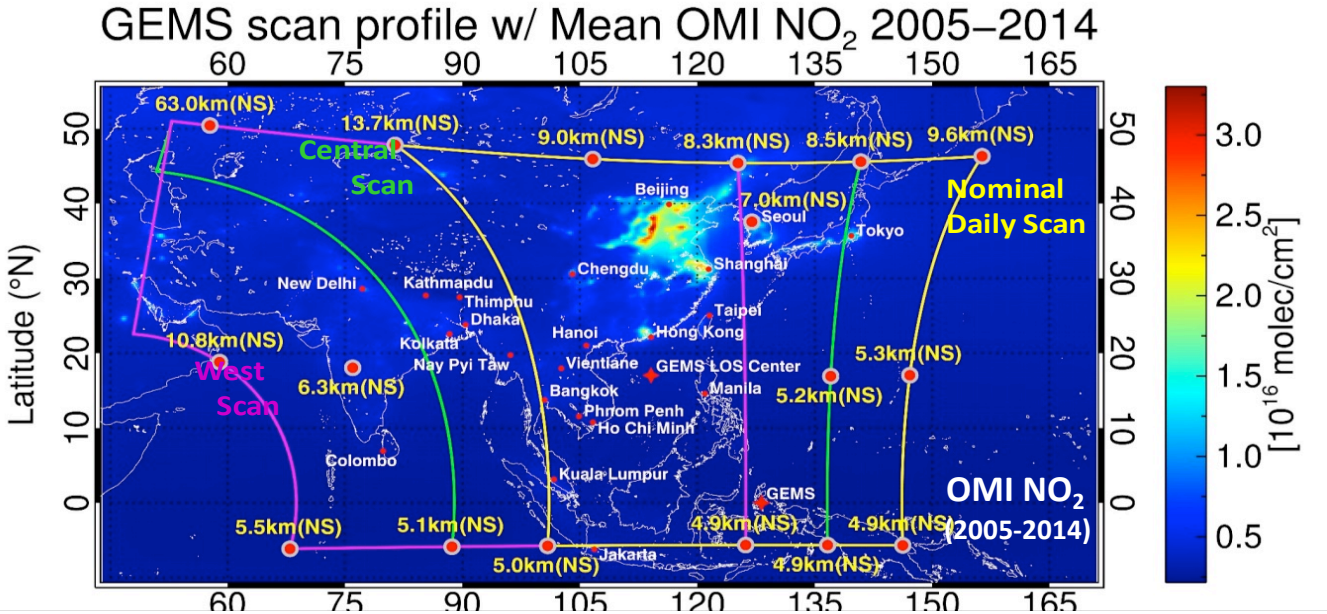
Recent developments in ground-based networks in East Asia and strategies for GEMS validation



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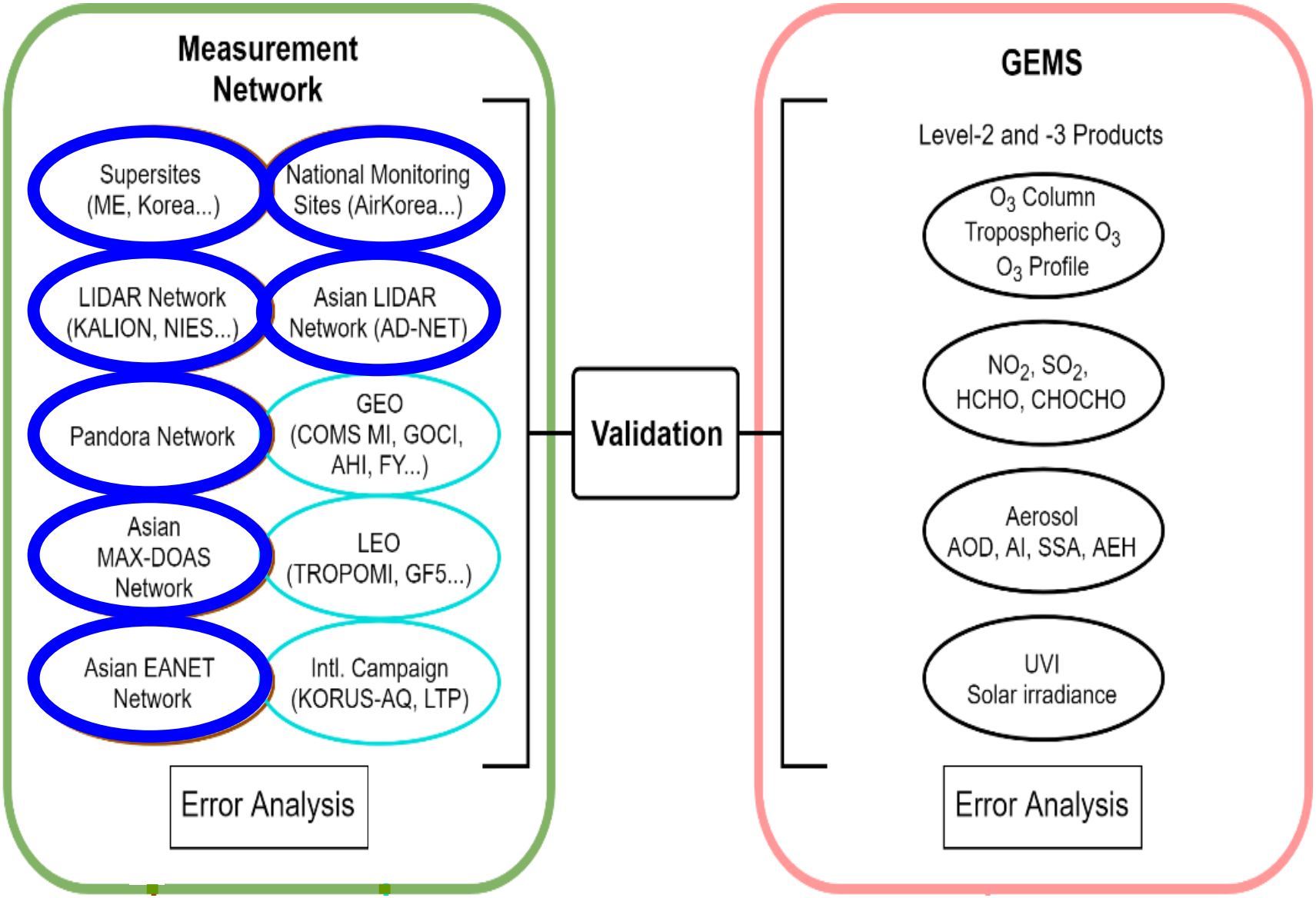
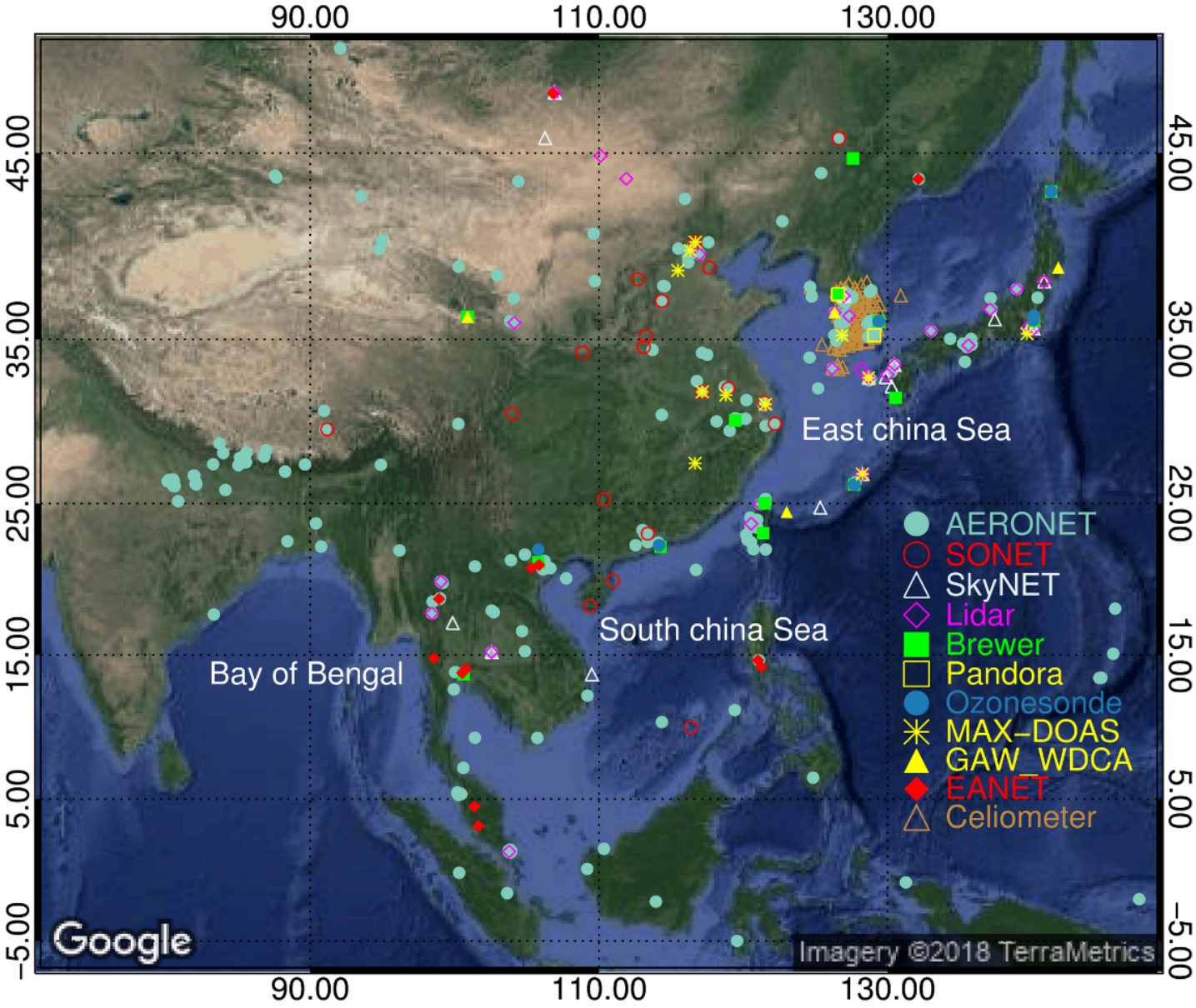
[1]Seoul National University (sangwookim@snu.ac.kr) [2]Ulsan National Institute for Science and Technology (cksong@unist.ac.kr) [3]Yonsei University (jkim2@Yonsei.ac.kr) [4]National Institute for Environmental Research

Validation network for aerosols and gases within GEMS domain



(Credit: J. Kim)

Validation network for aerosols and gases within GEMS domain

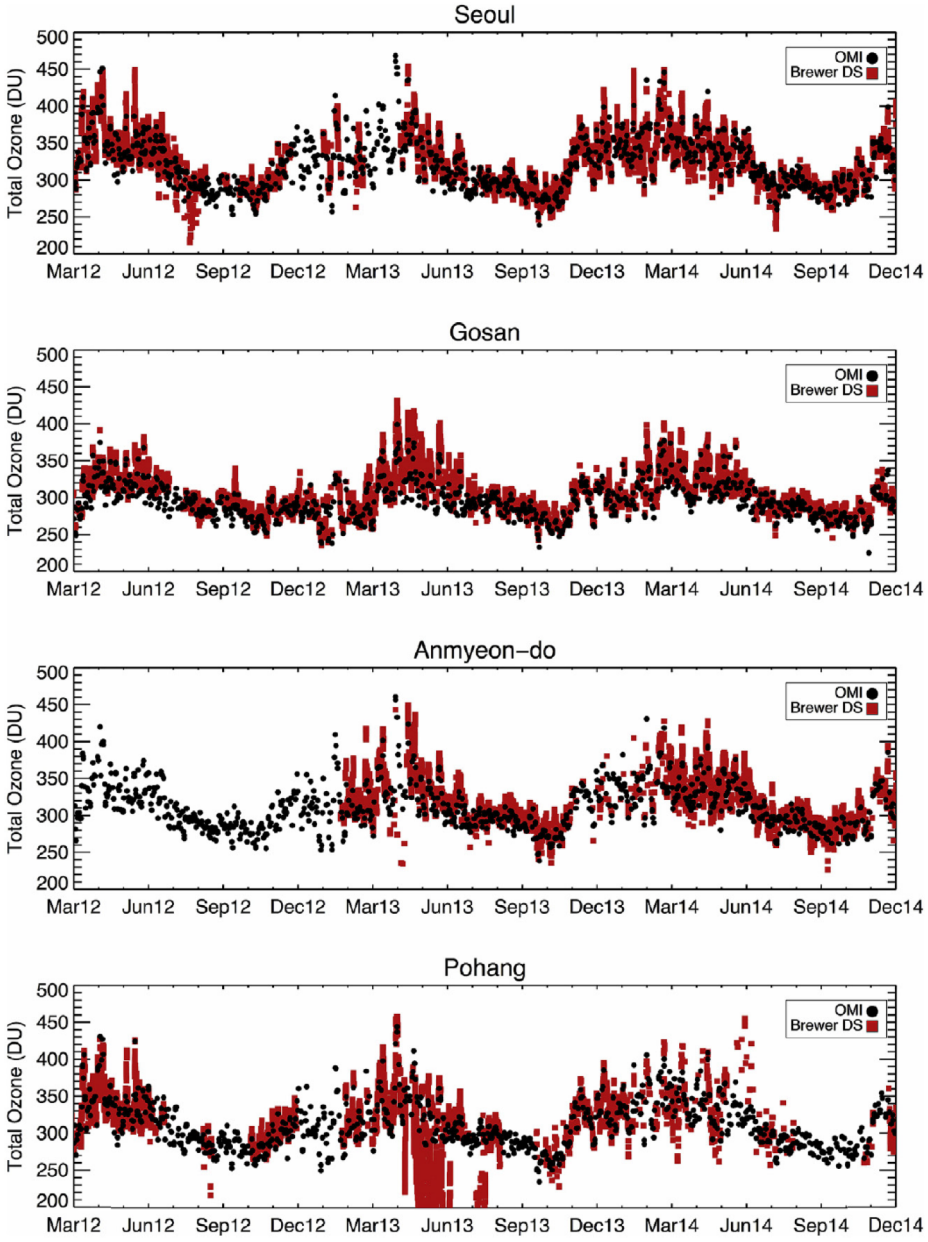


(Source: J. Kim et al., BAMS, 2019)

O_3 (Total)

	Instruments	References (TROPOMI Validation Examples)	Application to GEMS	
			Geographical coverage	Temporal coverage
G	• Brewer/Dobson spectrophotometer • Data access: WOUDC, NDACC, EVDC, AVDC	• Dobson vs. OMI TOMS • Brewer vs. OMI (SP) • Brewer vs. TROPOMI (TS/SP) • (Toronto, Canada) • Dobson vs. TROPOMI (SP) • Brewer vs. Pandora (for calibration, TS/SP)	• Dobson: Japan(3), Korea(1), Russia(2), Taiwan(1), Thailand(1) • Brewer: India(3), China(6), Korea(3), Japan(5), Taiwan(2), Vietnam(3), Thailand(2), Russia(1), Malaysia(1)	• Not real time
G	• Pandora	• Pandora vs. OMI TOMS • Pandora VCD vs. OMI VCD (SP)	• Seoul (Yonsei Univ.), Busan, • USTC (China), Palau, Yokosuka,….	• Near real time
G	• ZLS DOAS/ MAX-DOAS		• MAX-DOAS (5 stations) : Gwangju, Yokosuka, Hefei, etc.	• Not real time
G	• Airborne	• GCAS vs. Pandora (SP)	• Campaign obs. (KORUS-AQ)	• Not real time
S	• TROPOMI/OMI/OMPS/ GOME-2 IUP retrievals/ SCIAMACHY/TEMPO	• OMPS vs. TROPOMI • OMI vs. OMPS		

G: Ground-based remote sensing & in-situ observations (including airborne observations)
S: Satellite observations
TS: time series, **SP**: scatter plots, **BP**: bar plots, **GP** : Geo plots (areal comparison), **HP** : Histogram plots, **VC** : Vertical profile comparison



Time series of OMI (Black) and Brewer direct sun (DS) total ozone measurements over four stations in Korea during the DRAGON campaign.

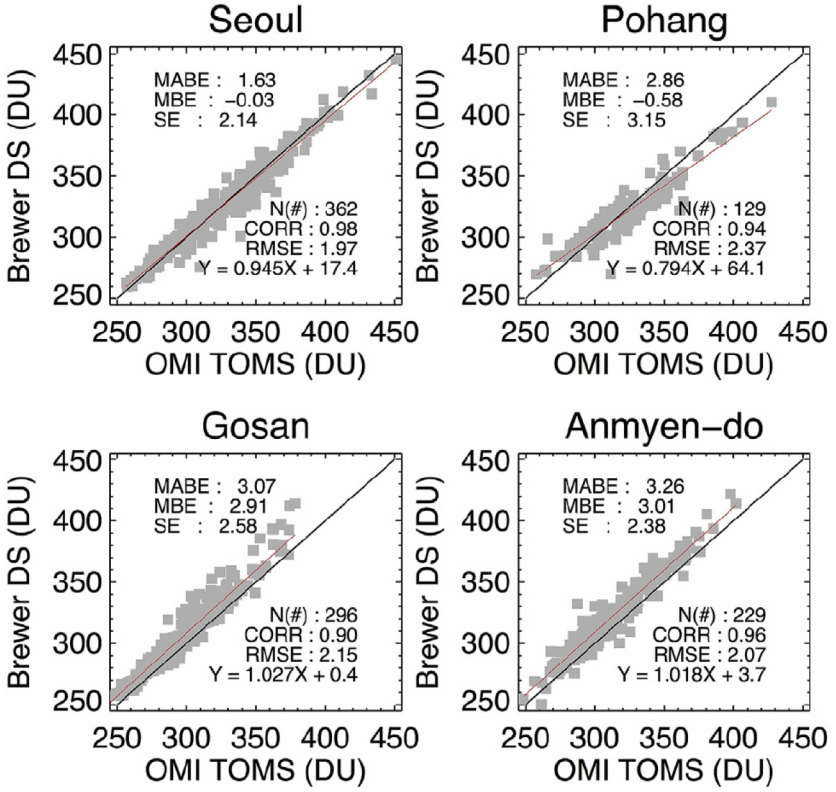


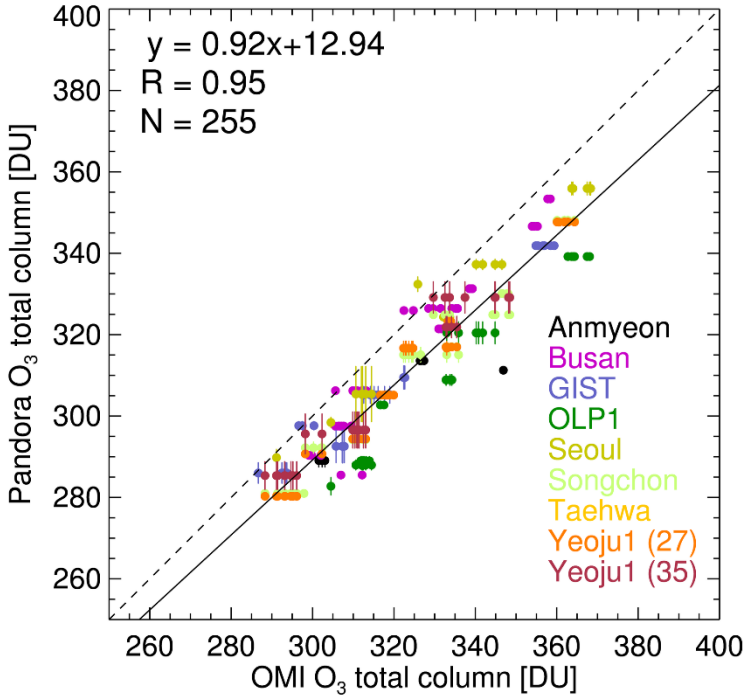
Fig. 3. Scatter plots of Brewer and OMI total ozone data over South Korea. The red and black lines represent the regression and unit line, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(Source: Baek et al., 2017)

Comparison between Pandora and other instruments during KORUS-AQ

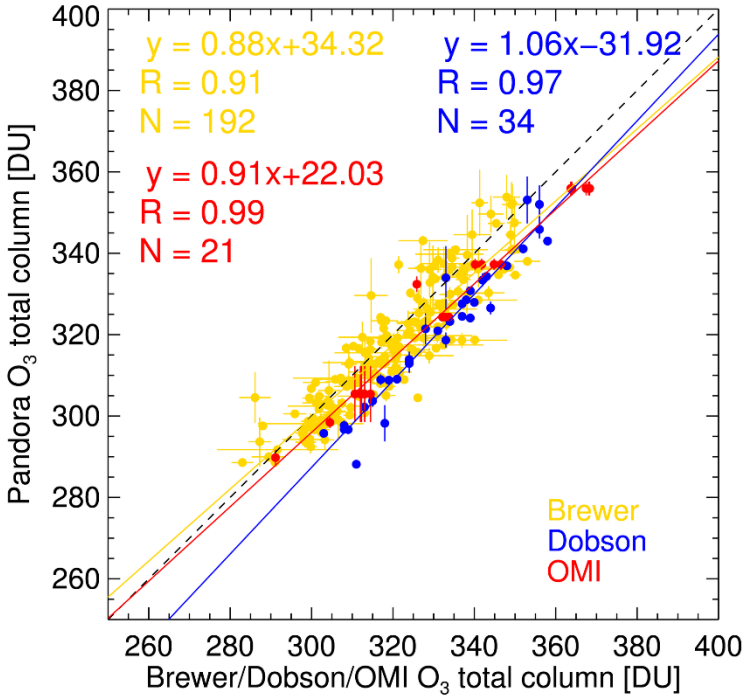
O_3 comparison

[Pandora vs. OMI at all sites]



- **Temporal co-location**: Average Pandora O_3 within ±30 min from OMI overpass time
- **Spatial co-location**: OMI pixels within 30 km from each Pandora site
- **Error bar**: standard deviation (1-σ)

[Pandora vs. Brewer/Dobson/OMI at Seoul site]

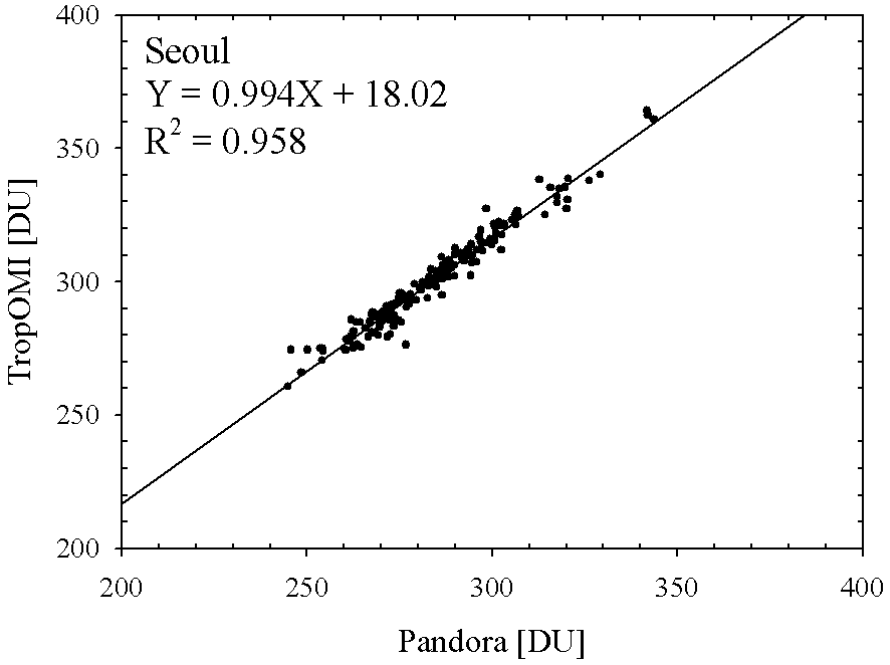


- **Dobson temporal co-location**: Average Pandora O_3 within ±30 min from Dobson observation time
- **Brewer temporal co-location**: hourly mean
- **Error bar**: standard deviation (1-σ)

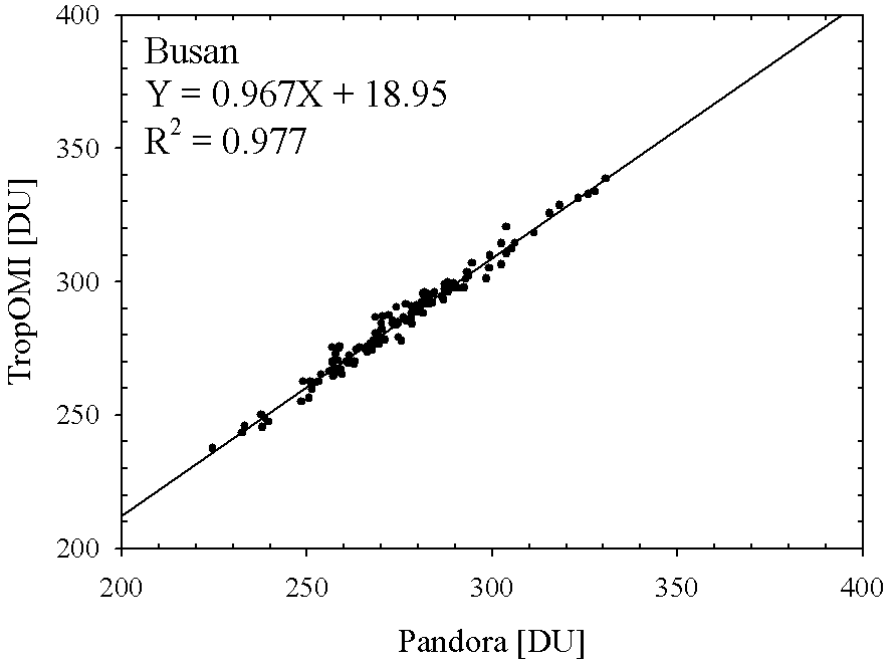
✓ Pandora and other instruments show high correlations (R > 0.9), however Pandora tends to slightly underestimate O_3.

Total Ozone: TROPOMI vs. Pandora

Seoul



Busan

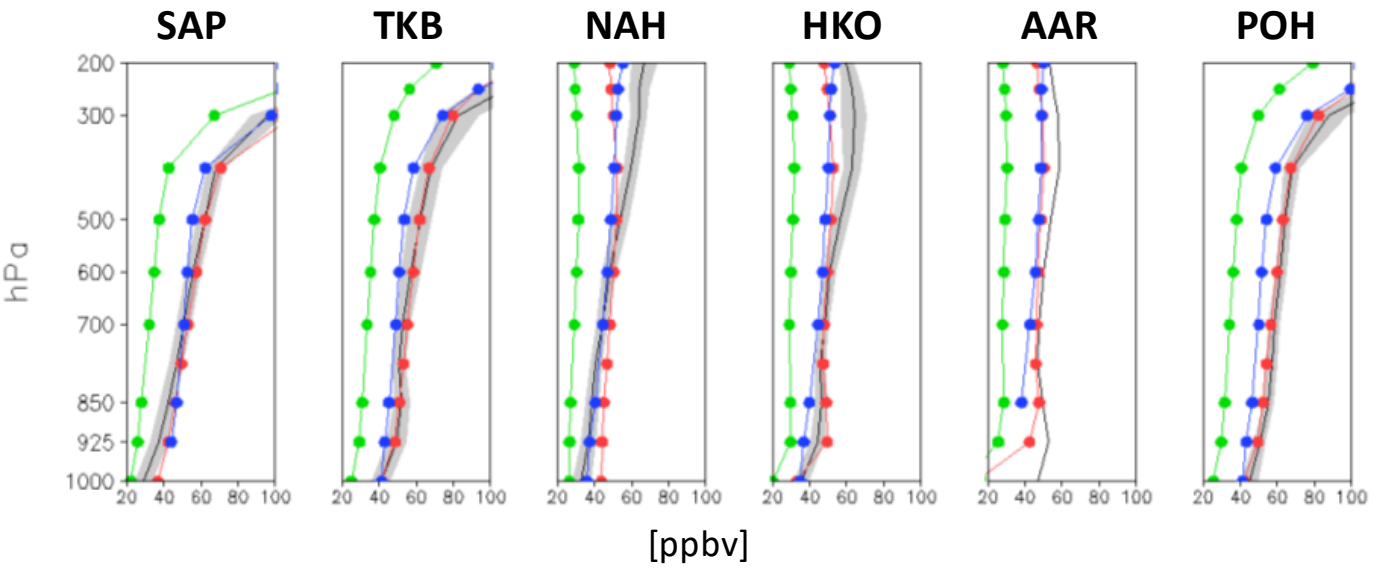


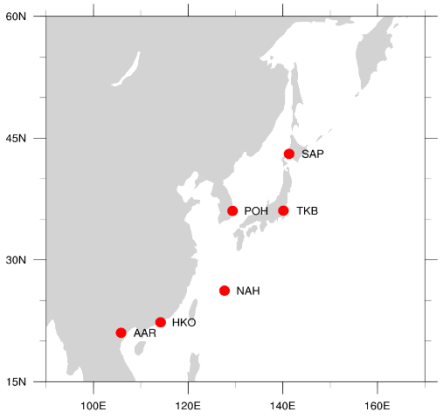
- Period : 2018.04.30 – 2019.03.05
- High Correlation, overestimate about 6%.
- Pandora : SZA < 75 deg., Error of Fit < 0.05, NO_2 VCD Error < 2 DU
- Colocation : Spatial - 0.5 degree, Temporal – 30 minutes

O_3 (Trop)

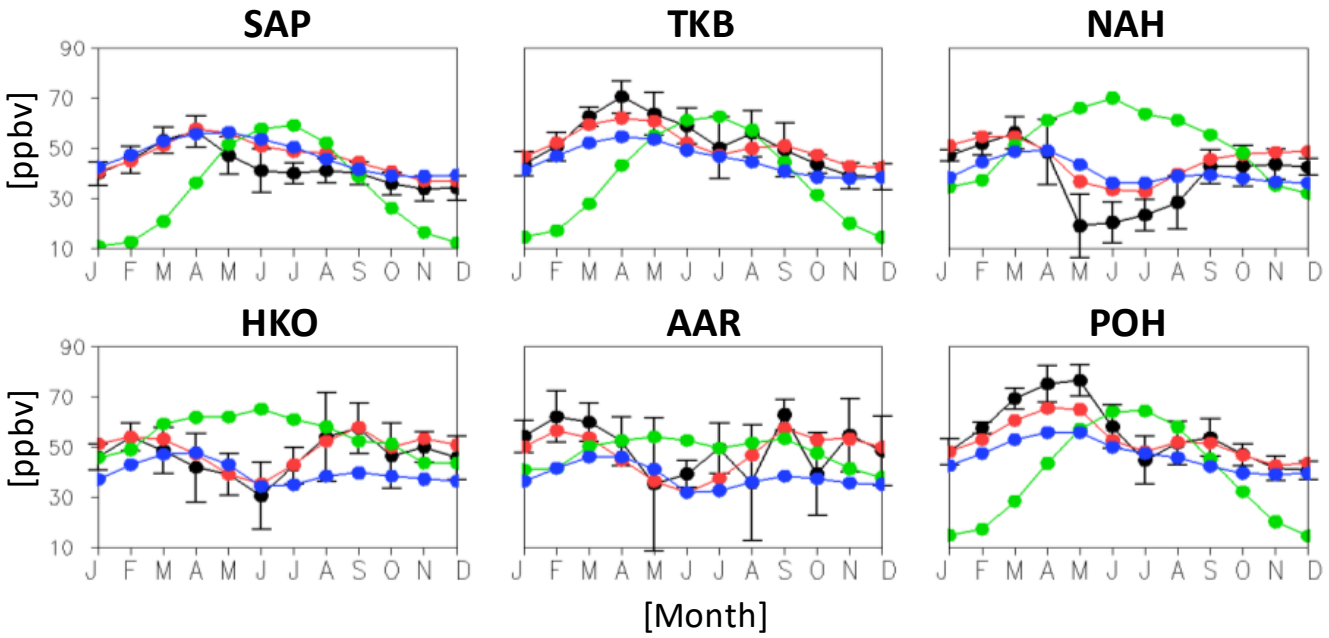
	Instruments	References (TROPOMI Validation Examples)	Application to GEMS	
			Geographical coverage	Temporal coverage
G	• Brewer/Dobson • Data access: WOUDC, NDACC, EVDC, AVDC		• Dobson: Japan(5), Korea(1), Russia(2), Taiwan(1), Thailand(1) • Brewer: India(3), China(6), Korea(3), Japan(5), Taiwan(2), Vietnam(3), Thailand(2), Russia(1), Malaysia(1)	• Not real time
	• Pandora		• Seoul (Yonsei Univ.), Busan, USTC China, Palau	• Near real time
	• FTIR		• N/A	• N/A
	• Ozone sondes • Data access: SHADOZ, GAW, NDACC, NASA DISC	• Ozone sondes vs. Pandora (VC)	• SHADOZ(2): • Hanoi, Kuala Lumpur	• Not real time
			• Pohang	• Not real time
			• NDACC : N/A	• N/A
			• GAW(5): Mt. Waliguan, Danum valley, etc.	• Not real time
	• Ozone lidar • Data access: NDACC		• Tsukuba (Japan): stratospheric ozone (stopped in 2010)	• Not real time
	• Airborne		• Campaign obs. (KORUS-AQ)	• Not real time
S	• GOME-2 IUP retrievals/OMPS nadir /OMPS limb IUP /OSIRIS/MLS limb /TEMPO			

Ozone sonde vs. Reanalysis (2003-2012)





Observation
MACC
ERA-I
MERRA2



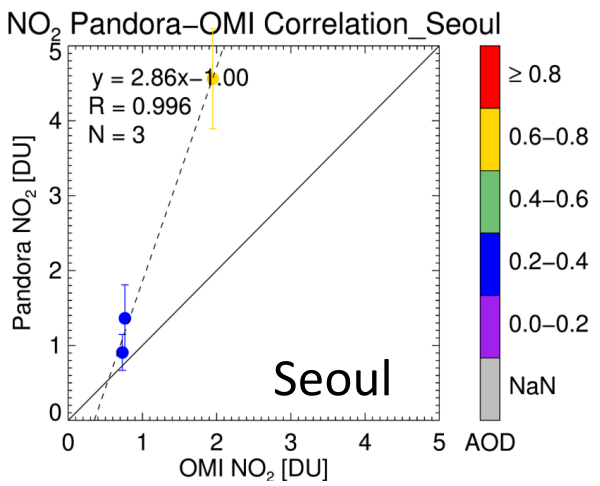
NO_2

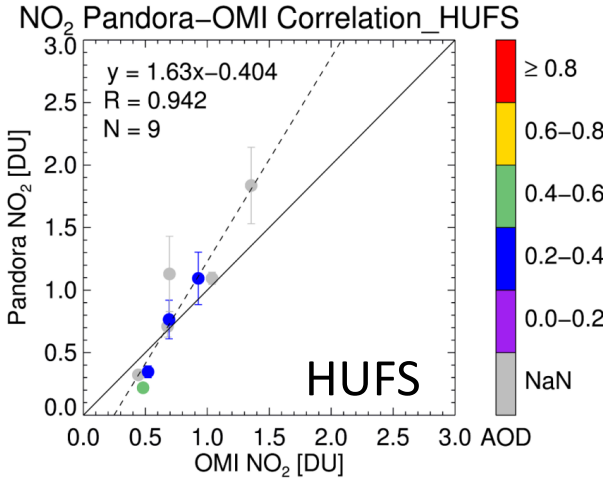
	Instruments	References (TROPOMI Validation Examples)	Application to GEMS: Geographical coverage	Application to GEMS: Temporal coverage
G	• DOAS/ZLS DOAS/ MAX-DOAS • Data access: Grou nd-based MAX-DO AS network	• MAX-DOAS vs. OMI (TS/SP) • MAX-DOAS vs. TROPOMI (BP/TS) • MAX-DOAS vs. GOME-2A (SP) • MAX-DOAS vs. Pandora (TS)	• MAX DOAS • (5 stations): Gwangju, Yokosuka, etc.	• Not real time
	• Pandora	• Pandora vs. TROPOMI (TS) • Pandora vs. OMI (TS, monthly) (SP) • Pandora vs. GeoTASO (SP)	• Seoul (Yonsei Univ.), Busan, USTC China, Palau, Yokosuka,….	• Near real time
	• NO_2 sonde		• Campaign obs.	
	• Airborne	• GeoTASO vs. TROPOMI (SP/GP) (binned to TROPOMI resolution) • GeoTASO vs. GCAS (GP, slant columns) • Pandora vs. P3B aircraft (VC)	• Campaign obs. (KORUS-AQ)	
S	• TROPOMI/OMI/G OME-2A/GOME-2 B/SCIAMACHY/TE MPO	• OMPS vs. TROPOMI • OMI vs. TROPOMI • SCIAMACHY vs. GOME-2 (TS) • NO2 data from OMI, GOME-2A and GOME -2B		

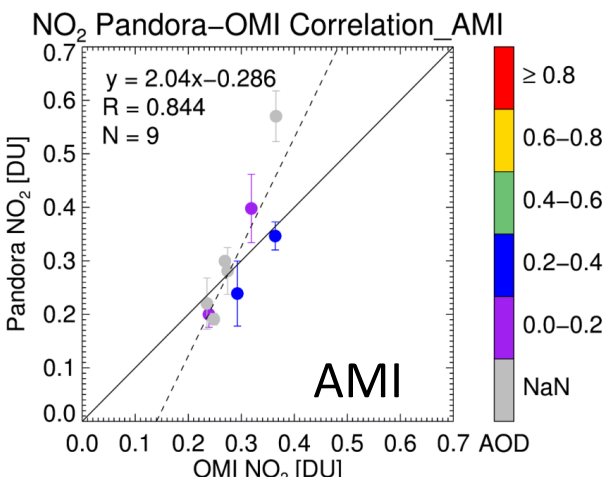
G: Ground-based remote sensing & in-situ observations (including airborne observations)
S: Satellite observations
TS: time series, **SP**: scatter plots, **BP**: bar plots, **GP** : Geo plots (areal comparison), **HP** : Histogram plots, **VC** : Vertical profile comparison

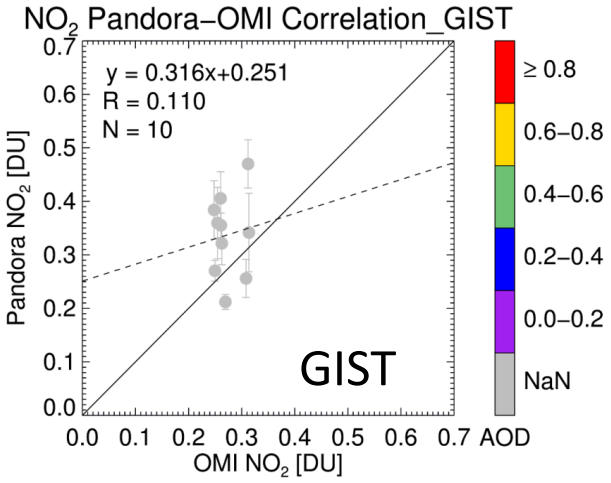
Pandora measurements during the MAPS-Seoul campaign (May- June 2015)

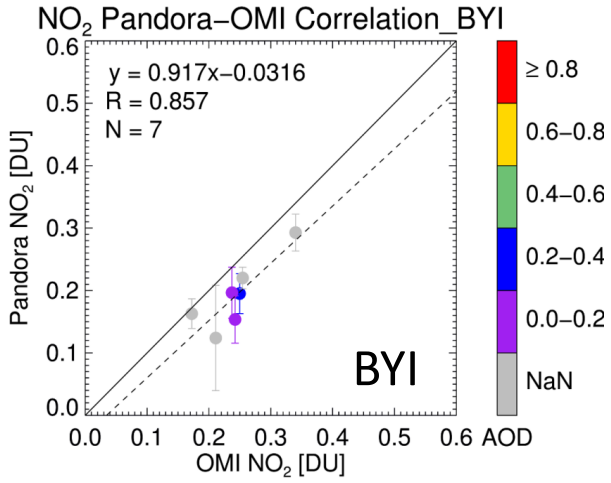
NO_2 : Pandora vs. OMI

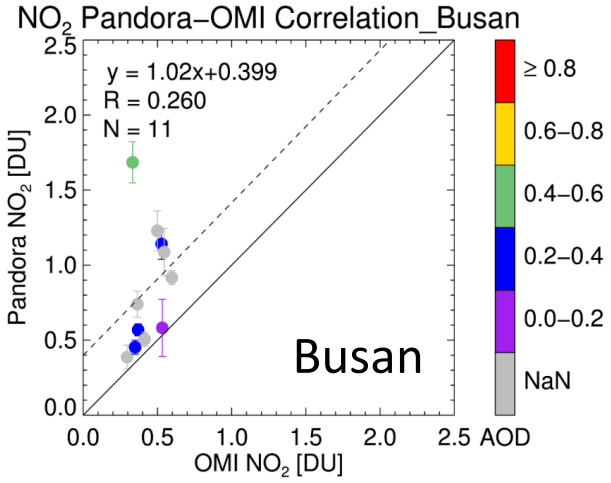






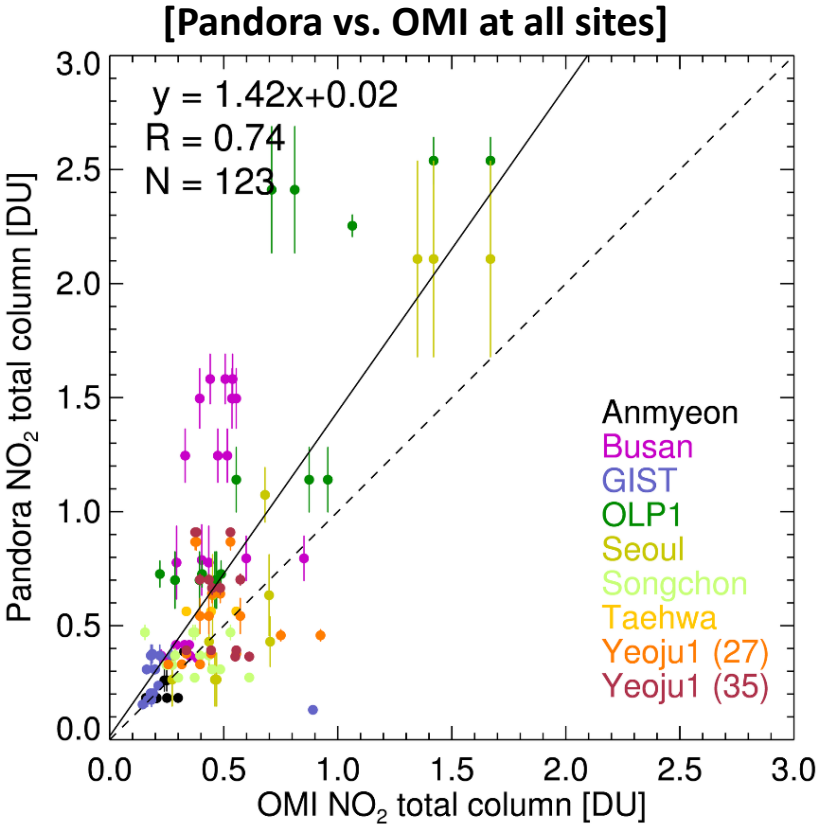






Comparison between Pandora and other instruments during KORUS-AQ

NO_2 comparison



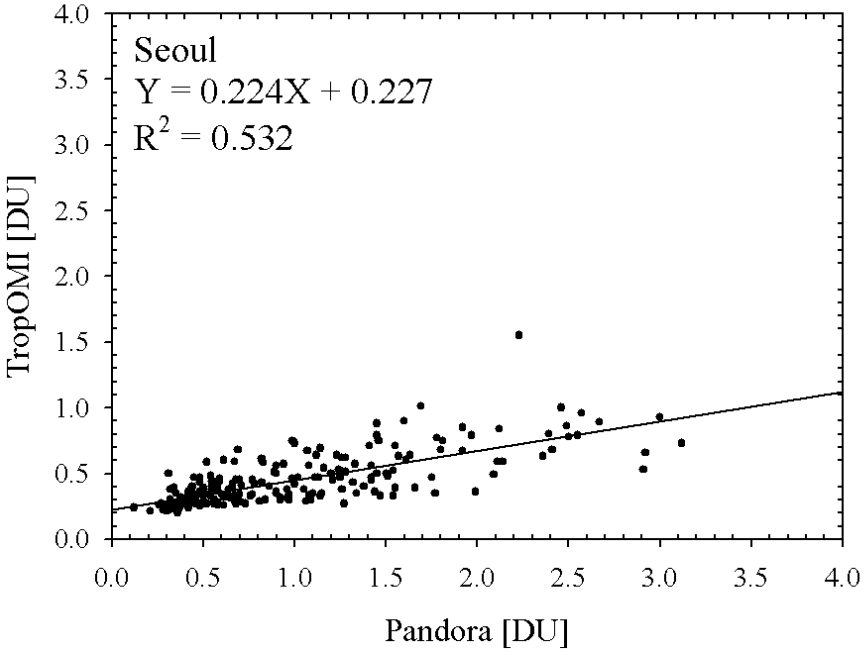
- **Temporal co-location**: Average Pandora O_3 within ±15 min from OMI overpass time
- **Spatial co-location**: OMI pixels within 20 km from each Pandora site
- **Error bar**: standard deviation (1-σ)

✓ OMI underestimates at high values of NO_2.

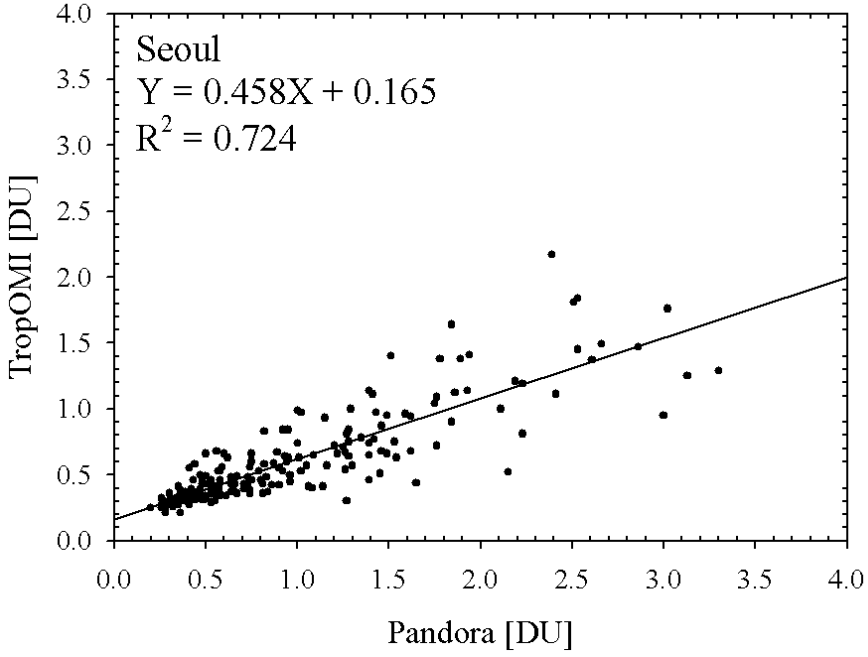
✓ Underestimation of OMI is partly due to coarse horizontal resolution of OMI pixel and chemical transport model grid used for computing AMF of operational products.

NO_2 : TropOMI vs. Pandora

Collocation : 0.5°& 30-min



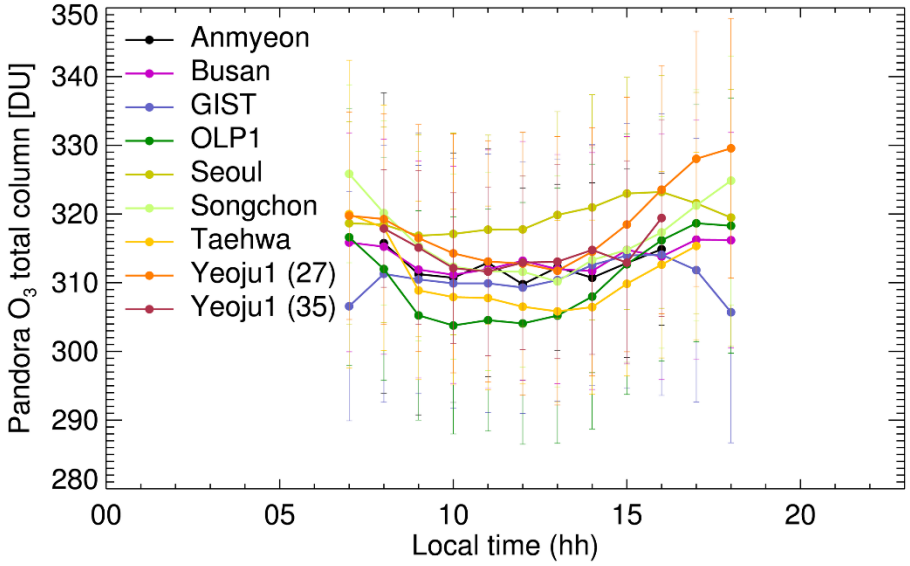
Collocation : 0.1°& 30-min



- Period : 2018.04.30 – 2019.03.05
- Megacity Seoul: NO_2 emissions local inhomogeneity → underestimation of TROPOMI NO_2 (relatively large FOV)
- Pandora : SZA < 75°, errorfit < 0.05, VCD Error < 0.05 DU
- Jay Herman et al. (AMTD, 2019): On a weekly or monthly average basis, OMI almost always underestimates the amount $TCNO_2$ by 50 to 100% → air mass factor, surface reflectivity, and the OMI 24x13 km^2 FOV (field of view) are three factors that can cause OMI to underestimate $TCNO_2$.

Diurnal variations of total column O_3 and NO_2 during KORUS-AQ

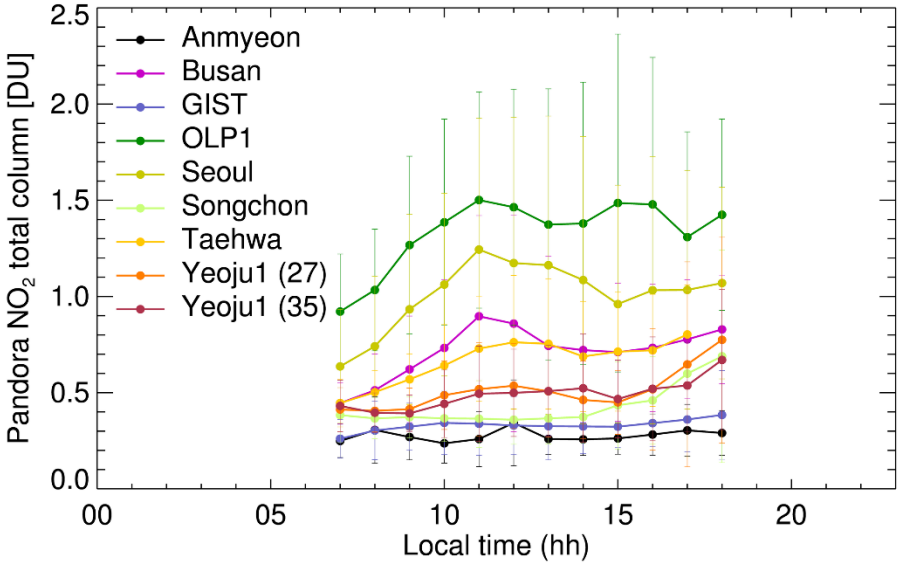
Diurnal variation of O_3



- **Error bar**: standard deviation (1-σ)

✓ Diurnal variations are found, probably reflecting the effect of solar zenith angle difference.

Diurnal variation of NO_2



- **Error bar**: standard deviation (1-σ)

✓ High NO_2 concentrations are found in Seoul (Seoul and OLP1).

✓ Diurnal variability is more distinct in urban sites (OLP1, Seoul, and Busan) than rural sites (GIST and Anmyeon) due to traffic.

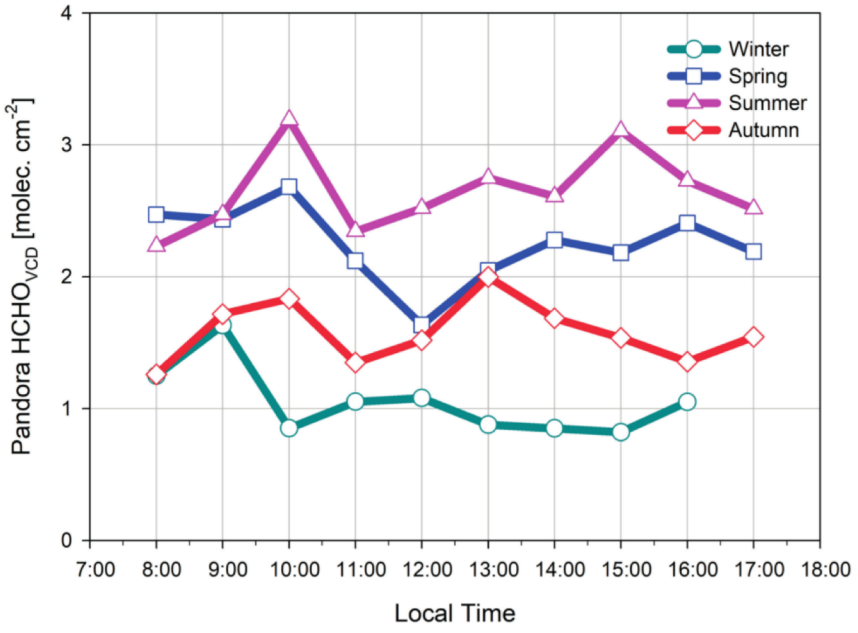
HCHO

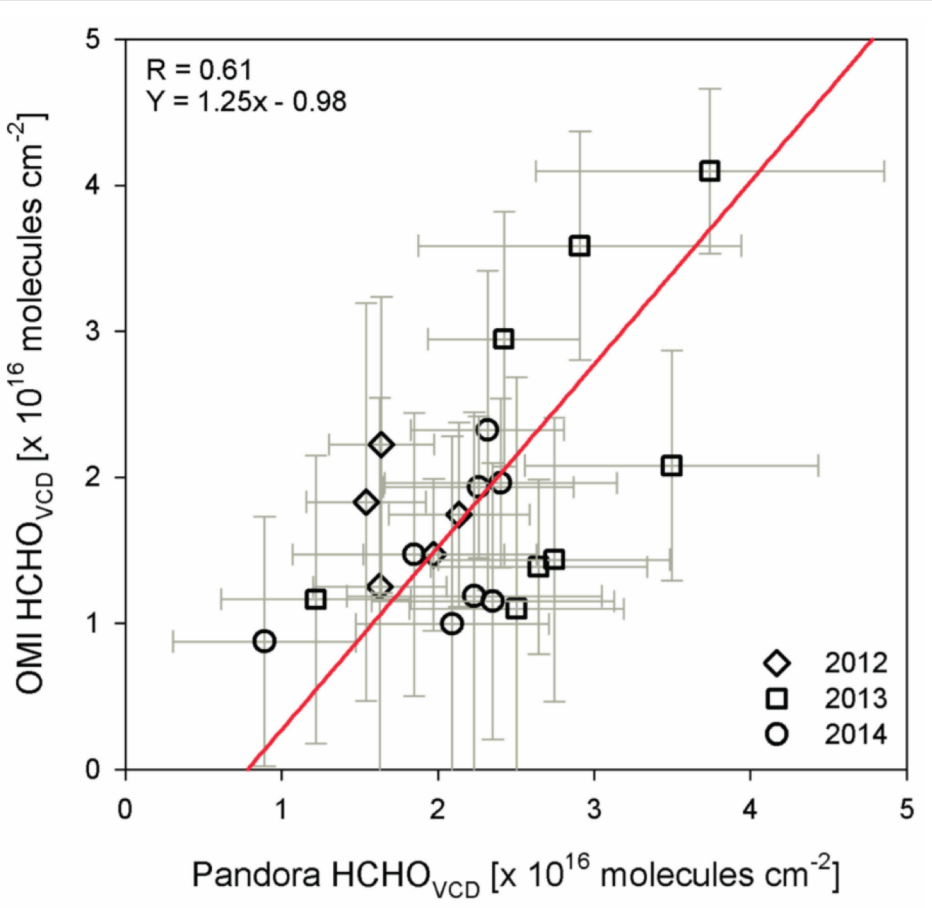
	Instruments	References (TROPOMI Validation Examples)	Application to GEMS	
			Geographical coverage	Temporal coverage
G	• FTIR • Data access: Ground-based network within TCCON		• Current 4 sites + 1 future site (Anmeyon, Rikubetsu, Tsukuba, Saga, Hefei)	• Not real time
G	• DOAS/MAX-DOAS • Data access: Ground-based MAX-DOAS net-work	• MAX-DOAS vs. OMPS (TS/SP) • MAX-DOAS vs. GOME-2 (TS/SP)	• MAX DOAS (5 stations) : Gwangju, Yokosuka, etc.	• Not real time
G	• Pandora	• Pandora vs. Airborne (DC-8) (TS, daily) • Pandora vs. DOAS (TS)	• Seoul (Yonsei Univ.), Busan, USTC China, Palau……..	• Near real time
G	• Airborne	• GCAS vs. P3B	• Campaign obs. (KORUS-AQ)	• Not real time
S	• OMI/OMPS/S5P /TEMPO	• Total column HCHO (S5P, OMI, OMPS)		

G: Ground-based remote sensing & in-situ observations (including airborne observations)
S: Satellite observations
TS: time series, **SP**: scatter plots, **BP**: bar plots, **GP** : Geo plots (areal comparison), **HP** : Histogram plots, **VC** : Vertical profile comparison

HCHO retrieval from Pandora measurements in Seoul, Korea

Diurnal Variation (Seoul, 2012- 2014)





(Park et al., 2018)

SO_2

	Instruments	References (TROPOMI Validation Examples)	Application to GEMS	
			Geographical coverage	Temporal coverage
G	• Brewer • Data access: WOUDC, NDACC, EVDC, AVDC	• Brewer vs. OMI • Brewer vs. OMPS	• Brewer: India(3), China(6), Korea(3), Japan(5), Taiwan(2), Vietnam(3), Thailand(2), Russia(1), Malaysia(1)	• Not real time
	• Pandora	• Pandora VCD vs. OMI VCD (SP)	• Seoul (Yonsei Univ.), Busan, USTC China, Palau, Yokosuka,….	• Near real time
	• BIRA DOAS / MAX-DOAS	• BIRA DOAS vs. OMI (SP)	• MAX DOAS (5 stations): Gwangju, Yokosuka, etc.	• Not real time
	• SO_2 sondes	• Sonde SO_2 vs. OMI (SP)	• Campaign obs.	
	• Airborne		• Campaign obs. (KORUS-AQ)	• Not real time
S	• TROPOMI/OMI/OMPS/GOME-2/IASI (MetOp-A and B)/AIRS/CRIS/ VIIRS/MODIS/TEMPO	• OMPS vs. TROPOMI • OMI vs. GOME-2 • OMI vs. OMPS (GP) • Total column SO_2 (S5P, OMI, OMPS)		

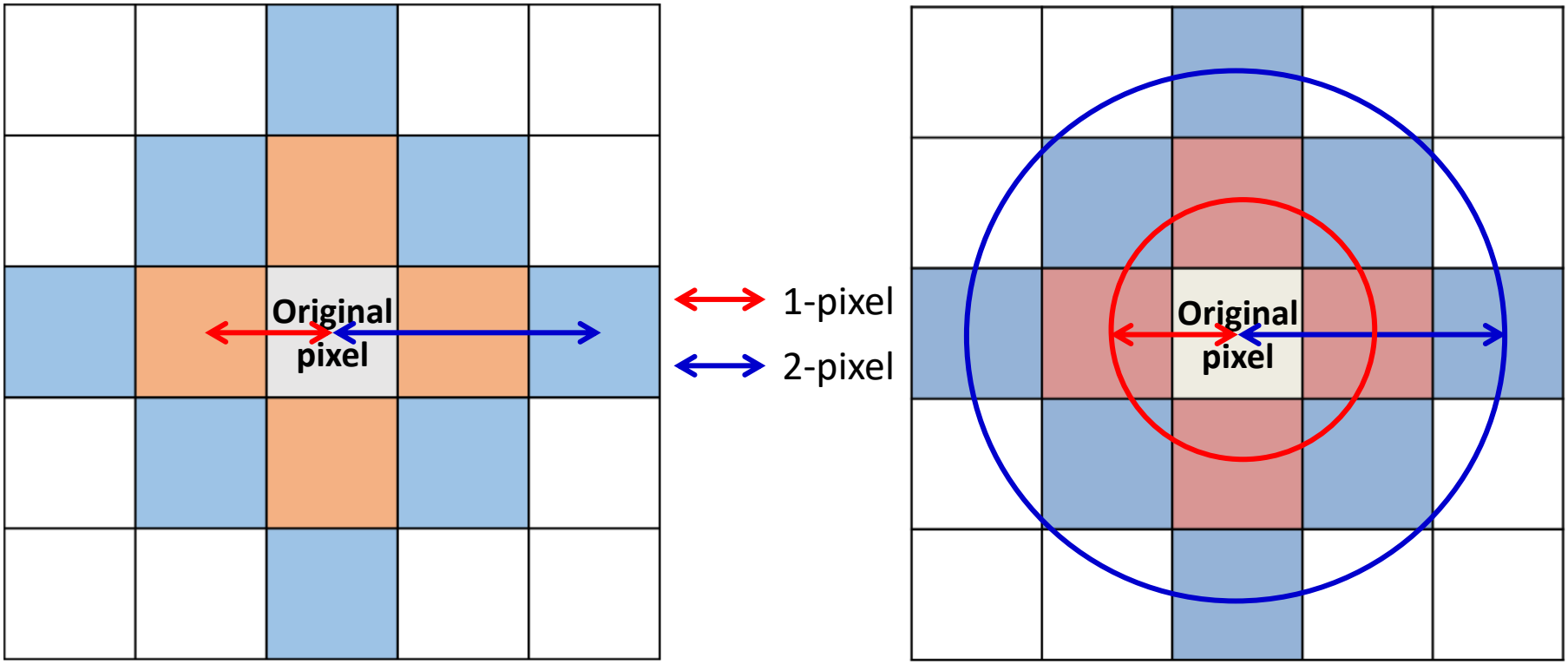
G: Ground-based remote sensing & in-situ observations (including airborne observations)
S: Satellite observations
TS: time series, **SP**: scatter plots, **BP**: bar plots, **GP** : Geo plots (areal comparison), **HP** : Histogram plots, **VC** : Vertical profile comparison

AOD (aerosol optical depth)

Instruments		References (TROPOMI Validation Examples)	Application to GEMS	
			Geographical coverage	Temporal coverage
G	• AERONET • SKYNET • MFRSR	• AERONET vs. GOCI (TS/GP)	• AERONET: almost 190 sites in the GEMS domain	• Near rea time
			• SKYNET (16 stations) : Seoul, Chiba, Osaka, etc.	• Near rea time
	• Brewer • Data access: WOUDC, ND ACC, EVDC, AVDC	• Brewer vs. OMI	• Brewer: India(3), China(6), Korea(3), Japan(5), Taiwan(2), Vietnam(3), Thailand(2), Russia(1), Malaysia(1)	• Not real time
	• Pandora		• Seoul (Yonsei Univ.), Busan, USTC China, Palau, Yokosuka,….	• Near real time
	• Lidar • Data access: EARLINET, MPLNET, ADNET, KALION	• Lidar vs. GOME-2A (SP) • Lidar vs. IASI	• MPLNET (8 stations) : Kaohsiung, Kanpur, etc. • AD-NET, KALION	• Near real time (for level 1 and level 1.5)
	• Airborne		• Campaign obs. (KORUS-AQ)	
S	• CALIOP/GOCI/OMI/ IASI/Himawari/KMA MI			• Near real time

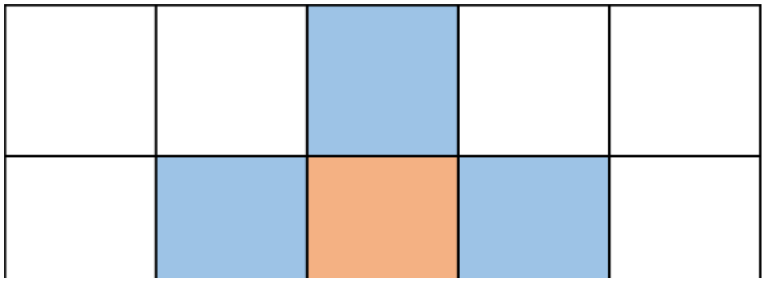
G: Ground-based remote sensing & in-situ observations (including airborne observations)
S: Satellite observations
TS: time series, **SP**: scatter plots, **BP**: bar plots, **GP** : Geo plots (areal comparison), **HP** : Histogram plots, **VC** : Vertical profile comparison

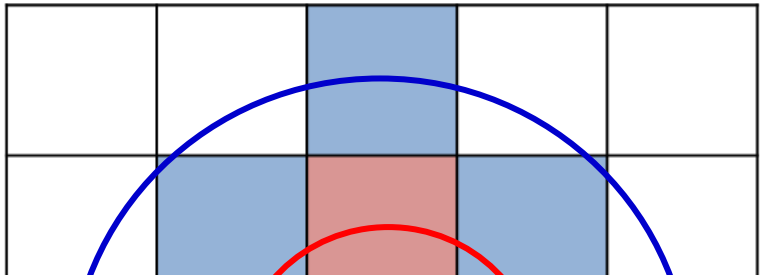
Spatial/Temporal Collocation Issues

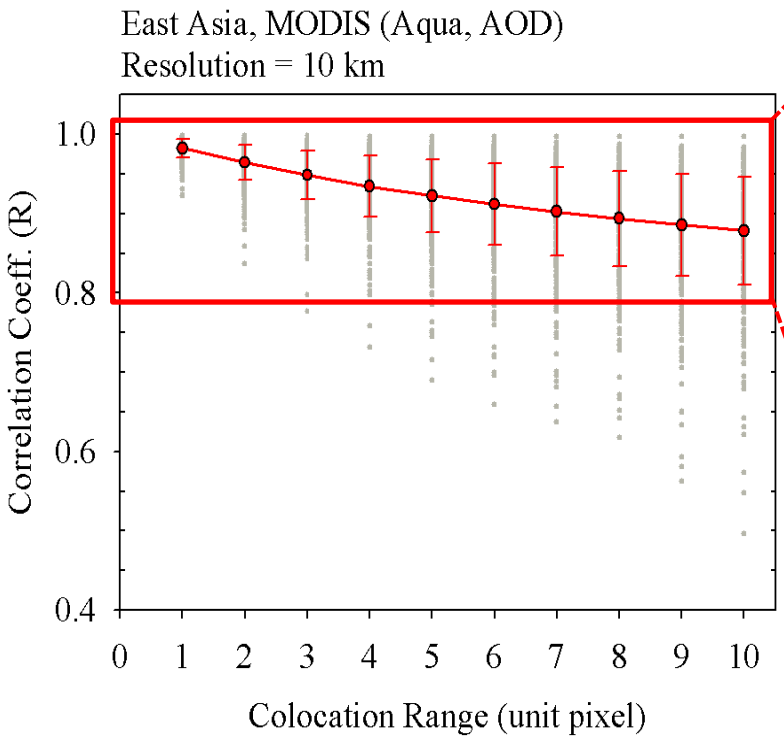


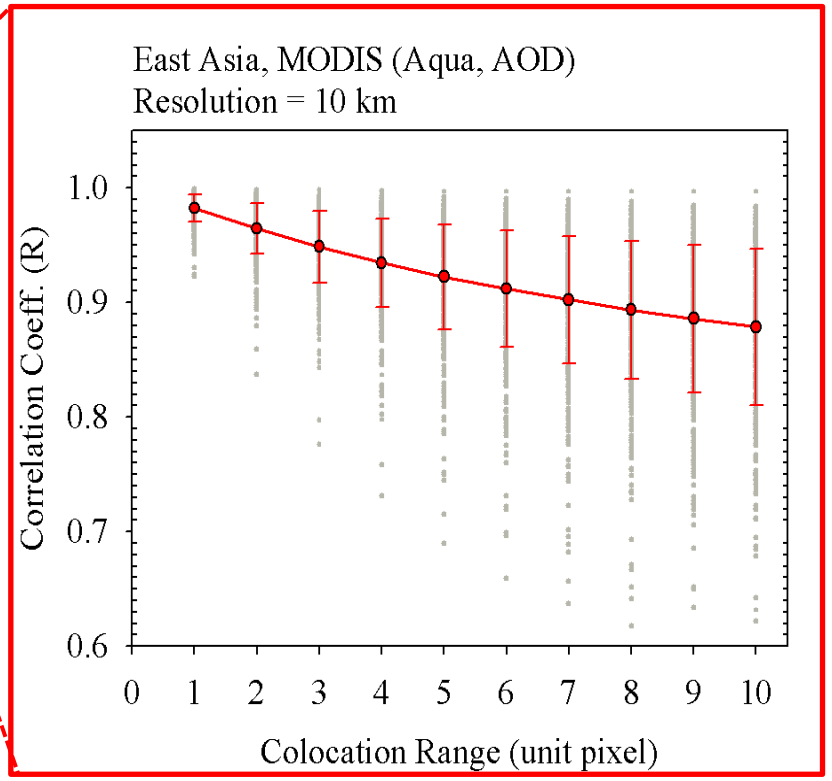
- Test : MODIS Level 2 AOD (Aqua, MYD04)
- Horizontal Resolution = 10 km * 10 km (almost same)
- Colocation Range unit = [pixel] = 10 km radius

Spatial/Temporal Collocation Issues

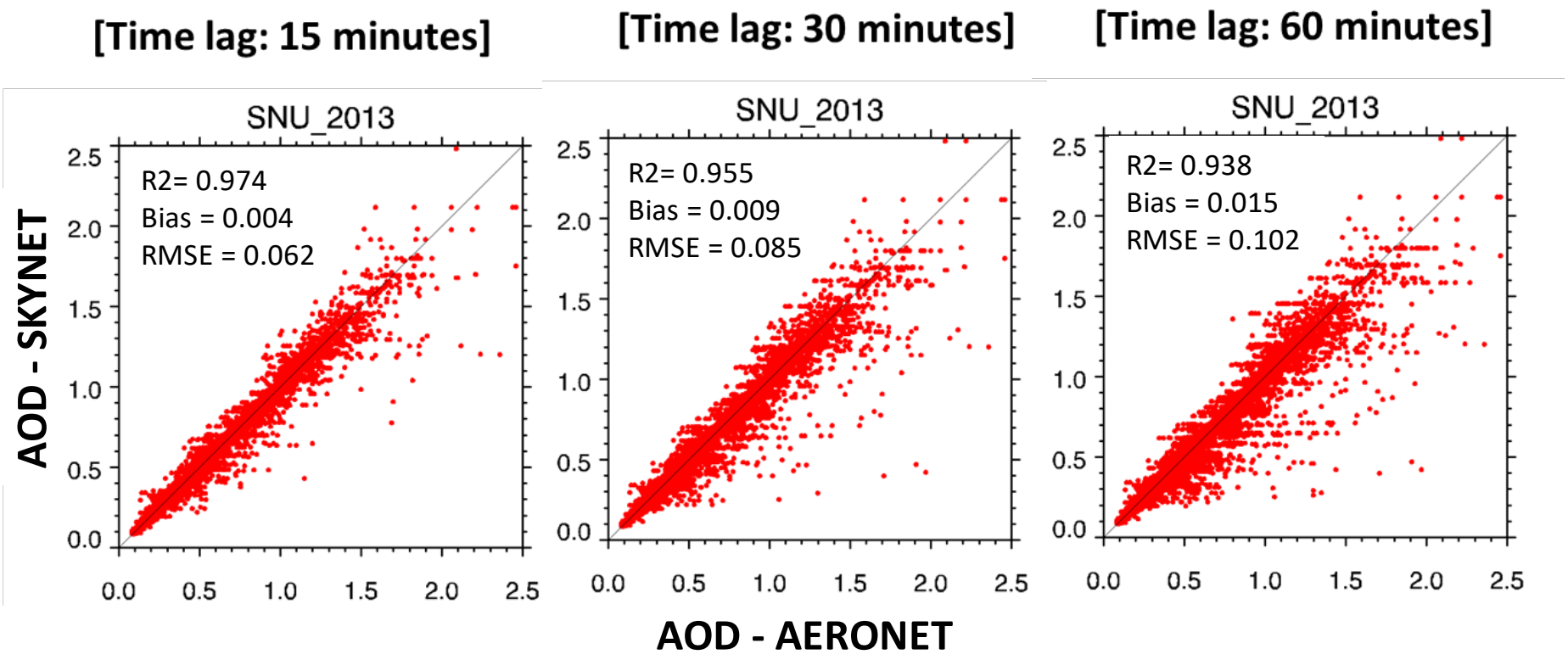




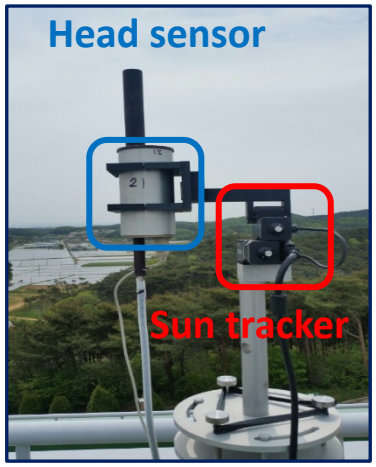




Spatial/Temporal Collocation Issues



Establishing Pandora Network in Korea

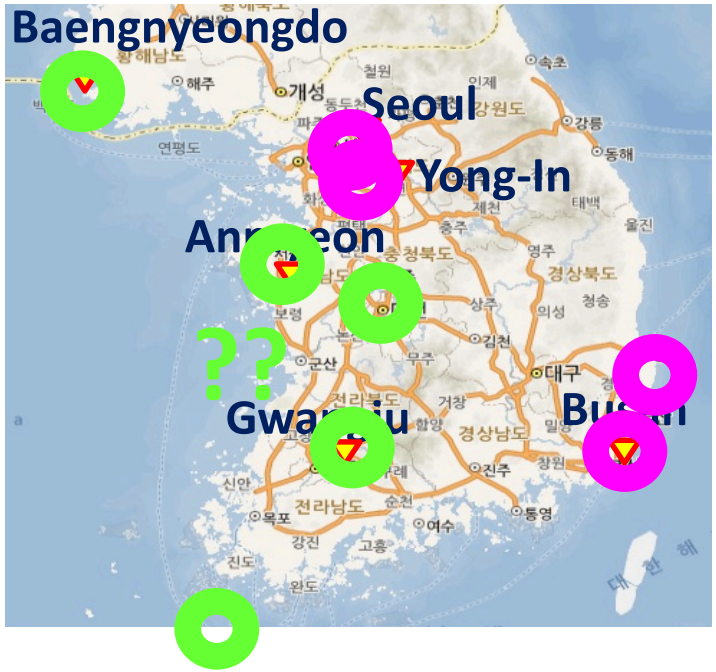


Korea

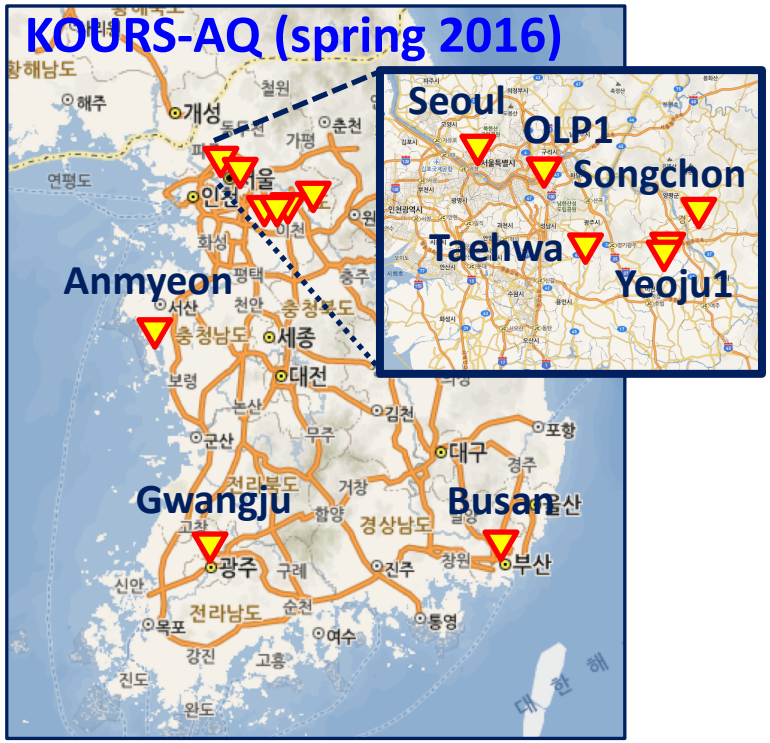
- Operating (2) : YSU and PNU
- Installation & Test (2) : SNU and UNIST
- 2020 – 2021 (6) : TBD (by NIER)

+ Japan (1) & China (1) by NIER

MAPS-Seoul campaign (spring 2015)



KOURS-AQ (spring 2016)



Short Summary

- For the validation of GEMS products, several studies have been made by comparing with ground-based remote sensing data.

- The collections of near real-time (NRT) and quality-assured data from existing ground-based networks are still in great need.

- NIER is considering issuing an Announcement of Opportunity for geophysical validation before and after launch, following the ESA S5P approach.

Baseline GEMS products

Product	Importance	Min (cm^{-2})	Max (cm^{-2})	Nominal (cm^{-2})	Accuracy	Window (nm)	Spatial Resol. (km^2) @Seoul	SZA (deg)
NO_2	O_3 precursor	$3x10^{13}$	$1x10^{17}$	$1x10^{14}$	$1x10^{15}$ cm^{-2}	425-450	7 x 8 x 2 pixels	< 70
SO_2	Aerosol precursor Volcano	$6x10^{8}$	$1x10^{17}$	$6x10^{14}$	$1x10^{16}$ cm^{-2}	310-330	7 x 8 x 4 pixels x 3 hours	< 50 (60*)
HCHO	VOC proxy	$1x10^{15}$	$3x10^{16}$	$3x10^{15}$	$1x10^{16}$ cm^{-2}	327-357	7 x 8 x 4 pixels	< 50 (60*)
CHOCHO							7 x 8 x 4 px	< 50
$TropLO_3$ **$TropUO_3$** **$StratO_3$** **$TotalO_3$**	Oxidant Pollutant O_3 layer	$4x10^{17}$	$2x10^{18}$	$1x10^{18}$	3%(TOz) 5%(Stra) 20(Trop)	300-340	7 x 8	< 70
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
[Clouds] **ECF, CCP**	Retrieval Climate	0 (COD)	50 (COD)	17 (COD)		300-500	7 x 8	< 70
Surface Property	Environment	0	1	-		300-500	3.5 x 8	< 70
UVI Solar Irad.	Public health	0	12	-			7 x 8	< 70