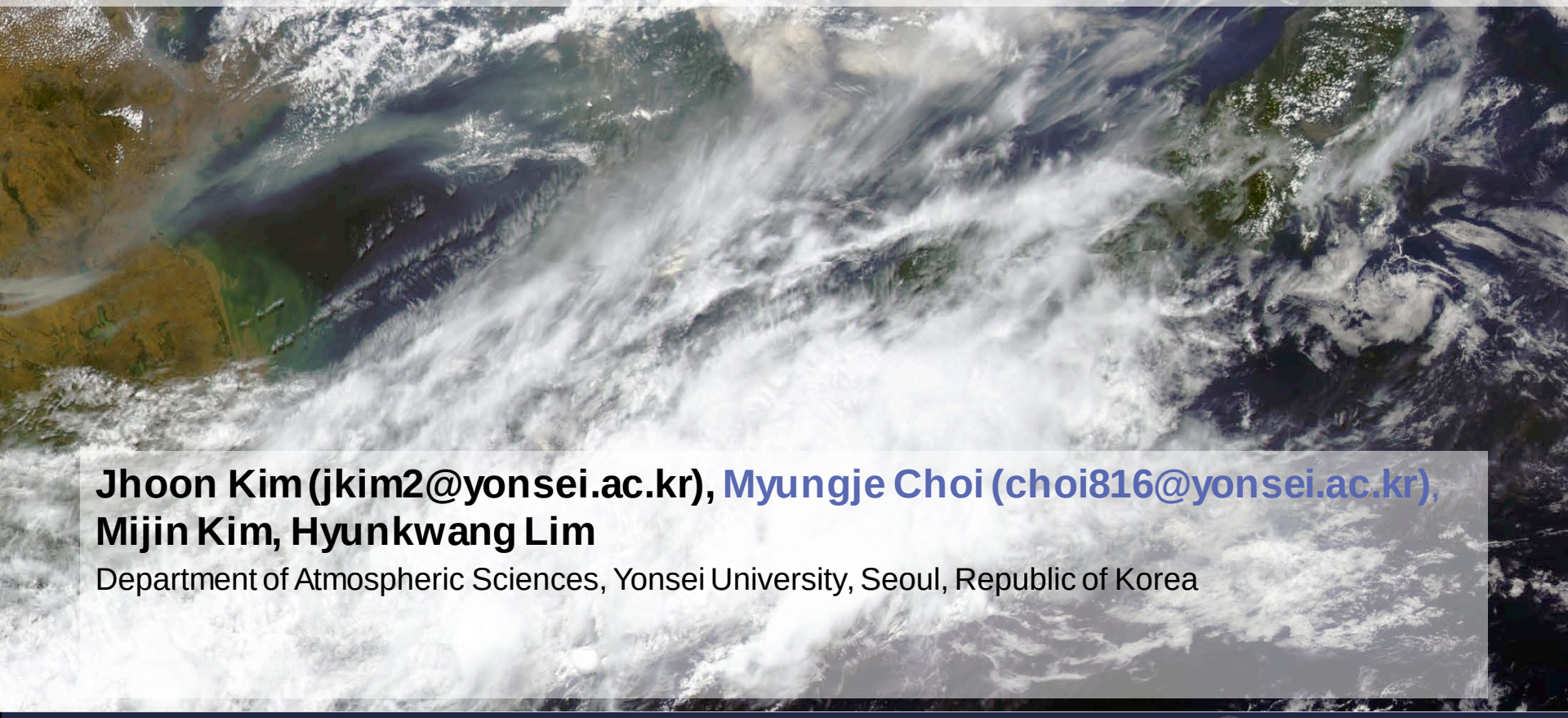
15th CAS-TWAS-WMO Forum / 15th AeroCOM / 4th AeroSAT workshops
19 – 27 September 2016, Beijing, China

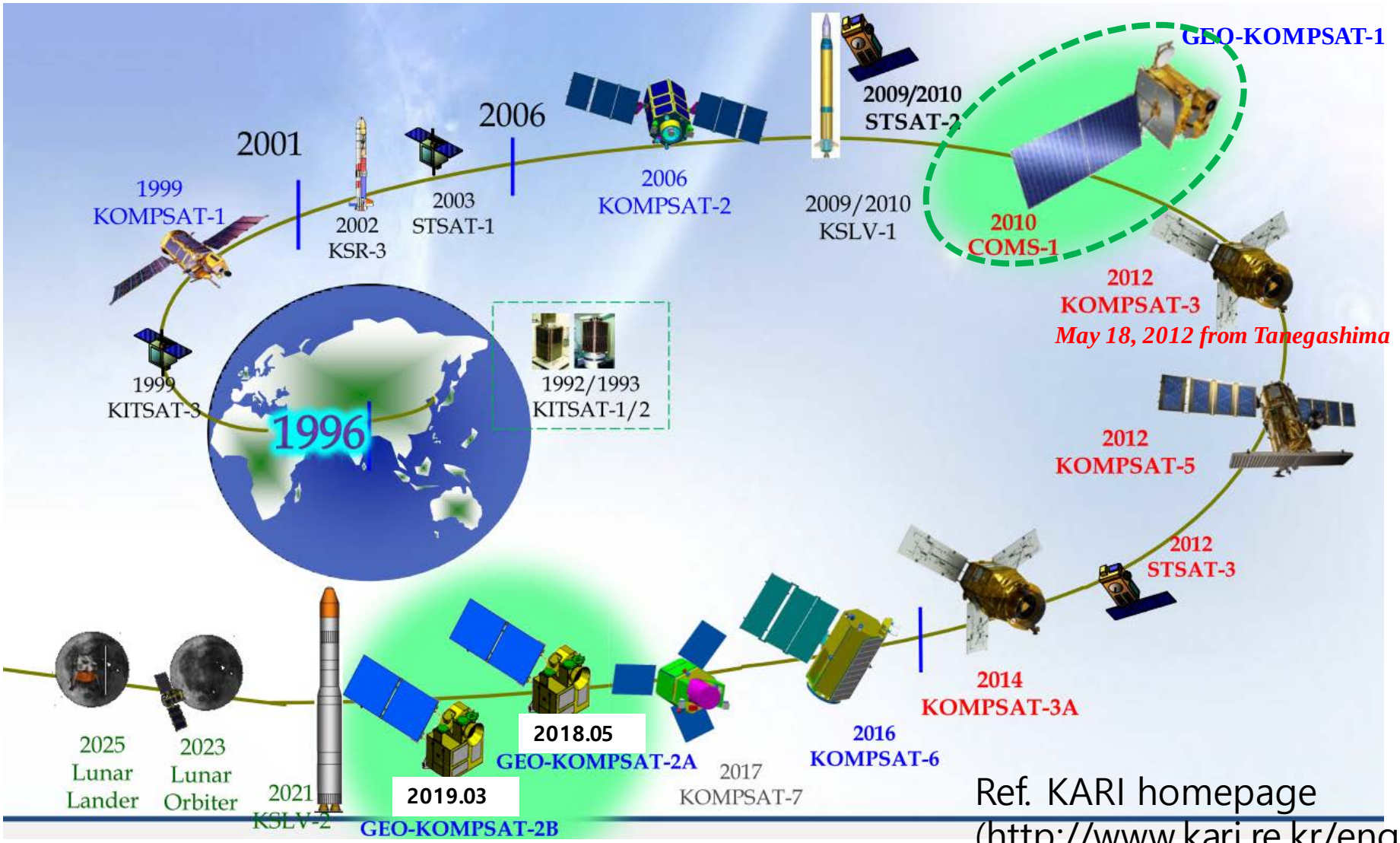
Aerosol remote sensing in South Korea using geostationary satellites



Jhoon Kim (jkim2@yonsei.ac.kr), Myungje Choi (choi816@yonsei.ac.kr), Mijin Kim, Hyunkwang Lim

Department of Atmospheric Sciences, Yonsei University, Seoul, Republic of Korea

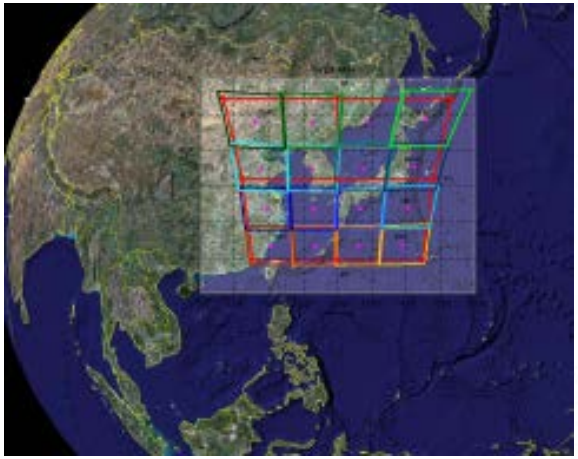
National Space Programs of South Korea



Ref. KARI homepage
(http://www.kari.re.kr/eng/)

Communication, Ocean and Meteorological Satellite (COMS)

Launch : June 27, 2010, Longitude : 128°E (GEO)



Geostationary Ocean Color Imager

GOCI

[Choi et al., 2016, AMT]
[Lee et al., 2012, ACP]
[Lee et al., 2010, RSE]

- Wavelengths:
  412, 443, 490, 555, 660, 680, 745, 865 nm
- Spatial resolution: **500 m x 500 m**
- Temporal resolution: 1 hr (8 times per day)
- Spatial coverage: East Asia

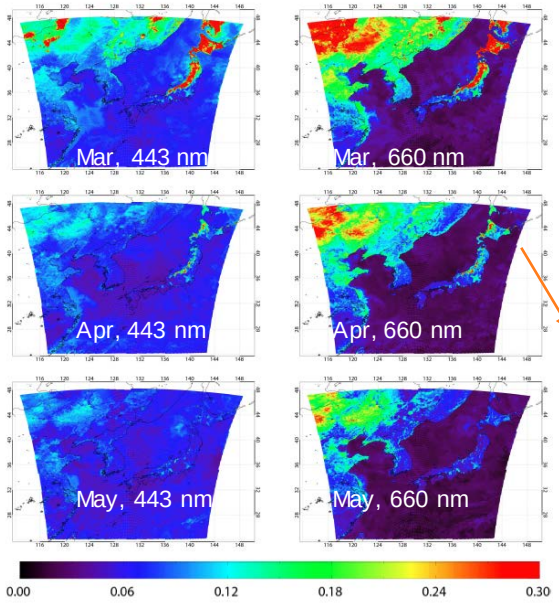
Meteorological Imager

MI

[Kim et al., 2016, ACP]
[Kim et al., 2014, RSE]

- Wavelengths:
  Visible (0.55-0.80 μm), IR1(10.3-11.3 μm), IR2(11.5-12.5 μm), WV (6.5-7.0 μm), NIR (3.5-4.0 μm)
- Spatial resolution: **1 km x 1 km**, 4 km x 4 km
- Temporal resolution: 15 min.
- Spatial coverage: Full disk / NH

Flowchart of GOCI Yonsei Aerosol retrieval (Y



GOCI L1B data
TOA spectral reflectance
in 500m × 500m resolution

Land — Land-Ocean Mask — Ocean

Cloud masking

Turbid water — Turbid water test — Clear water

Surface Reflectance database (minimum reflectivity technique)

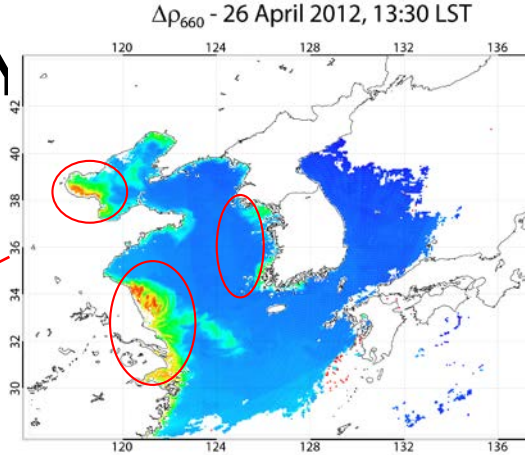
Surface Reflectance according to wind speed

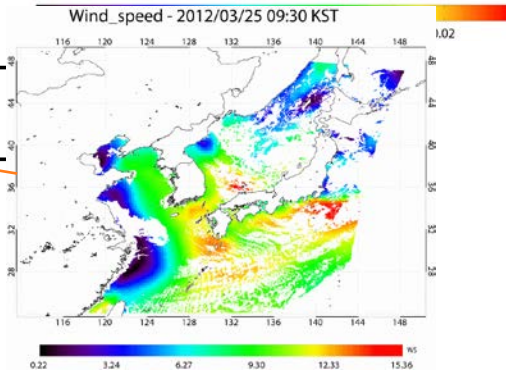
LUT
Aerosol models from
AERONET level 2.0 (26 types)

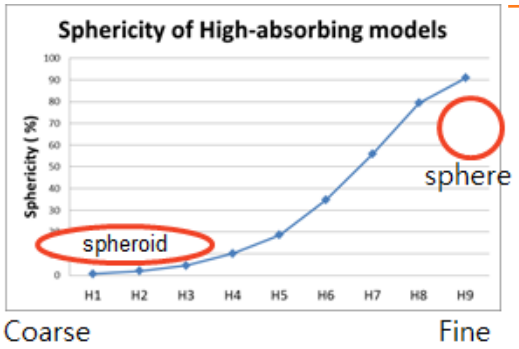
Inversion
Spectral matching of AOD at 550 nm

Final Products

AOD (550 nm)
FMF (550 nm)
SSA (440 nm)
Angstrom Exponent (440-870 nm)
Aerosol type
(6km x 6km resolution)



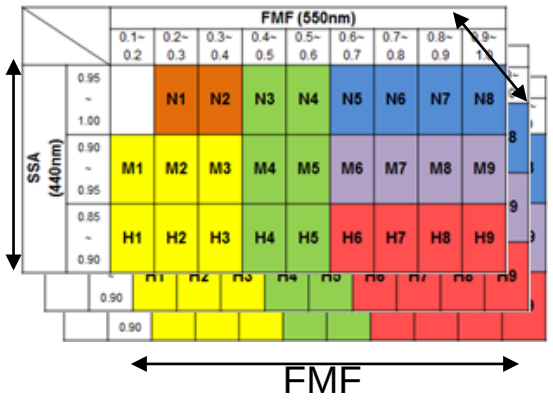




AERONET Inversion database

AOD

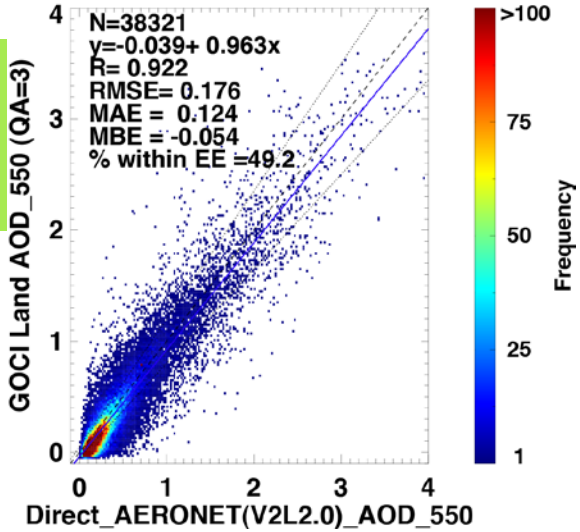
SSA

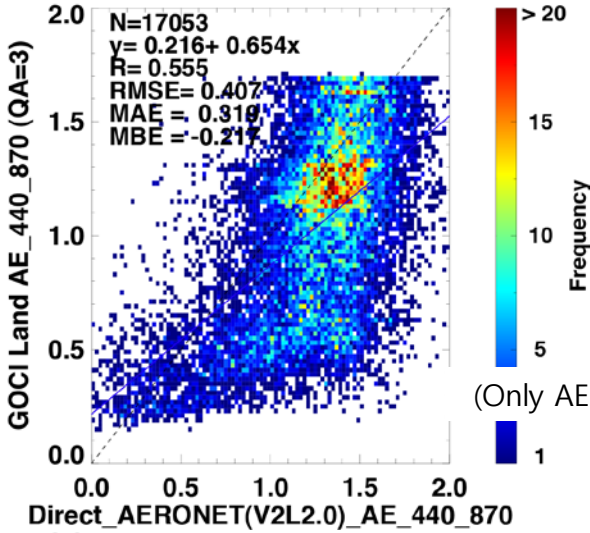


[Choi et al., 2016, AMT]
[Lee et al., 2012, ACP]
[Lee et al., 2010, RSE]

GOCI AOD and AE validation using AERONET

Land -algorithm AOD

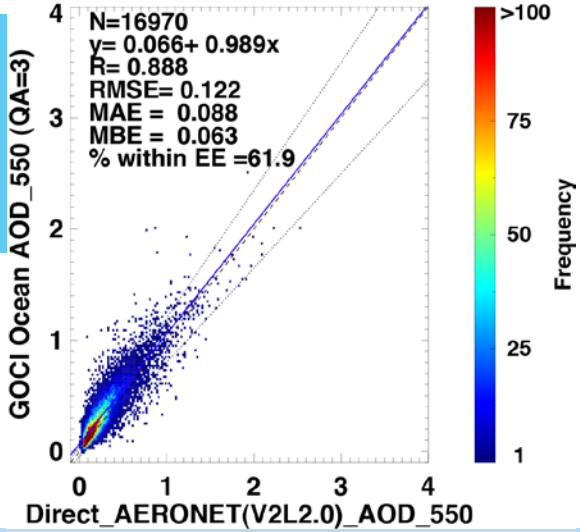


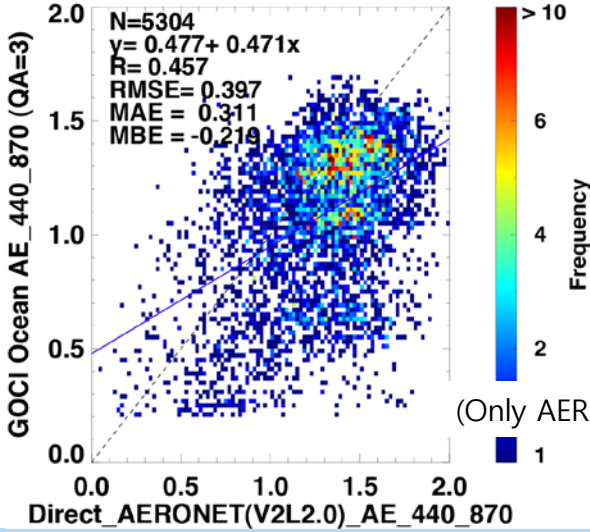


Land AE

(Only AERONET AOD > 0.3)

Ocean -algorithm AOD (coastal sites)





Ocean AE

(Only AERONET AOD > 0.3)

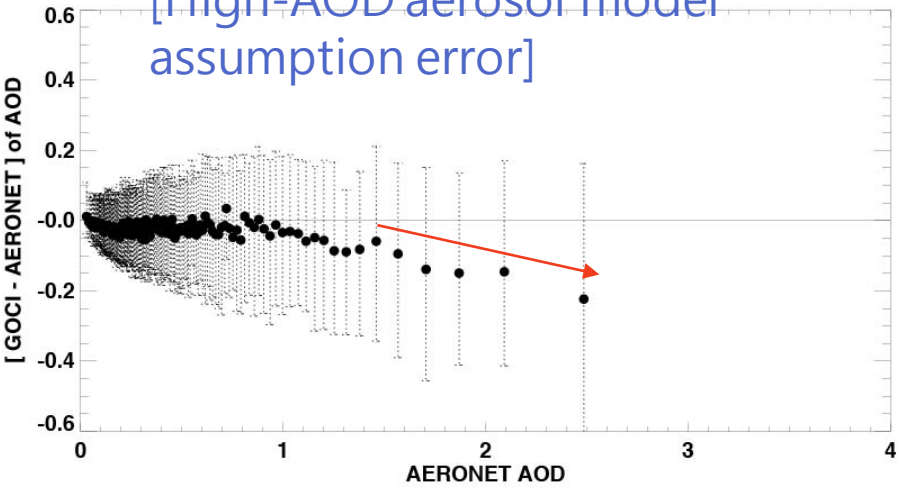
- 27 AERONET sites, 2011.03.01 – 2016.02.29 (5 years)
- Spatial collocation: average of GOCI pixels within 25km at AERONET site (at least one GOCI data is available)
- Temporal collocation: average of AERONET data within 30min at satellite measurement time (at least one AERONETdata is available)
- Expected Error: ±(0.05+0.15×AERONET AOD), Reference from MODIS DT

[In prep.]

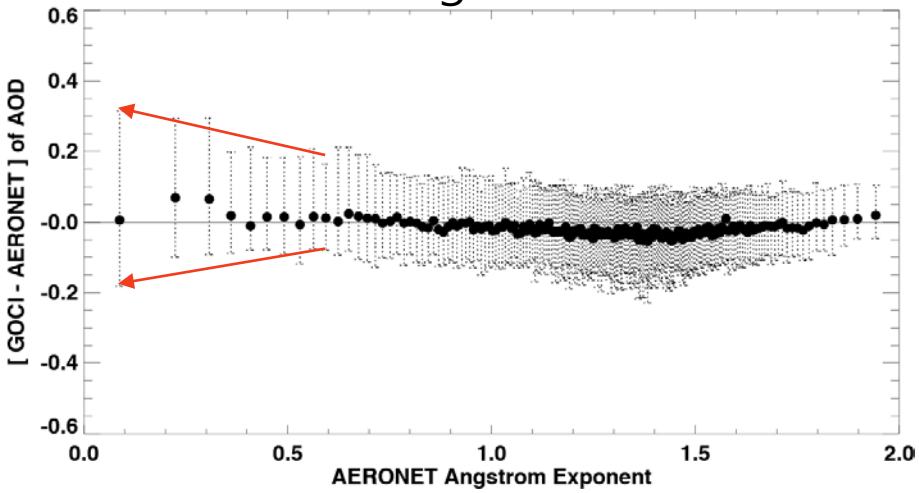
GOCI AOD error analysis

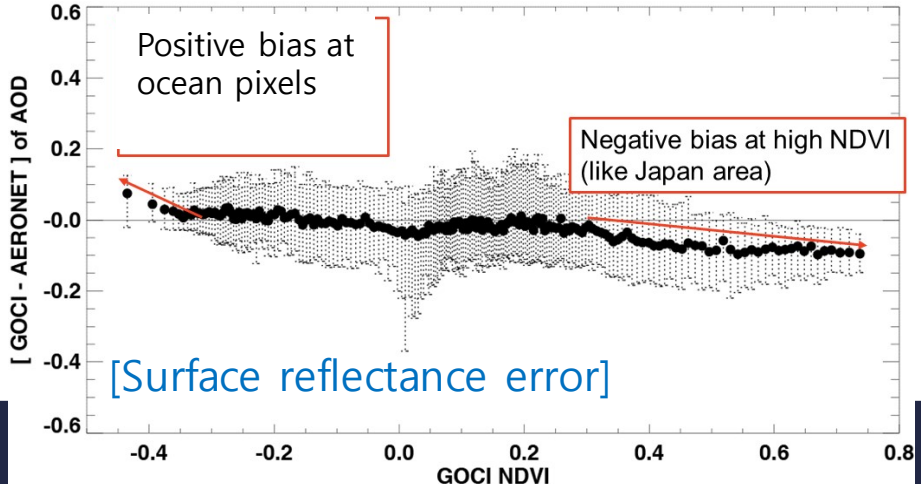
Next step: How to quantify uncertainties of AOD considering various error sources together?

Negative bias at high AOD
[High-AOD aerosol model assumption error]

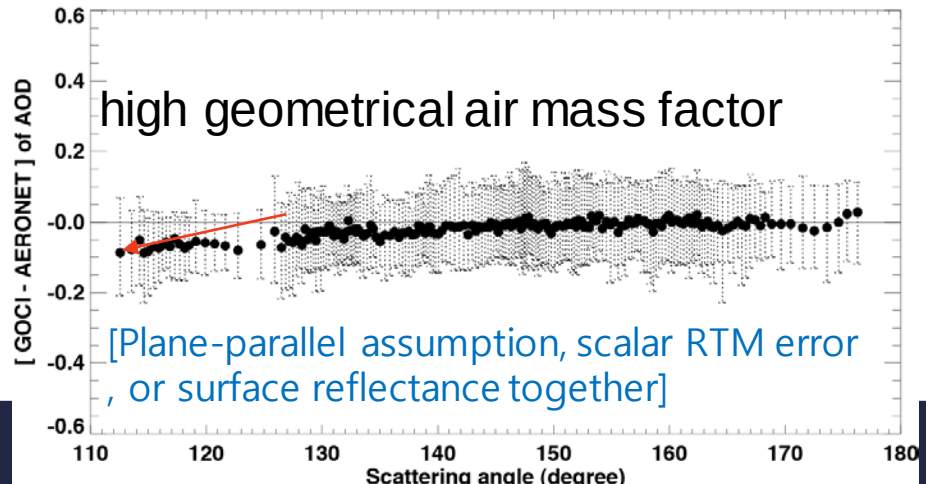


Broad error range at low AE





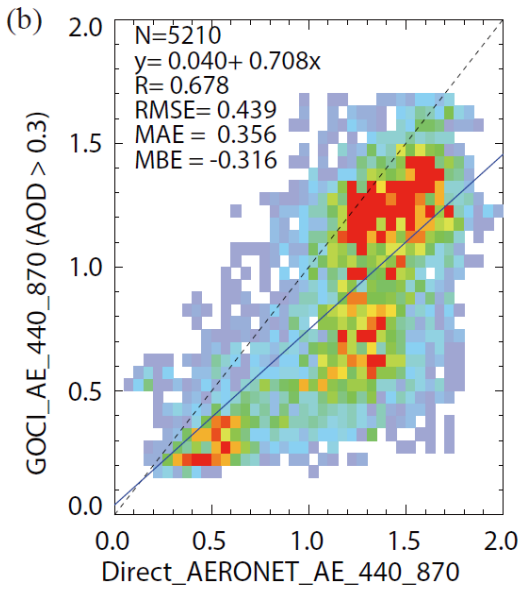
[Surface reflectance error]



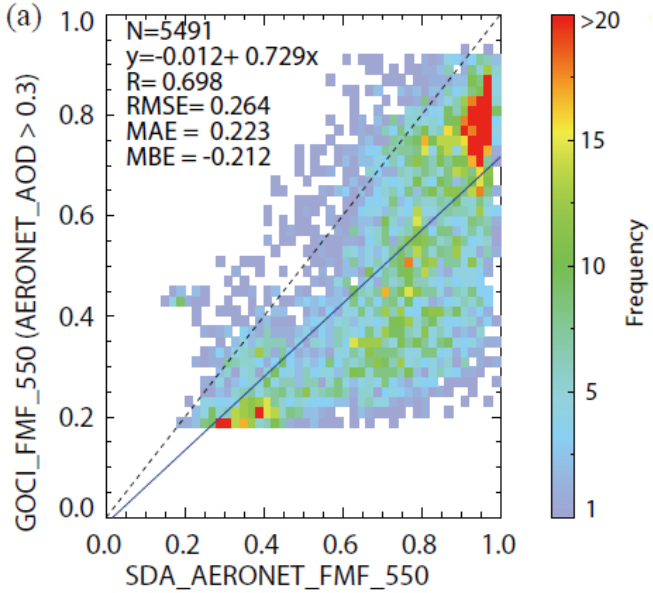
[Plane-parallel assumption, scalar RTM error , or surface reflectance together]

Validation of other optical properties over land
2012.03-05 DRAGON-NE Asia Campaign period (Korea and Japan)

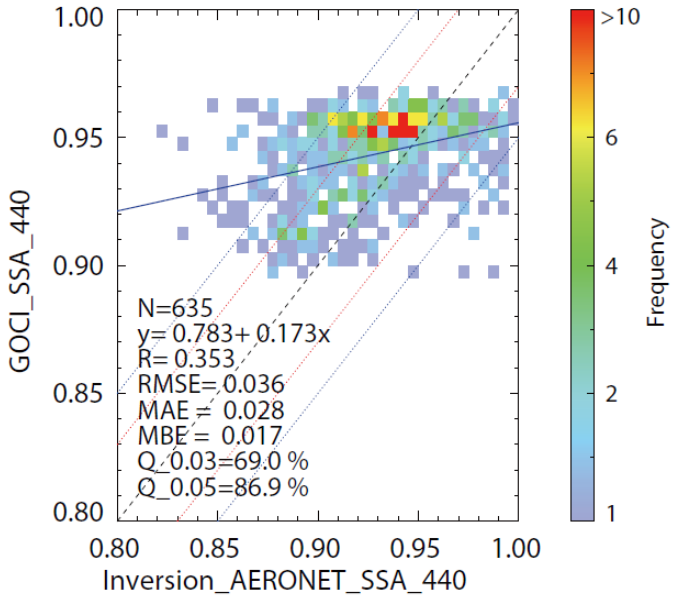
AE b/w 440 – 870 nm



FMF at 550 nm



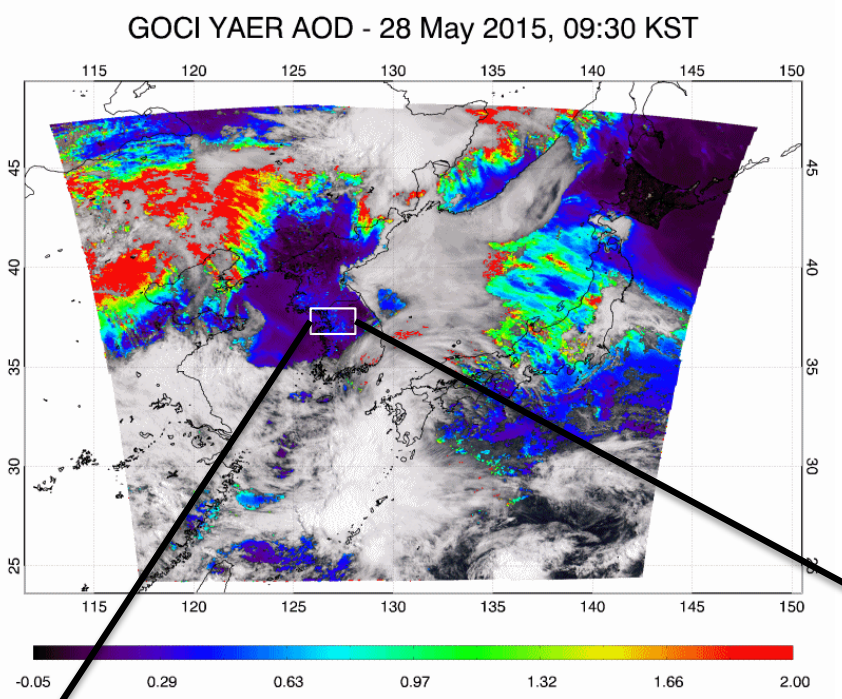
SSA at 440 nm

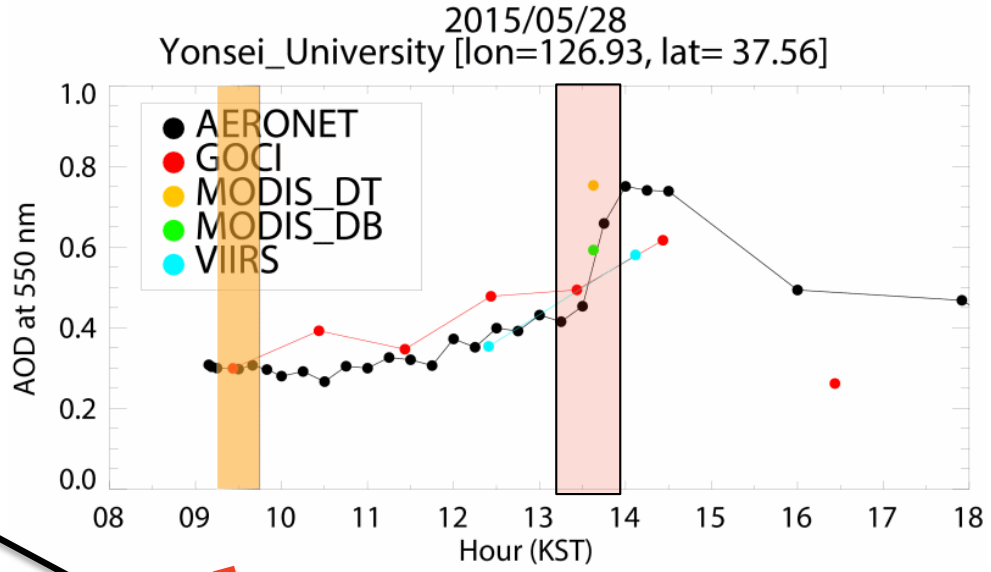


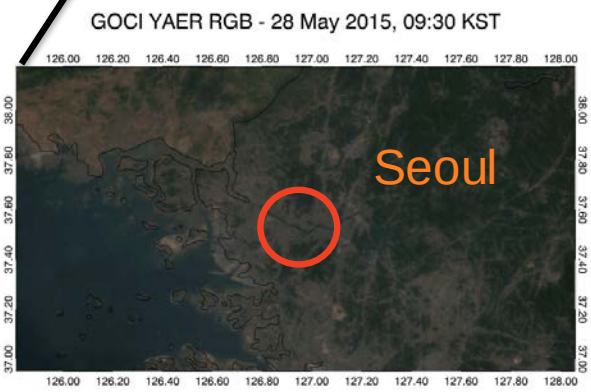
- DRAGON-NE Asia Campaign 38 sites
- Spatial colocation: average of GOCI pixels within 25km at AERONET site
- Temporal colocation: average of AERONET data within 30min at satellite measurement time

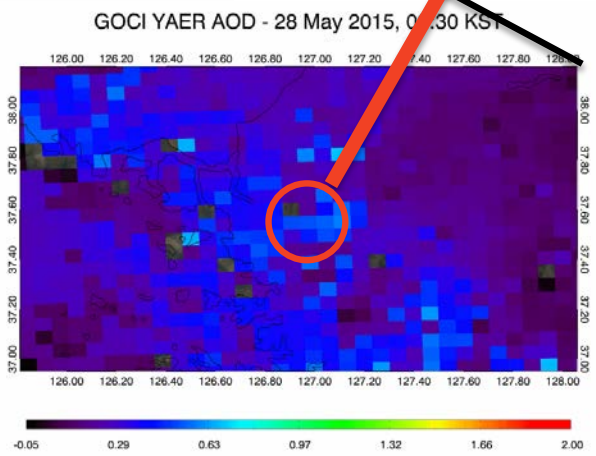
GOCI YAER FMF, AE, and SSA shows lower accuracy than AOD, but still shows some values for qualitative use than quantitative use. (More improvements are necessary)

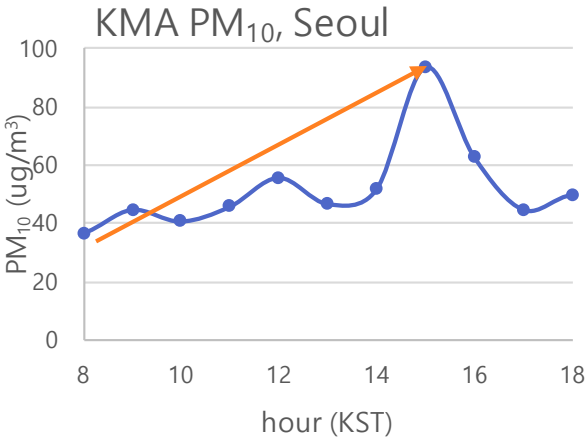
Diurnal variation case: 28 May 2015 (MAPS-Seoul campaign)



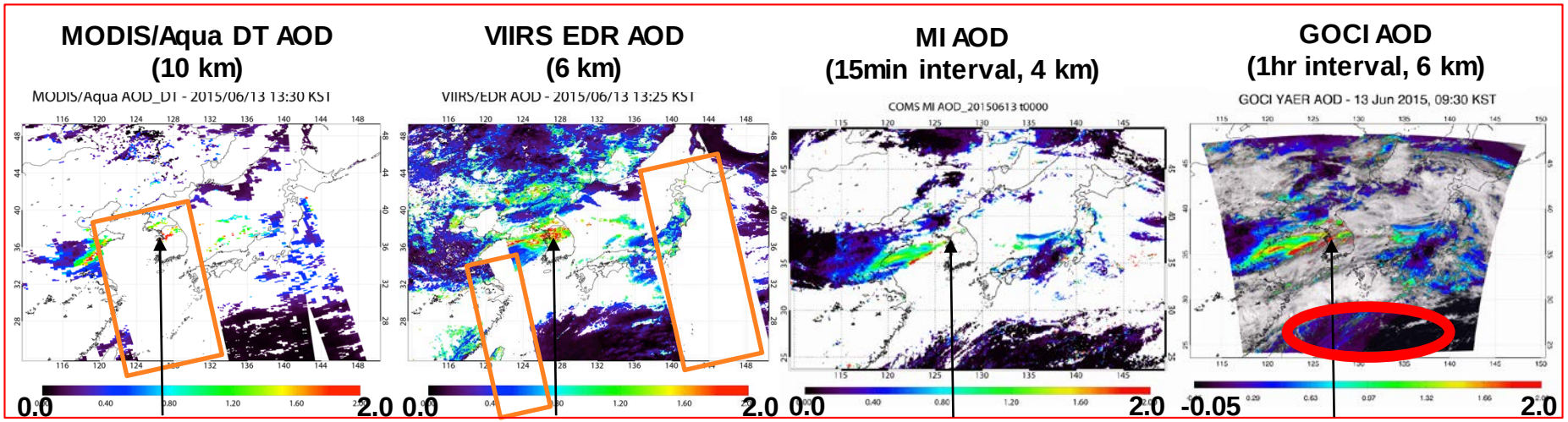




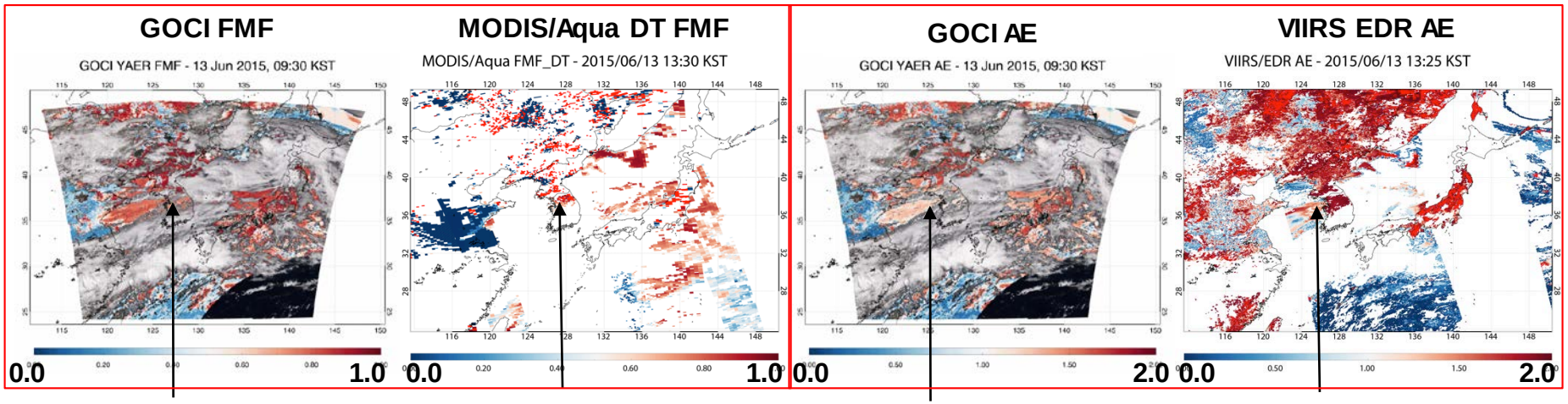




High AOD case: 13 June 2015



[AOD: 1.0~2.0]

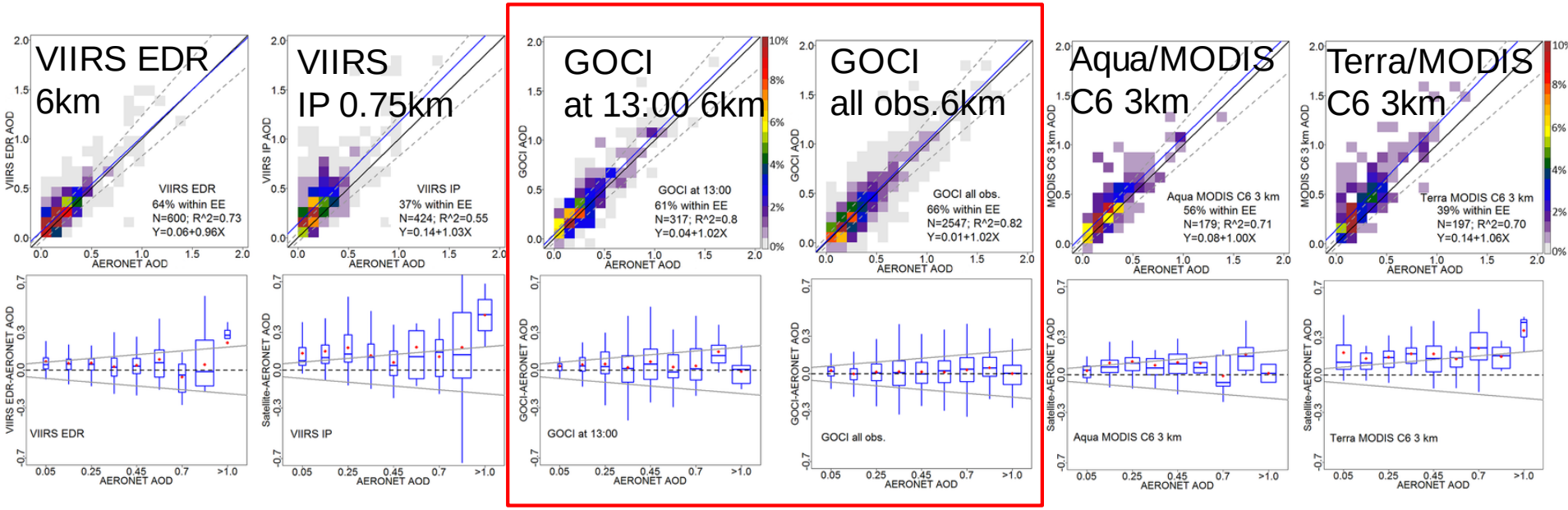


[FMF: 0.8]

[AE: 1.5-2.0]

Evaluation of VIIRS, GOCI, and MODIS C6 3K

2012-2013, East Asia (including China sites), high spatial resolution products



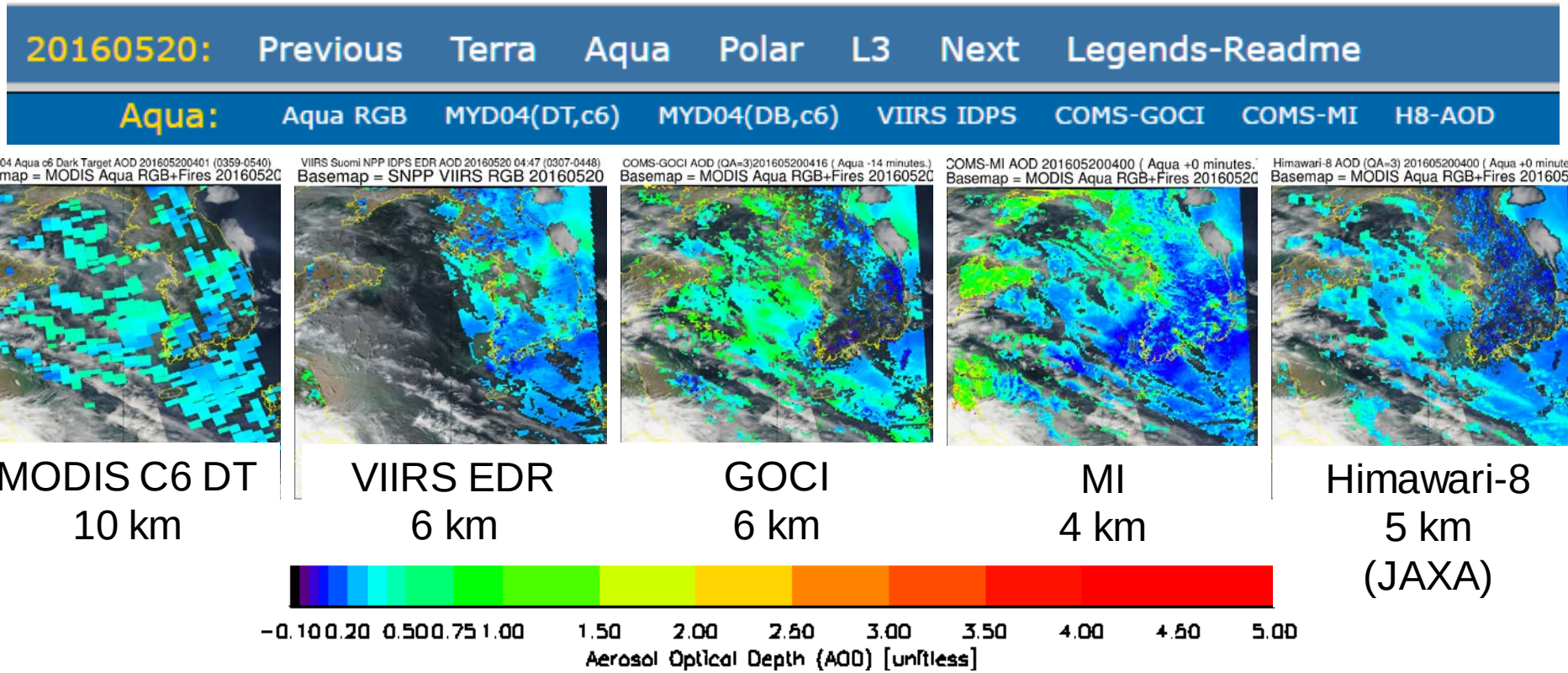
	N	R^2	Slope	Intercept	Bias	%EE
Temporal Comparison						
VIIRS EDR	600	0.74	0.96	0.06[b]	0.05	64
VIIRS IP	424	0.55	1.03	0.14[b]	0.15	37
GOCI	317	0.80	1.02	0.04[b]	0.05	61
GOCI all obs.	2547	0.82	1.02	0.01[a]	0.02	66
Aqua MODIS C6 3 km	179	0.71	1.00	0.08[b]	0.08	56
Terra MODIS C6 3 km	197	0.70	1.06	0.14[b]	0.16	39

GOCI AOD shows less biased, and well matched with AERONET.

[Qingyang Xiao et al., 2015, ACP]

Near-real-time retrieval during 2016 KORUS-AQ

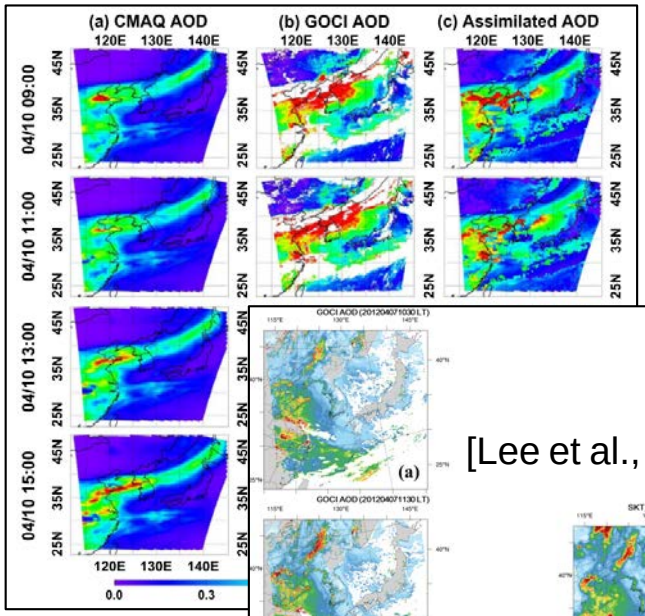
- Near real time retrieval and intercomparison with other satellite AODs are carried out for evaluation of several models accuracy and data assimilation with forecasting model during the campaign.

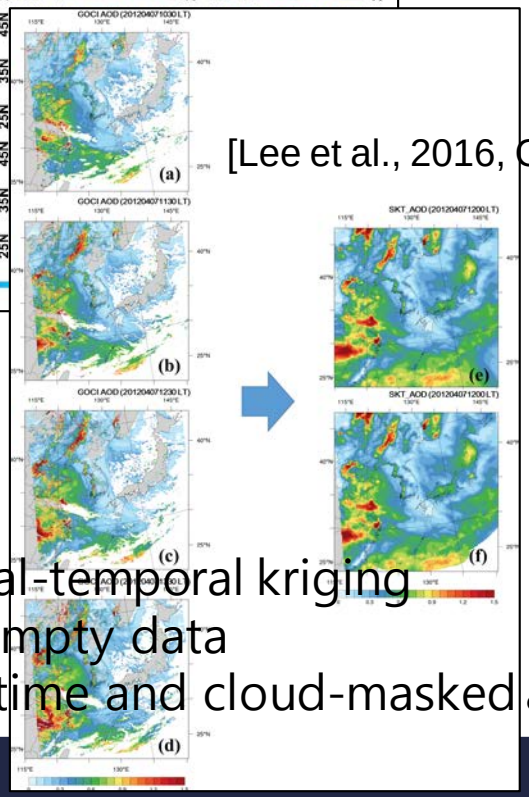


20 May 2016, 04-05utc – US Naval Research Lab. Marin Meteorology Division homepage
http://www.nrlmry.navy.mil/aerosol/modis_geo_aod_compare/korea/html_files/20160520/modis_geo_aod_compare_frame.html

Application of GOCI YAER AOD to Air quality modeling studies

Data assimilation of GOCI AOD with **CMAQ**
Application to the PM_{10} (GIST)
[Park et al., 2014, ACP]



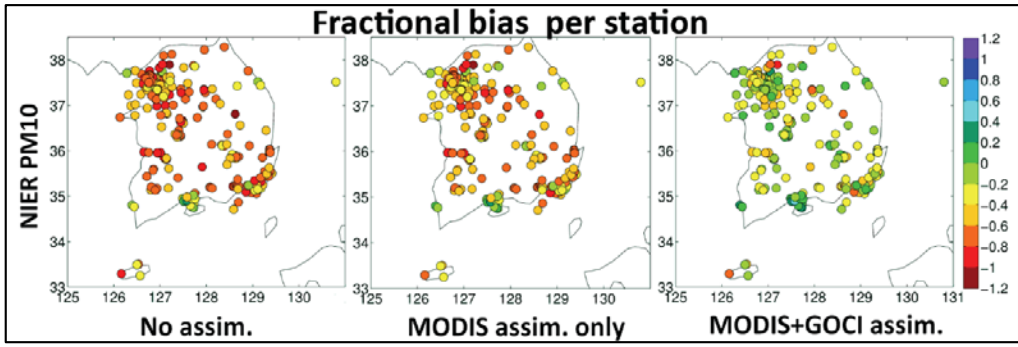


[Lee et al., 2016, GMD]

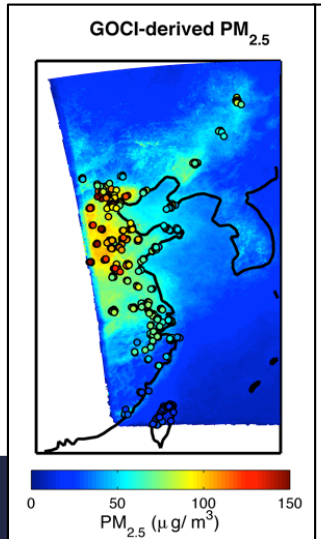
GIST: spatial-temporal kriging
to fill the empty data
for model time and cloud-masked area

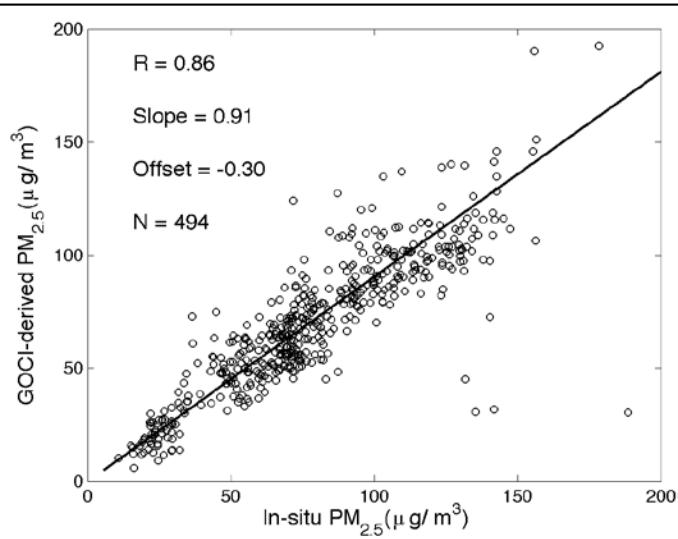
Data assimilation of GOCI & MODIS AOD with **WRF-chem**
Application to the PM_{10} (Univ. of Iowa and NCAR)
[Saide et al., 2014, GRL]

(also carried out during 2016 KORUS-AQ as NRT)



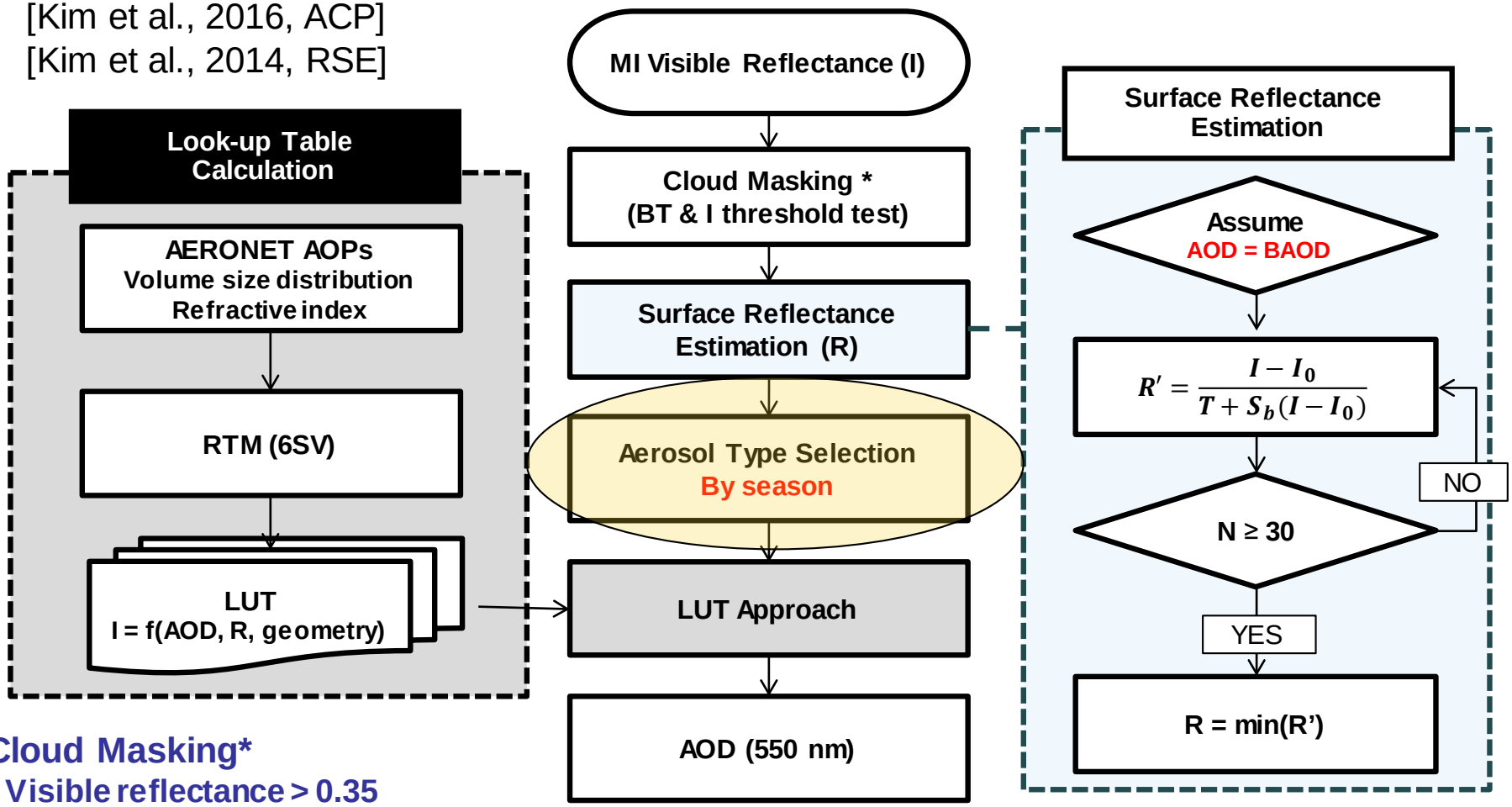
Estimation ground-level $PM_{2.5}$
from GOCI AOD and **GEOS-chem**
[Xu et al., 2015, ACP] (Dalhousie Univ.)





Single Channel Retrieval Algorithm for MI

[Kim et al., 2016, ACP]
[Kim et al., 2014, RSE]

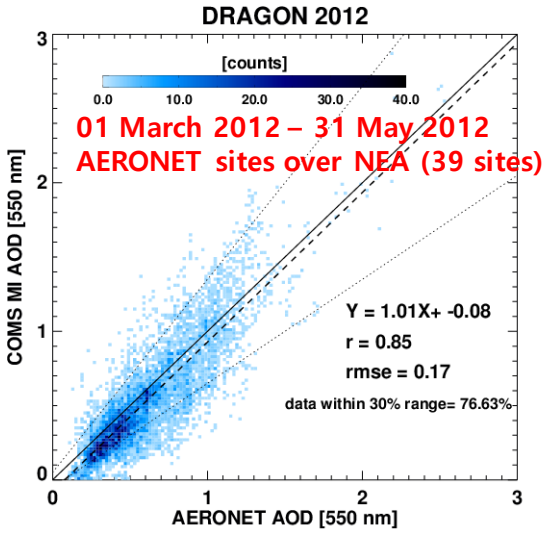


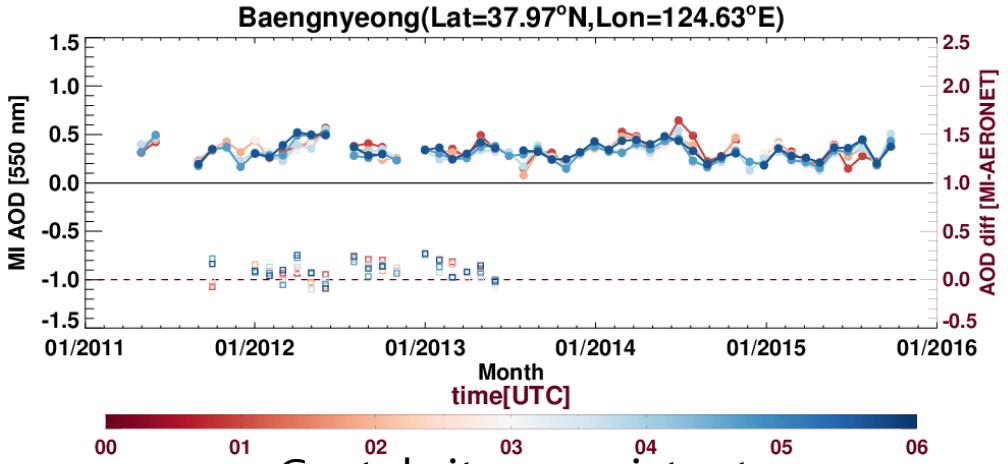
Cloud Masking*

- Visible reflectance > 0.35
- IR1-IR2 > 0.5 K & IR1 < 268 K
- IR1-IR2 > 0.5 K & IR1max-IR1 > 5 K
- IR1-IR2 > 1.5 K & IR1-IR4 < -6 K for Ocean (Frey et al., 2008)
- IR1-IR2 >-0.5 K & IR1-IR4 <-18 K for Ocean
- IR1-IR2 > 0.5 K & IR1-IR4 < -10 K for Ocean
- IR1-IR2 > 1.5 K & IR1-IR4 < -14 K for Land

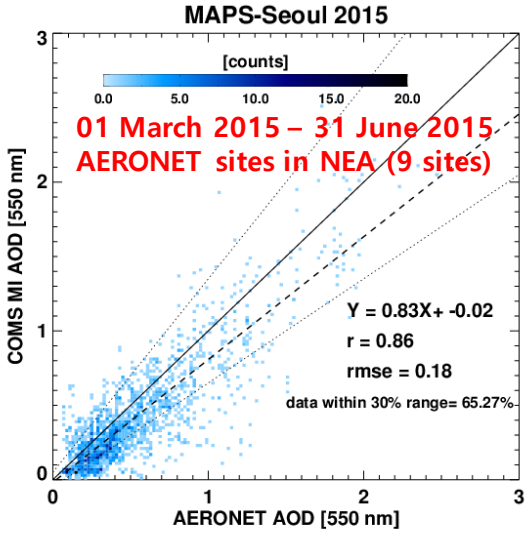
I : TOA reflectance
I_0 : Rayleigh scattering
T : Transmittance
Sb : Spherical albedo
R : Surface reflectance

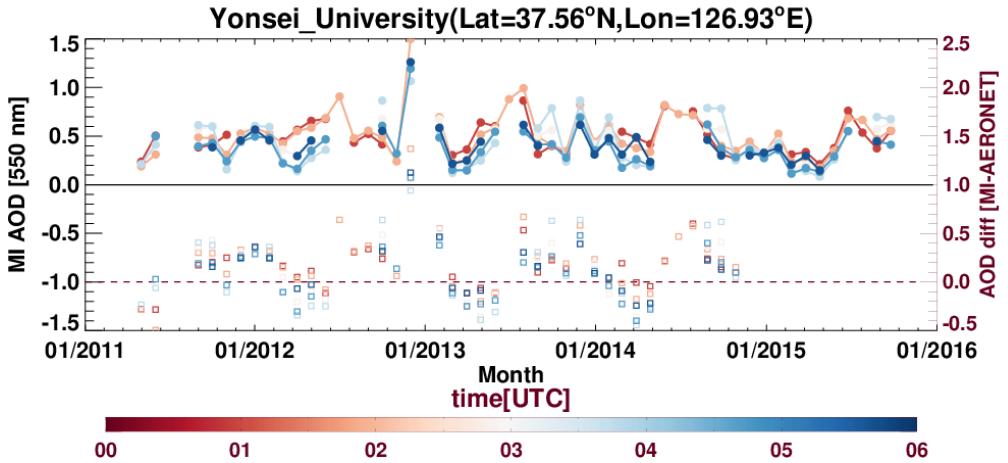
MI AOD validation and Time series





Costal site: consistent accuracy

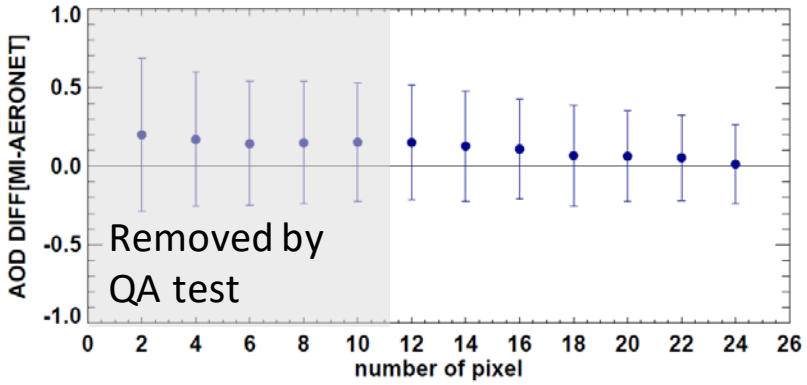




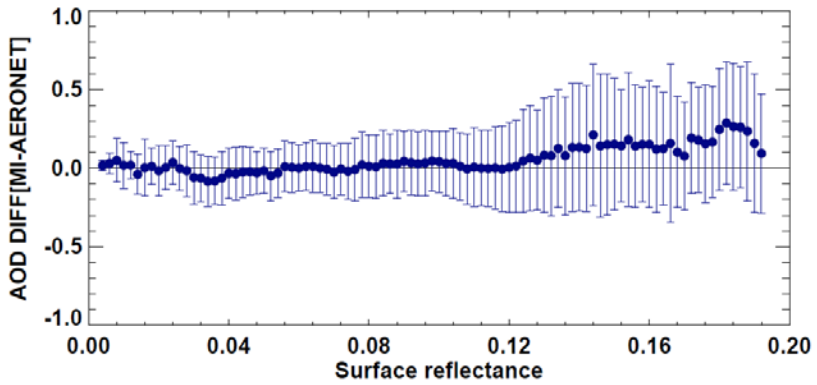
Urban site: larger errors due to bright surface

MI AOD Retrieval uncertainties

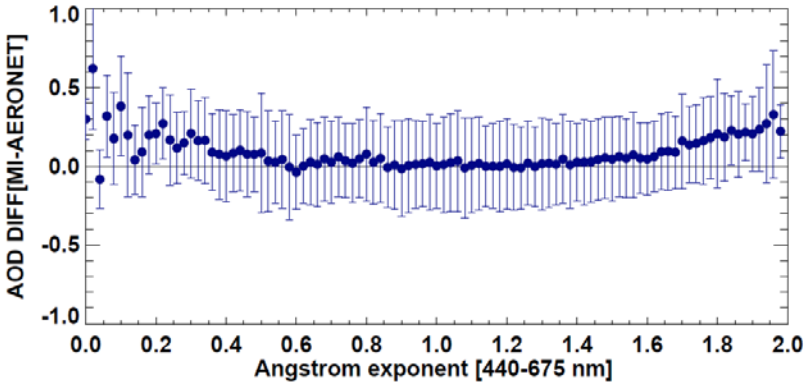
Number of collocation pixel (within 5 x 5 pixel) : Cloud Contamination



Surface reflectance



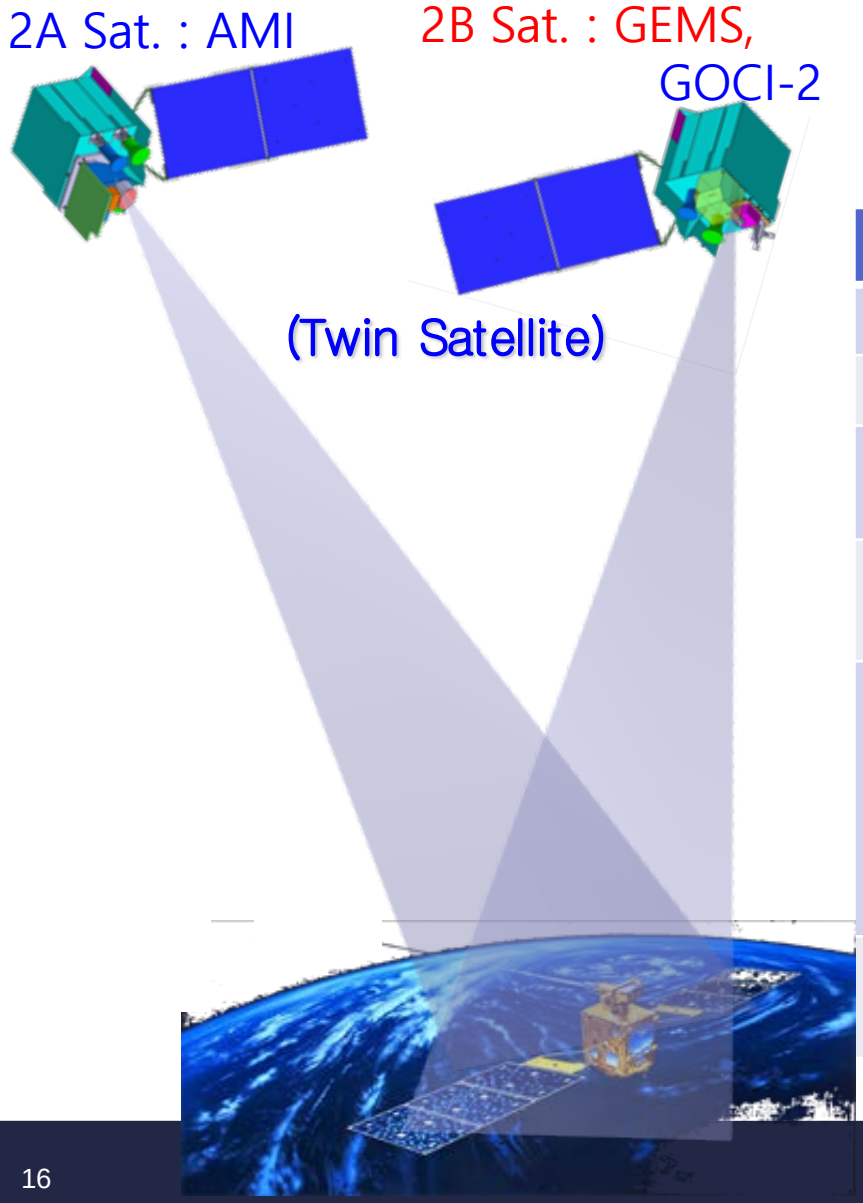
Angstrom exponent [440 – 675 nm] : Aerosol Type



- AERONET lev2.0 Data
- 10 May 2011 – 31 Oct. 2015
- AERONET sites over NEA (63 sites)
- Space collocation : within 25km at each AERONET site
- Time collocation : ± 30 min. AERONET at each satellite center measurement time

GEO-KOMPSAT 2

- Launch: May 2018(2A), Mar. 2019 (2B)



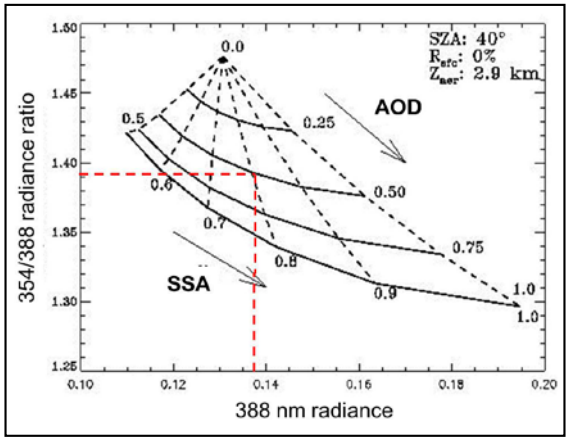
****GEMS products**
: Aerosol, O3, NO2, SO2, HCHO, and etc.

Specification

	2A	2B	
Payload	AMI	GOCI-2	GEMS
Lifetime		10 years !!	
Channels	16	13	1000
Wavelength range	0.4 - 13 μm	375 - 860 nm	300-500 nm
Spatial resolution	0.5 / 1 km (Vis) 2 km (IR)	250 m 1 km (FD)	7 x 8 km^2 @ Seoul 3.5x8 km^2 (aerosol)
Temporal resolution	10 min (FD)	1 hour (1 FD/day)	1 hour

Long-term monitoring of diurnal variations.

GEMS Aerosol Algorithm Flowchart



GEMS Lv1B Radiance spectrum

Aerosol Type Selection
UV/VIS AI
$AI = -100\log_{10}(I_\lambda^{meas.}/I_\lambda^{calc.}(\rho_{\lambda_0}))$

Look-up Table

Cloud Masking
Reflectance Test

Radiative Transfer Model (VLIDORT)

Surface Reflectance Correction

OMI climatology LER data

- **Aerosol Optical Properties**
  - **Refractive index**
  - **Volume size distribution**
- **Aerosol Optical Depth**
- **Aerosol Height**
- **Surface Reflectance**
- **Surface elevation**
- **Sun-Satellite Geometry**

Inversion Retrieval
A priori values
[AOD, SSA, HGT]

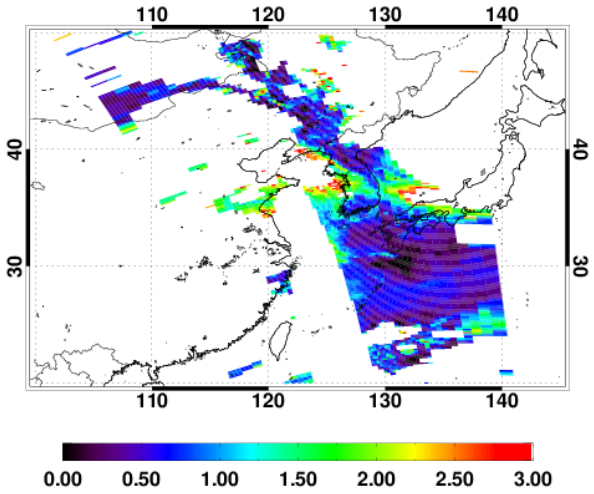
Spectral Fitting
Optimal Estimation

AOD, SSA, HGT retrieval

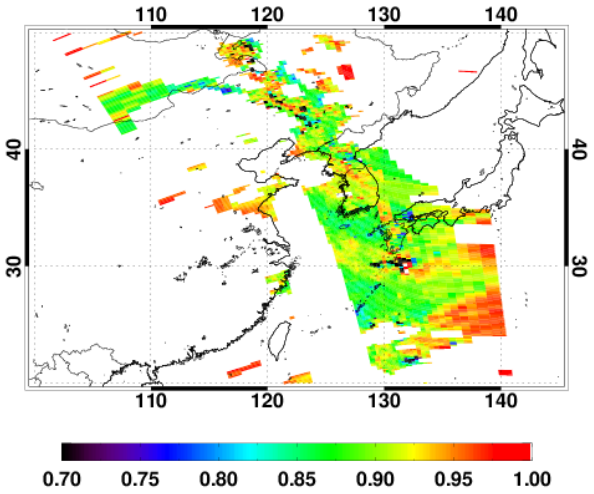
AOD, SSA

GEMS Aerosol Algorithm Results : 2006.04.08

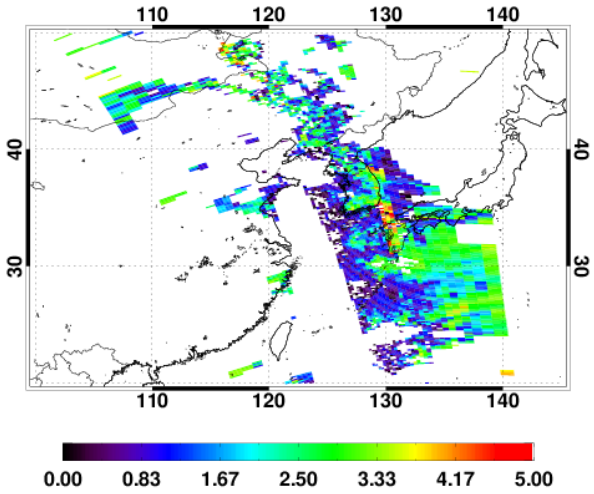
Retrieved AOD [443 nm]



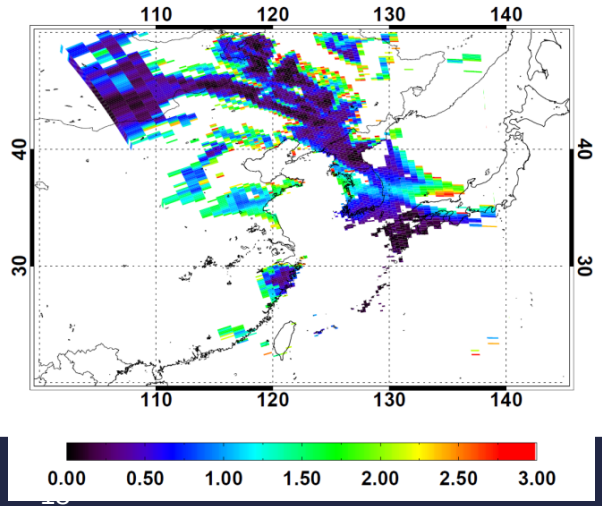
Retrieved SSA [443 nm]



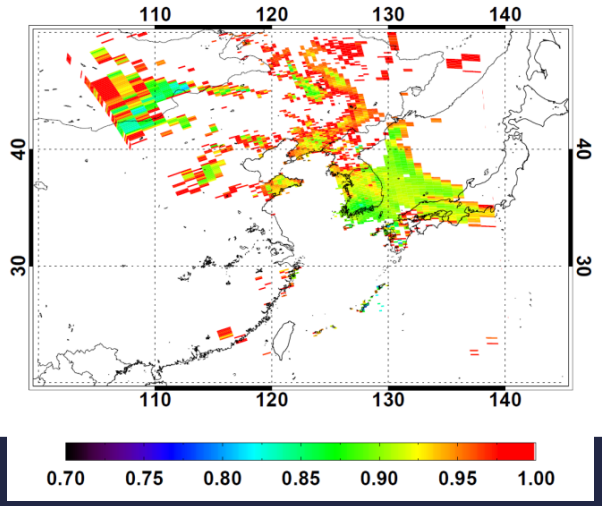
Retrieved HGT [km]



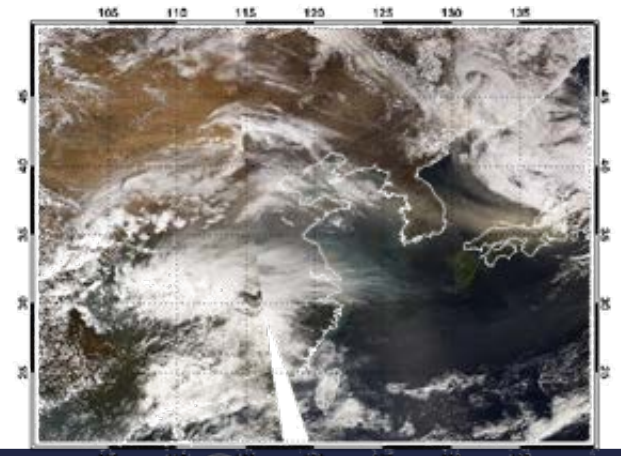
OMI AOD [388 nm]



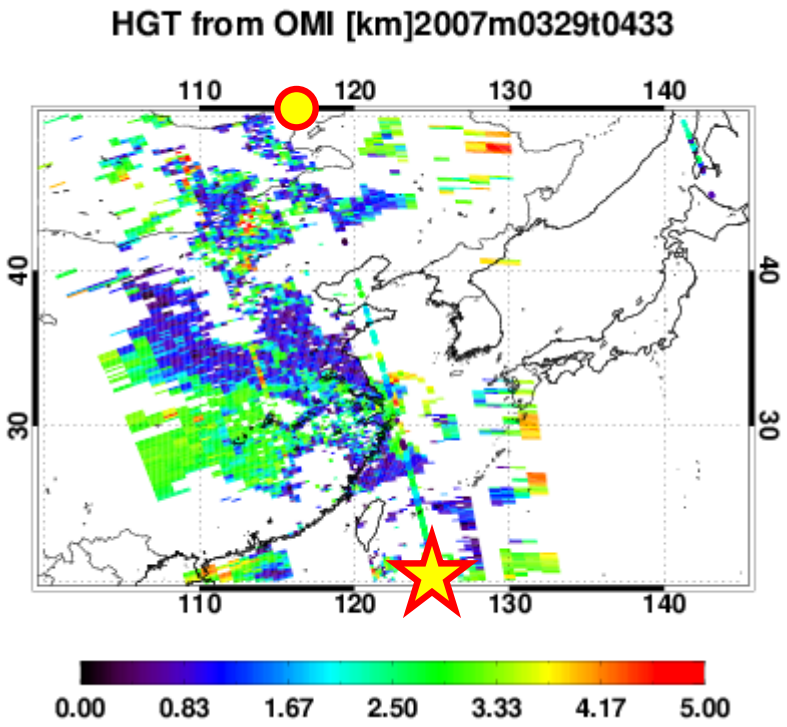
OMI SSA [388 nm]

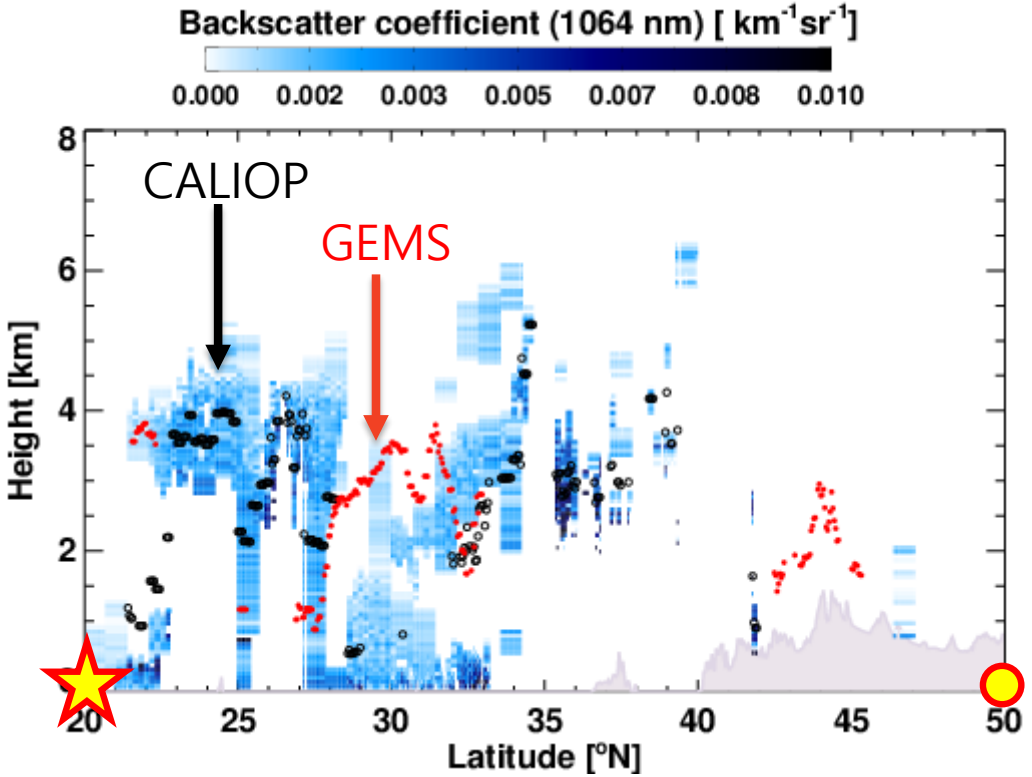


MODIS RGB :2006/04/08



GEMS Aerosol Algorithm Results : 2007.03.29

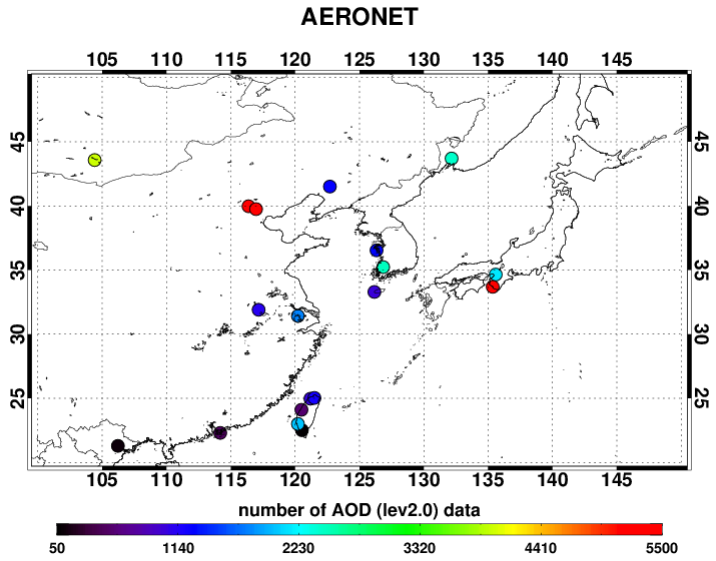




$$Z_{aer} = \sum_{i-1}^{n} H(i) \left[\frac{B_{sc}(i)}{\sum_{i=1}^{n} B_{sc}(i)} \right]$$

Attenuated-backscatter-weighted height

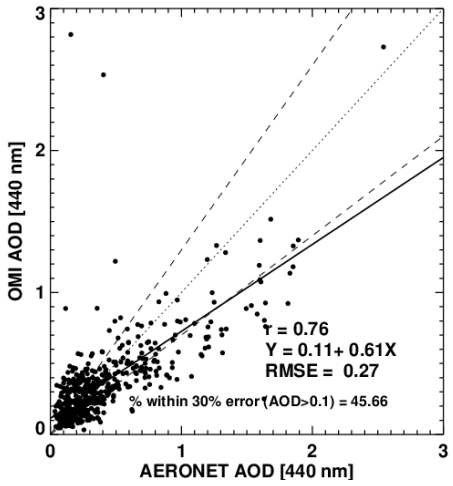
Validation of GEMS AOD and SSA

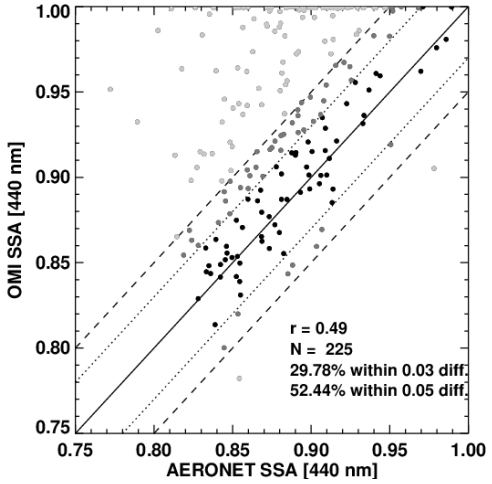


AOD validation
AERONET direct measurement(lev2.0)
2005. 01 ~ 12,
Within ±10 min., 0.4˚ x 0.4˚

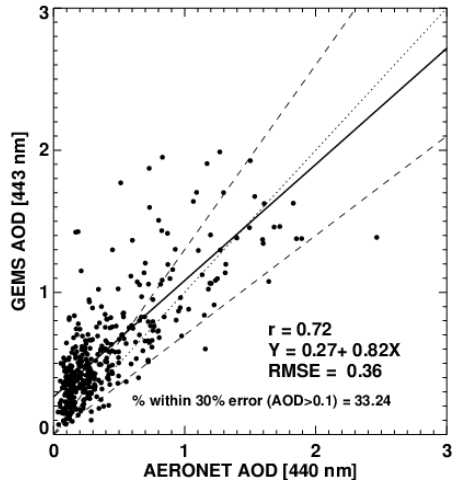
SSA validation
AERONET inversion data(lev2.0)
2005. 01 ~ 12,
Within ±4 hr, 0.4˚ x 0.4˚

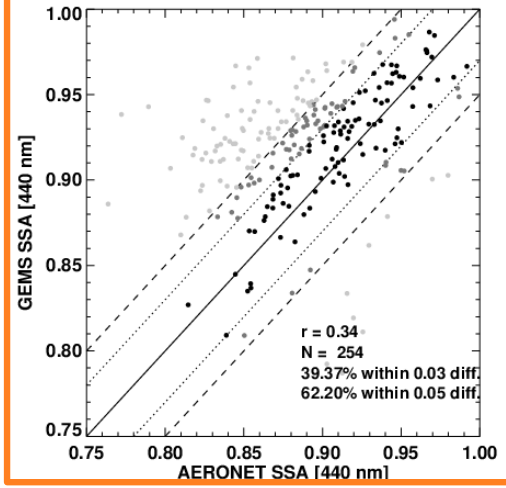
OMI Operated Algorithm





GEMS Developed Algorithm





HIMAWARI-8 satellite (AHI), proxy data for AMI

Launched on 7. Oct 2014 at 140.7° East,
Entered operational service on 7.Jul 2015

Temporal resolution : 10minute
Targeting area : full disk

Table 1. Imager specifications.

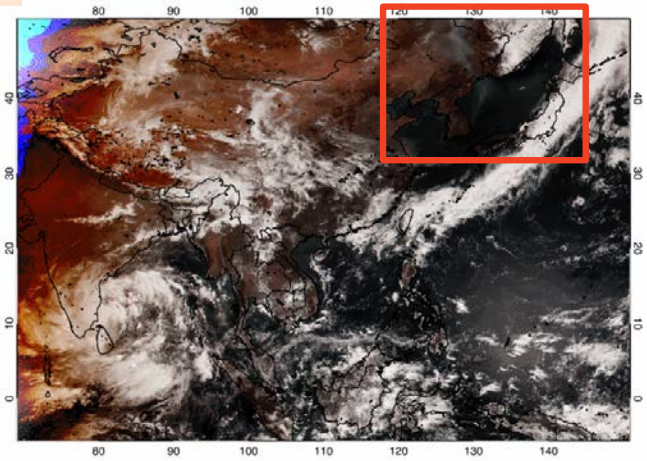
Wave length [μm]	Himawari-8/9				MTSAT-1R/2	
	Band number	Spatial resolution at SSP [km]	Central wave length [μm]		Channel name	Spatial resolution at SSP [km]
			AHI-8 (Himawari-8)	AHI-9 (Himawari-9)		
0.47	1	1	0.47063	0.47059	-	-
0.51	2	1	0.51000	0.50993	-	-
0.64	3	0.5	0.63914	0.63972	VIS	1
0.86	4	1	0.85670	0.85668	-	-
1.6	5	2	1.6101	1.6065	-	-
2.3	6	2	2.2568	2.2570	-	-
3.9	7	2	3.8853	3.8289	IR4	4
6.2	8	2	6.2429	6.2479	IR3	4
6.9	9	2	6.9410	6.9555	-	-
7.3	10	2	7.3467	7.3437	-	-
8.6	11	2	8.5926	8.5936	-	-
9.6	12	2	9.6372	9.6274	-	-
10.4	13	2	10.4073	10.4074	IR1	4
11.2	14	2	11.2395	11.2080	-	-
12.4	15	2	12.3806	12.3648	IR2	4
13.3	16	2	13.2807	13.3107	-	-

Central wavelengths of the AHIs are "Moment center wavelength" (provided by Exelis).
SSP : sub satellite point

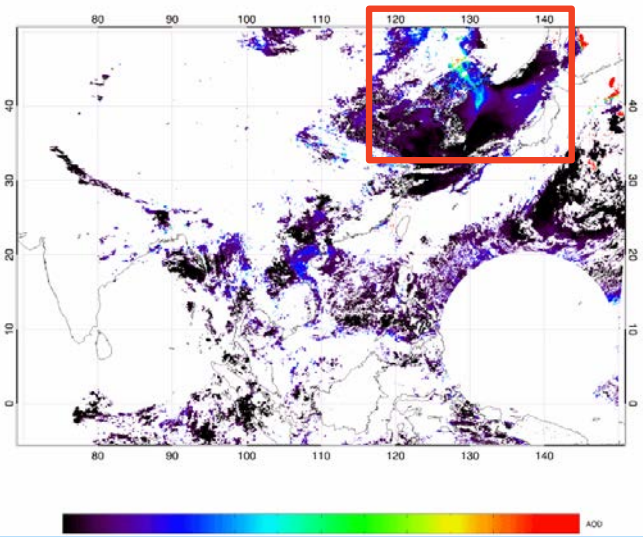
AHI AOD Retrieval samples and comparison with GOCI

17 May 2016

AHI True color

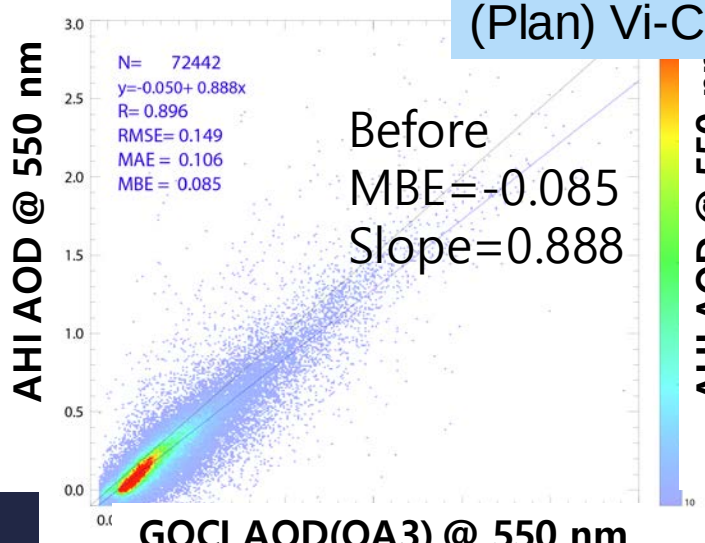


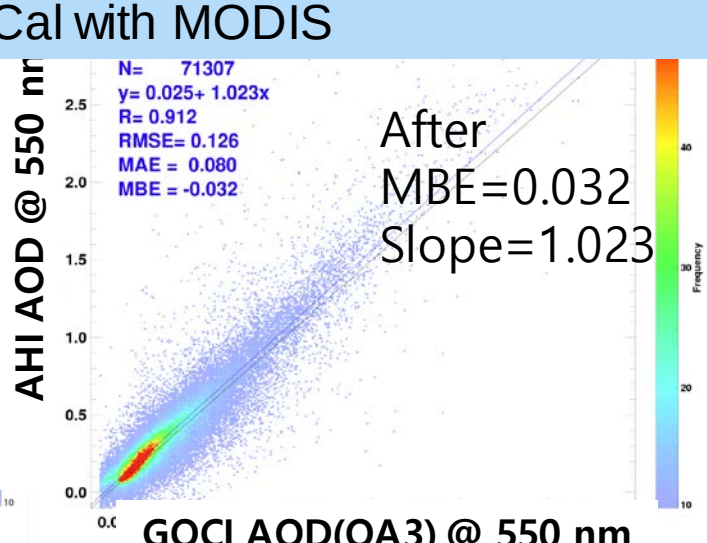
AHI-AOD (Yonsei)



August 2015

Vicarious calibration with GOCI → bias decrease.
(Plan) Vi-Cal with MODIS



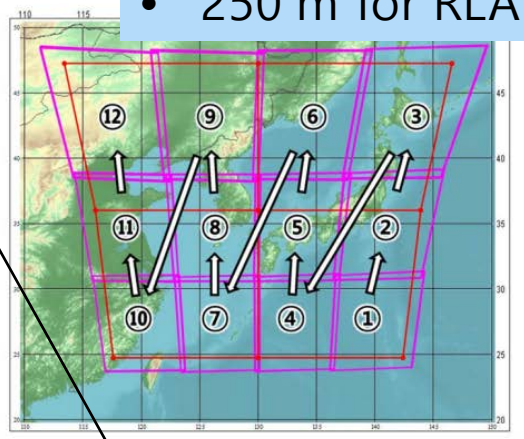


GOCI-2

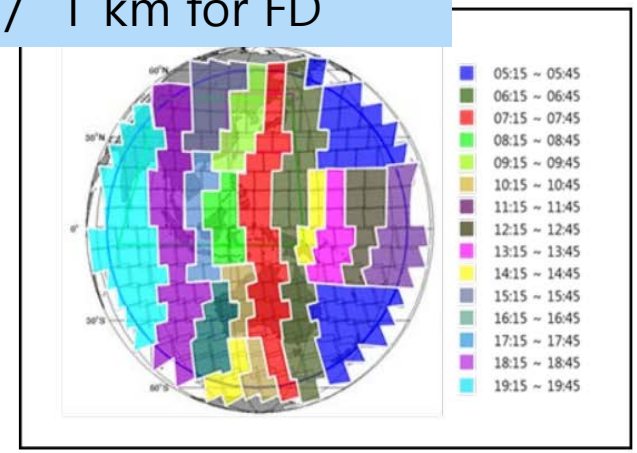
- Spectral bands

GOCI Band	GOCI-II Band	Band center	Bandwidth
-	1	380 nm	20 nm
1	2	412 nm	20 nm
2	3	443 nm	20 nm
3	4	490 nm	20 nm
-	5	510 nm	20 nm
4	6	555 nm	20 nm
-	7	620 nm	20 nm
5	8	660 nm	20 nm
6	9	680 nm	10 nm
-	10	709 nm	10 nm
7	11	745 nm	20 nm
8	12	865 nm	40 nm
-	13	643.5 nm	483 nm

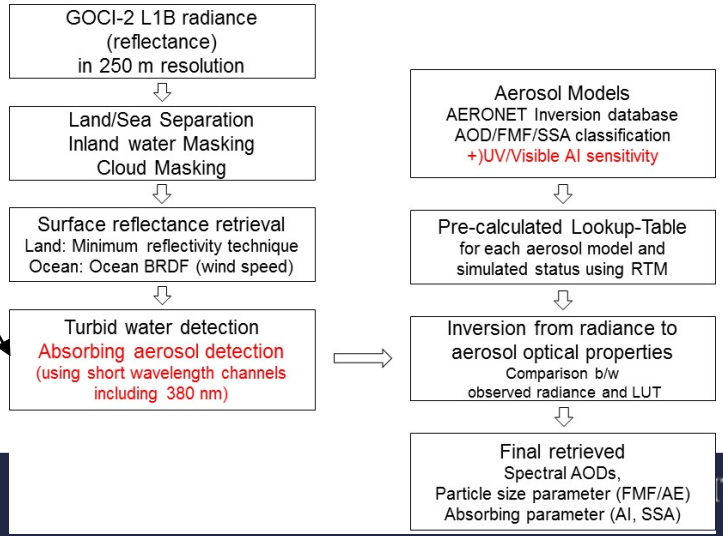
- Reference Local Area (RLA), 10 images a day
- Full Disk (FD), once a day
- 250 m for RLA / 1 km for FD



GOCI-II Reference Local Area coverage by 12 slots



- Concept of GOCI -2 Aerosol algorithm



Courtesy of Dr. Youngje Park (KOSC/KIOST)

Conclusions

- Hourly aerosol optical properties from GOCI and MI Yonsei aerosol retrieval algorithm can provide aerosol diurnal variation information. And, continuous AOPs between land and ocean can be provided in the East Asia.
- Therefore, it becomes valuable dataset for assimilation with several air-quality forecasting model over East Asia.

- The follow-up mission, GEO-KOMPSAT-2 is expected to provide more accurate information on the atmospheric environment with the gas concentration and aerosol information in high spatial and temporal resolution.
- GEMS and AHI aerosol retrieval algorithm is developed and improved continuously. GOCI-2 aerosol algorithm is also planned through the heritage of GOCI-1 algorithm.

- AOD from GEO-sensors over East Asia will be good reference for evaluation of AeroCOM models as high-temporal resolution.

- *** We hope to have some contribution to AeroCOM and AeroSAT with GEO-satellite aerosol optical products dataset.*

Thank you for your attention.

References

- Choi, M., Kim, J., Lee, J., Kim, M., Park, Y. J., Jeong, U., Kim, W., Hong, H., Holben, B., Eck, T. F., Song, C. H., Lim, J. H., and Song, C. K.: GOCI Yonsei Aerosol Retrieval (YAER) algorithm and validation during the DRAGON-NE Asia 2012 campaign, Atmos. Meas. Tech., 9, 1377-1398, 2016.

- Kim, M., Kim, J., Wong, M. S., Yoon, J., Lee, J., Wu, D., Chan, P. W., Nichol, J. E., Chung, C. Y., andOu, M. L.: Improvement of aerosol optical depth retrieval over Hong Kong from a geostationary meteorological satellite using critical reflectance with background optical depth correction, Remote Sens Environ, 142, 176-187, 2014.

- Kim, M., Kim, J., Jeong, U., Kim, W., Hong, H., Holben, B., Eck, T. F., Lim, J. H., Song, C. K., Lee, S., and Chung, C. Y.: Aerosol optical properties derived from the DRAGON-NE Asia campaign, and implications for a single-channel algorithm to retrieve aerosol optical depth in spring from Meteorological Imager (MI) on-board the Communication, Ocean, and Meteorological Satellite (COMS), Atmos Chem Phys, 16, 1789-1808, 2016.

- Lee, J., Kim, J., Song, C. H., Ryu, J. H., Ahn, Y. H., and Song, C. K.: Algorithm for retrieval of aerosol optical properties over the ocean from the Geostationary Ocean Color Imager, Remote Sens Environ, 114, 1077-1088, 2010.

- Lee, J., Kim, J., Yang, P., and Hsu, N. C.: Improvement of aerosol optical depth retrieval from MODIS spectral reflectance over the global ocean using new aerosol models archived from AERONET inversion data and tri-axial ellipsoidal dust database, Atmos Chem Phys, 12, 7087-7102, 2012.

- Lee, S., Song, C. H., Park, R. S., Park, M. E., Han, K. M., Kim, J., Choi, M.,Ghim, Y. S., and Woo, J.-H.: GIST-PM-Asia v1: development of a numerical system to improve particulate matter forecasts in South Korea using geostationary satellite-retrieved aerosol optical data over Northeast Asia, Geosci. Model Dev., 9, 17-39, doi:10.5194/gmd-9-17-2016, 2016.

References

- Park, M. E., Song, C. H., Park, R. S., Lee, J., Kim, J., Lee, S., Woo, J. H., Carmichael, G. R., Eck, T. F., Holben, B. N., Lee, S. S., Song, C. K., and Hong, Y. D.: New approach to monitor transboundary particulate pollution over Northeast Asia, Atmos Chem Phys, 14, 659-674, 2014.

- Saide, P. E., Kim, J., Song, C. H., Choi, M., Cheng, Y. F., and Carmichael, G. R.: Assimilation of next generation geostationary aerosol optical depth retrievals to improve air quality simulations, Geophys Res Lett, 41, 9188-9196, 2014.

- Xiao, Q., Zhang, H., Choi, M., Li, S., Kondragunta, S., Kim, J., Holben, B., Levy, R. C., and Liu, Y.: Evaluation of VIIRS, GOCI, and MODIS Collection 6 AOD retrievals against ground sunphotometer observations over East Asia, Atmos. Chem. Phys., 16, 1255-1269, doi:10.5194/acp-16-1255-2016, 2016.

- Xu, J.-W., Martin, R. V., van Donkelaar, A., Kim, J., Choi, M., Zhang, Q., Geng, G., Liu, Y., Ma, Z., Huang, L., Wang, Y., Chen, H., Che, H., Lin, P., and Lin, N.: Estimating ground-level PM2.5 in eastern China using aerosol optical depth determined from the GOCI satellite instrument, Atmos. Chem. Phys., 15, 13133-13144, doi:10.5194/acp-15-13133-2015, 2015.