

# Status of GEMS

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P.I., GEMS,

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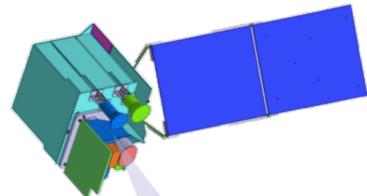
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<sup>2</sup> National Institute of Environmental Research

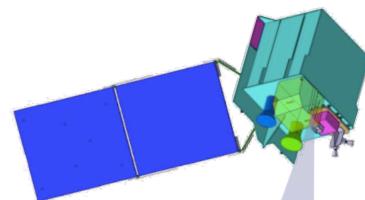


# GEO-KOMPSAT 2

2A Sat. : AMI  
Launch : 5/2018



2B Sat. : GEMS, GOCI-2  
Launch : 3/2019



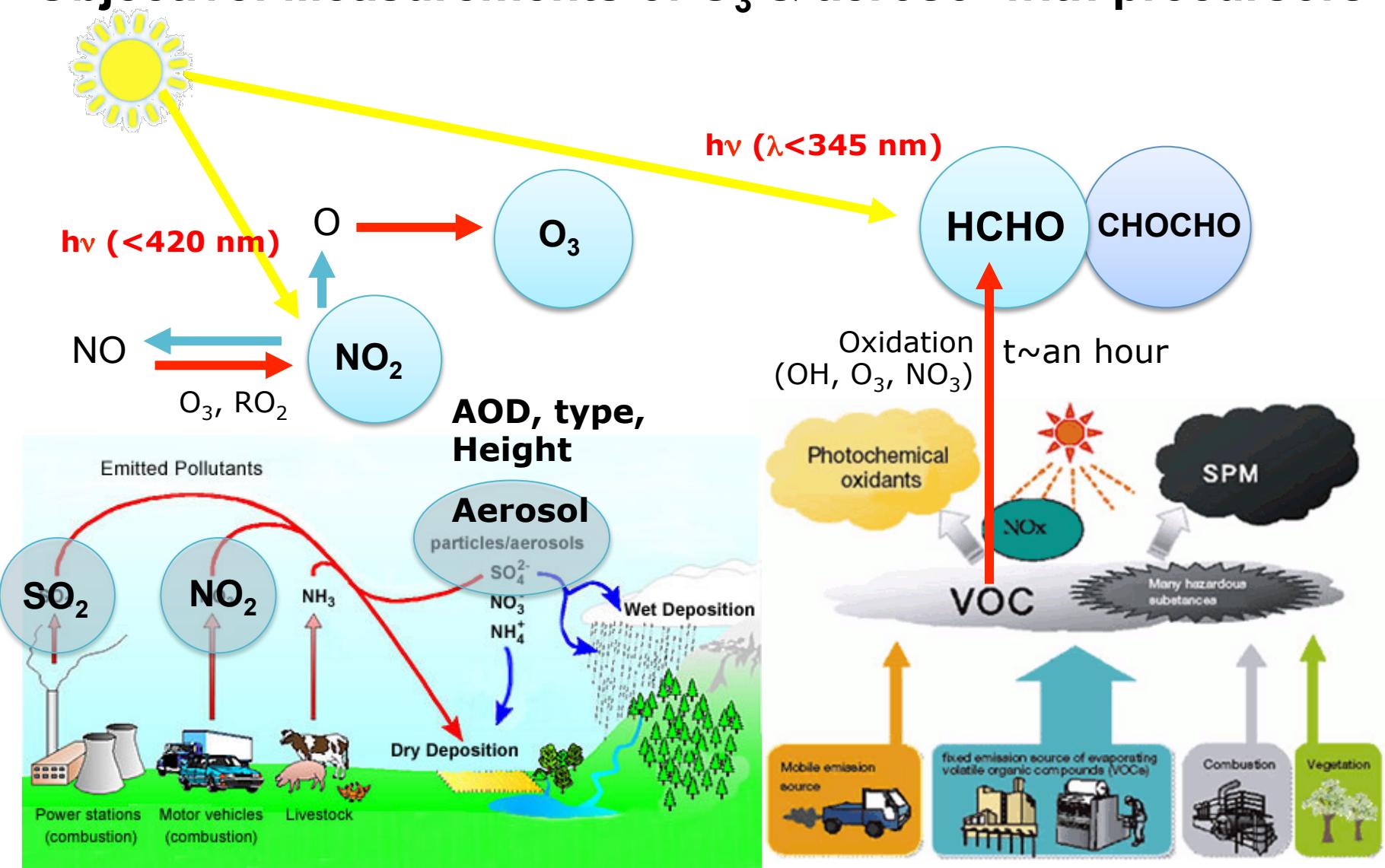
(Twin Satellite)



## Specification

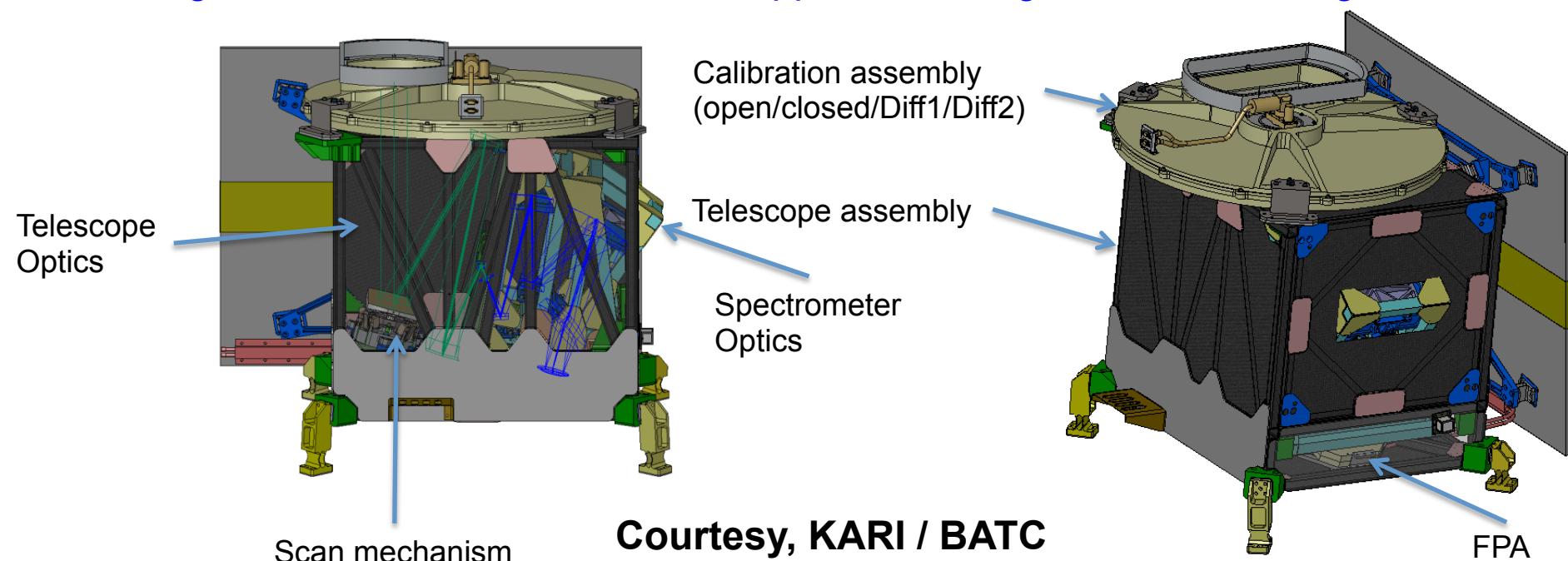
	2A	2B	
Payload	AMI	GOCI-2	GEMS
Lifetime		10 years	
Channels	16	13	1000
Wavelength range	0.4 - 13 $\mu\text{m}$	375 - 860 nm	300-500 nm
Spatial resolution	0.5 / 1 km (Vis) 2 km (IR)	250 m@ eq 1 km (FD)	7 x 8 km <sup>2</sup> @ Seoul 3.5x8 km <sup>2</sup> (aerosol)
Temporal resolution	10 min (FD)	1 hour	1 hour
Major Products	CTP, CTT, CF, AOD, FMF, OLR, SI, CSR, SST, LST, AMV, ... (56)	Ocn. current, chlorophyll, DOM, Phytoplankton, ...	AOD, AI, SSA, ACH, CCH, CRF, NO <sub>2</sub> , O <sub>3</sub> , SO <sub>2</sub> , UVI, HCHO, CHOCHO

# Objective: Measurements of O<sub>3</sub> & aerosol with precursors



# GEMS Instrument

- Step-and-stare UV-Vis imaging spectrometer scanning at least 8/day in 30 min
- Daily solar and dark calibration
- Images coadded at each position + mirror move back < 30 minutes
- Diffusers for on-orbit solar calibration and onboard LED light source
- 2-axis scan mechanism with gyro feed capability
- Redundant electronics for 10-year lifetime
- ✓ Hot pixel issues in southern part of the GEMS domain.
- ✓ Conflict in solar calibration time with GOCI-2. GEMS BTDF characterized at 30 deg. GEMS solar calibration can happen at 31 deg instead of 30 deg.

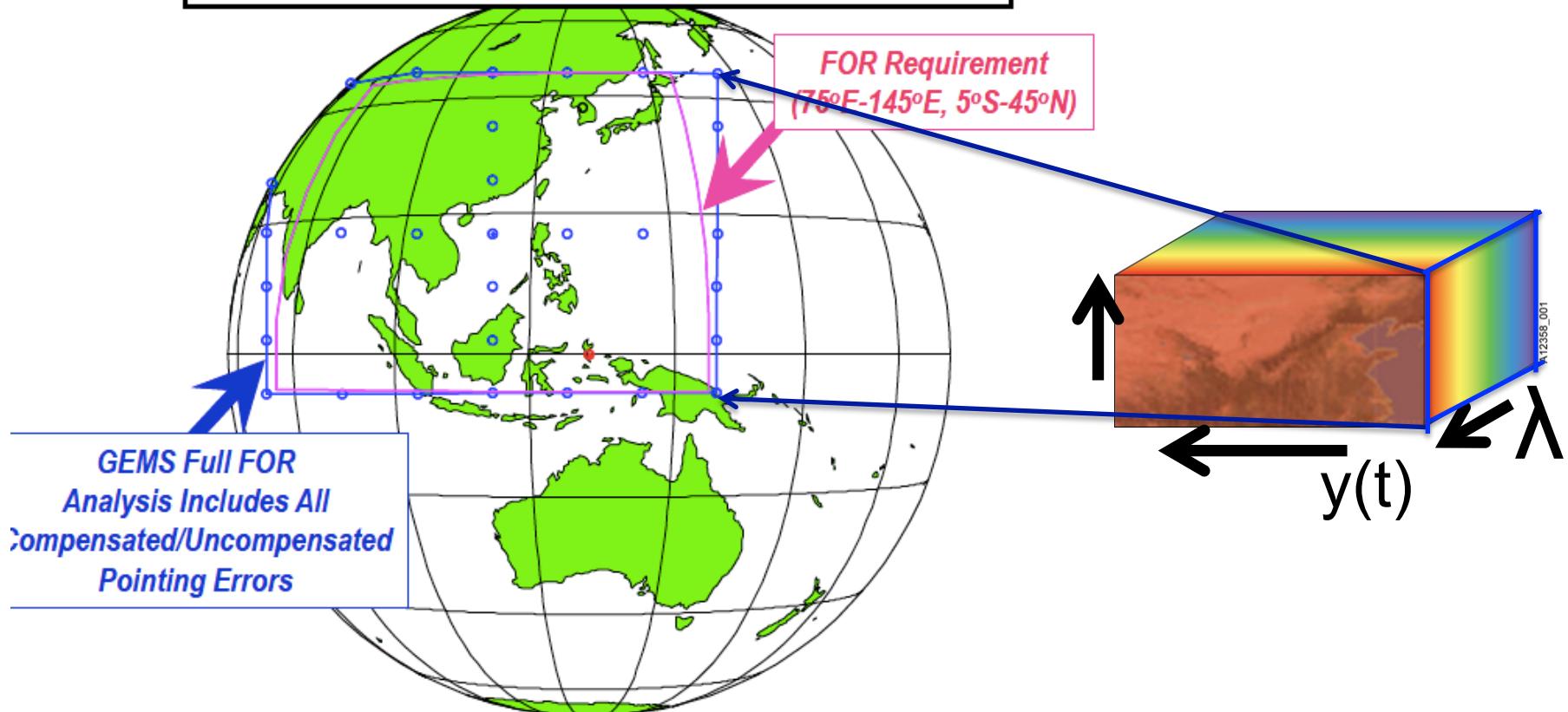


Courtesy, KARI / BATC

# Spatial coverage

GEMS East-West Coverage =  $10.91^\circ$

Orbit Long =  $128.2^\circ\text{E}$ , Scan Center at  $17.04^\circ\text{N}, 114.1^\circ\text{E}$



Magenta = GEMS Full FOR Requirement (75°E-145°E)

Blue = GEMS Full FOR Performance Estimate

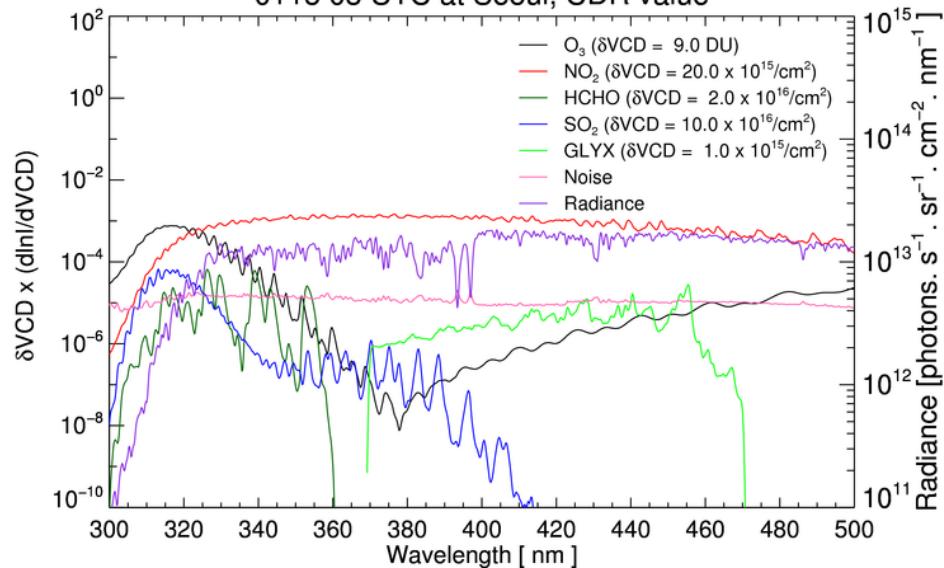
# Baseline products (16)

Product	Importance	Min (cm <sup>-2</sup> )	Max (cm <sup>-2</sup> )	Nominal (cm <sup>-2</sup> )	Accuracy	Window (nm)	Spat Resol (km <sup>2</sup> )@Seoul	SZA (deg)	Algorithm
NO <sub>2</sub>	O <sub>3</sub> precursor	3x10 <sup>13</sup>	1x10 <sup>17</sup>	1x10 <sup>14</sup>	1x10 <sup>15</sup> cm <sup>-2</sup>	425-450	7 x 8 x 2 pixels	< 70	BOAS DOAS
SO <sub>2</sub>	Aerosol precursor Volcano	6x10 <sup>8</sup>	1x10 <sup>17</sup>	6x10 <sup>14</sup>	1x10 <sup>16</sup> cm <sup>-2</sup>	310-330	7 x 8 x 4 pixels x 3 hours	< 50 (60*)	
HCHO	VOC proxy	1x10 <sup>15</sup>	3x10 <sup>16</sup>	3x10 <sup>15</sup>	1x10 <sup>16</sup> cm <sup>-2</sup>	327-357	7 x 8 x 4 pixels	< 50 (60*)	
CHOCHO					1x10 <sup>16</sup> cm <sup>-2</sup>	437-452	7 x 8 x 4 px	< 50	
TropLO3 TropUO3 StratO3 TotalO3	Oxidant Pollutant O <sub>3</sub> layer	4x10 <sup>17</sup>	2x10 <sup>18</sup>	1x10 <sup>18</sup>	3% (TOz) 5% (Stra) 20 (Trop)	300-340	7 x 8	< 70	OE TOMS
AOD AI SSA AEH	Air quality Climate	0 (AOD)	5 (AOD)	0.2 (AOD)	20% or 0.1@ 400nm	300-500	3.5 x 8	< 70	Multi-λ O <sub>2</sub> O <sub>2</sub>
[Clouds] ECF CCP	Retrieval Climate	0 (COD)	50 (COD)	17 (COD)		300-500	7 x 8	< 70	O <sub>2</sub> O <sub>2</sub> RRS
Surface Property	Environment	0	1	-		300-500	3.5 x 8	< 70	Multi-λ
UVI	Public health	0	12	-			7 x 8	< 70	

# Radiance perturbation by trace vmr (for VCD)

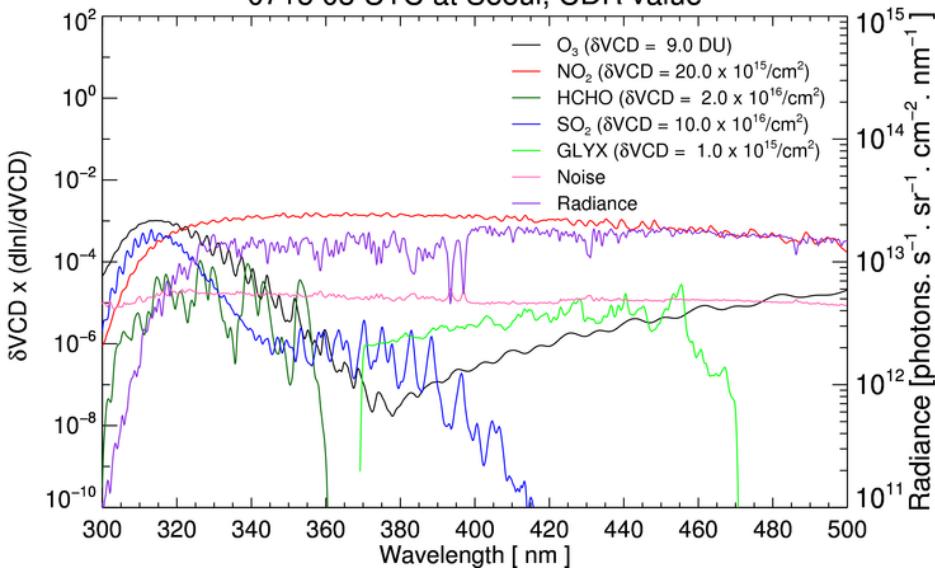
Noon, Jan. 15<sup>th</sup> at Seoul

0115 03 UTC at Seoul, CDR value

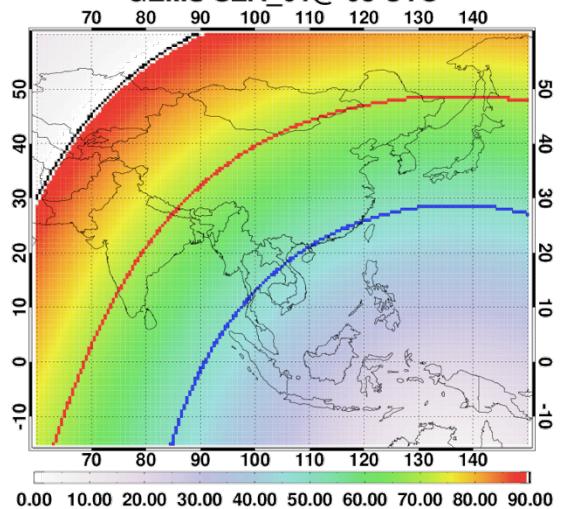


Noon, Jul. 15<sup>th</sup> at Seoul

0715 03 UTC at Seoul, CDR value



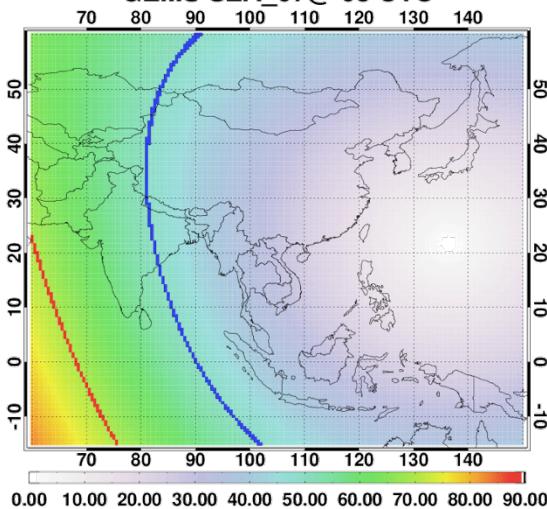
GEMS SZA\_01@ 03 UTC



SZA

50°  
70°  
90°

GEMS SZA\_07@ 03 UTC



# Performance Prediction

## Error analysis Using the Optimal Estimation Method

$$\begin{aligned}\hat{\mathbf{x}} - \mathbf{x} &= (\mathbf{A} - \mathbf{I}_n)(\mathbf{x} - \mathbf{x}_a) && \rightarrow \text{Smoothing error} \\ &+ \mathbf{G}_y \mathbf{K}_b (\mathbf{b} - \hat{\mathbf{b}}) && \rightarrow \text{Model parameter error} \\ &+ \mathbf{G}_y \Delta \mathbf{f}(\mathbf{x}, \mathbf{b}, \mathbf{b}') && \rightarrow \text{Forward model error} \\ &+ \mathbf{G}_y \boldsymbol{\varepsilon} && \rightarrow \text{Retrieval noise}\end{aligned}$$

Solution error ( $S_{sn}$ ) : square-root-sum of the diagonal elements of smoothing error and retrieval noise covariance matrices

$\hat{\mathbf{x}}$  : retrieved value

$\mathbf{x}$  : true value

$\mathbf{A}$  : averaging kernel

$\mathbf{I}_n$  : identity matrix

$\mathbf{X}_a$  : a priori estimates of  $\mathbf{x}$

$\mathbf{G}$  : contribution function  
(generalized inverse of  $\mathbf{K}$ )

$\mathbf{K}$  : Jacobian matrix

$\mathbf{b}$  : true model parameter

$\hat{\mathbf{b}}$  : best estimate of model parameters

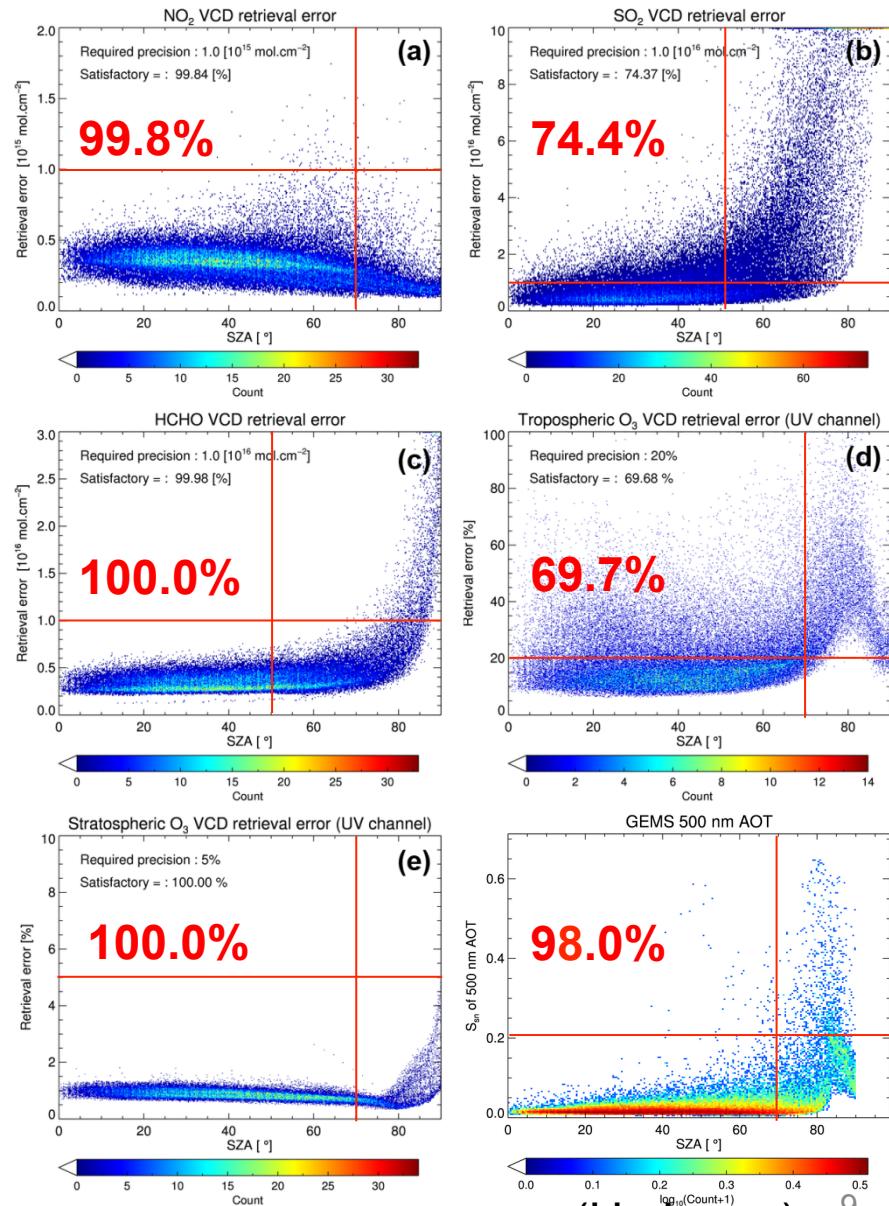
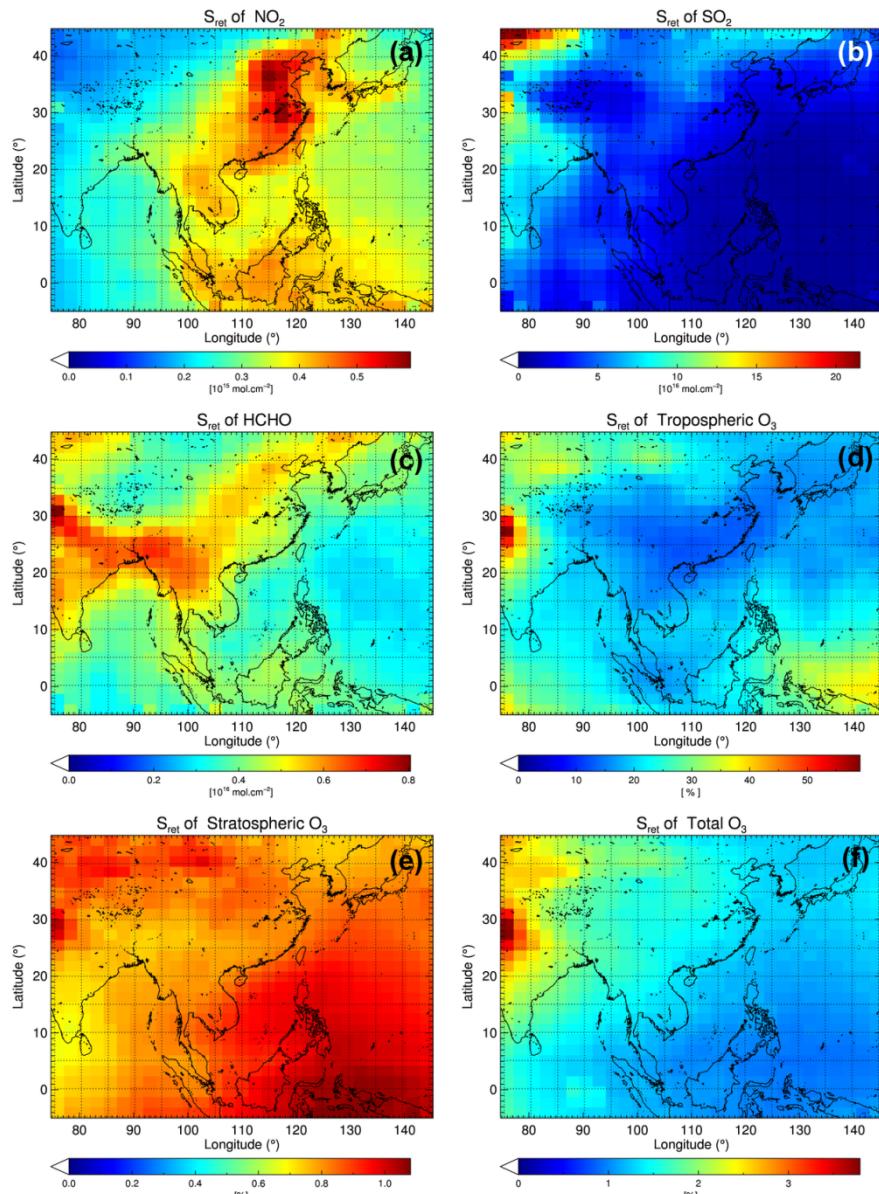
$\Delta \mathbf{f}$  : forward model error

$\mathbf{b}'$  : unknown forward model parameters

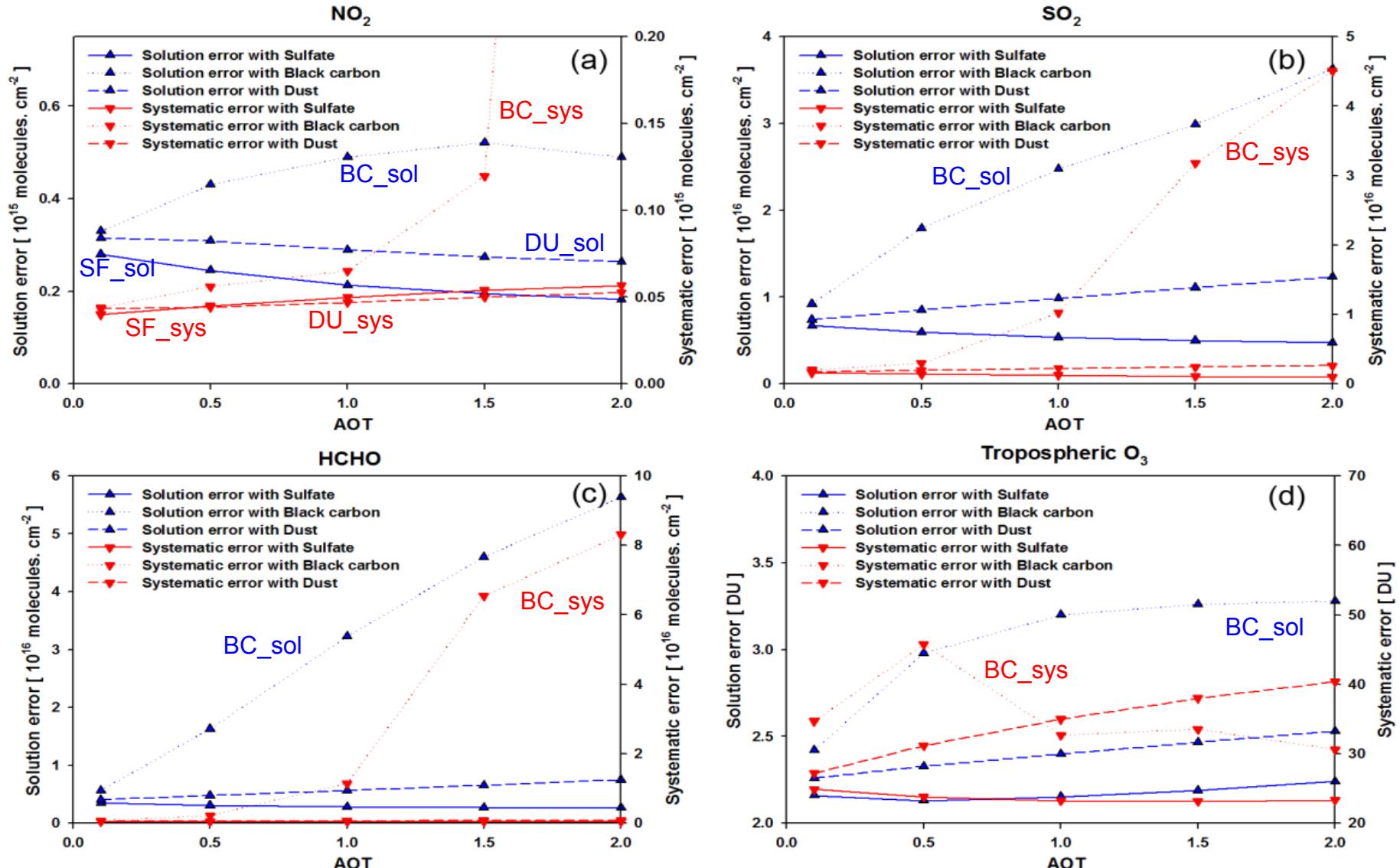
$\boldsymbol{\varepsilon}$  : measurement error

(Rogers, 2000)

# Results

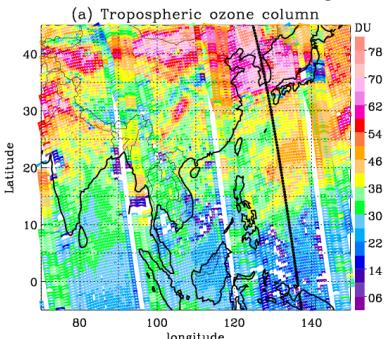


# Effect of aerosol on retrieved gas column density

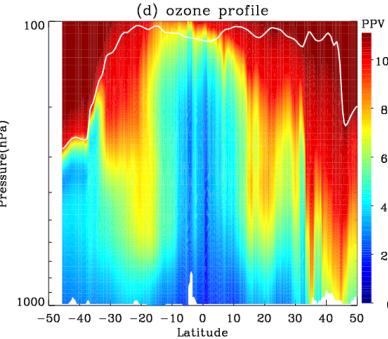


# Examples of retrieved products using OMI

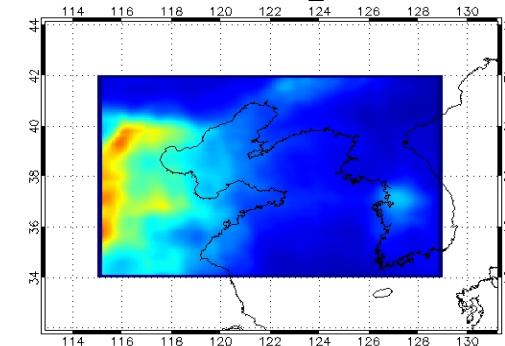
Troposp. O<sub>3</sub>



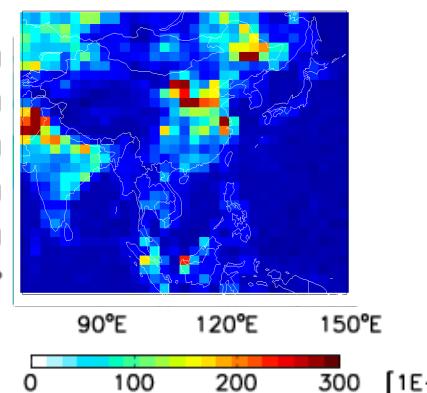
O<sub>3</sub> profile



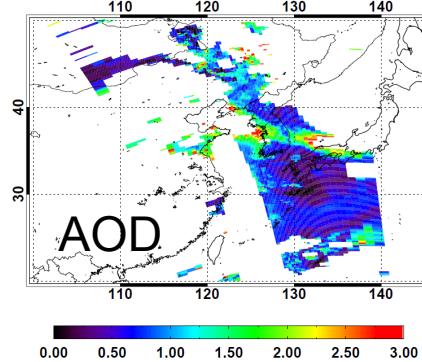
NO<sub>2</sub>



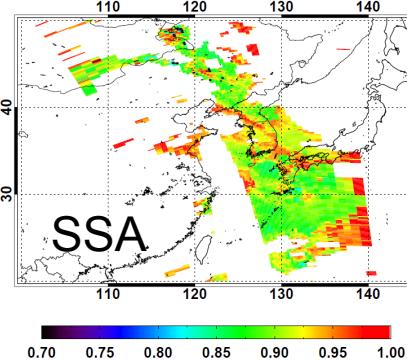
HCHO



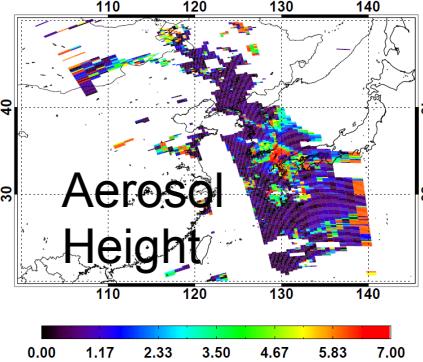
AOD [443 nm] from OMI2006m0408t0400



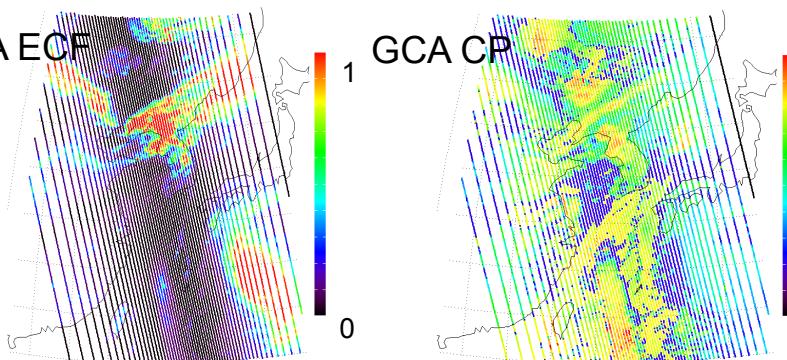
SSA [443 nm] from OMI2006m0408t0400



HGT from OMI [km]2006m0408t0400



GCA EOF



GCA CP

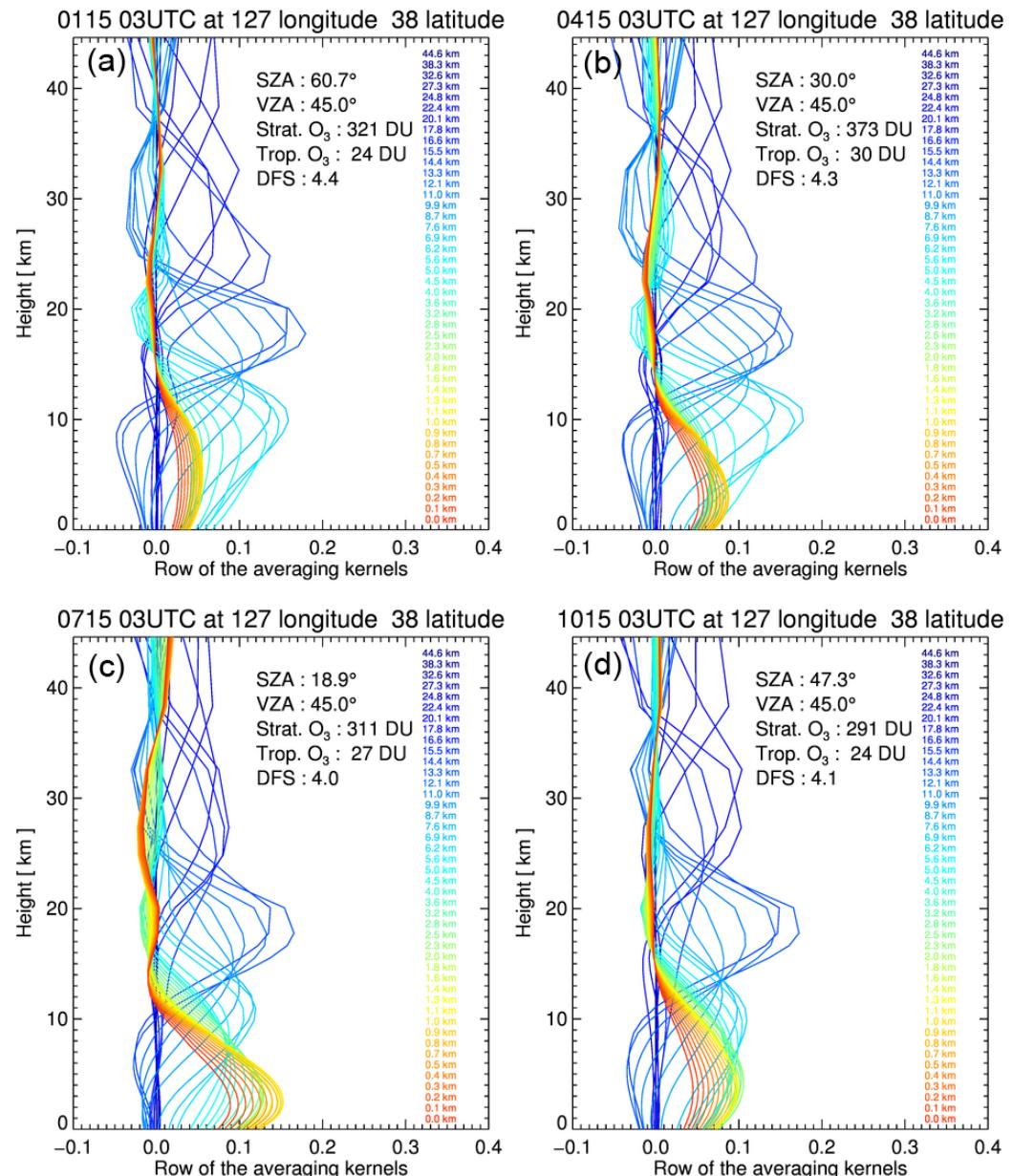
Credit :

Mijin Kim (Yonsei U) – Aerosol  
Y.S. Choi (EWU) - Cloud  
Jae H. Kim (Busan NU) – O<sub>3</sub>  
Hanlim Lee (Pukyung NU) - NO<sub>2</sub>  
Rokjin Park (SNU) – HCHO, CHOCHO  
Y.J. Kim (GIST) – SO<sub>2</sub>  
J.M. Yoo(EWU), M.J. Jeong(GWNU) – Sfc prod  
M.H. Ahn (EWU) - calibration

# Averaging kernel for O<sub>3</sub> retrieval

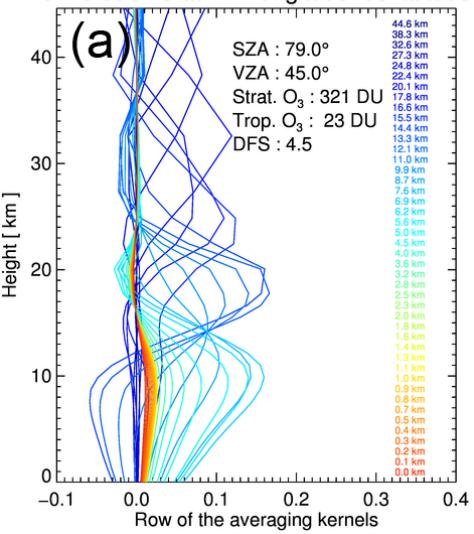
Retrieval sensitivity of tropospheric O<sub>3</sub> is high when SZA and VZA is low, or the amount of stratospheric O<sub>3</sub> is small.

Profile	Degrees of Freedom of O <sub>3</sub>	
	Mean $\pm \sigma$	Median
Troposphere	<b>0.8 <math>\pm</math> 0.2</b>	<b>0.9</b>
Stratosphere	<b>2.9 <math>\pm</math> 0.5</b>	<b>2.8</b>
Total	<b>3.8 <math>\pm</math> 0.4</b>	<b>3.7</b>

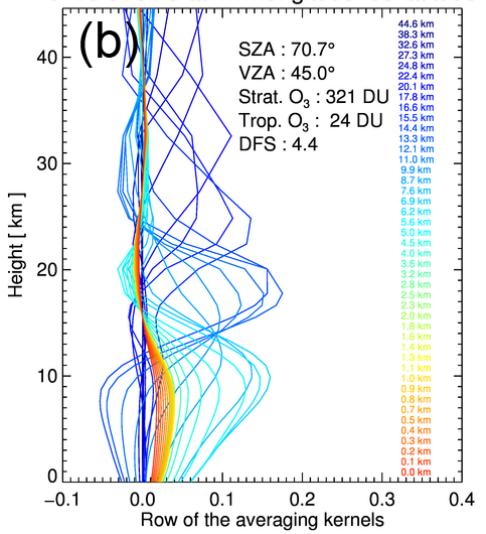


# Diurnal variations of averaging kernel of $O_3$

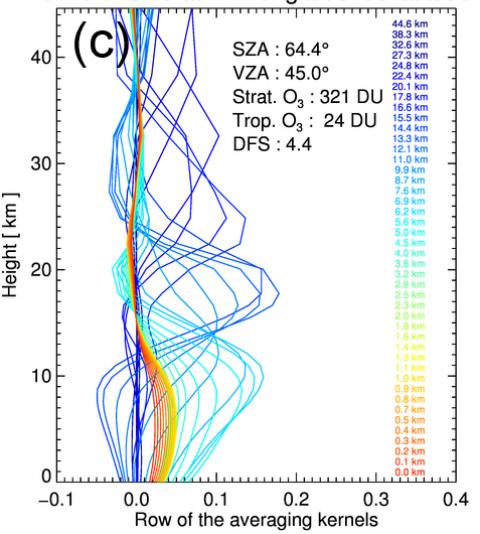
0115 00UTC at 127 longitude 38 latitude



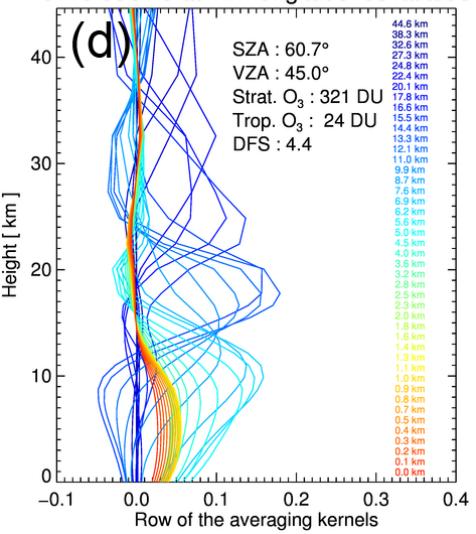
0115 01UTC at 127 longitude 38 latitude



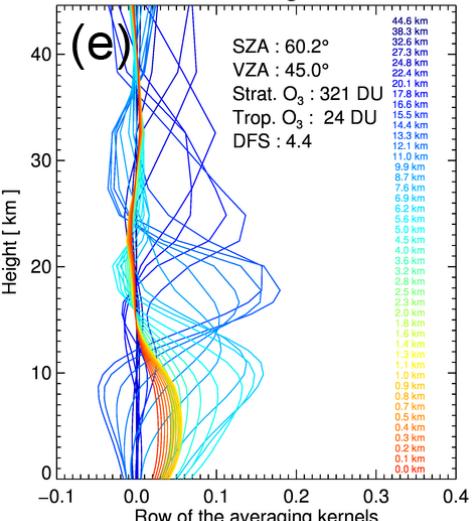
0115 02UTC at 127 longitude 38 latitude



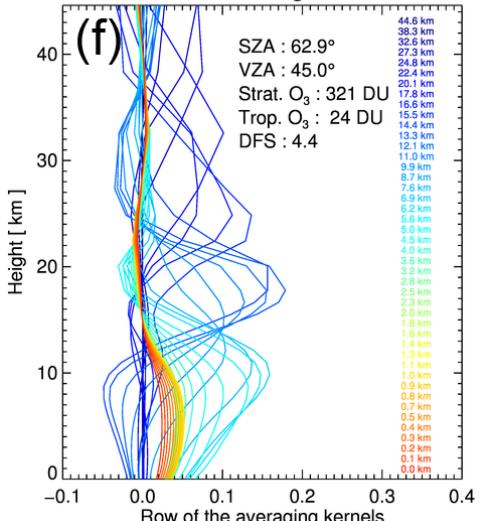
0115 03UTC at 127 longitude 38 latitude



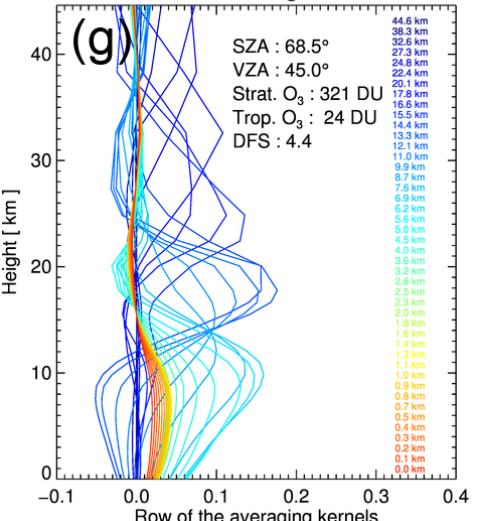
0115 04UTC at 127 longitude 38 latitude



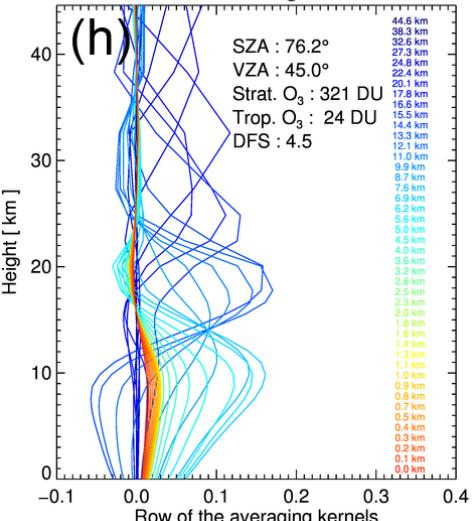
0115 05UTC at 127 longitude 38 latitude



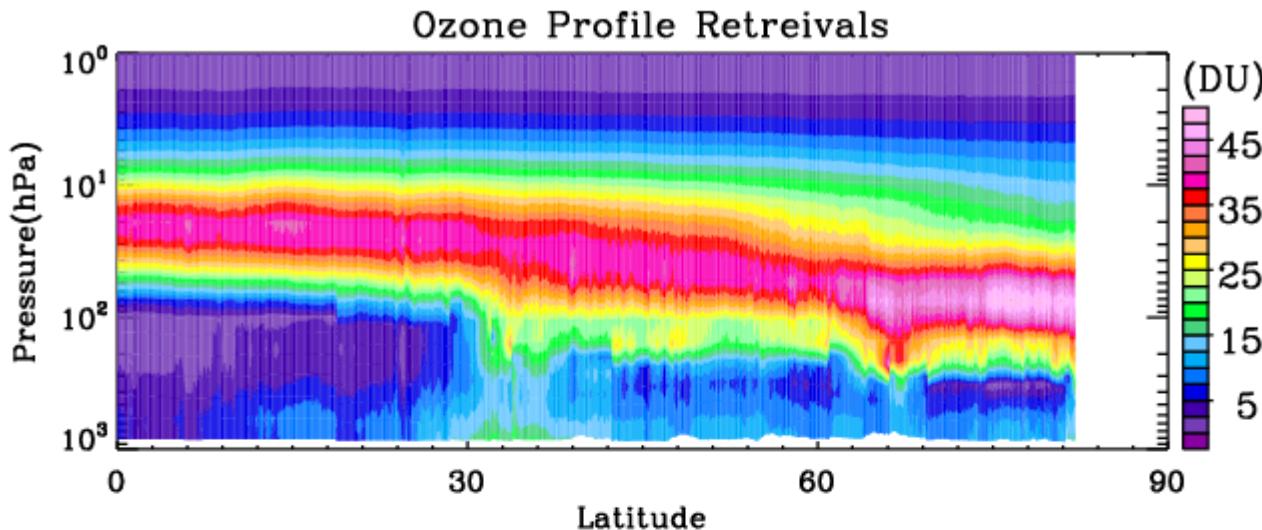
0115 06UTC at 127 longitude 38 latitude



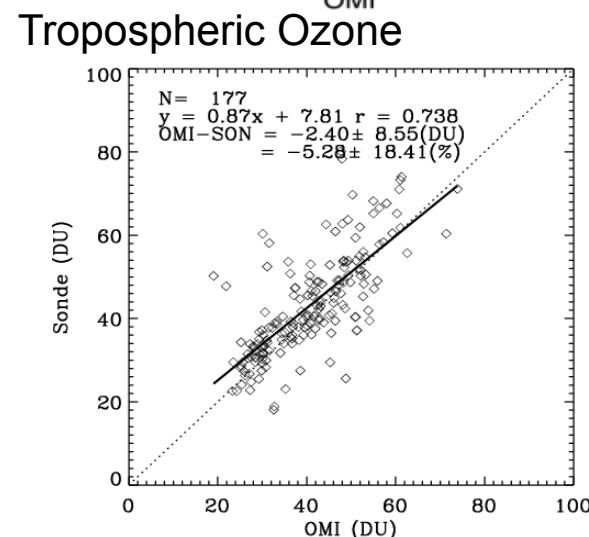
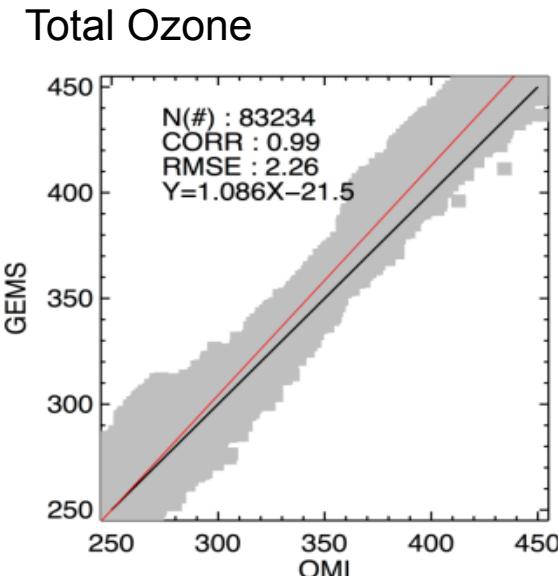
0115 07UTC at 127 longitude 38 latitude



# Retrieval of O<sub>3</sub>



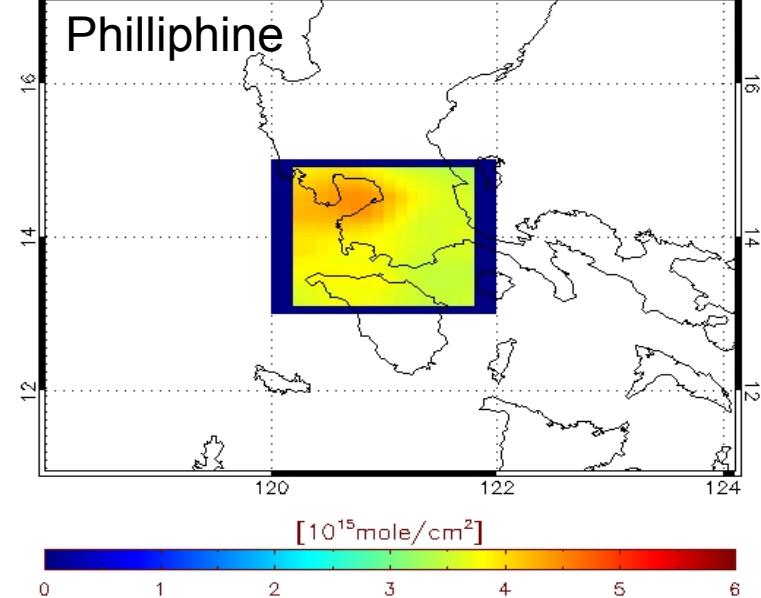
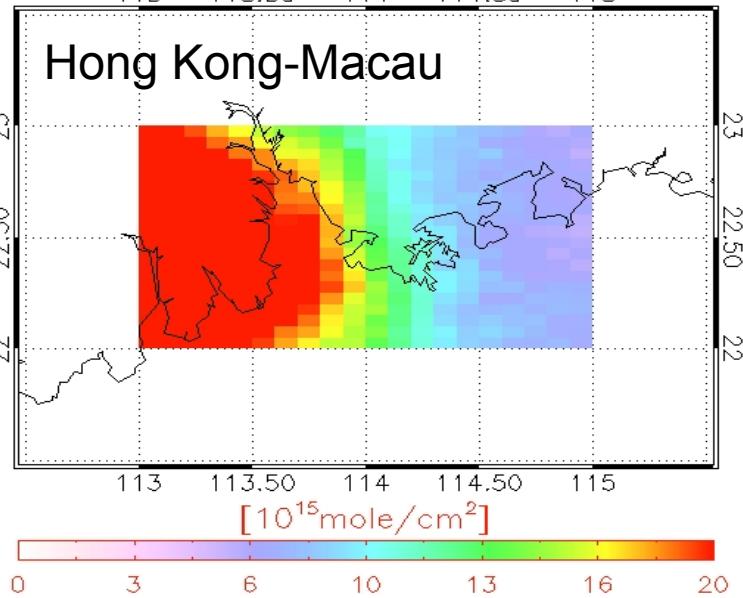
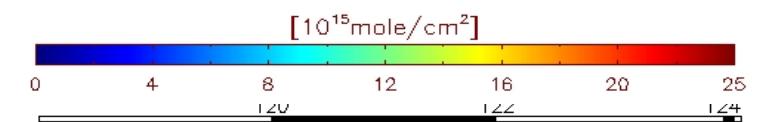
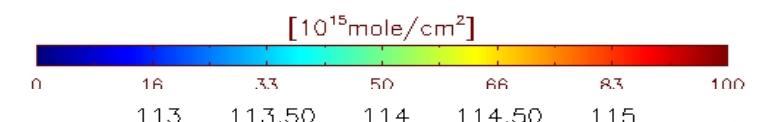
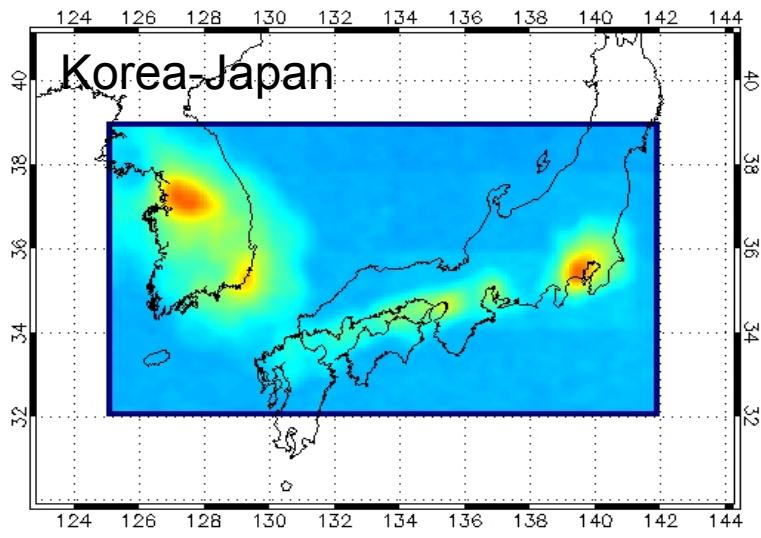
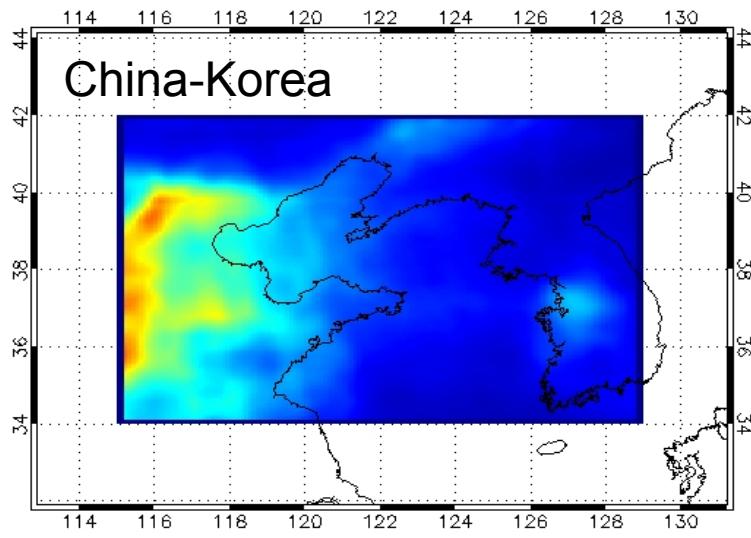
		Goal	Performance
O3 (Total)	R	0.57-0.68	0.99
	A, Slope	0.58-0.68	1.086
	B, Intercept	45.5 DU	21.5 DU
	RMSE	9.1	2.26
O3 (Trop)	R	0.35-0.56	0.74
	A, Slope	0.35-0.64	0.87
	B, Intercept	19.5 DU	8.55 DU
	RMSE	6.5-13DU (13-26%)	8.55 DU (18.41 %)



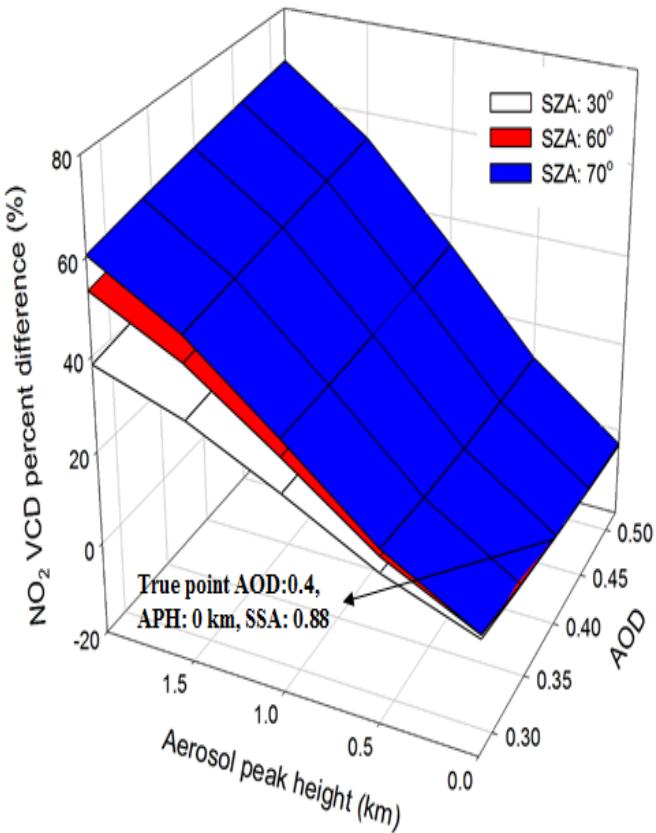
(Courtesy, J.S. Park, K.H. Paik,  
Jae H. Kim)

# $\text{NO}_2$ Retrieval using OMI L1B data

(Courtesy, H.K. Hong, H. Lee)



# $\text{NO}_2$ VCD changes due to AMF error with the presence of aerosol

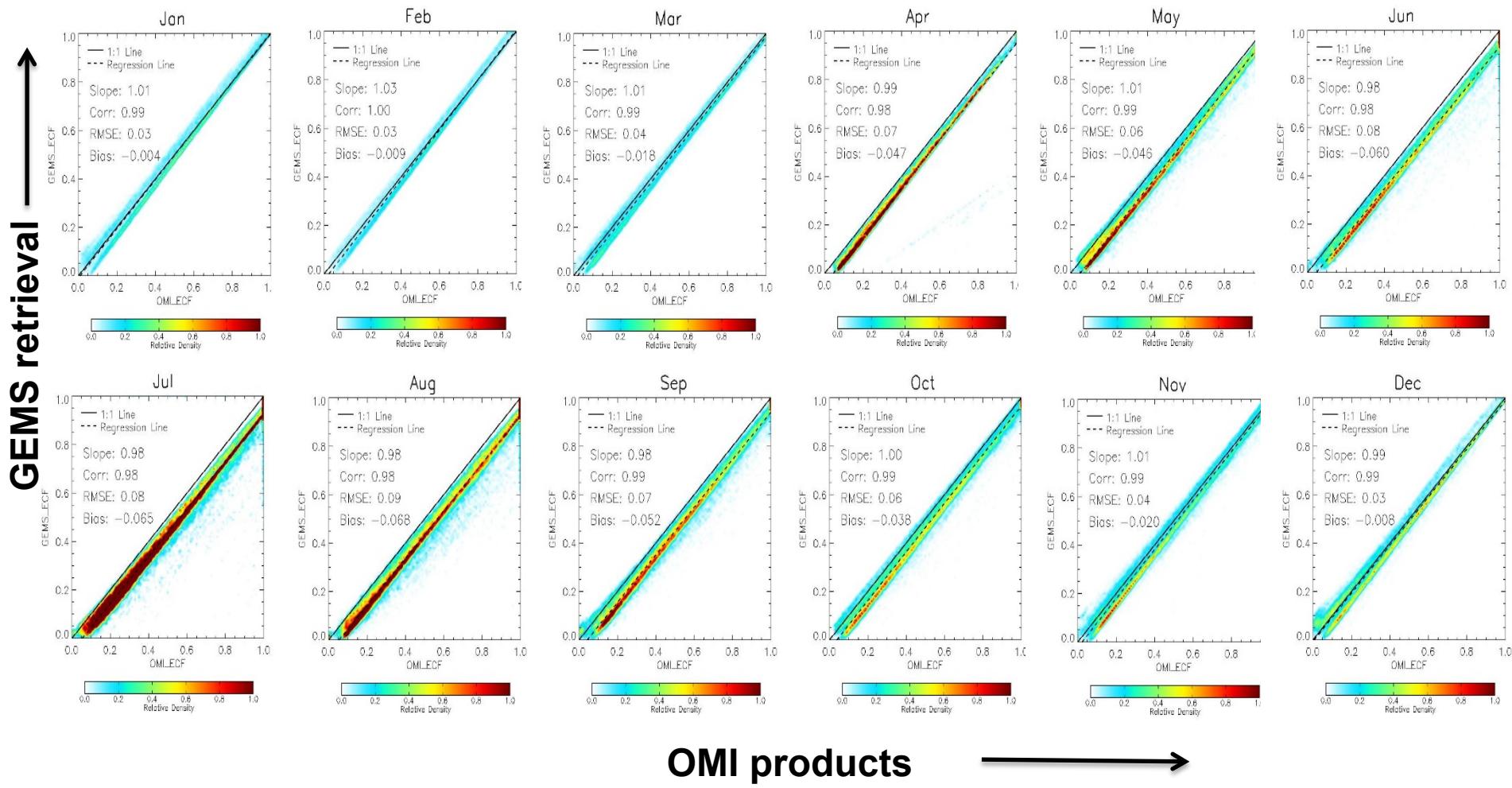


- ✓ The presence of aerosol layer at higher altitude results in larger errors in  $\text{NO}_2$  VCD up to ~60%.
- ✓ Lower SSA of aerosol than true value results in the underestimation of  $\text{NO}_2$  VCD.
- ✓ Further work is underway to separate tropospheric and stratospheric VCDs, by using  $\text{NO}_2$  vertical profiles from CTM and the method of Buscela et al. (AMT 2013).

# Cloud RF retrieval : Validation Results

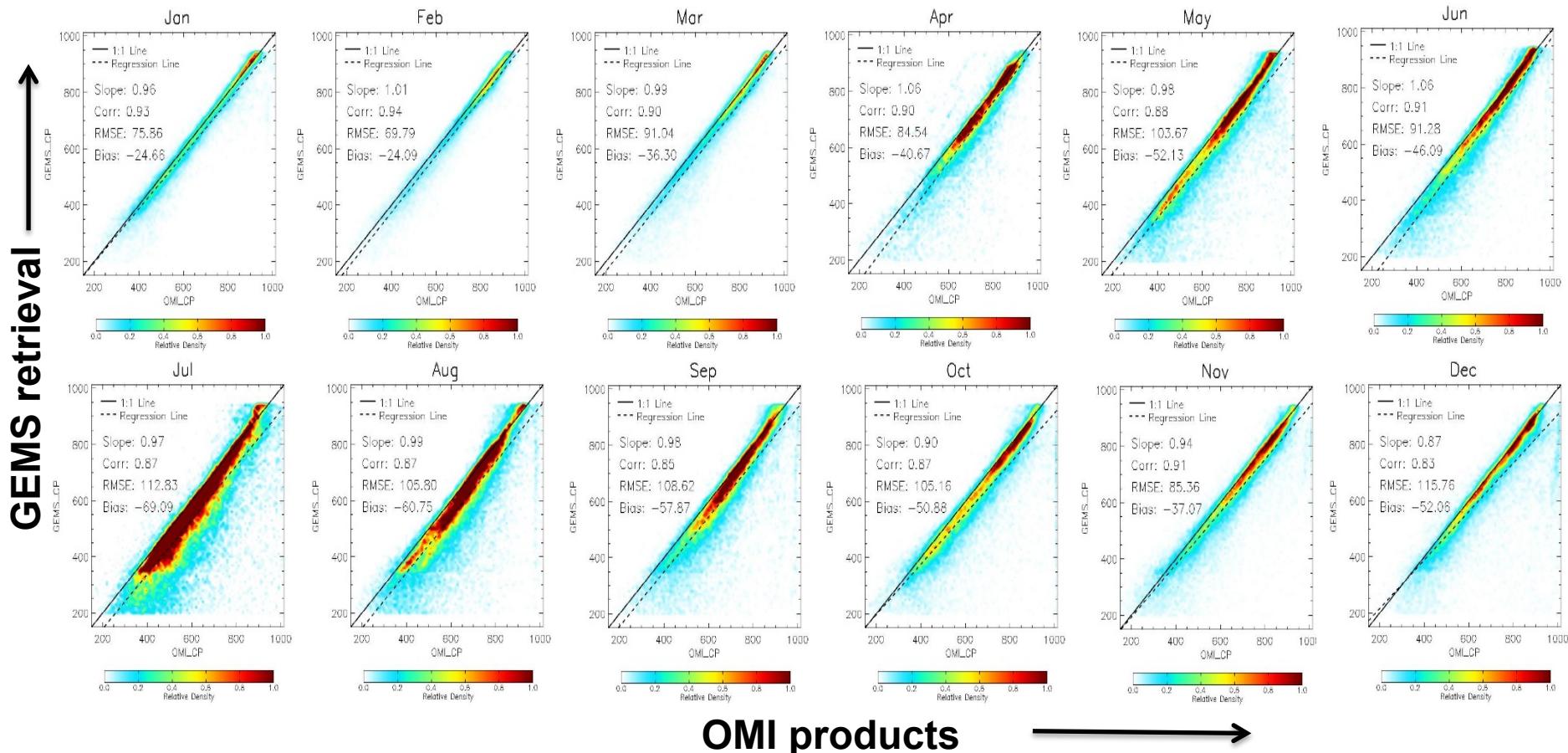
(ECF, every 1<sup>st</sup> day of each month, 2007)

(Courtesy, B.R. Lee, Y.S. Choi)



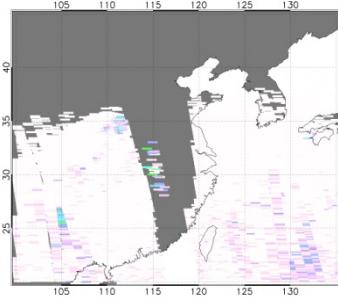
# Cloud pressure retrieval : Validation Results (CP, every 1<sup>st</sup> day of each month, 2007)

(Courtesy, B.R. Lee, Y.S. Choi)

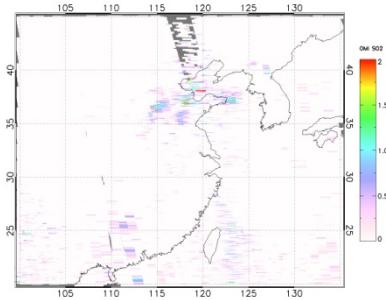


- ✓ More underestimated data in CP especially in summer.

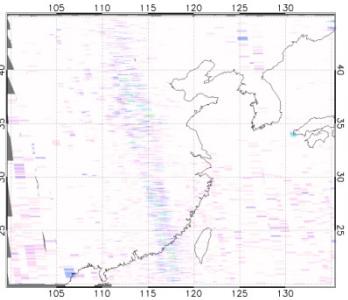
1/2014



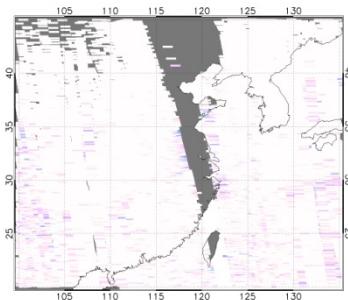
4/2014



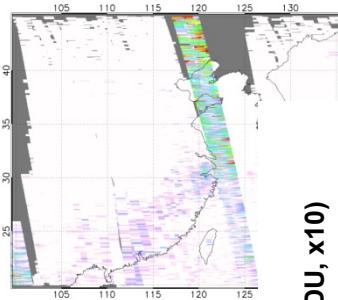
7/2014



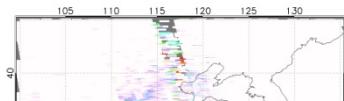
10/2014

**SO<sub>2</sub>**

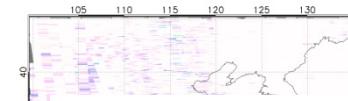
7



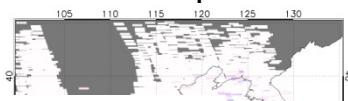
1



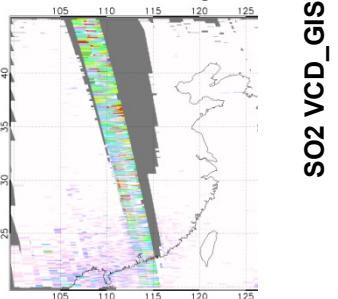
2



1



20



21

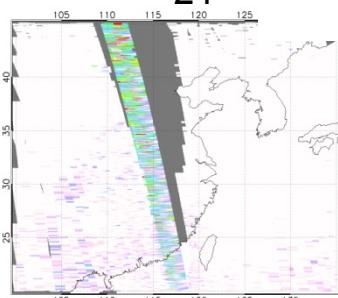
SO2 VCD\_GIST(DU, x10)

Anthropogenic  
 $y = 0.40x + 0.06$   
 $R = 0.88$

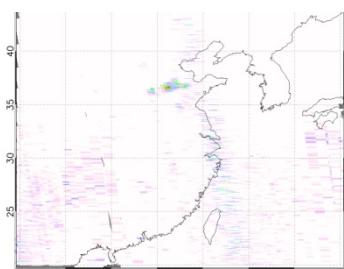
SO2 VCD\_NASA(DU, x10)

Volcanic  
 $y = 1.17x + 2.35$   
 $R = 0.98$

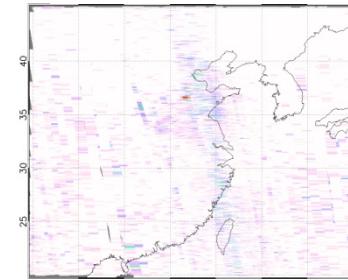
SO2 VCD\_NASA(DU, x10)



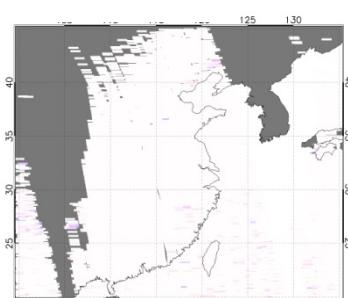
23



13



13



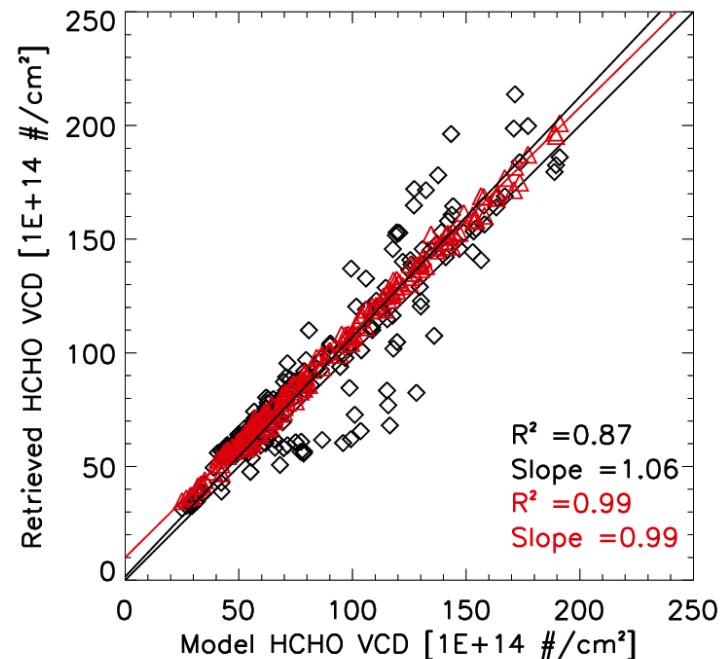
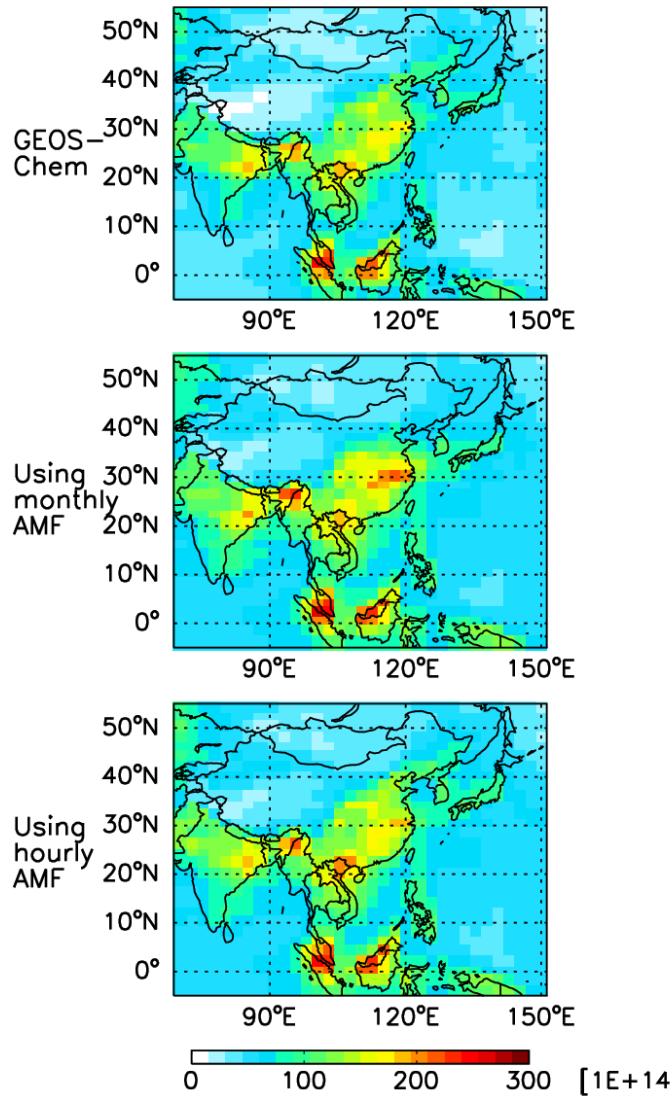
30

(Courtesy,  
J.H. Jeong,  
Y.J. Kim)

# HCHO retrieval

(Courtesy, H.A. Kwon, R. Park)

**HCHO VCDs mean for 11-13 LST  
(June 21. 2009)**

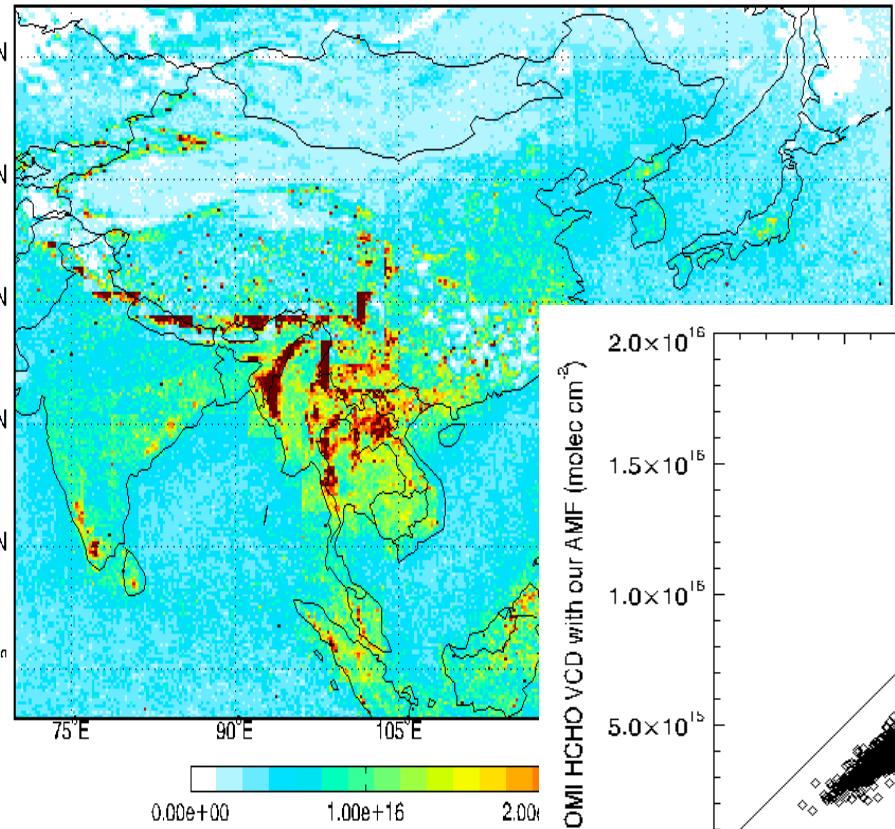


- Hourly AMF
- w/o consideration of noises

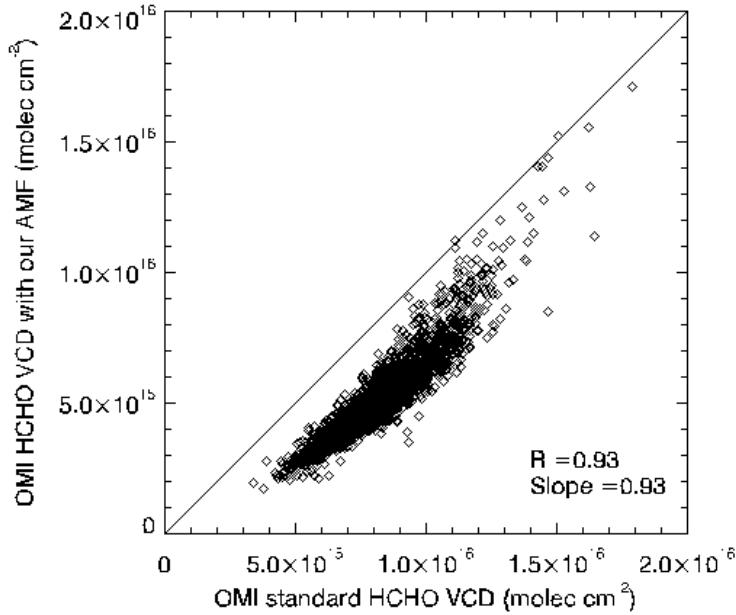
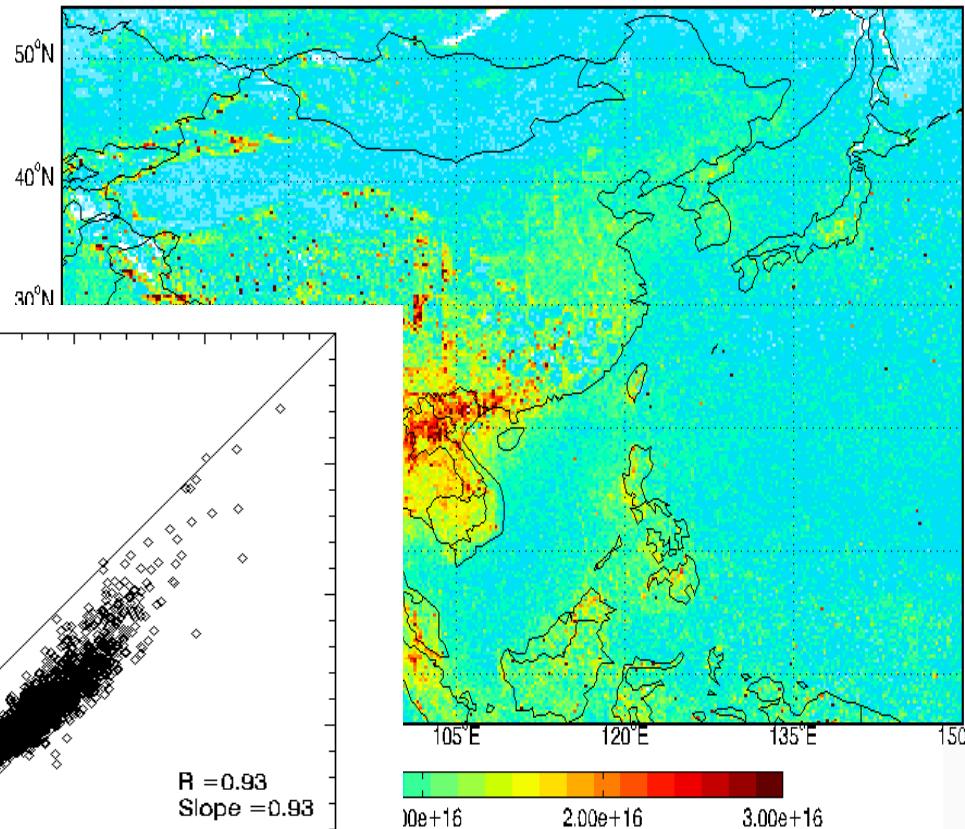
# HCHO retrieval with aerosol (March, 2006)

(Courtesy, H.A. Kwon, R. Park)

HCHO VCD with aerosols



OMI standard product

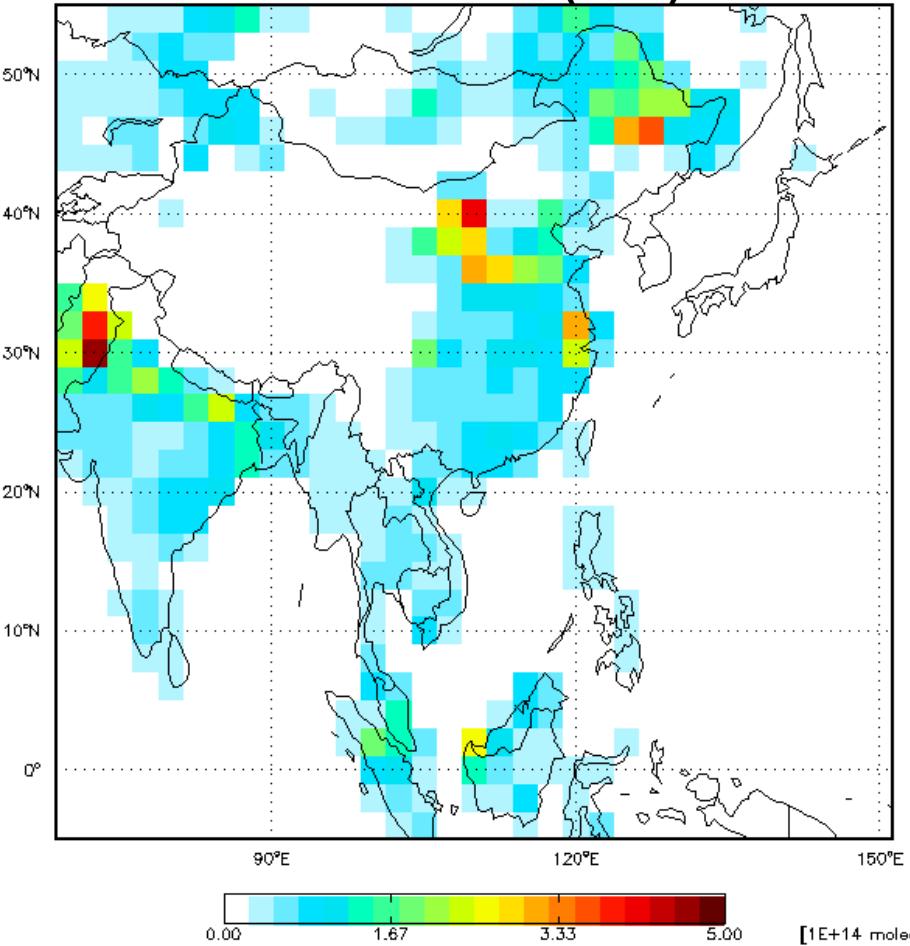


- ✓ Systematic underestimation of HCHO VCD is largely due to AMF.

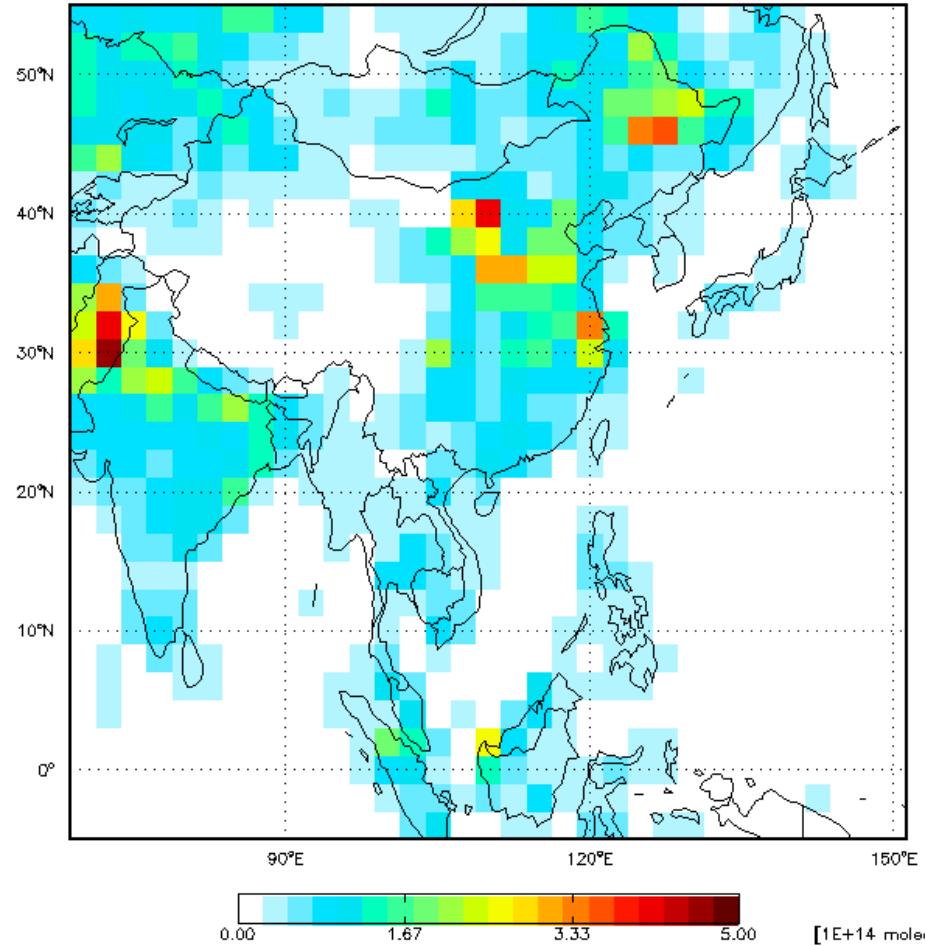
# CHOCHO retrieval (437-452.2nm at 13 KST in July 1, 2006)

(Courtesy, H.A. Kwon, R. Park)

GEOS-Chem (true)

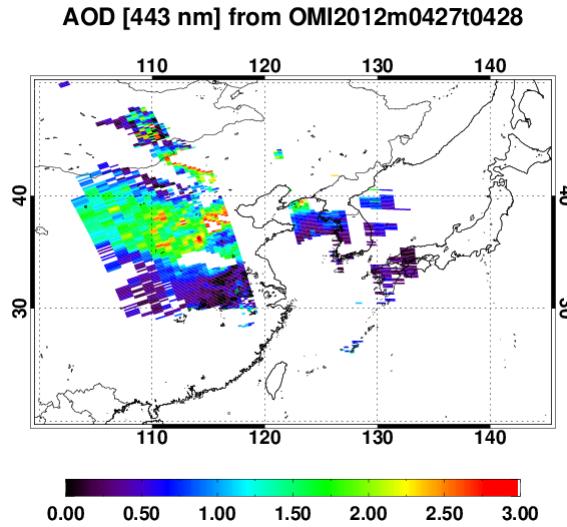


Retrieved VCD

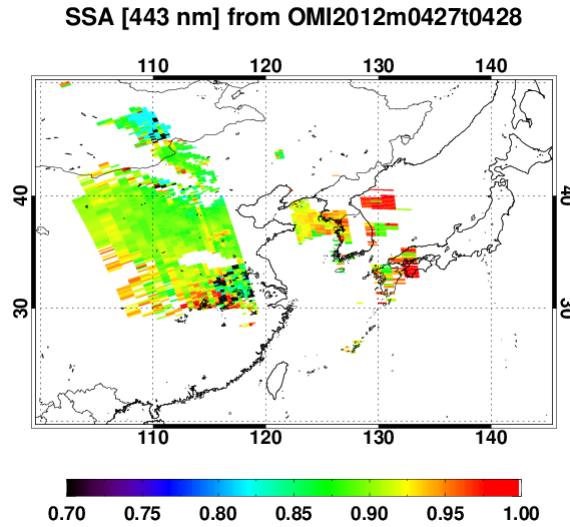


# Retrieval of AOD, SSA, and HGT

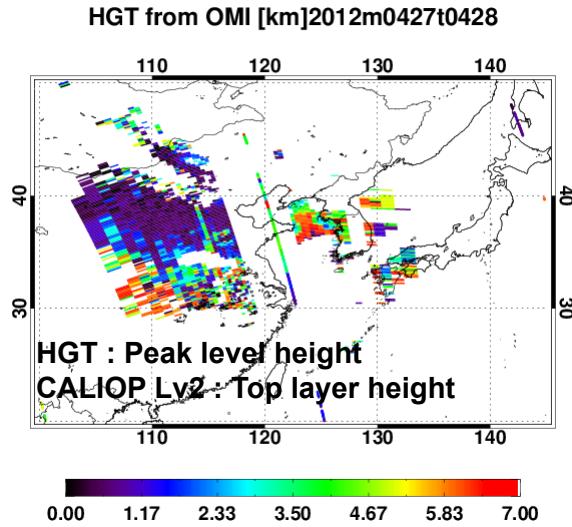
**Retrieved AOD [443 nm]**



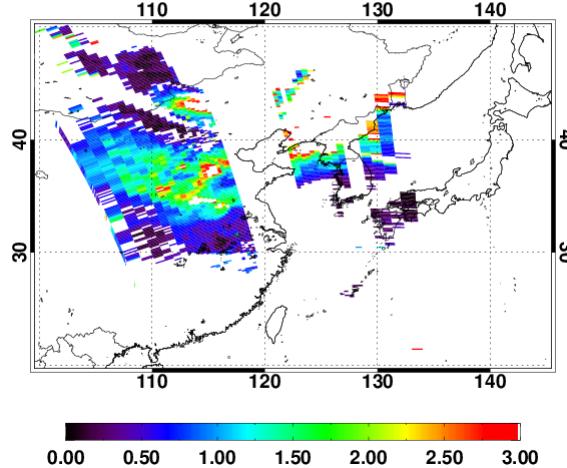
**Retrieved SSA [443 nm]**



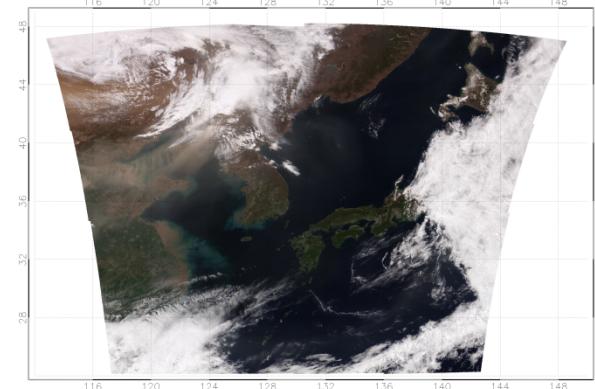
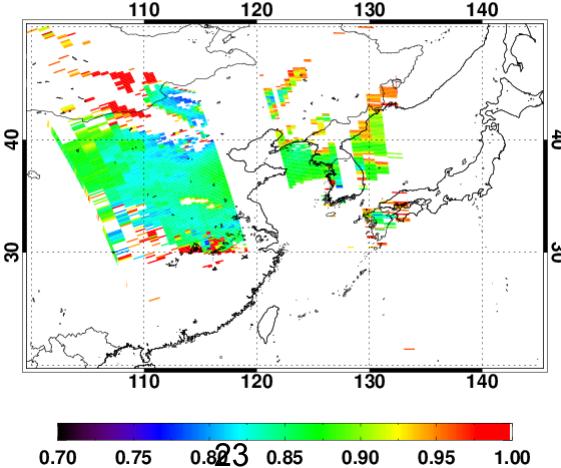
**Fitted HGT [km]**



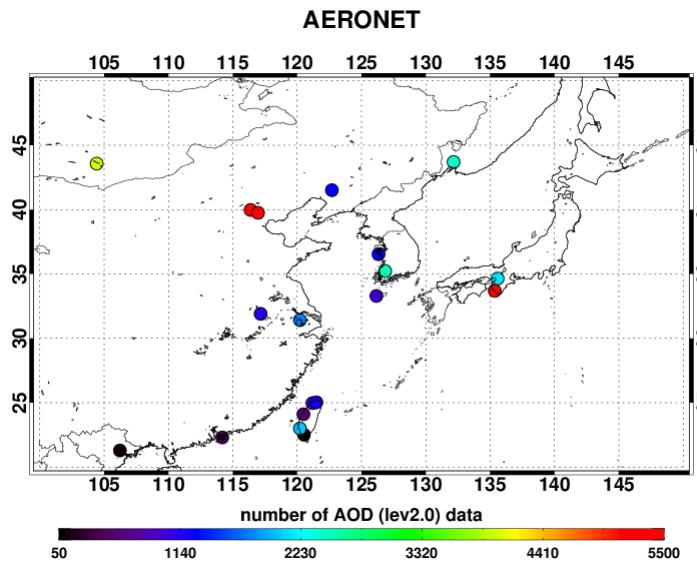
**MODIS RGB :2012/04/27**



**OMI SSA [388 nm]**



# Validation of AOD and SSA



## AOD validation

AERONET direct measurement(lev2.0)

2005. 01 ~ 12,

Within  $\pm 10$  min.,  $0.4^\circ \times 0.4^\circ$

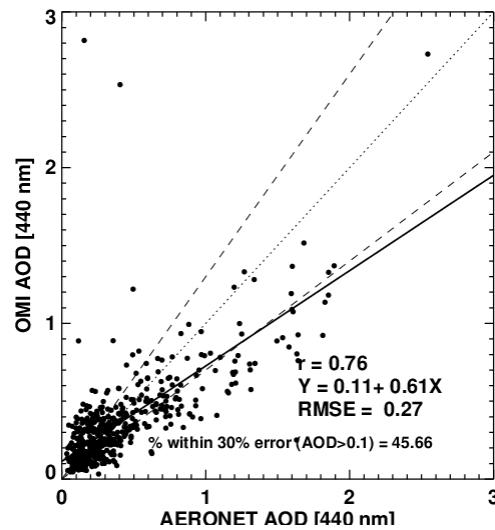
## SSA validation

AERONET inversion data(lev2.0)

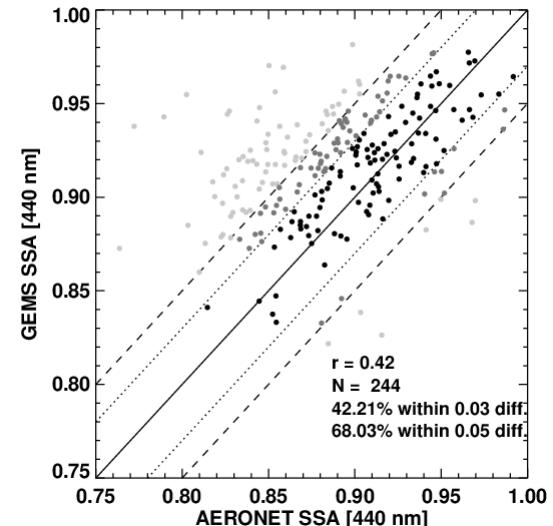
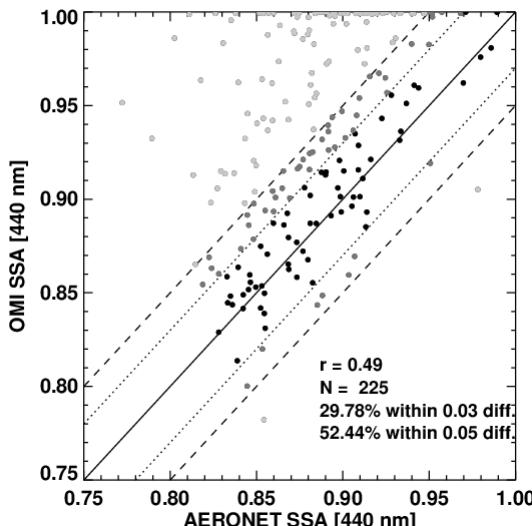
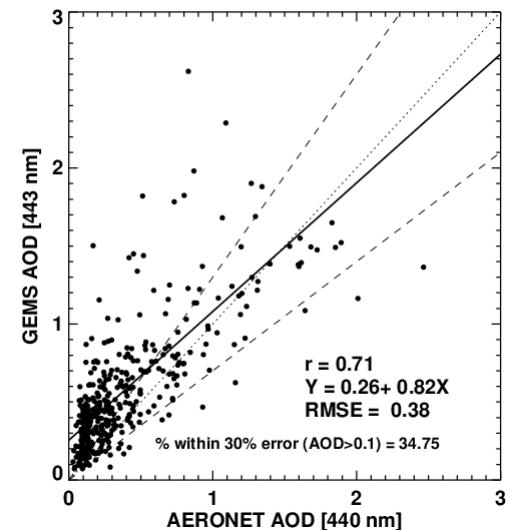
2005. 01 ~ 12,

Within  $\pm 4$  hr,  $0.4^\circ \times 0.4^\circ$

## Operated Algorithm



## Developed Algorithm



# Prelaunch Test and Characterization

- Spectral Tests (spectrometer+focal plane)
  - Spectral Bandpass
  - Spectral Range
  - Smile & Keystone
- Stray Light Tests for Stray Light Model Validation (spectrometer+focal plane)
  - Diffuser can be placed in the light path
  - Various light source (tunable laser, spectral line source, Xenon arc lamp, Quartz-tungsten-halogen lamp)
- Spatial Characterization
  - MTF
  - Field of View
- Boresight and Spectral Stability
- Diffuser BTDF
- NIST Traceable Radiometric Calibration
  - GEMS in ambient or thermal condition
  - Large Spherical Source(LSS) integrating sphere illumination
- Polarization Sensitivity
  - Rotatable polarizer



GOHI  
VIIRS  
OMPS  
OMI  
MOPITT  
TROPOMI  
GEMS

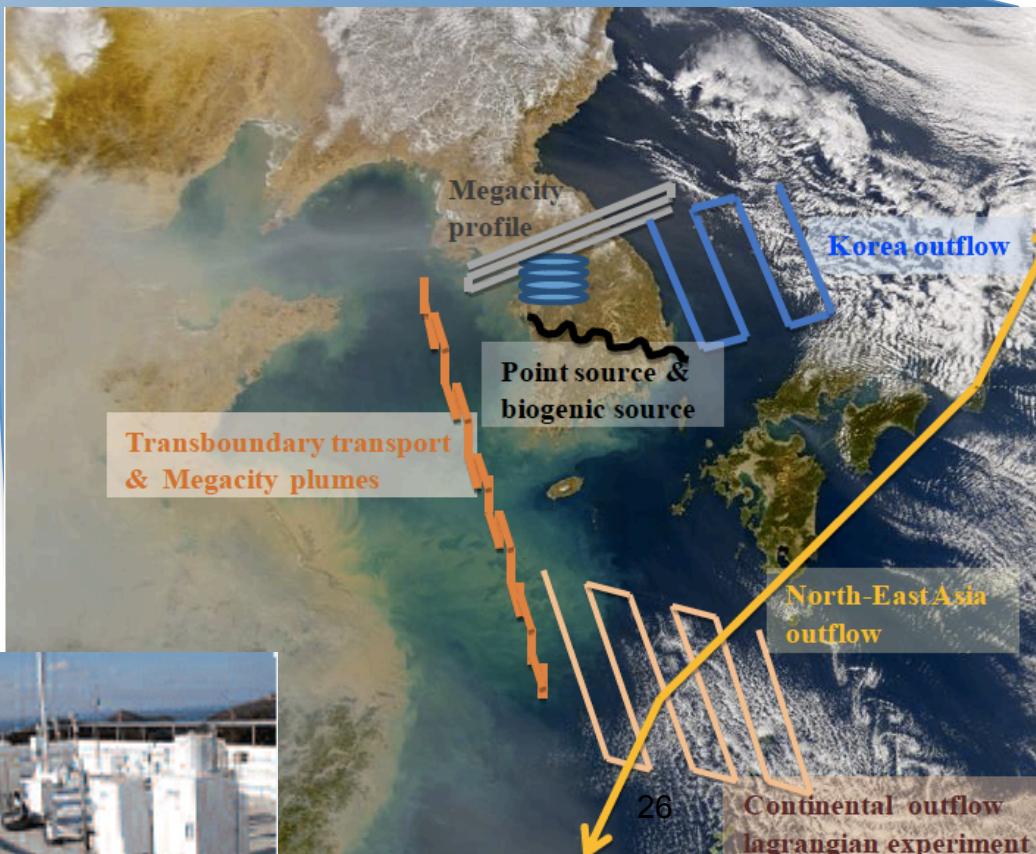
- O<sub>3</sub> sonde
- O<sub>3</sub> LIDAR
- Aerosol LIDAR

• **Ground Network:**

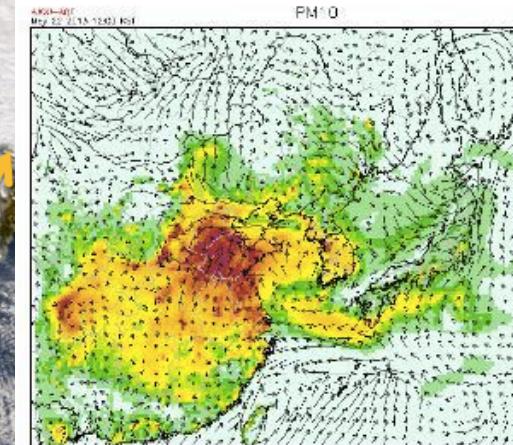
PANDORA  
AERONET  
SKYNET  
EANET  
Air Korea



Airborne  
GEOTASO / B200  
Aerosol LIDAR / DC8  
Gas / King Air  
MOS / B200



**Air quality forecast**



**Shipborne**



# Summary

- GEMS onboard the Geo-KOMPSAT-2B is expected to provide information on aerosol and O<sub>3</sub> together with their precursors in high spatial and temporal resolution
  - O<sub>3</sub> NO<sub>2</sub> HCHO SO<sub>2</sub> AOD/AI/AEH CHOCHO
  - Clouds (CP, CRF), surface reflectance, UVI
- The predicted performance for the retrieval of trace gas column densities from the current design of GEMS satisfies the product accuracy requirements of NO<sub>2</sub>, HCHO, stratospheric O<sub>3</sub>, but partially satisfy for SO<sub>2</sub> and tropospheric O<sub>3</sub>. Meanwhile, the performance is expected to be poor in winter near Korea in particular.
- Careful consideration of aerosol is required to retrieve trace gas concentration from geostationary satellite remote sensing, especially for absorbing aerosols in particular.
- Preflight tests to characterize stray light, polarization, spectral accuracy, diffuser BTDF etc can provide more accurate analysis on the GEMS performance .
- Synergy with AMI and GOCI-2 will provide more reliable products of aerosol and cloud products, which eventually improve the accuracy of trace gas column density.

# **Acknowledgement**

**GEMS Science Team**

**Ministry of Environment (MoE)**

**NIER, MoE**

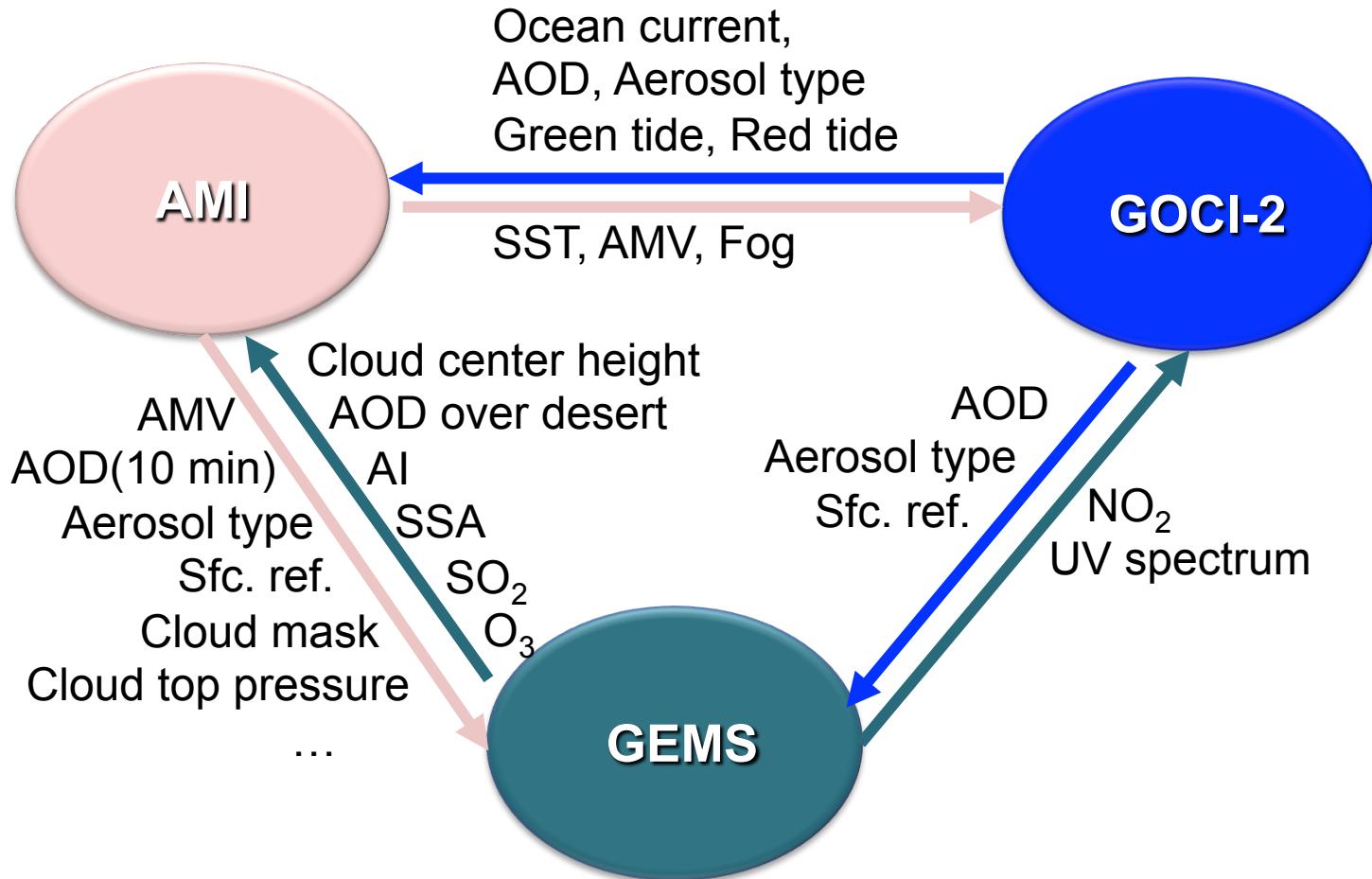
**KEITI, MoE**

**Korea Meteorological Administration (KMA)**

**Korea Ocean R&D Institute (KORDI)**

**Ministry of Science, ICT & future Planning (MSIP)**  
**KARI**

# Synergistic products



- ✓ 24 hr Asian dust monitoring over dark and bright surface
- ✓ Cloud morphology (thickness, fraction, type ...)

# GEMS Science Team

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# Unified Data Retrieval Algorithm

- Basic design for the unified algorithm to be operated at system level
- In the order of CLD/SFC/AOD, then O3T/O3P/HCHO/NO2/SO2

