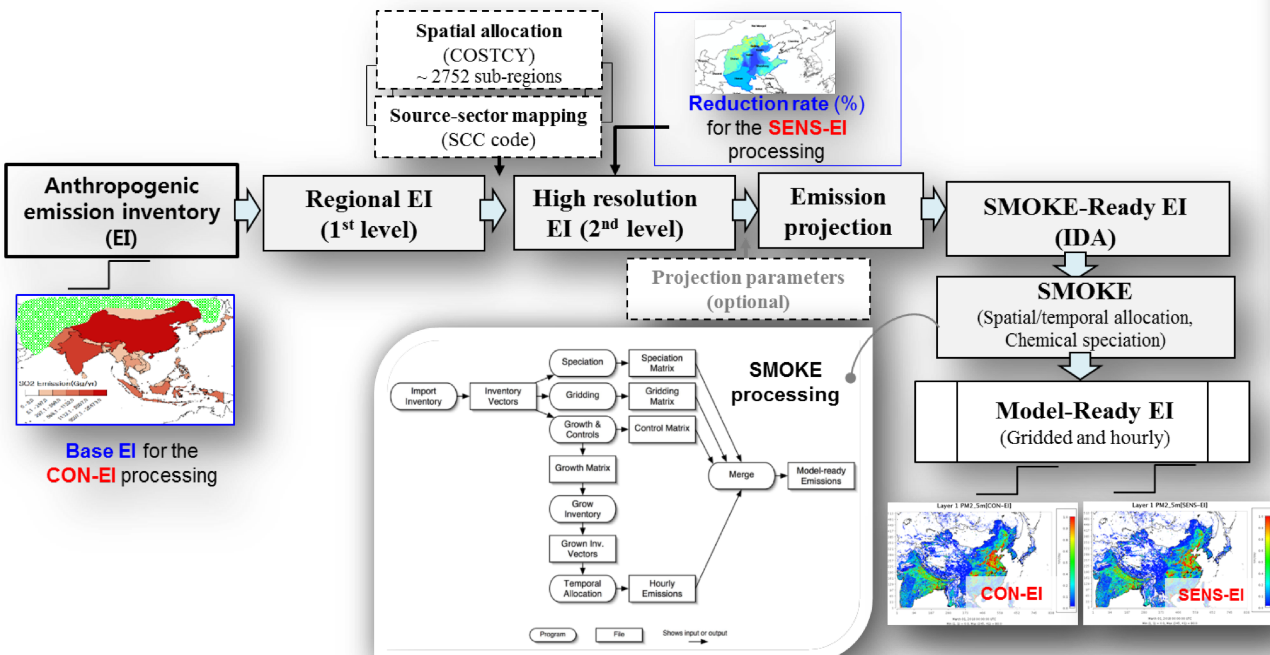
III-3. Emission inventory with new data

- **New reduction information into emission inventory (EI)**

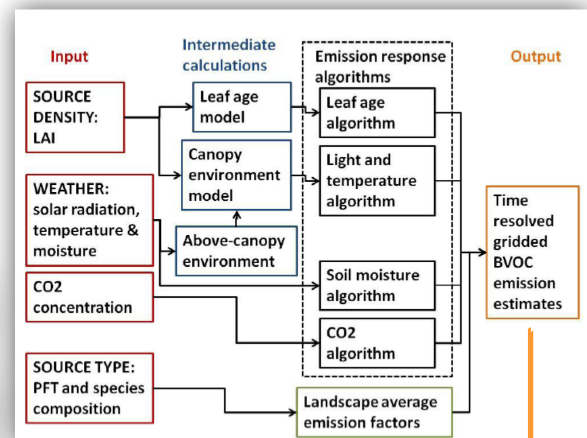
CON-EI: EI without emission reductions (**CREATE2015_Extended**)	**SENS-EI**: EI with emission reduction rates in JJJ China in 2018 (**CON-EI * 2018 Reduction rates**)

- **Addition of biogenic emissions into EI with an aim to improve OM prediction**

Anthropogenic emissions processing
(한중 공동연구 2차년도)

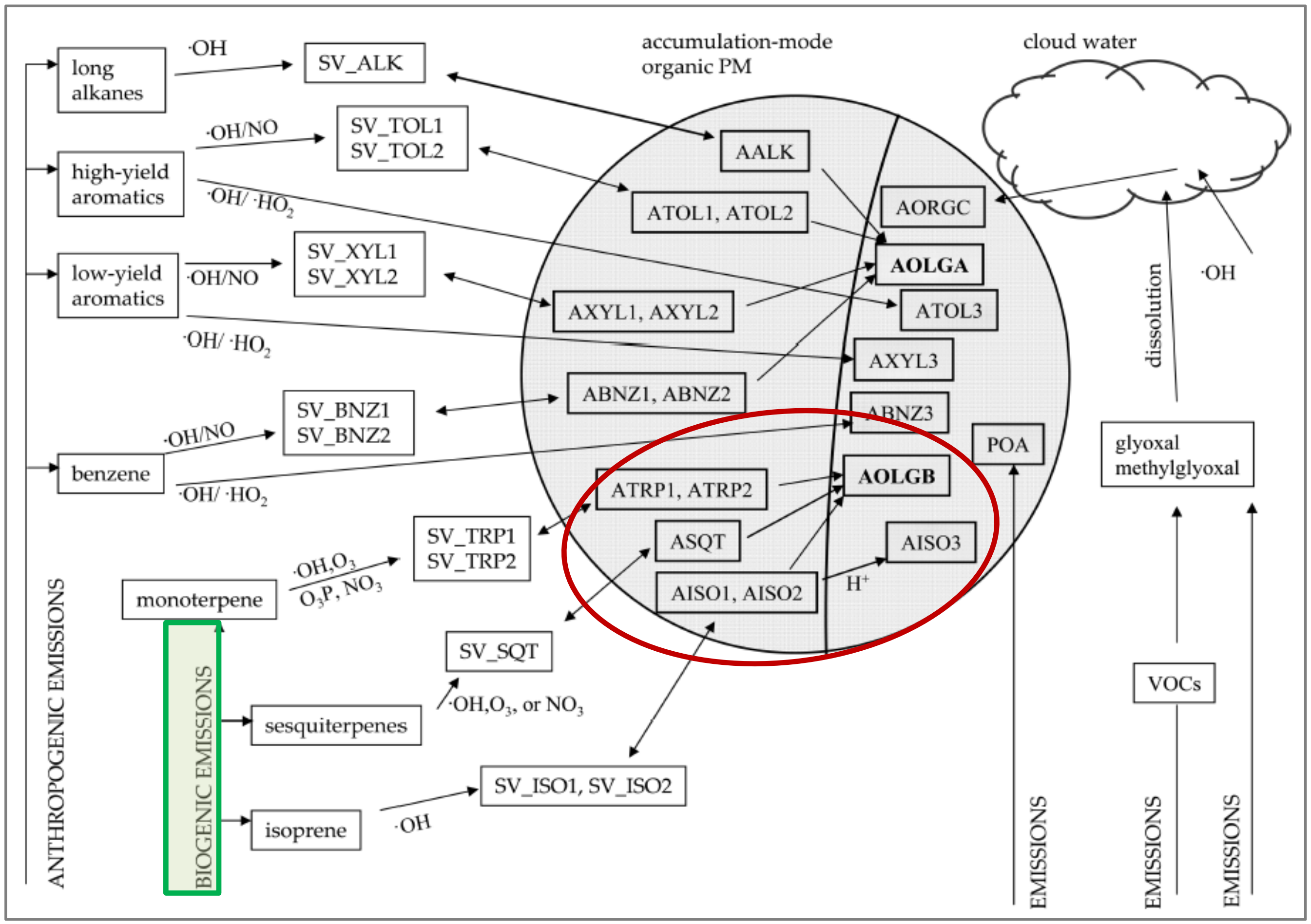


Biogenic emissions modeling
with MEGANv2.1 (Guenther et al., 2012)



Merging
(Anthropogenic + biogenic emissions)

Expected to increase OM formation by adding biogenic emissions

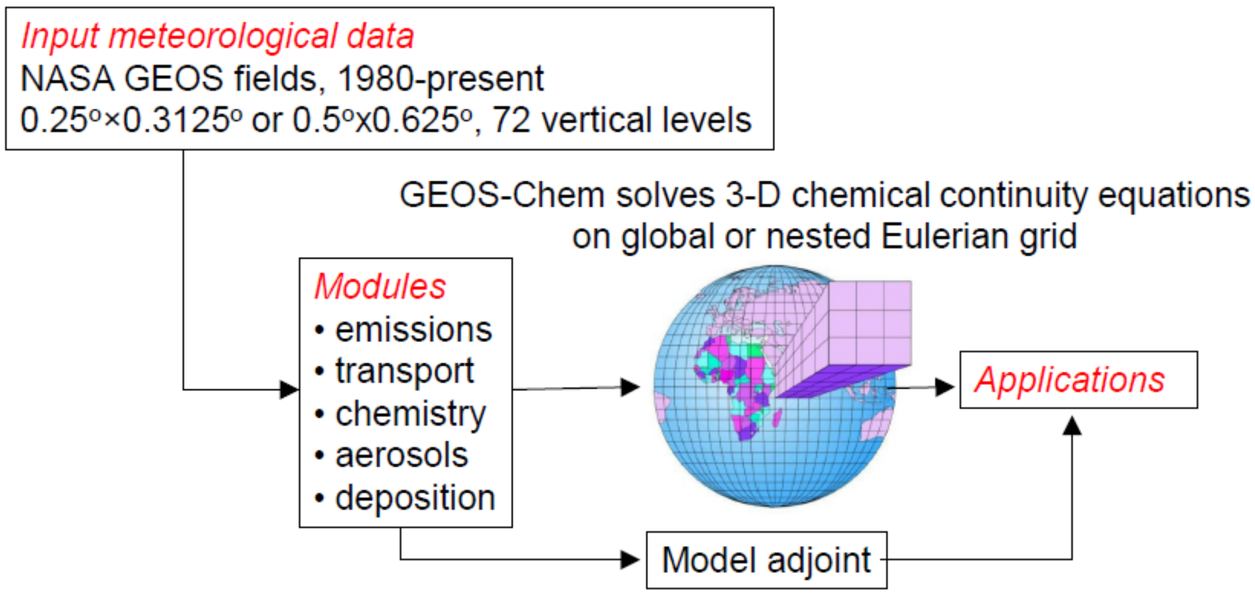


Schematic of CMAQv4.7 SOA module (Carlton et al., 2010)

III-4. OM simulation experiment

Employment of GEOS-Chem

- Perform GEOS-Chem modeling with anthropogenic emissions that used in CMAQ
- Comparison of the simulated organic aerosols (OA) by GEOS-Chem with these by CMAQ in China
- Perform quantitative analysis regarding OA simulation issues
- Comparison of various OA schemes that tried in the previous study, such as KORUS-AQ
- Attempt to improve OA performance based on the modeled results and in-situ measurements



- Tropospheric and stratospheric chemistry+aerosols, aerosol microphysics, carbon gases, mercury, POPs, isotopes…
- New major version releases every year: version 12.0.0 (June 2018) includes updated chemistry for SOA, isoprene, halogens, mercury, new emissions…
- Grid-independent architecture for MPI and coupling to Earth System models, transparent to GEOS-Chem Classic users

Source: Jacob D., 2017

III-4. OM simulation experiment (continued)

Employment of GEOS-Chem

Secondary organic aerosols in GEOS-Chem

- parent hydrocarbons + OH, O_3, NO_3 →→→→→ γ SOA (γ : SOA yield)

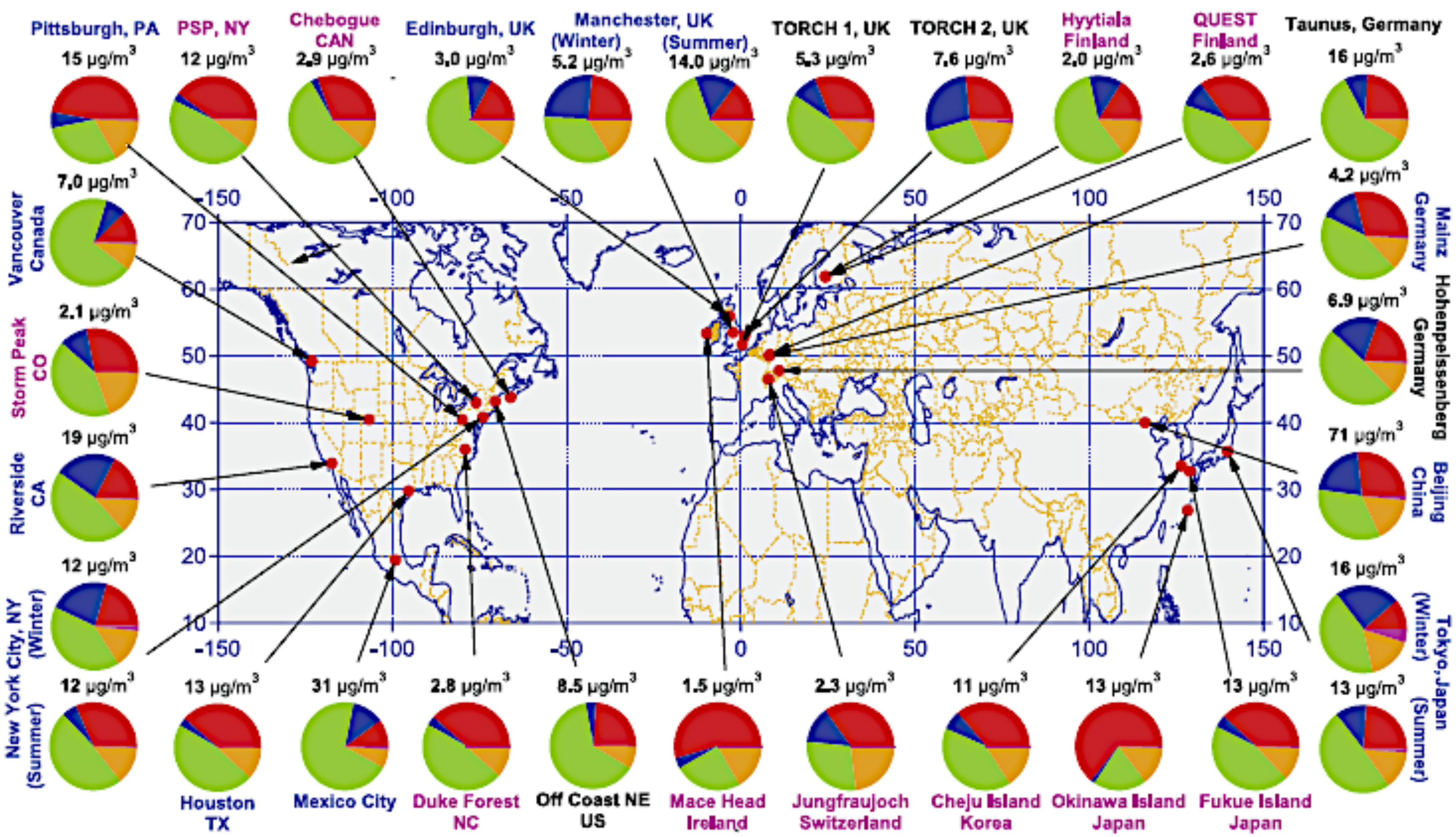
SOA scheme	parent HC	VBS	SOA aging	SVPOA	updated yield	additional description
Pye *(Pye et al., 2010)*	isoprene, terpenes, aromatics	○	×	×	×	• GC default (complex) SOA scheme
Simple *(Hodzic and Jiminez, 2011; Hayes et al., 2015; Shrivastava et al., 2017)*	SOAP (lumped)	×	×	×	×	• SOAP → SOAS (τ_{SOAP}=1day) • SOAP directly emitted proportional to CO ($SOAP_{fossil}$/CO=0.069 g/g, $SOAP_{biomass}$/CO=0.013 g/g)
Hodzic *(Hodzic et al., 2016)*	isoprene, terpenes, aromatics, S/IVOCs	○	×	×	○	• stronger production (wall-corrected yields) • faster and additional removal (updated Henry's law coeff., photolysis, oxidation)
Jo *(Jo et al., 2013)*	isoprene, terpenes, aromatics, S/IVOCs	○	○	○	×	• chemical aging of aromatic SOA • semi-volatile POA with VBS (further oxidizes POA)

ULSAN NATIONAL INSTITUTE OF SCIENCE AND TECHNOLOGY

Major components of PM in observations

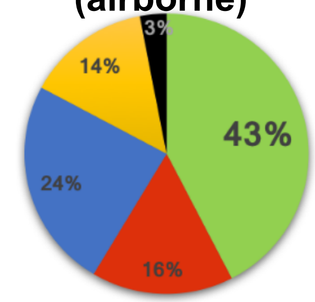
- indicates the need of considering organic sources

■ Black carbon ■ Ammonium ■ Nitrate ■ Sulfate ■ Organic (POA+SOA)

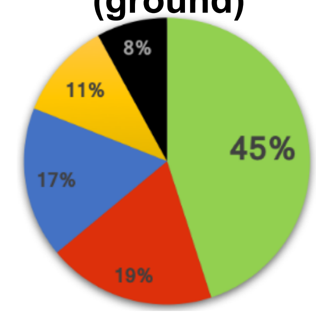


Seoul (2016)

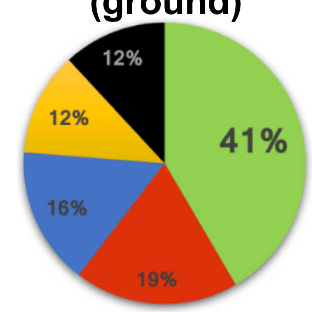
DC-8 (airborne)



Wolgok (ground)

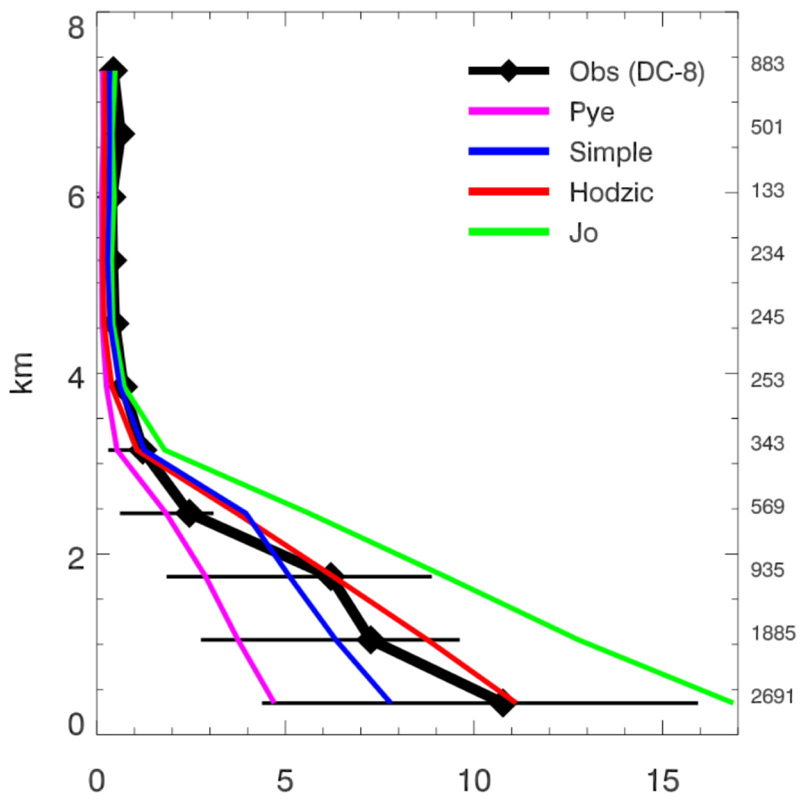


Bangi (ground)

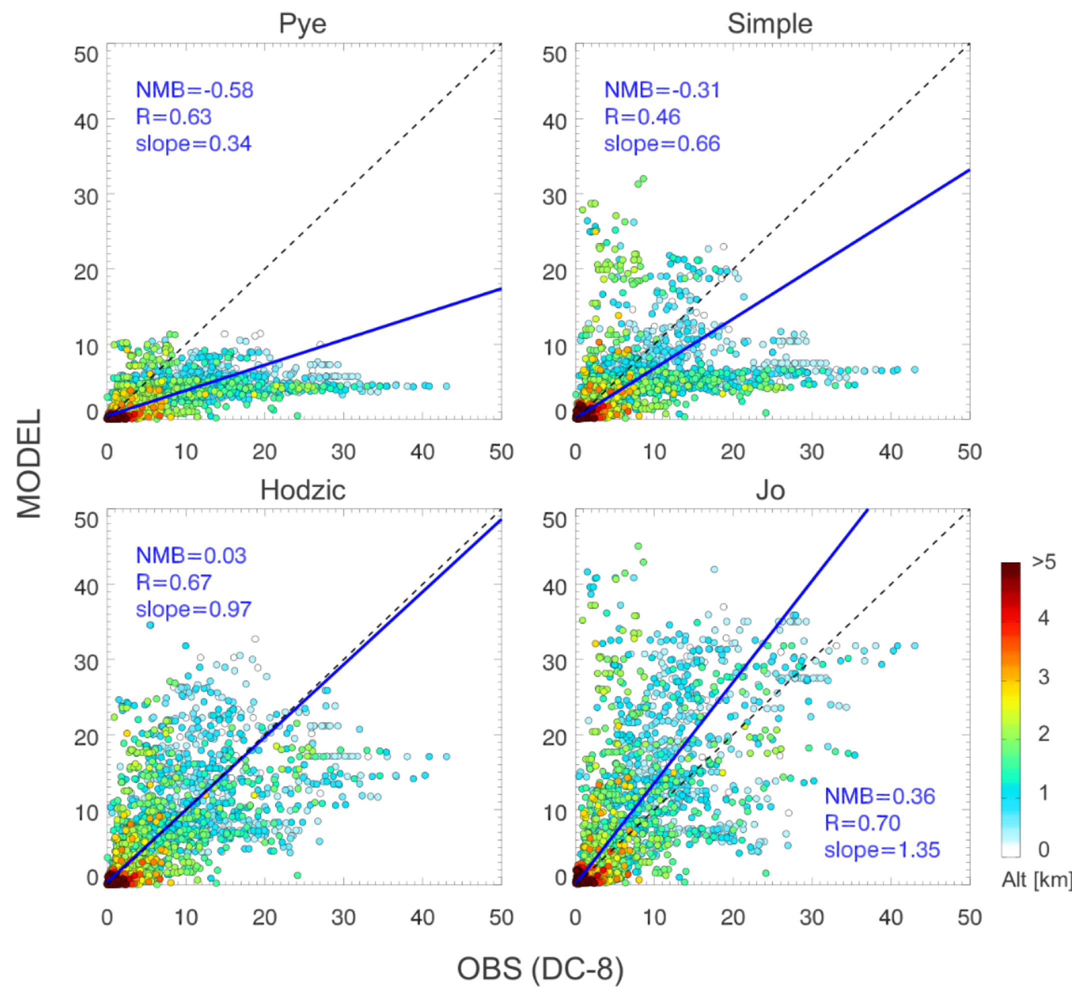


(Example) GEOS-Chem // Evaluation of simulated OA concentrations

Comparison with airborne (DC-8) observations over Seoul



OA (POA+SOA) [μg/m³]

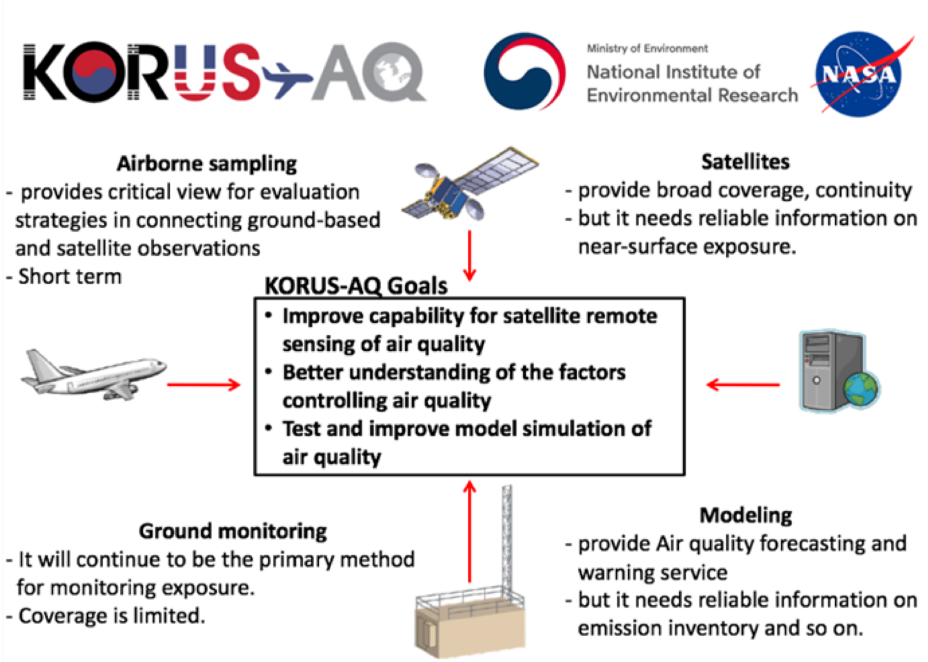


(Example) GEOS-Chem model simulation during KORUS-AQ

Model configuration and observations (KORUS-AQ 사례)

GEOS-Chem v12 (v10 for Jo SOA scheme)   simulation period: 2016/05/01 – 2016/06/10

Horizontal resolution	Meteorology	Biogenic emissions	Anthropogenic emissions	Biomass Burning	PBL mixing
0.25°x 0.3125° (nested)	GEOS-FP	MEGAN v2.1	KORUS v2.0 (East Asia)	GFED4 (daily)	non-local mixing (VDIFF)



Korea-US Air Quality field campaign (May-June 2016)

- International cooperative air quality monitoring campaign held in Korea
- Extensive **surface and airborne measurements** with high temporal resolutions conducted
- **Airborne measurements** (20 flights onboard DC-8 aircraft)
- **Ground measurements** at super sites

ULSAN NATIONAL INSTITUTE OF SCIENCE AND TECHNOLOGY

III-5. Meteorological model experiment

Test of WRF model sensitivity to the different input data

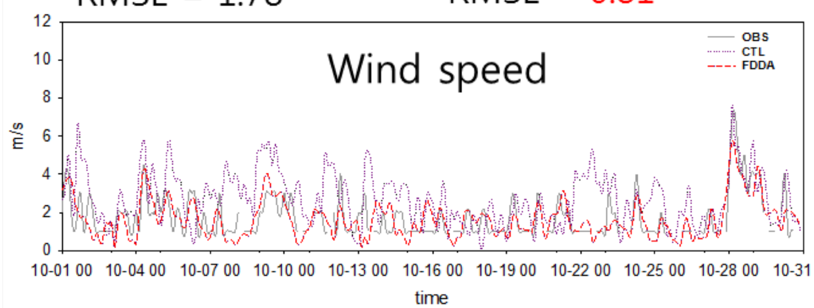
- Investigation of the model accuracy when applying different reanalysis input datasets to the WRF-FDDA(Nudging)
  ~~ NCEP 1° × 1°, GSF 0.25°× 0.25°, ECMWF 1.125° × 0.703°, etc

(Example of applying NCEP 1° × 1°)

Beijing

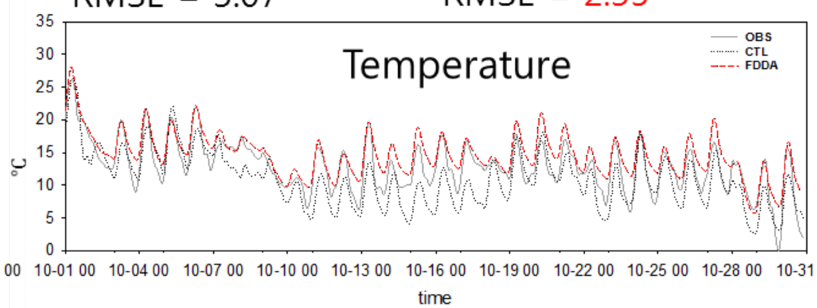
CTL
r = 0.40, P < 0.001
RMSE = 1.78

FDDA
r = 0.67, P < 0.001
RMSE = 0.81



CTL
r = 0.83, P < 0.001
RMSE = 3.07

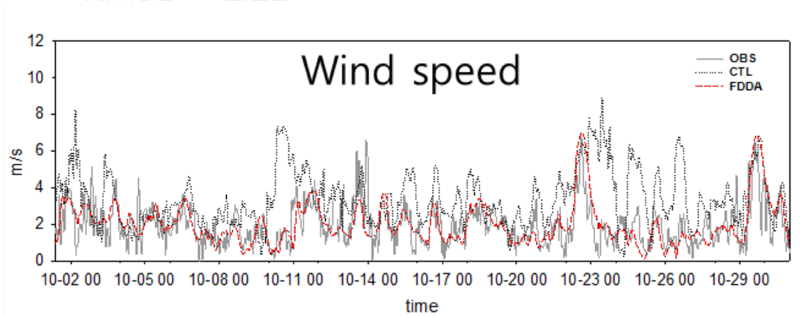
FDDA
r = 0.92, P < 0.001
RMSE = 2.35



Seoul

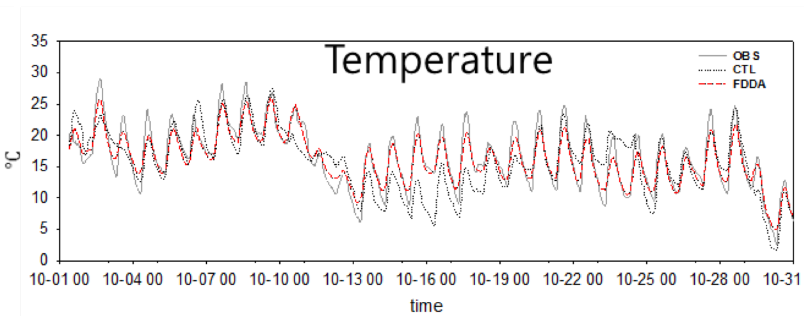
CTL
r = 0.23, P < 0.001
RMSE = 2.22

FDDA
r = 0.65, P < 0.001
RMSE = 0.96



CTL
r = 0.75, P < 0.001
RMSE = 3.57

FDDA
r = 0.94, P < 0.001
RMSE = 1.80



III-6. China emission reduction effects

Synthesis of previous and new results to derive a comprehensive conclusion base on the synthesis of previous and new results

Monthly average effects: ???????

Effects during high episodes: ???????