An investigation of transboundary PM over northeast Asia

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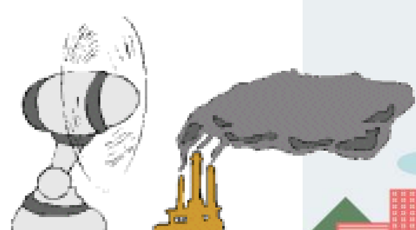
Research backgrounds I

Transboundary air pollution between countries

- **Cause of serious international problems in Europe, Asia, and North America**

  e.g., acid precipitation, regional-scale formation of ground-level ozone and particles, visibility impairment

- **Efforts to manage transboundary air pollution**
  - **[Europe]** Convention on Long-Range Transboundary Air Pollution (**CLRTAP**) supported by **UNECE** (United Nations Economic Commission for Europe) and European Monitoring and Evaluation Programme (**EMEP**)
  - **[Northeast Asia]** Long-range Transboundary Air pollutants (**LTP**) in northeast Asia conducted as part of international joint research among Korea, Japan, and China



Research backgrounds II

- **Quantitative evaluations of Long-Range Transport (LRT)**
  - **Chemistry-transport model (CTM) simulations**
    - Large uncertainties in the emission rates
    - Uncertainties related to the CTM and meteorological model simulations
    - Uncertainties in atmospheric secondary particle formation and particle generation/transport
  - **Combination of CTM simulations with remote-sensing data**
    - Data assimilation
    - Utilization of **AOD as a proxy for surface-level PM** concentrations
  - **Geostationary Ocean Color Imager (GOCI)**
    - High temporal resolution (every ~1 hour interval during the daytime)
    - Level-2 AOD data converted by “Yonsei aerosol retrieval algorithm”

Research objectives

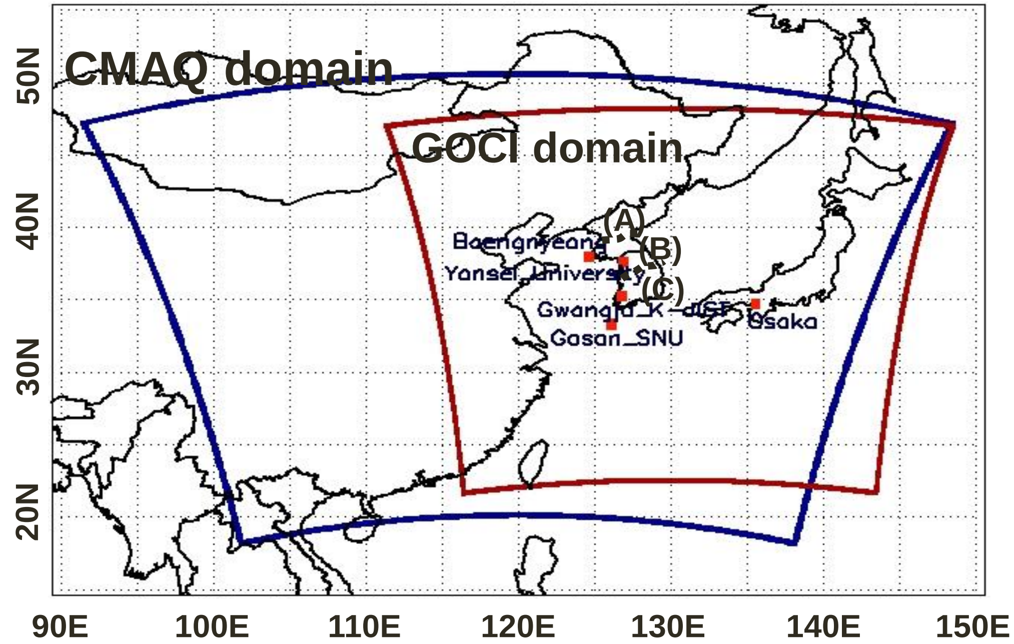
- To evaluate transboundary **long-range transport PM pollution** using AODs as a proxy for PM concentrations over **northeast Asia**

- To obtain more accurate AODs, by combining **hourly GOCI-retrieved** and CMAQ-simulated AODs through a data assimilation technique

Modeling descriptions

Modeling domain

- 95-145˚E; 20-50˚N
- 30km×30km (137×113)
- 14 vertical layers



Modeling periods

- 1st April – 31st May, 2011

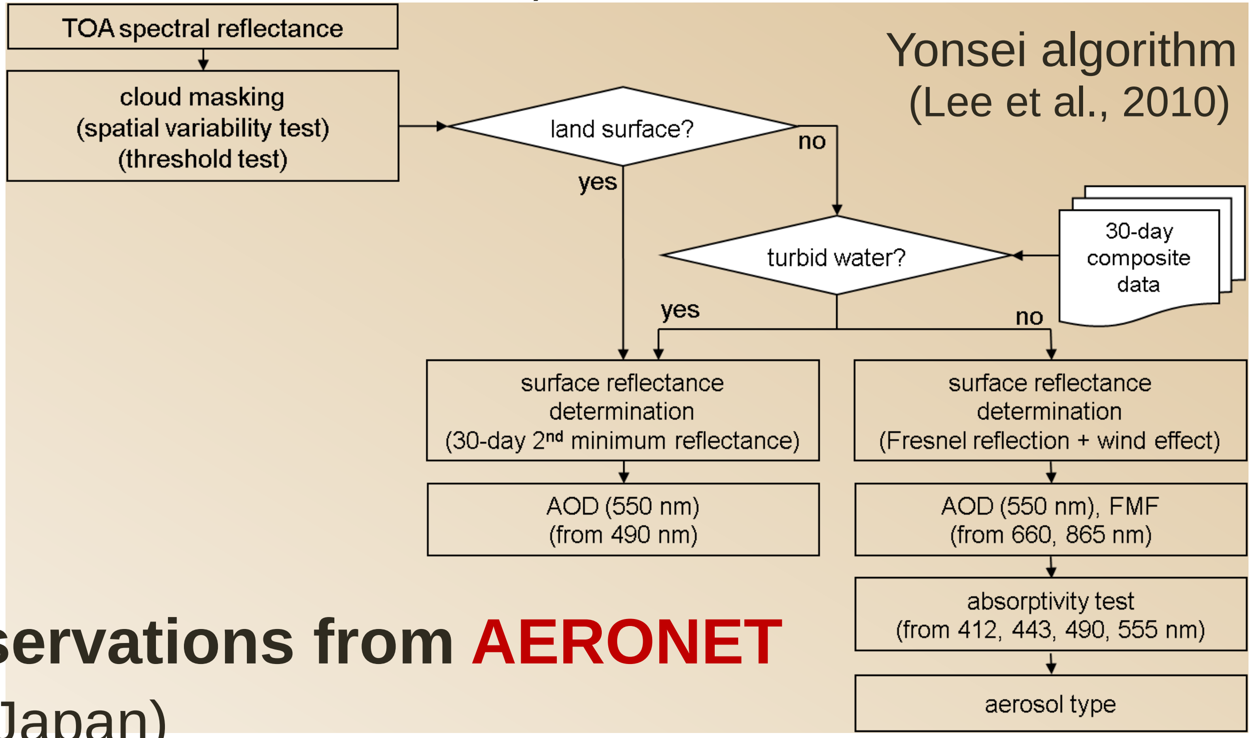
US EPA/CMAQ v4.5.1

- Meteorological fields from PSU/MM5
- Emission inventories
  - Output for the year 2011, using the projection factors based on the GAINS emission scenarios (CO, NO_x, VOC, SO_2, NH_3, CO_2, CH_4, $PM_{2.5}$) (In collaboration with Prof. Woo at Kunkuk Univ.)
  - Inclusion of Fire Inventory from NCAR (FINN) (Wiedinmyer et al., 2011)

Observation data

Satellite observations

- Hourly AOD data retrieved from the COMS/GOCI (09:00 – 16:00 LST) sensor through Yonsei aerosol retrieval algorithm
  (In collaboration with Prof. Kim at Yonsei Univ.)



Ground-based observations from AERONET

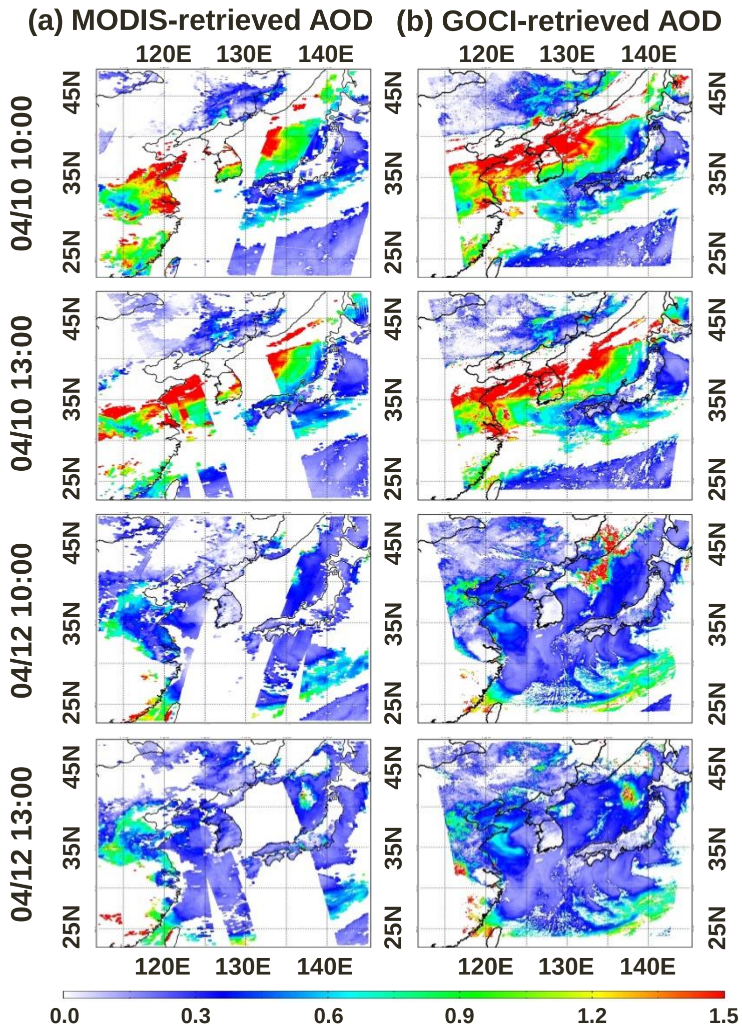
- 5 sites (Korea & Japan)
- AOD: Level 2.0 (quality-assured)

Aerosol optical property (AOP) retrievals from geostationary satellites

Satellite & Sensor	GMS5[1] VISSR[7]	MTSAT-1 R[2] JAMI[8]	MSG[3] SEVIRI[9]	GOES[4] GOES-8	COMS[5] GOCI[10]	GOES-R ABI[11]	GEO-KOMPSAT[6] GEMS[12] & ABI & GOCI-2
Sensor type	MET[13] sensor	MET sensor	MET sensor	MET sensor	Ocean color imager	MET sensor	Environ. & Ocean color imager
Temporal resolution	1 hour	30 min	15 min	15 min	1 hour	TBD[17]	1 hour (GEMS)
Spatial resolution	[a]1.25 km / [b]5 km	1.25 km / 5 km	1 km / 3 km	1 km / 4 km	0.5 km / 0.5 km	0.5 km / 2 km	0.25 km / 1 km
Number of bands	1 VIS[14] / 3 IR[16]	1 VIS / 4 IR	2 VIS/ 2 NIR / 8 IR	1 VIS / 4 IR	6 VIS / 2 NIR[15]	2 VIS / 4 NIR / 10 IR	13 VIS/NIR
Covering region	East Asia & West Pacific Ocean	East Asia & West Pacific Ocean	Central Europe	Eastern US	Northeast Asia	US	East, Southeast & Central Asia
Launch year	March 1995	February 2005	August 2002	April 1994	June 2010	Schedule to be launched in 2015	Schedule to be launched in 2018
References	Wang et al., 2003, Masuda et al., 2002	Kim et al., 2008	Popp et al., 2007	Knapp et al., 2002, Christopher et al., 2002, Knapp et al., 2005	Lee et al., 2010, this study	Laszlo et al., 2008	

1) GMS: Geostationary Meteorological Satellite
2) MTSAT-1R: Multi-functional Transport Satellite
3) MSG: Meteosat Second Generation
4) GOES: Geostationary Operational Environmental Satellite
5) COMS: Communication, Ocean, and Meteorological Satellite
6) GEO-KOMPSAT: Geostationary Earth Orbit KOrea Multi-Purpose SATellite
7) VISSR: Visible and Infra-Red Spin Scan Radiometer
8) JAMI: Japanese Advanced Meteorological Imager
9) SEVIRI: Spinning Enhanced Visible and infra-Red Imager
10) GOCI: Geostationary Ocean Color Imager
11) ABI: Advanced Baseline Imager
12) GEMS: Geostationary Environment Monitoring Spectrometer
13) MET: Meteorological
14) VIS: VISible
15) NIR: Near Infra-Red
16) IR: Infra-Red
17) TBD: To Be Determined
a) Resolution for the visible channels
b) Resolution for the infra-red channels

Evaluation of GOCI-retrieved AOD



AOD assimilation: Optimal Interpolation (OI)

$$\tau_m{}' = \tau_m + K(\tau_o - H\tau_m)$$

$$K = BH^T(HBH^T + O)^{-1}$$

$$O = \left[(f_o\tau_o)^2 + (\varepsilon_o)^2\right]I$$

$$B(d_x, d_z) = \left[(f_m\tau_m)^2 + (\varepsilon_m)^2\right]\exp\left[\frac{-d_x^2}{2l_{mx}^2}\right]\exp\left[\frac{-d_z^2}{2l_{mz}^2}\right]$$

τ_m : modeled values of AOD
τ_o : observed values of AOD
H : linear operator for interpolation from the model grid to the location of the observation
K : Kalman gain matrix (Kalman filter)

Assumptions
1. The errors are Gaussian distributed.
2. The errors in model and data are uncorrelated.

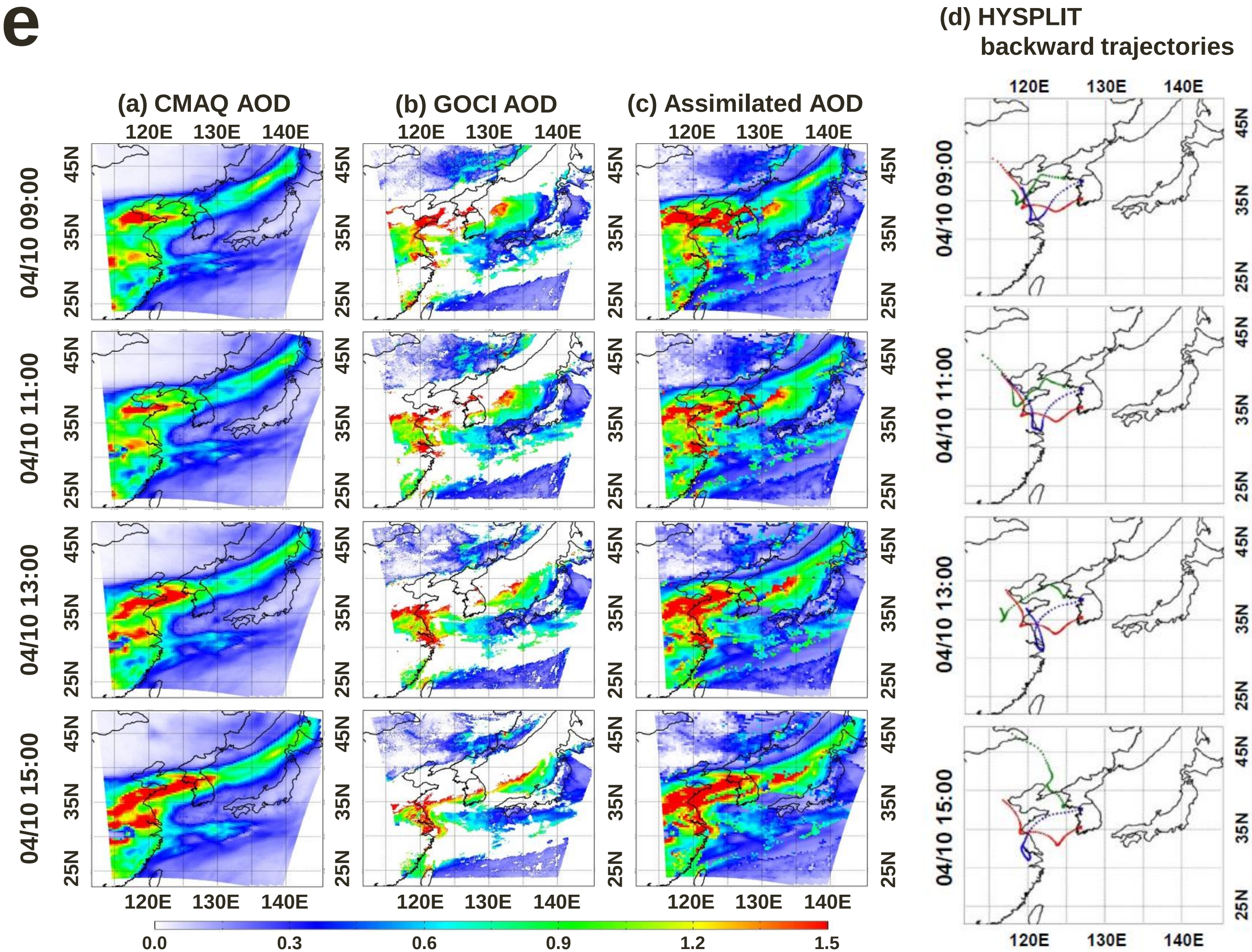
B : covariance of modeled field
O : covariance of observed field

[Collins et al., 2001; Yu et al., 2003; Adhikary et al., 2008; Chung et al., 2010; Park et al., 2011]

Statistical Parameters		This study Experiment ranges
Fractional error coefficient in model τ	f_m	0.20-1.80
Fractional error coefficient in observation τ	f_o	0.20-1.80
Minimum RMS error in model τ	ε_m	0.00-0.05
Minimum RMS error in observation τ	ε_o	0.00-0.05
Horizontal correlation length for errors in model τ	L_m	30 km
Horizontal correlation length for errors in observation τ	L_o	0 km

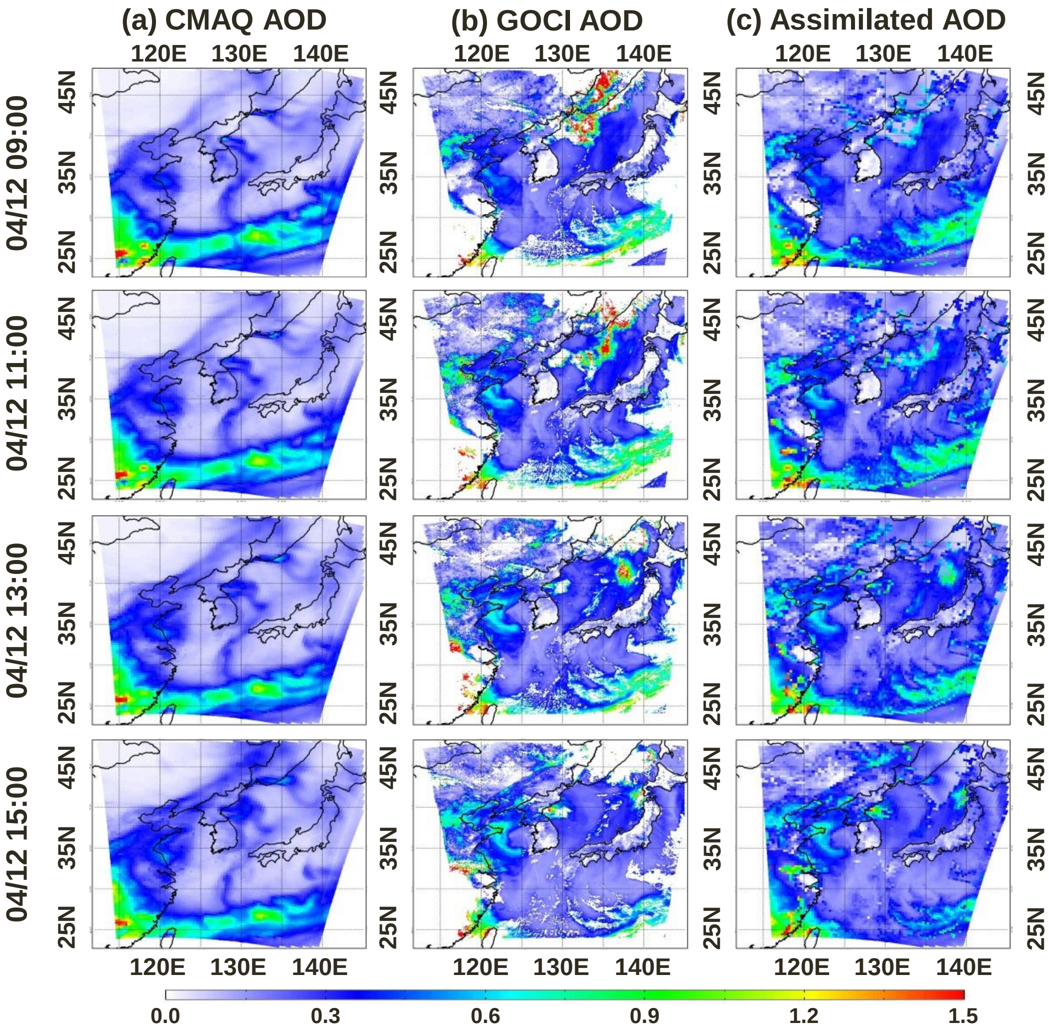
Spatial and temporal distributions of AODs

LRT case



Spatial and temporal distributions of AODs

Non-LRT case



Statistical analysis of AODs

AOD	vs. AERONET					
	N[1)]	R[2)]	RMSE[3)]	MNGE[4)]	MB[5)]	NMB[6)]
CMAQ	**946**	**0.47**	**0.31**	**46.52**	**-0.09**	**-14.51**
GOCI	**499**	**0.84**	**0.19**	**42.42**	**-0.03**	**-15.15**
Assimilation	**695**	**0.63**	**0.28**	**35.75**	**-0.04**	**-6.50**

1) N: number of data

2) R: correlation coefficient =

$$\frac{\dfrac{\sum_1^N \left(AOD_{i,M} - \overline{AOD}_M\right)\left(AOD_{i,O} - \overline{AOD}_O\right)}{N-1}}{\sqrt{\dfrac{\sum_1^N AOD_{i,M}^2 - \dfrac{\left(\sum_1^N AOD_{i,M}\right)^2}{N}}{N-1}}\sqrt{\dfrac{\sum_1^N AOD_{i,O}^2 - \dfrac{\left(\sum_1^N AOD_{i,O}\right)^2}{N}}{N-1}}}$$

3) RMSE: Root Mean Square Error =

$$\sqrt{\frac{1}{N}\sum_1^N \left(AOD_{i,M} - AOD_{i,O}\right)^2}$$

4) MNGE: Mean Normalized Gross Error (%) =

$$\frac{1}{N}\sum_1^N \left(\frac{\left|AOD_{i,M} - AOD_{i,O}\right|}{AOD_{i,O}}\right) \times 100$$

5) MB: Mean Bias =

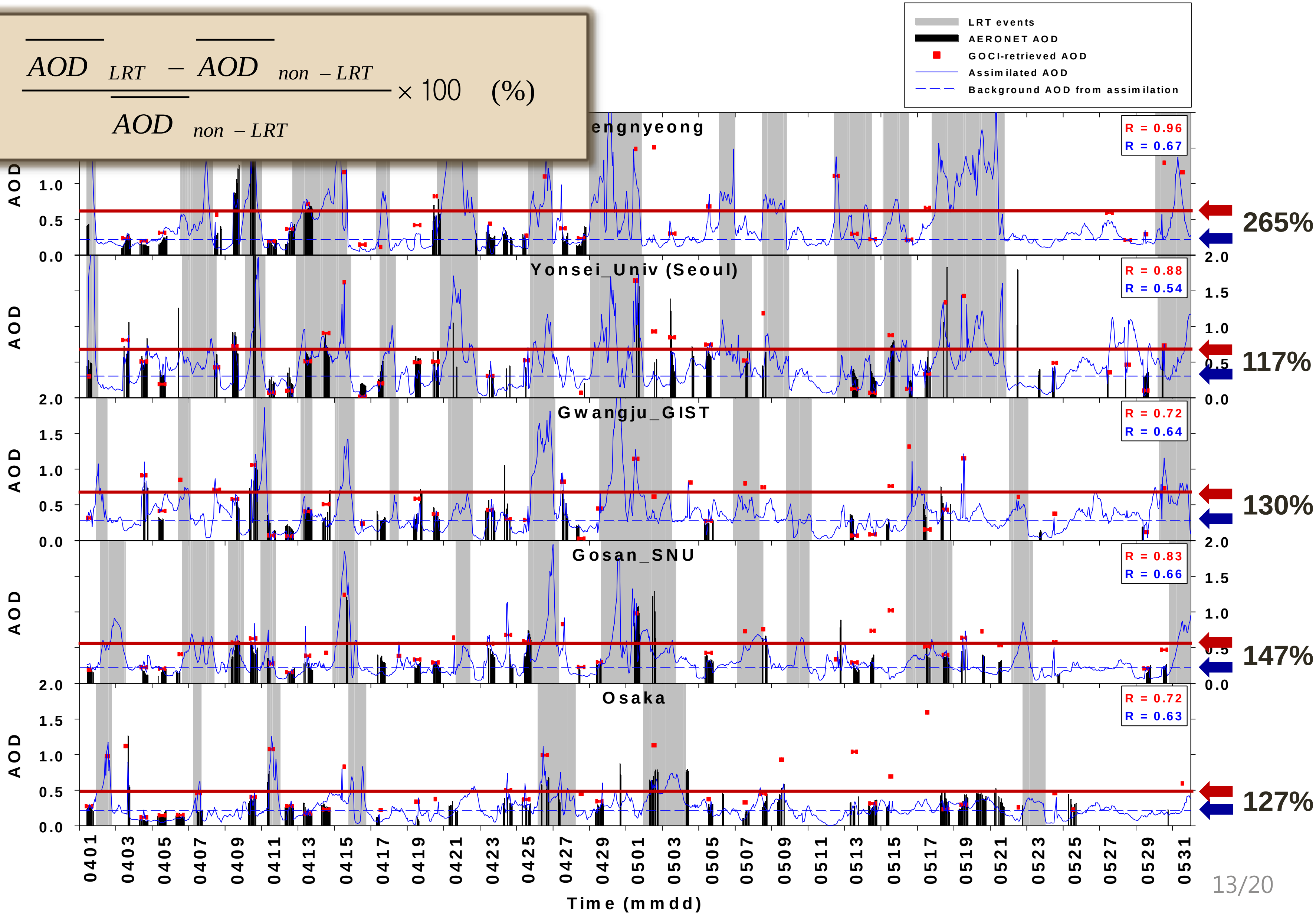
$$\frac{1}{N}\sum_1^N \left(AOD_{i,M} - AOD_{i,O}\right)$$

6) MNB: Mean Normalized Bias (%) =

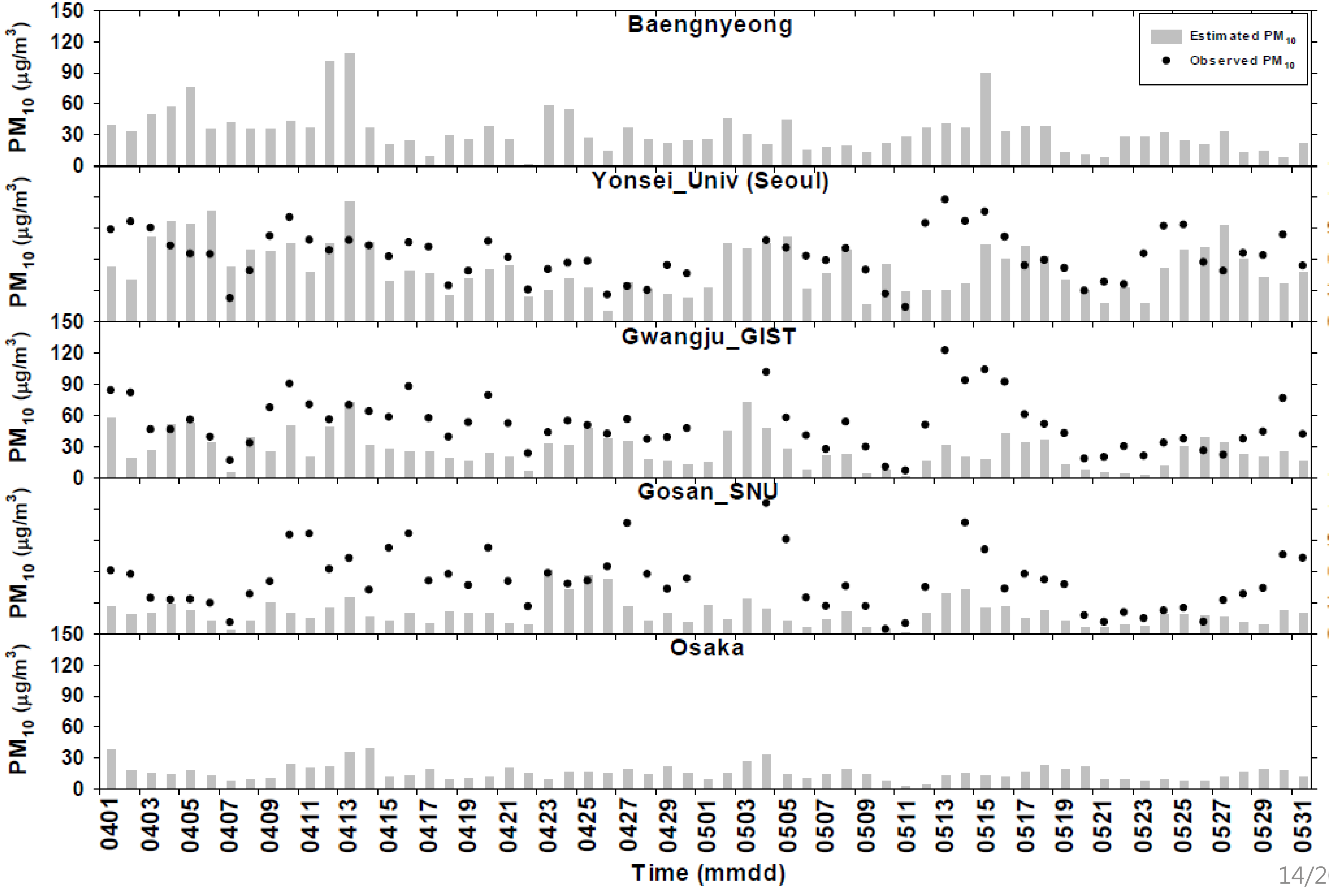
$$\frac{1}{N}\sum_1^N \left(\frac{AOD_{i,M} - AOD_{i,O}}{AOD_{i,O}}\right) \times 100$$

Time-series analysis of AODs at five AERONET sites

$$\frac{\overline{AOD}_{LRT} - \overline{AOD}_{non-LRT}}{\overline{AOD}_{non-LRT}} \times 100 \quad (\%)$$



Time-series analysis of PM at five AERONET sites

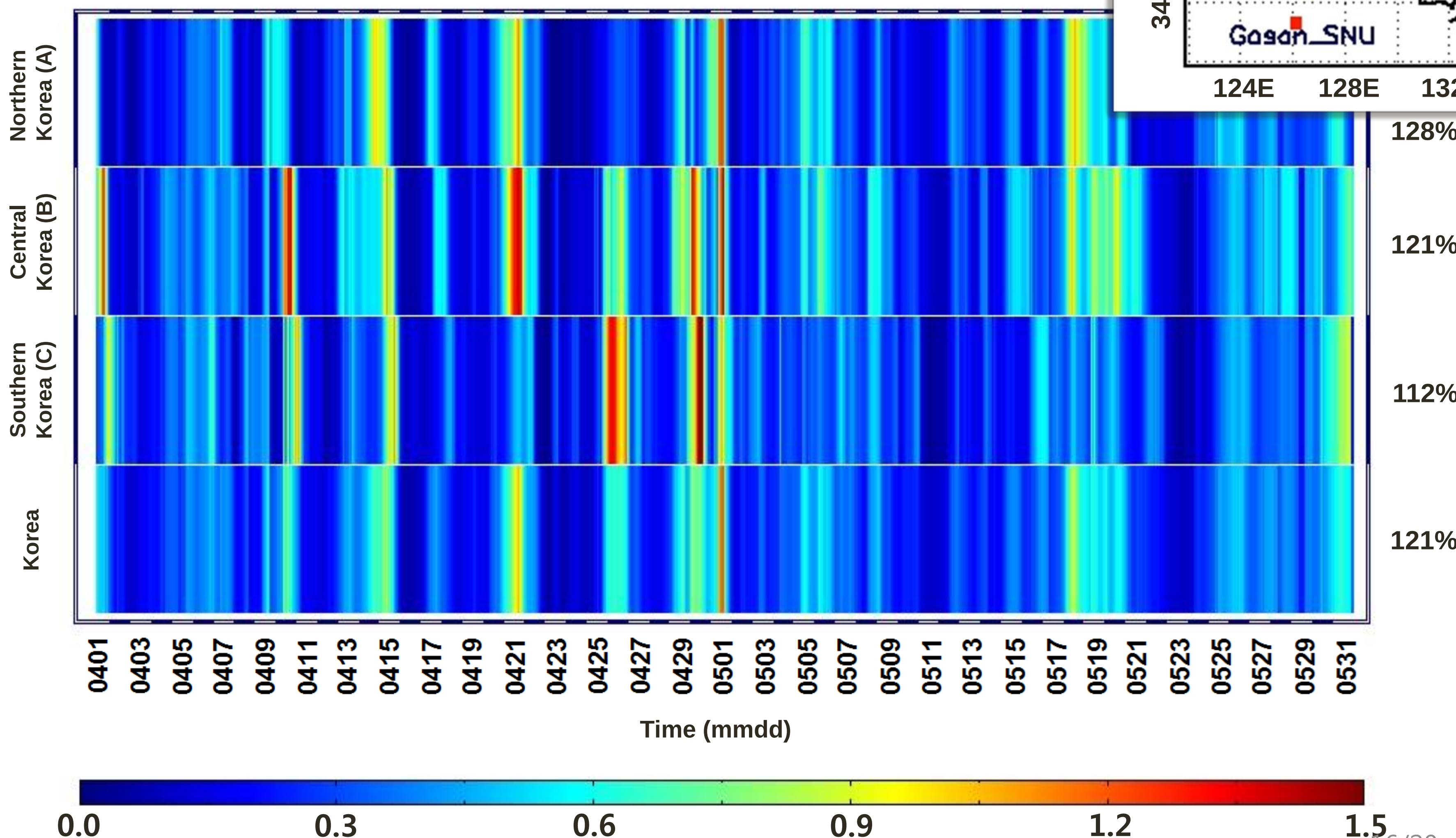


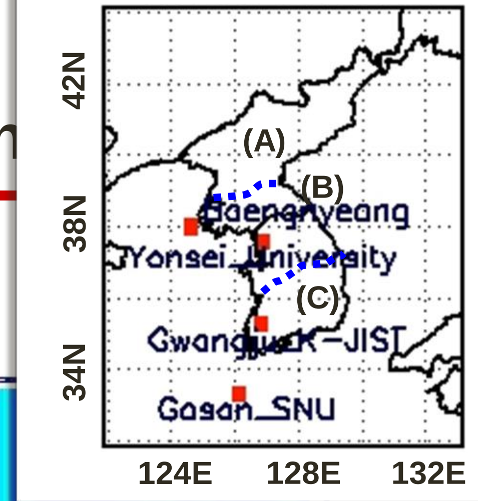
Comparison analysis of the assimilated AOD for LRT & non-LRT events

	Non-LRT events				LRT events				Data fraction of LRT events	[3]AOD increase during LRT events	[4]Ratio of AOD increase during LRT events
	[1]N	[2]σ	Avg.	Max.	[1]N	[2]σ	Avg.	Max.			
Baengnyeong	849	0.12	0.22	0.98	606	0.48	0.79	2.79	0.42	0.57	2.65
Yonsei_Univ (Seoul)	821	0.21	0.30	1.13	634	0.37	0.66	2.93	0.44	0.35	1.17
Gwangju_GIST	1024	0.16	0.27	1.22	431	0.40	0.63	2.50	0.30	0.36	1.30
Gosan	967	0.12	0.22	1.14	488	0.31	0.54	1.95	0.34	0.32	1.47
Osaka	1247	0.11	0.21	0.90	208	0.22	0.48	1.26	0.14	0.27	1.27
Total		0.15	0.24	1.22		0.40	0.65	2.93	0.33	0.40	1.67

1) N: the number of data for non-LRT or LRT events for the entire modeling period
2) Standard deviation
3) AOD increase by LRT events above the average background AOD calculated during non-LRT periods
4) $\frac{\overline{AOD}_{LRT} - \overline{AOD}_{non-LRT}}{\overline{AOD}_{non-LRT}}$

Time-series plots of AODs over the three sub-regions of the Korean penin



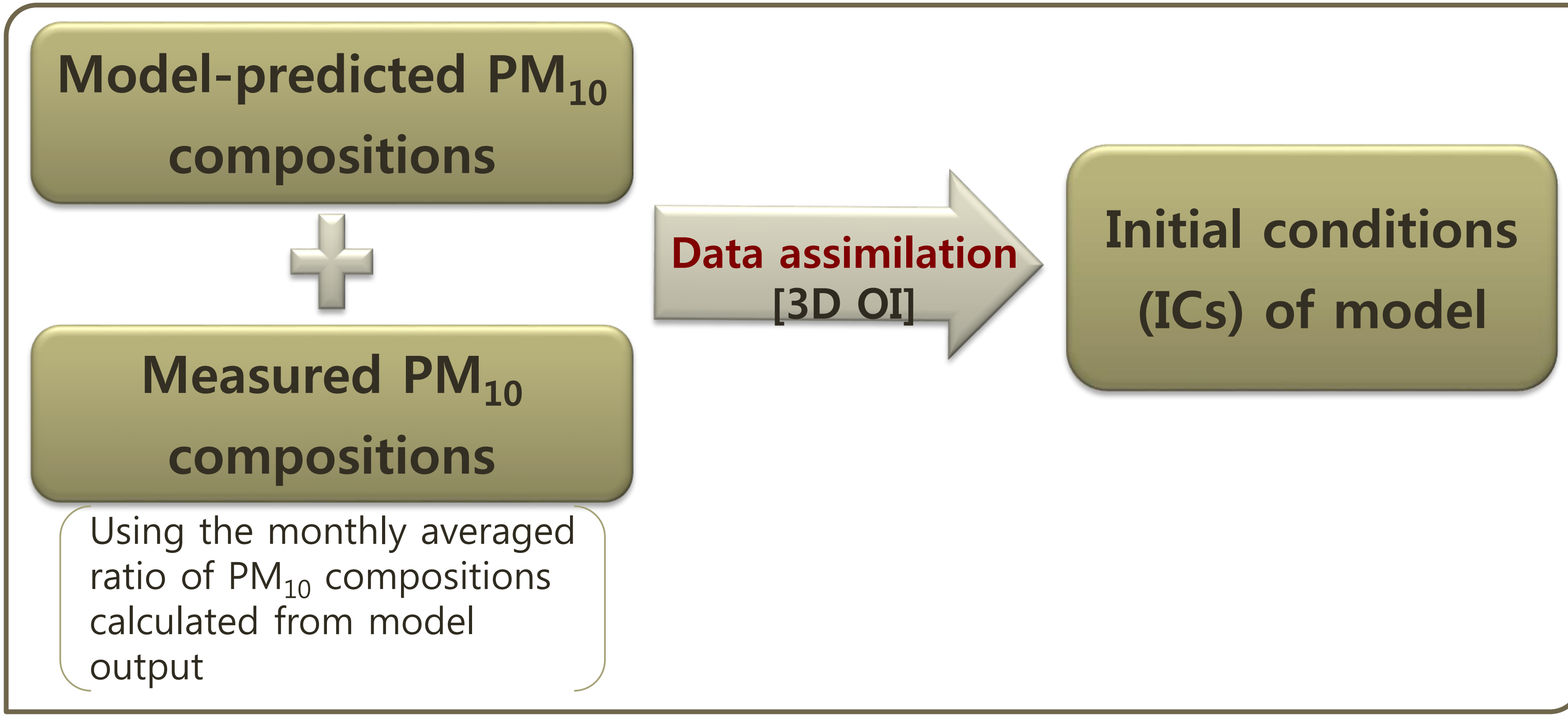


Summaries & Conclusions

- To more accurately monitor and evaluate transboundary PM pollution, this research combined two AOD products (as a proxy for surface-level PM conc.) from GOCI and CTM simulations through a data assimilation technique.
- The transboundary PM pollution from China to the Korean peninsula was quantitatively evaluated for a period from 1 April to 31 May, 2011. The average AOD increases of 117-265% at five AERONET sites and the average AOD increases of 121% over the entire Korean peninsula were found.
- This study is a preceding investigation for full-scale analysis with data from GOCI-2 and GEMS aboard GEO-KOMPSAT that is scheduled to be launched in 2018.

Application plans for data assimilation of aerosols at KMA

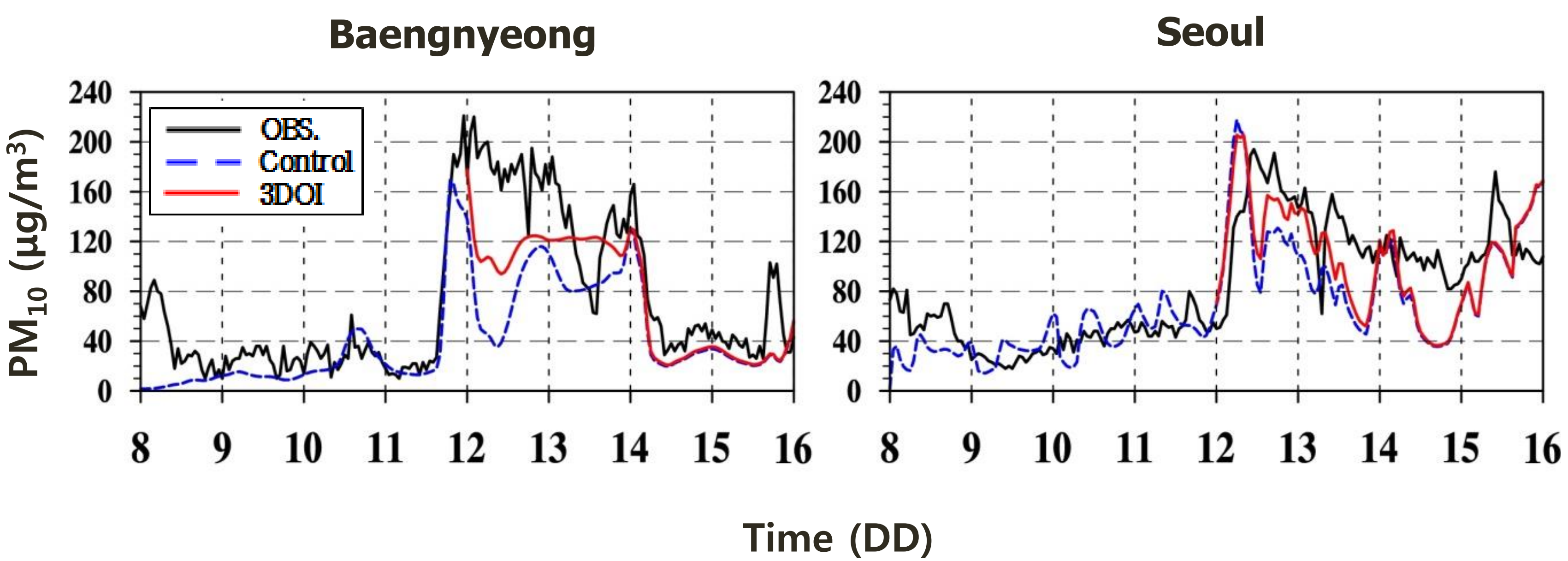
Improvements in Initial Conditions with DA



- With surface PM_{10}, AOD would be also assimilated with satellite (or ground)-observed AOD and vertical information.
- More sophisticated techniques (3DVAR, 4DVAR, KF) would be adopted for the data assimilation of aerosols.

Improvements in Initial Conditions with DA

- Preliminary results of DA for surface PM_{10}
  - Case : Haze (10-16 Jan, 2013)
  - Modeling periods: 8-16 Jan, 2013
  - 3D OI : 9-12 Jan, 2013 (3hr-interval)



Thank you for your attention!

Any question and comment will be appreciated!