Interpretation and improvement of air quality data from Geostationary Environment Monitoring Spectrometer (GEMS)

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GK-2B launch: 2020.02.19 (Korea Standard Time)
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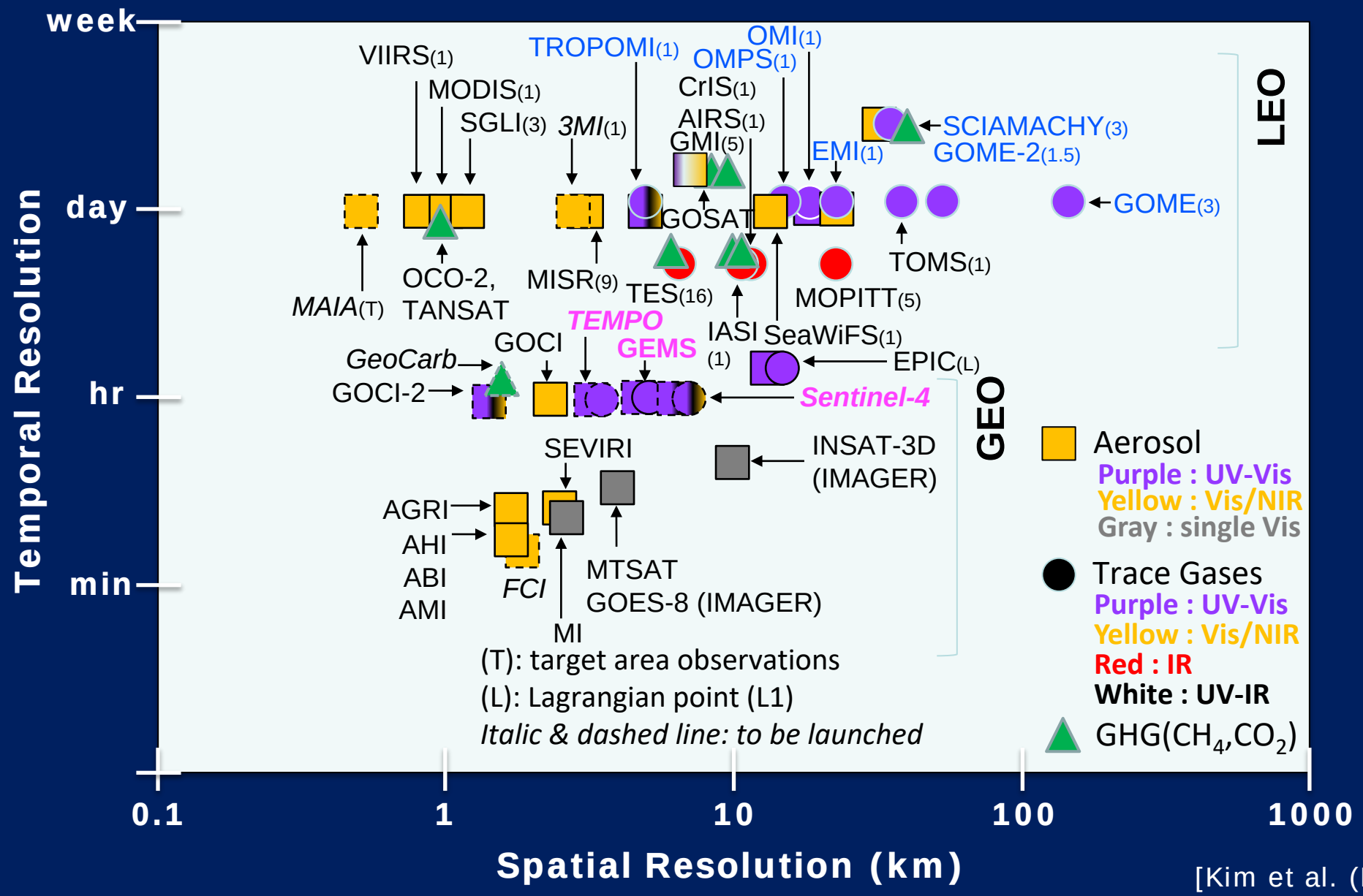
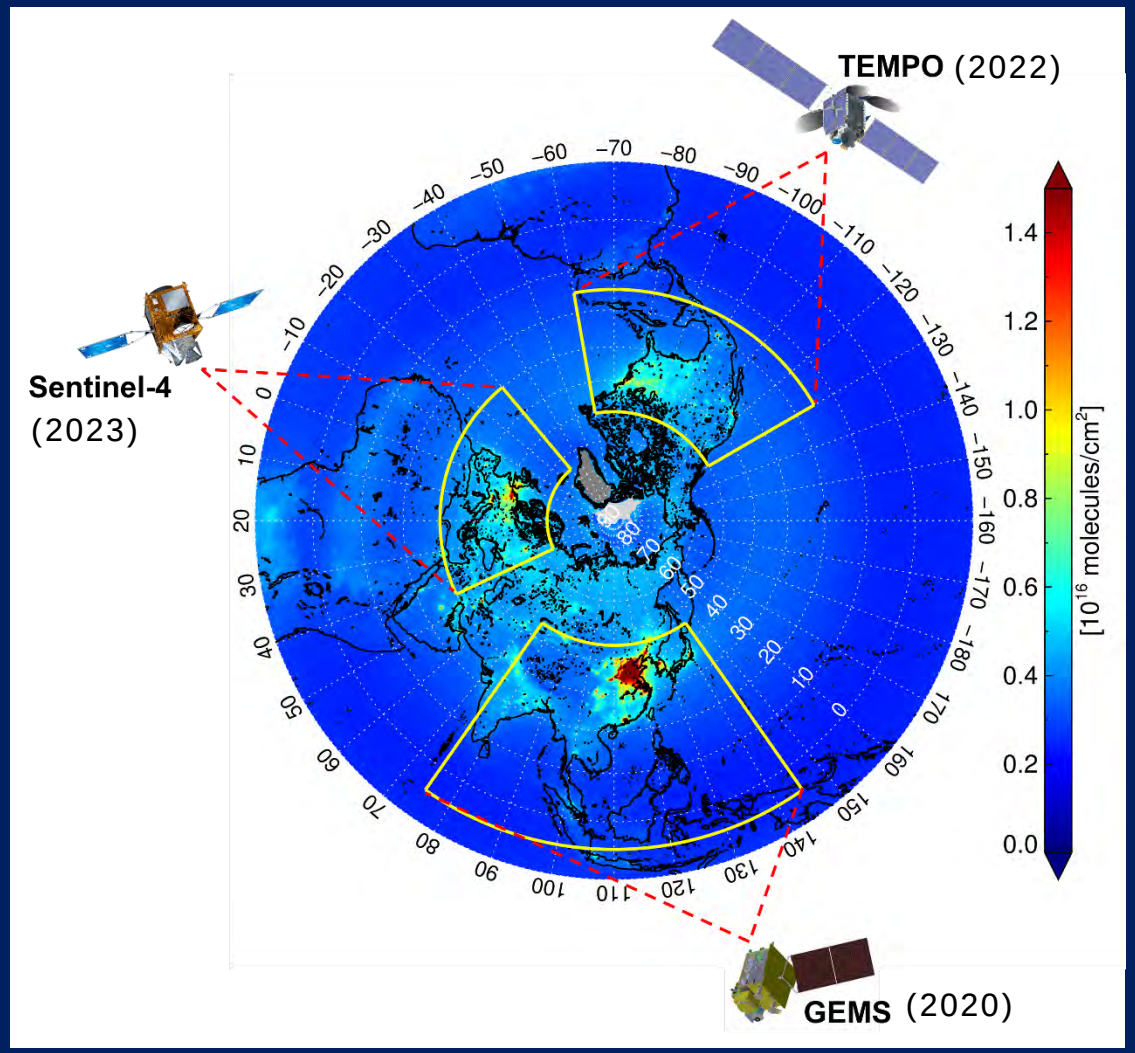
Satellite remote sensing for aerosols & gases



[Kim et al. (BAMS 2020)]

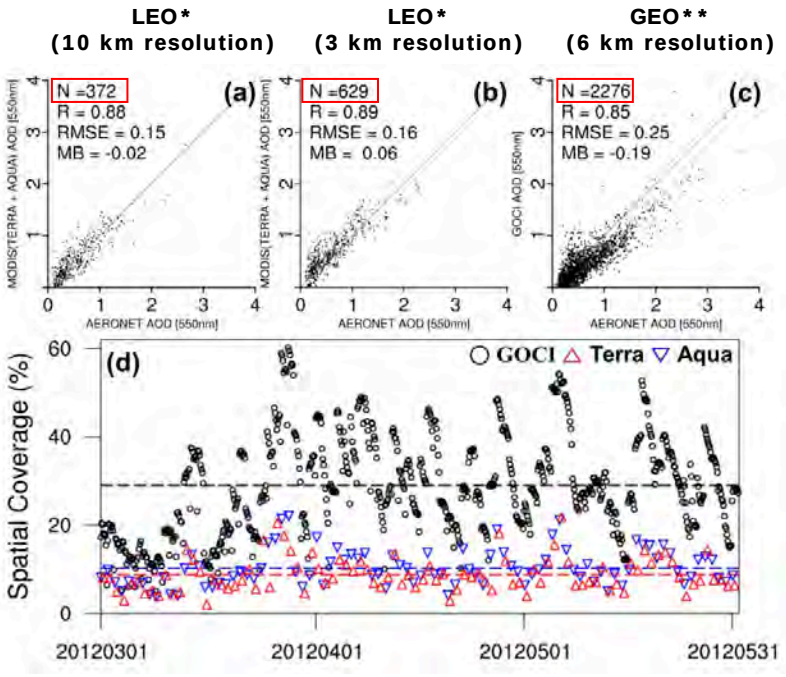
Geostationary air quality constellation



	Sentinel-4	TEMPO	GEMS
Domain	Europe	North America	Asia-Pacific
Revisit	1 hour	1 hour	1 hour
(Planned) Launch	~2023	2022	2020
Payload	UV–Vis–NIR 305–500 nm 750–775 nm	UV–Vis 290–490 nm 540–740 nm	UV–Vis 300–500 nm
Products	O_3, trop. O_3, NO_2, SO_2, HCHO, CHOCHO, AAI, AOD, ALH	O_3, trop. O_3, 0-2km O_3, NO_2, SO_2, HCHO, CHOCHO, BrO, H_2O, AOD	O_3, trop O_3, NO_2, SO_2, HCHO, CHOCHO, AOD, AAI, AEH, (BrO, IO, H_2O …)
Spatial sampling	8 km x 8 km at 45°N	≤ 2.2 km N/S x 5.2 km E/W @36.5°N	3.5 km N/S x 8 km E/W @38°N
Nominal product resolution	8.9 km N/S x 11.7 km E/W @40°N	≤ 8.88 km N/S x 5.15 km E/W @35°N	7 km N/S x 8 km E/W @38°N (gas), 3.5 km N/S x 8 km E/W @38N (aerosol)
Accompanied instruments	MTG-S, MTG-I	GOES-R/S ABI	AMI, GOCI-2

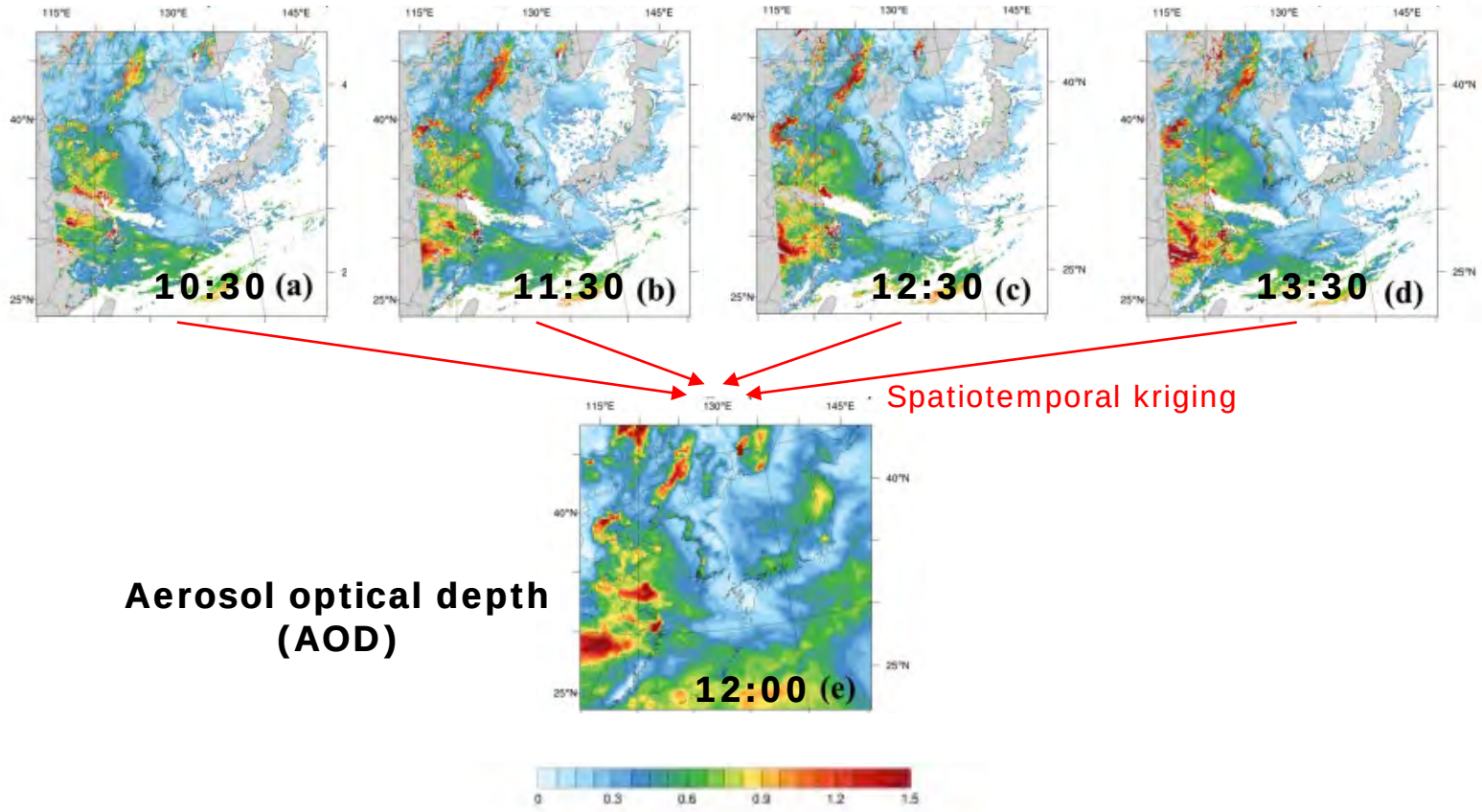
Merits of geostationary satellite applications

Aerosol optical depth (AOD)



*LEO: Low-Earth Orbit
**GEO: Geostationary Earth Orbit

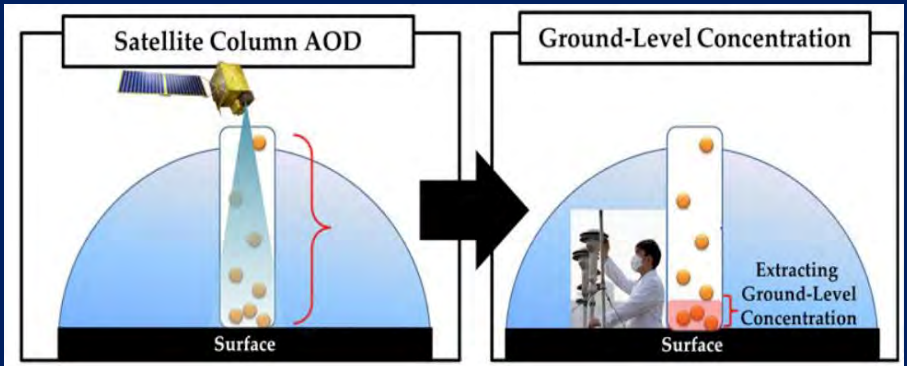
April 7, 2012



[Lee et al. (GMD 2016)]

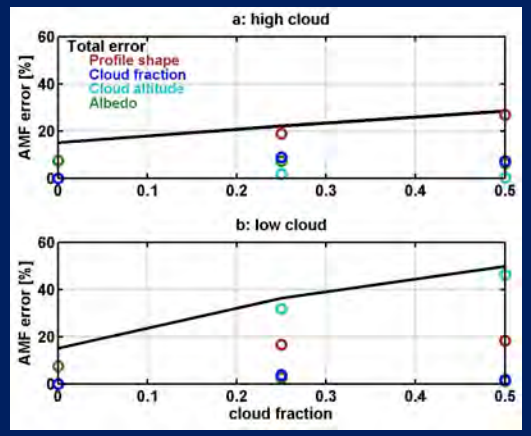
Considerations for satellite applications

- **Column amount vs. Surface mixing ratio**



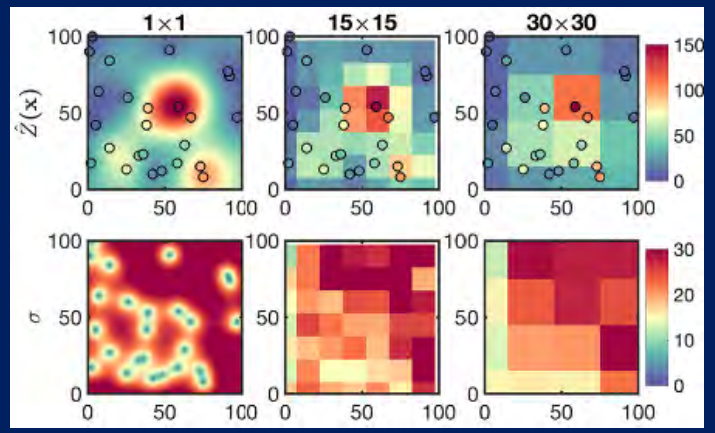
[Courtesy of NIER]

- **Clouds**



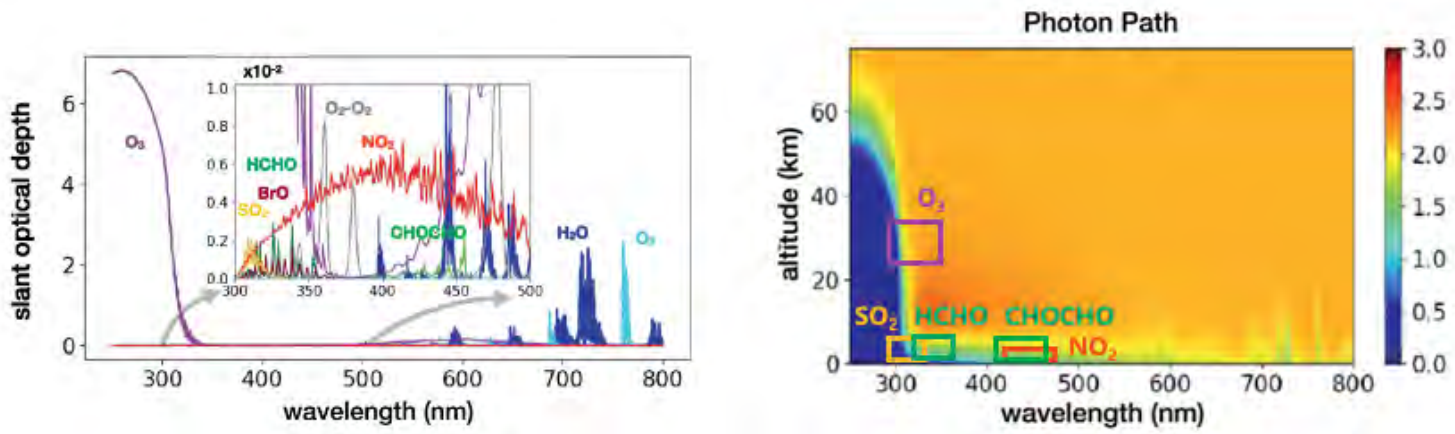
[De Smedt et al. (ACP 2008)]

- **Spatial resolution**



[Souri et al. (AMT 2022)]

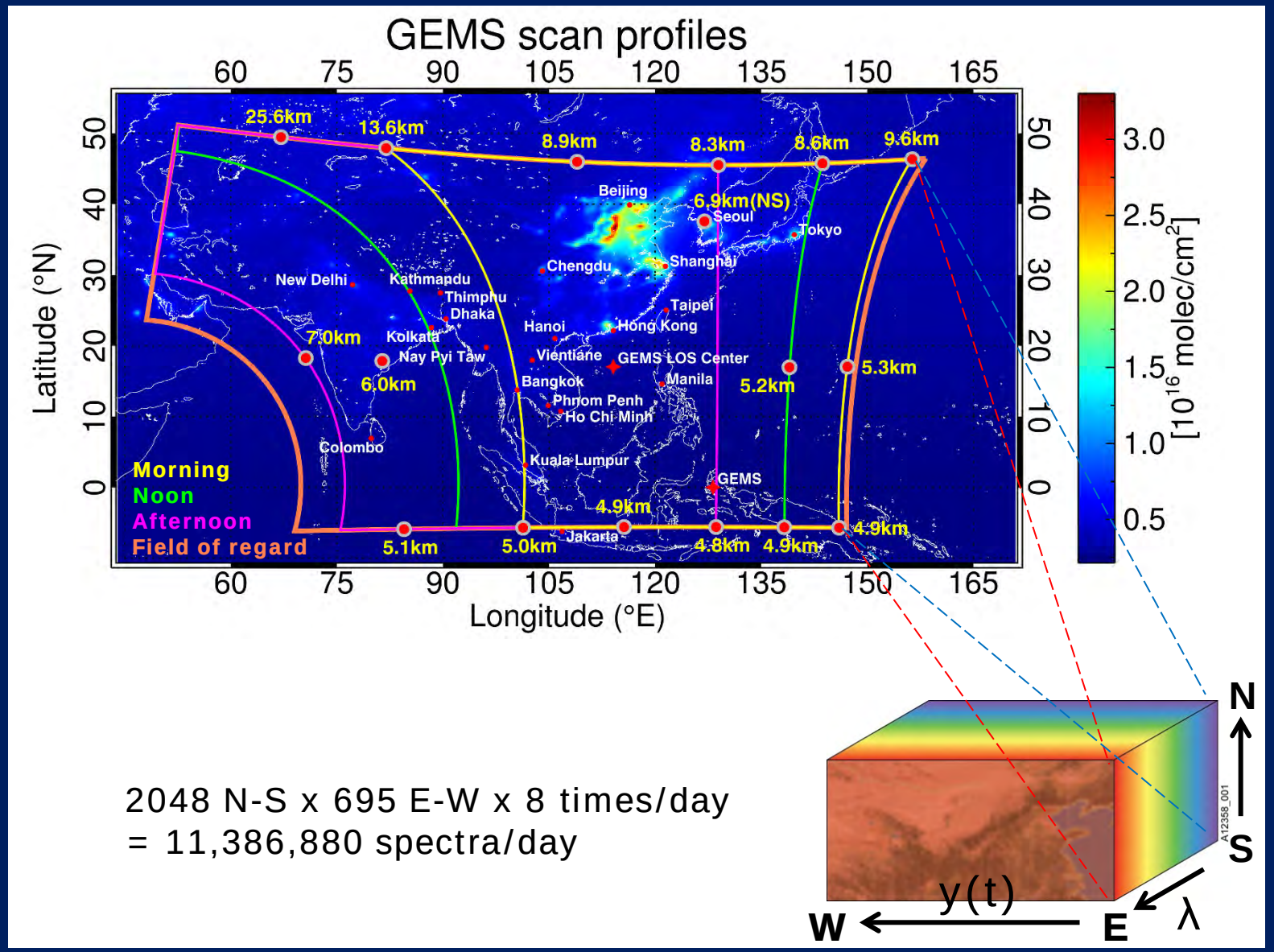
- **Species-dependent sensitivity**



[González Abad et al. (JQSRT 2019)]

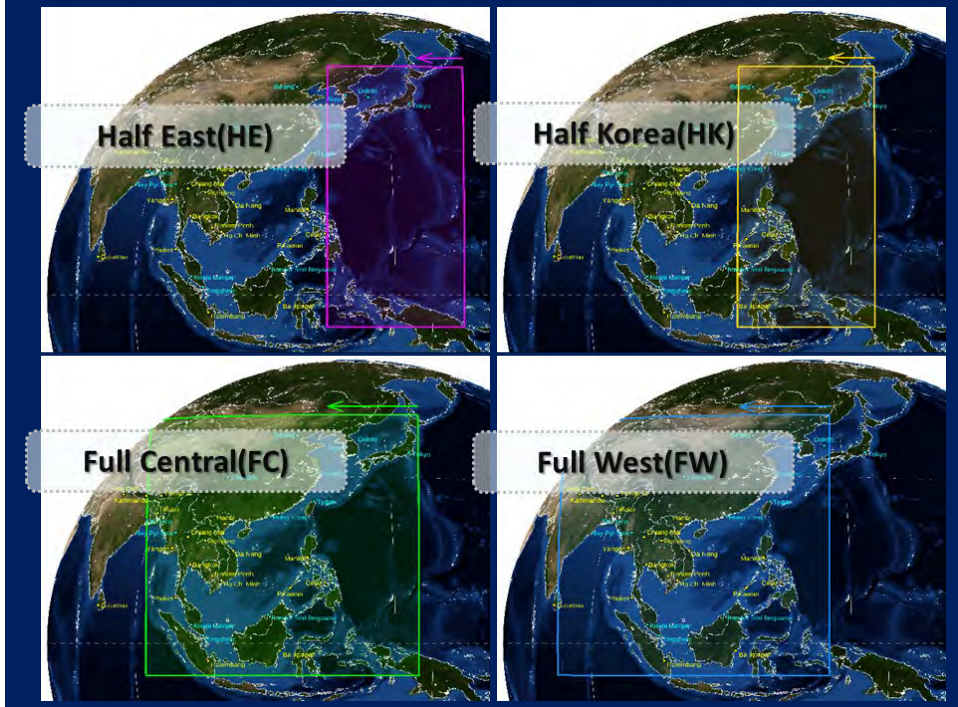
The uncertainties are quantified by validation with independent datasets or estimated during retrievals.

GEMS E-W scan scenario



2048 N-S x 695 E-W x 8 times/day
= 11,386,880 spectra/day

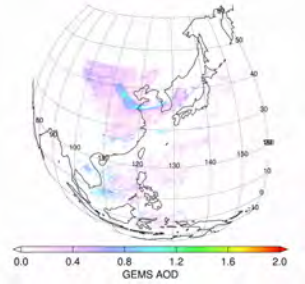
[Kim et al. (BAMS 2020)]



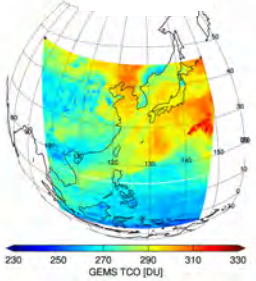
[Courtesy of NIER]

GEMS baseline products

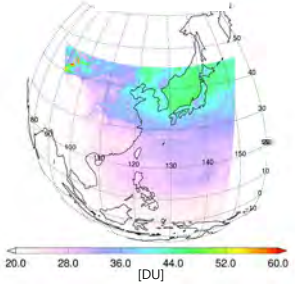
AOD at 443 nm
2020.05.12.
00:45 UTC



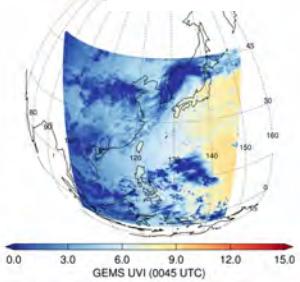
Total O_3
2020.08.06.
00:45 UTC



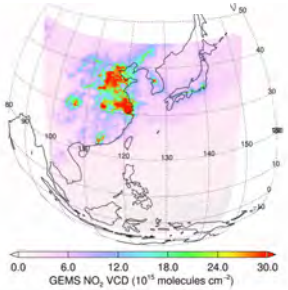
Tropospheric O_3
2020.06.16.
00:45 UTC



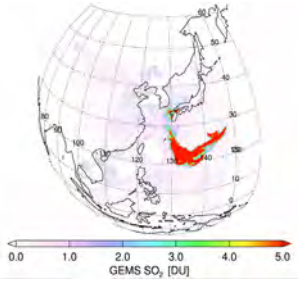
UV Index
2020.08.06.
00:45 UTC



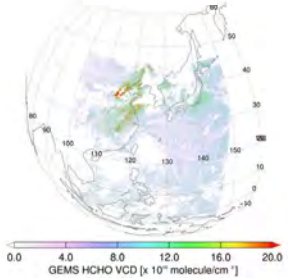
NO_2 (total VCD)
2020.06.16.
00:45 UTC



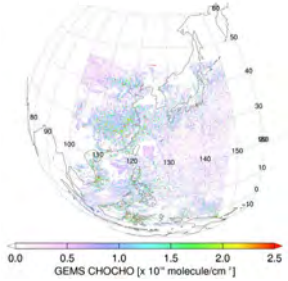
SO_2 (total VCD)
2020.08.03.
00:45 UTC



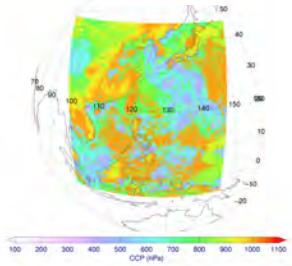
HCHO (total VCD)
2020.08.03.
00:45 UTC



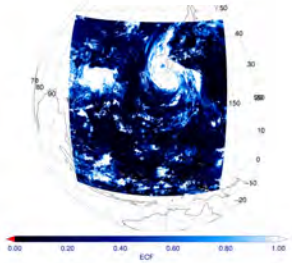
CHOCHO (total VCD)
2020.08.03.
00:45 UTC



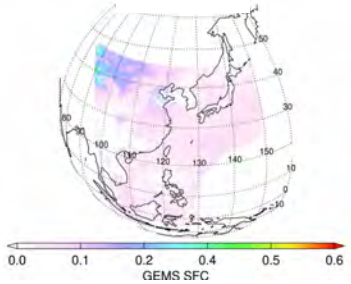
Cloud centroid pressure
2020.09.06.
00:45 UTC



Effective cloud fraction
2020.09.06.
00:45 UTC



Surface albedo at 477 nm
2020.08.02.
00:45 UTC

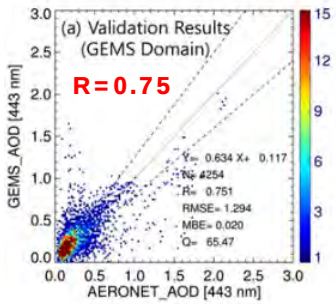


GEMS validation results

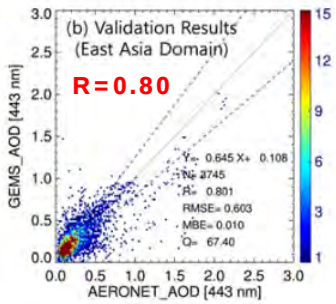
Period : August–October 2020

AOD Versus AERONET

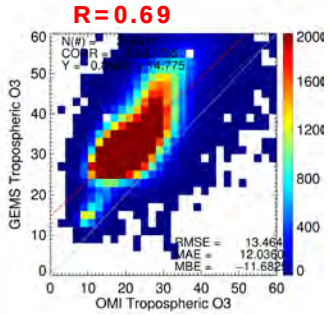
GEMS domain



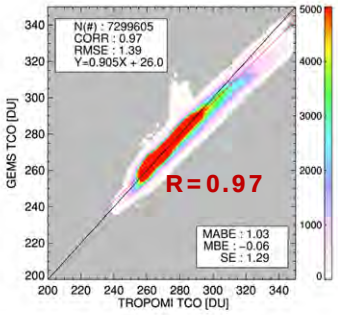
East Asia domain



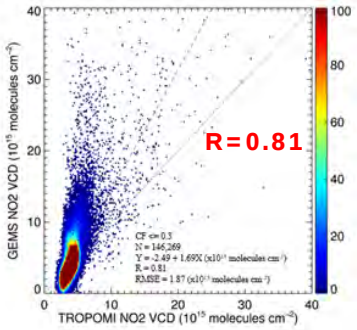
Trop. O_3 Versus OMI



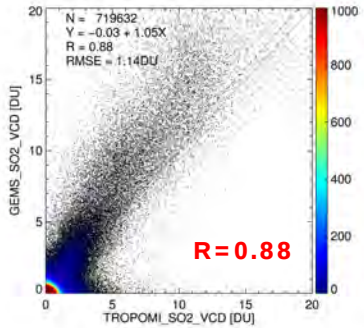
Total O_3 Versus TROPOMI



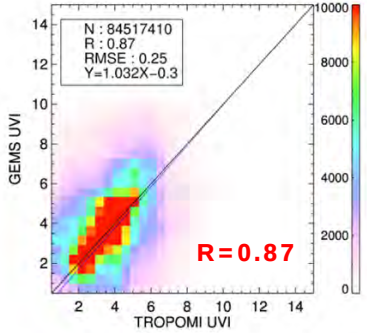
NO_2 Versus TROPOMI



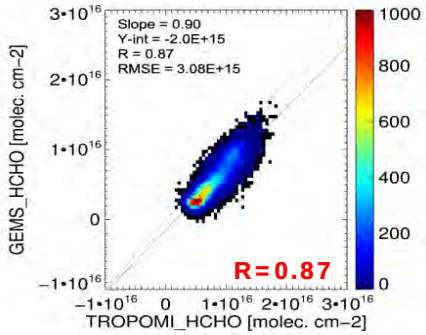
SO_2 Versus TROPOMI



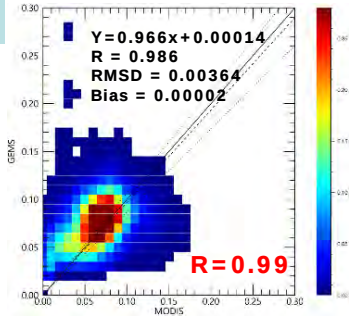
UVI Versus TROPOMI



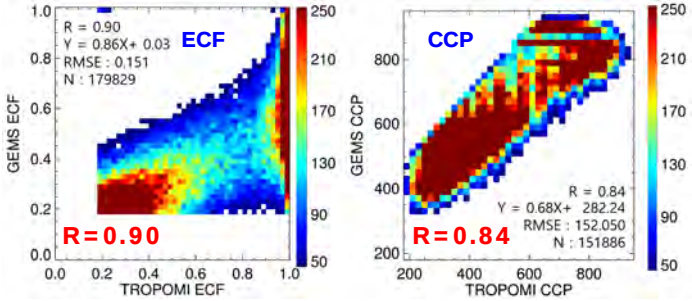
HCHO Versus TROPOMI



Surface albedo Versus MODIS



Cloud Versus TROPOMI

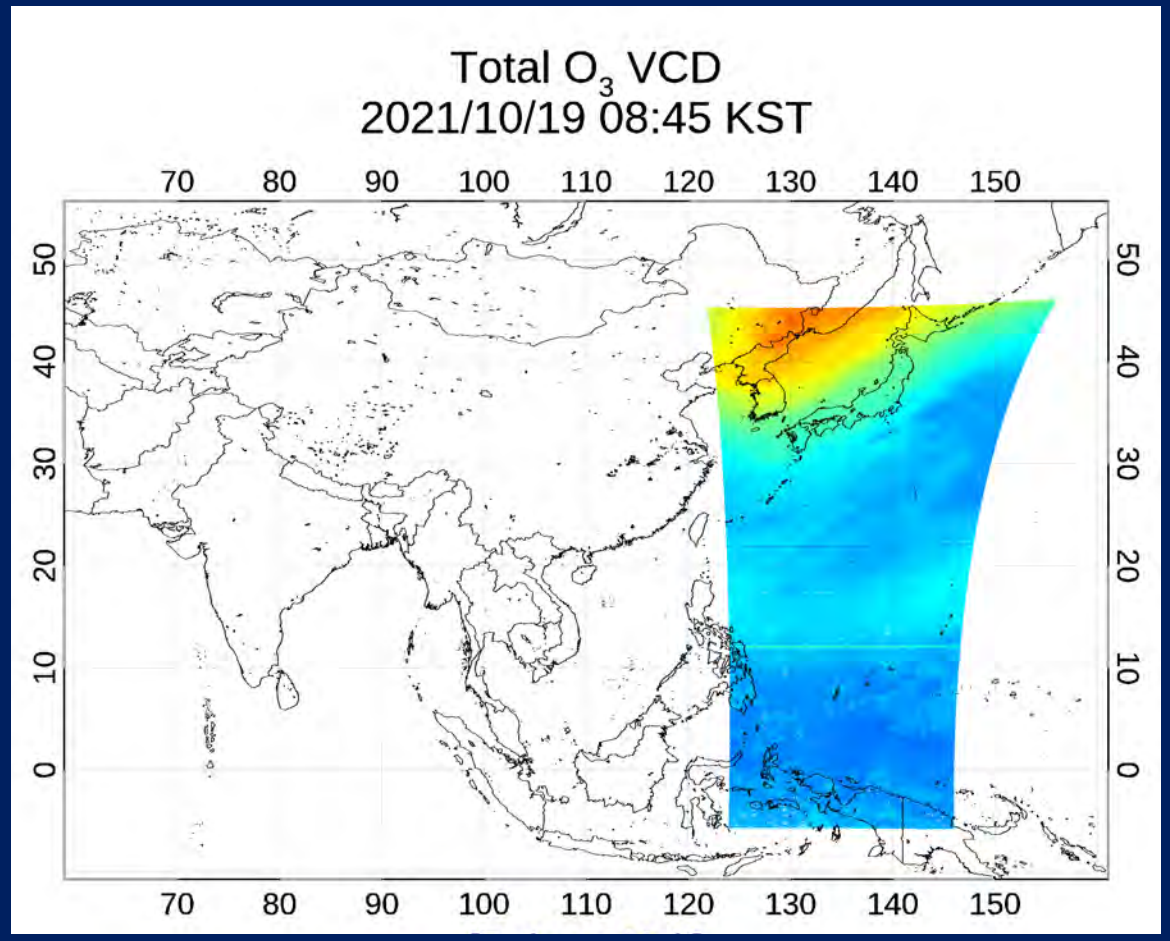


GEMS validation results

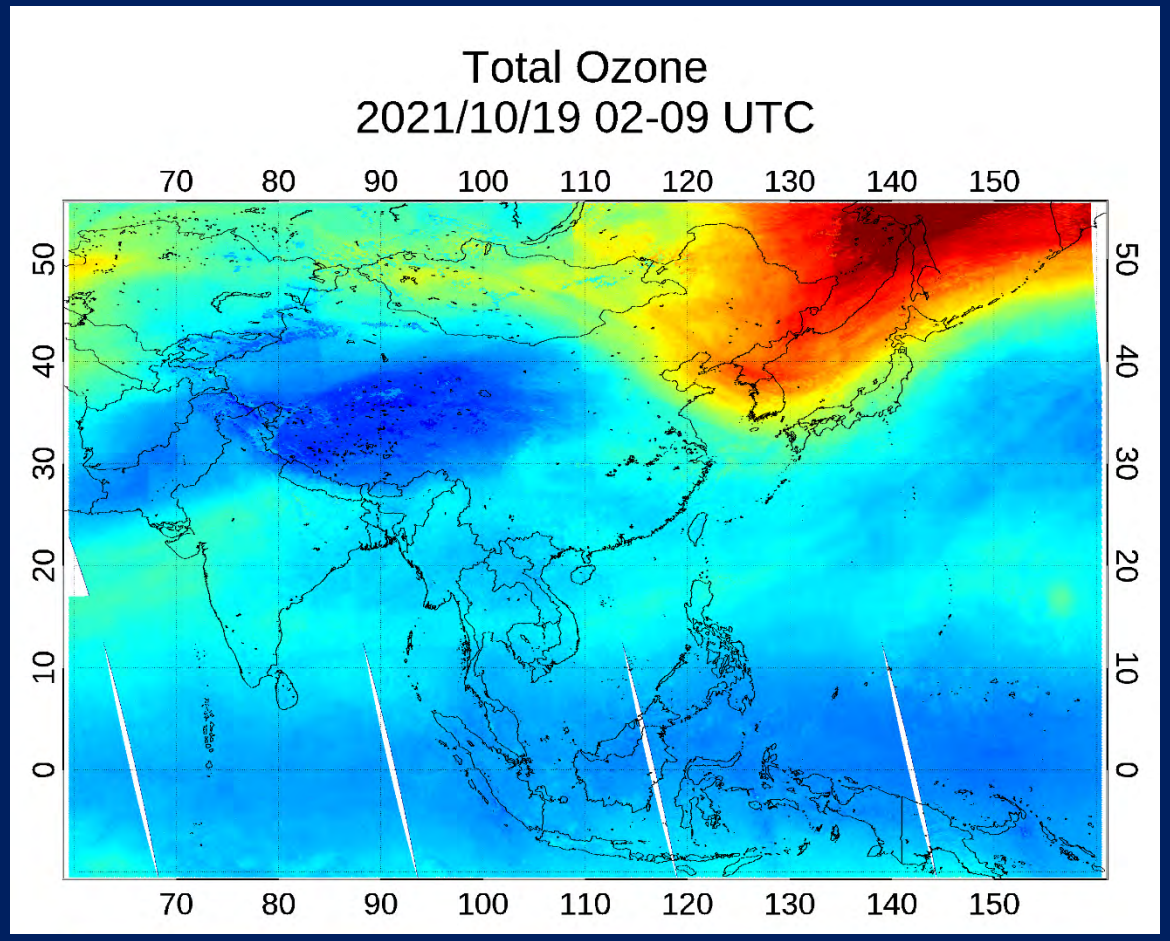
Parameter	Goal correlation (R)	Achieved correlation (R)	Slope (a)	Intercept (b)	RMSE	Reference	Region	Period
O_3 (Trop.)	0.5–0.8	0.69	0.86	14.78 DU	13.46 DU	OMI	East Asia	2020.08–2020.10
O_3 (Total)	0.82–0.97	0.89	0.94	24 DU	1.83 DU	Pandora	Busan & Ulsan	2020.08–2020.10
NO_2	0.80	0.81	1.69	-2.49×10^{15} molec. cm^{-2}	1.87×10^{15} molec.cm^{-2}	TROPOMI	GEMS domain	2020.08–2020.10
SO_2	0.70	0.88	1.05	-0.03 DU	1.14 DU	TROPOMI	GEMS domain	2020.08–2020.10
HCHO	0.81	0.87	0.90	-2.0×10^{15} molec. cm^{-2}	3.08×10^{15} molec. cm^{-2}	TROPOMI	East Asia	2020.08–2020.10
AOD	0.70	0.75	0.63	0.10	0.18	AERONET	GEMS domain	2020.08–2020.10
UVI	0.86–0.96	0.87	1.03	-0.30	0.25	TROPOMI	GEMS domain	2020.08–2020.10
ECF	0.90	0.90	0.86	0.03	0.15	TROPOMI	GEMS domain	2020.08–2020.10
CCP	0.80	0.84	0.68	282.24 hPa	152 hPa	TROPOMI	GEMS domain	2020.08–2020.10
SFC	0.70–0.91	0.99	0.97	0.0001	0.0036	MODIS	GEMS domain	2020.08–2020.10

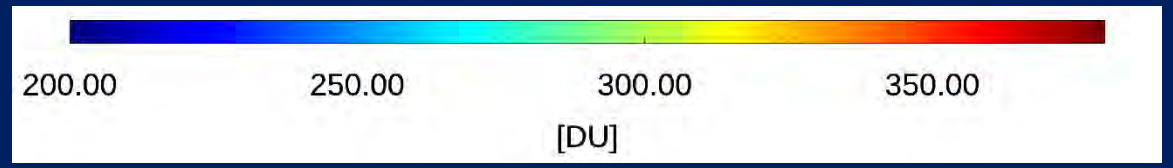
Results: O_3

GEMS



TROPOMI

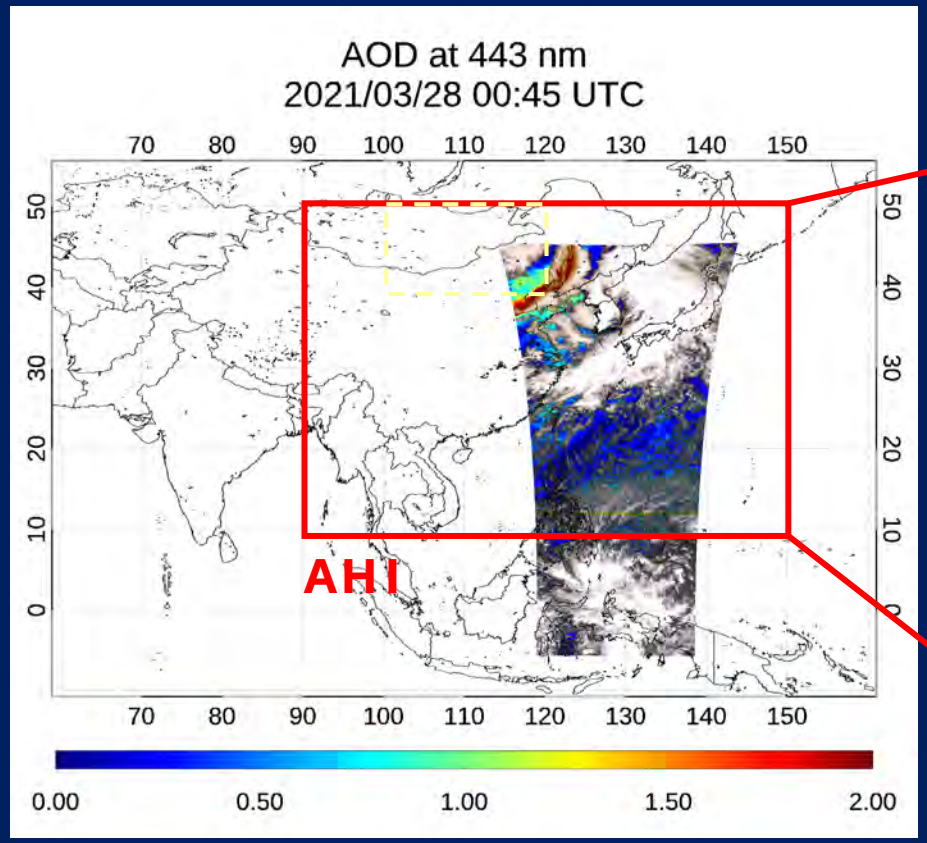




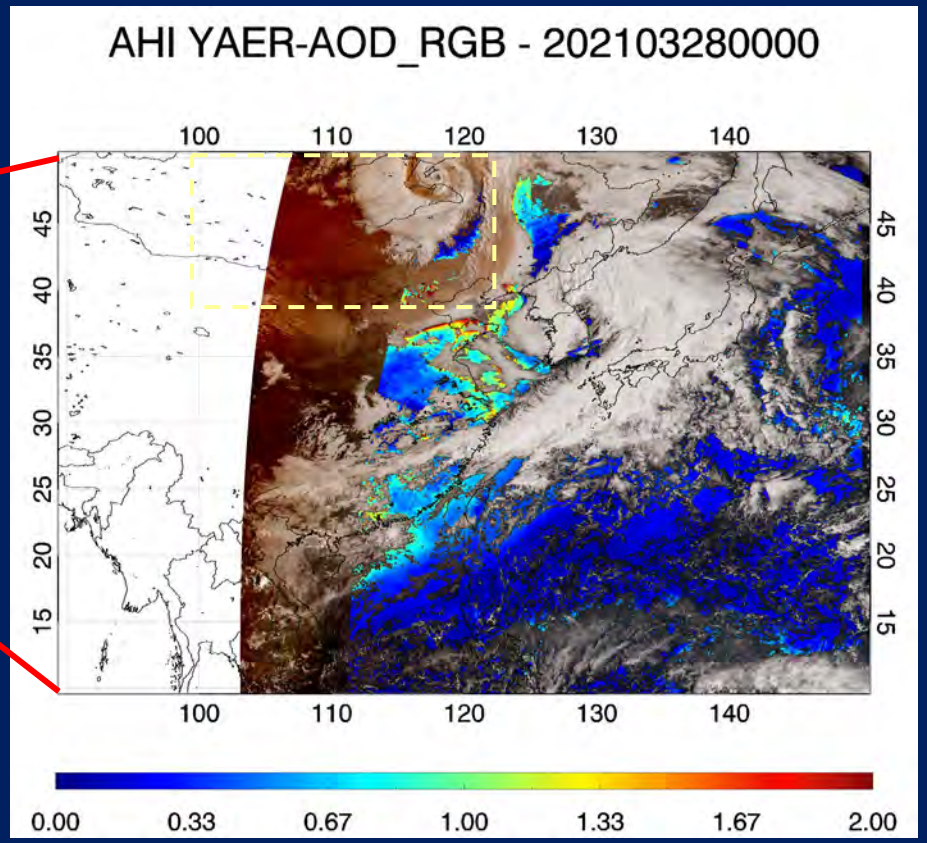
[Courtesy of Jae H. Kim (PNU)]

Results: Aerosols – Dust case

GEMS AOD at 443 nm



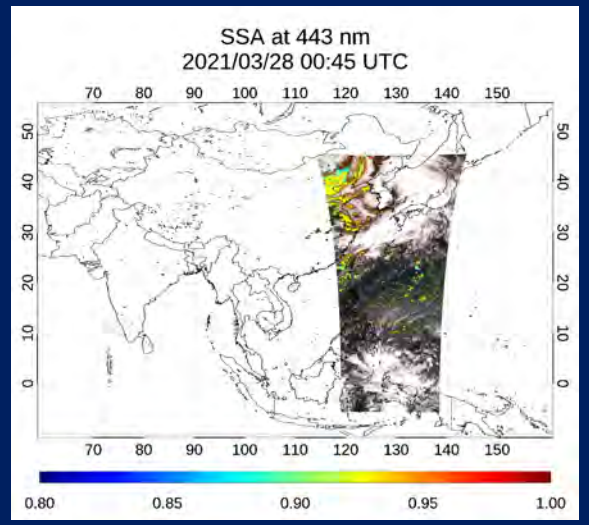
AHI AOD at 550 nm



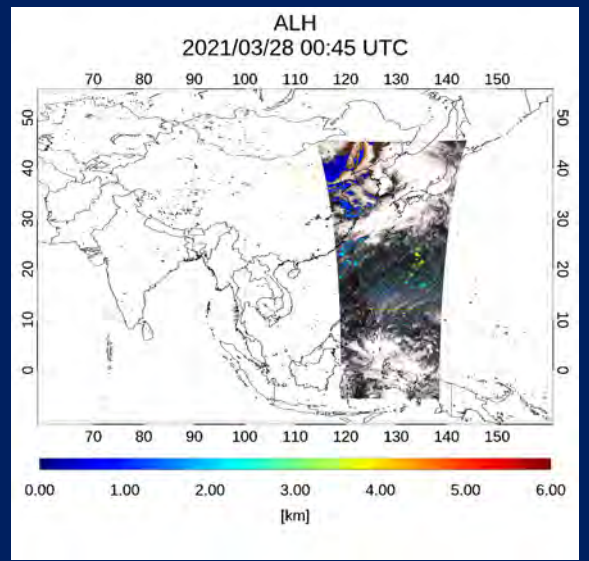
[Lim et al. (RS 2018, AMT 2021)]

(AOD>0.4)

GEMS SSA at 443 nm



GEMS ALH

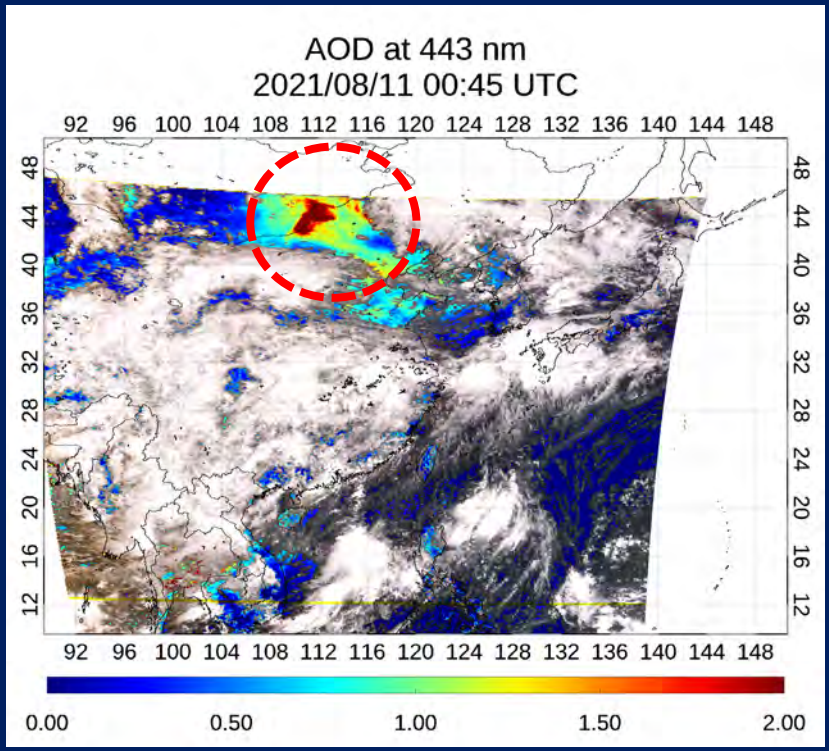


- ✓ Consistent features
- ✓ Retrieval over bright surface

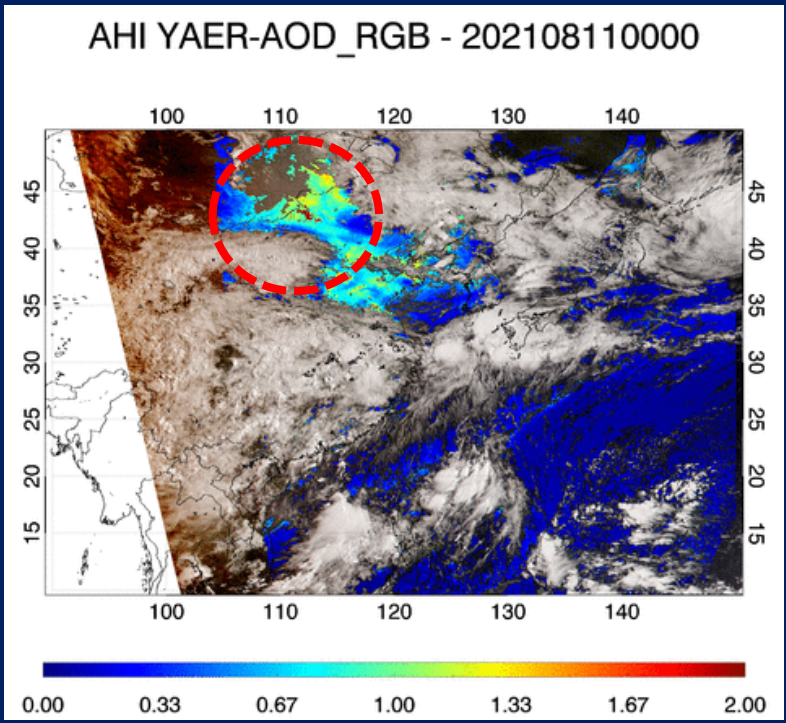
Results: Aerosols – Siberian wildfire

(ABC NEWS)

GEMS AOD at 443 nm



AHI AOD at 550 nm

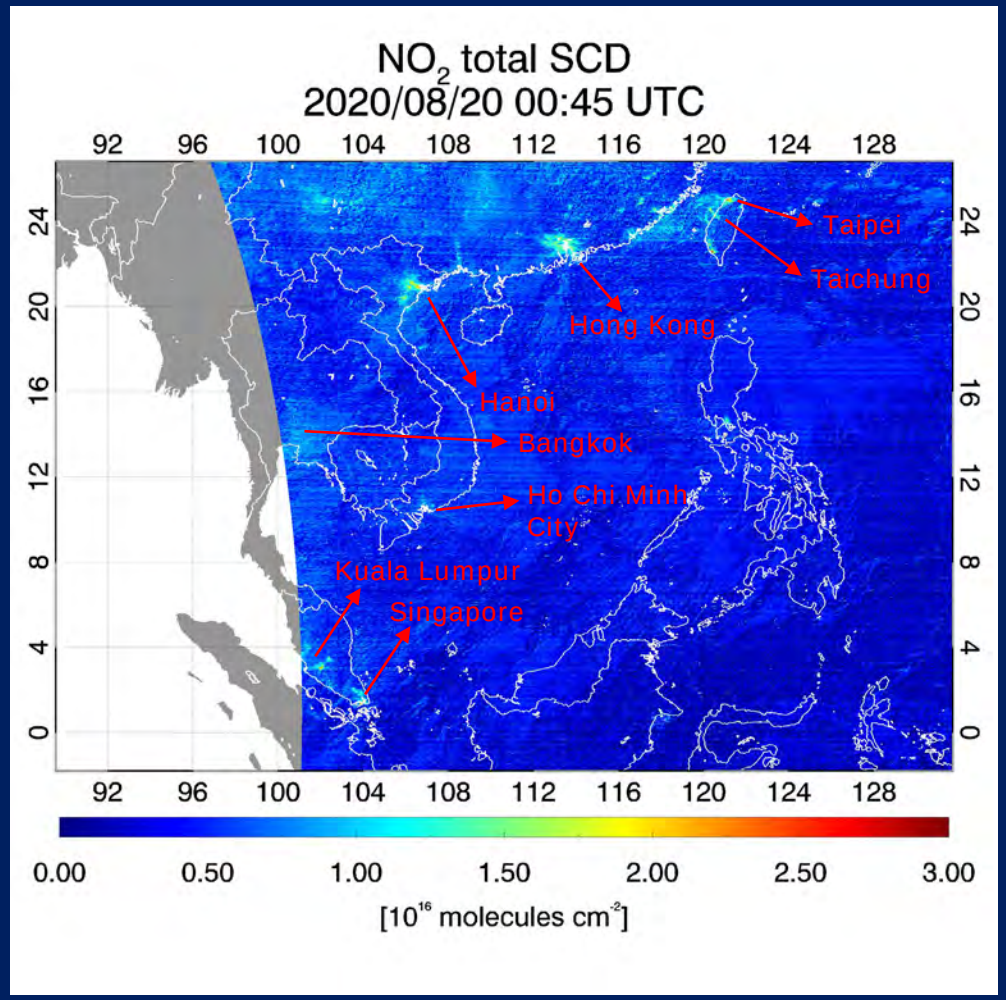


Lim et al. (RS 2018, AMT 2021)

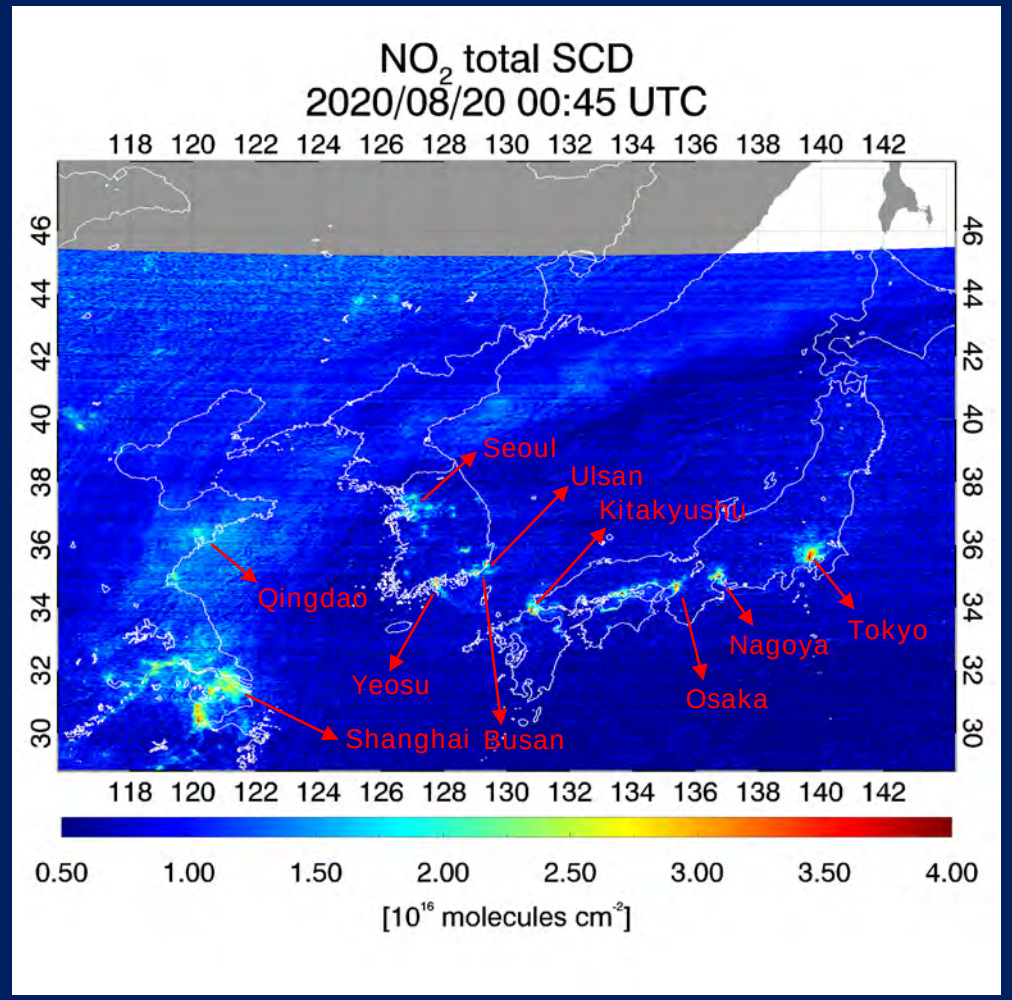
- ✓ The fires have burned ~62,000 square miles across Russia since the start of the year (ABC NEWS, 13 August 2021)
- ✓ Smoke coming from the Siberian wildfires

Results: NO_2

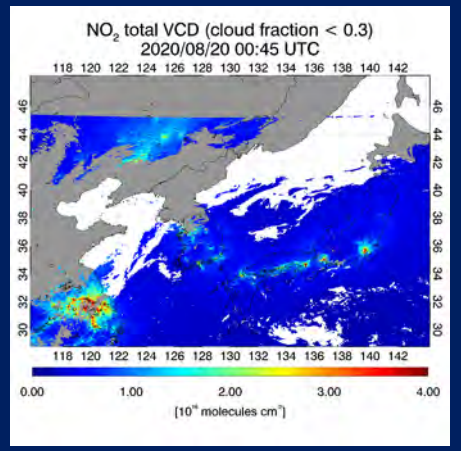
GEMS SCD



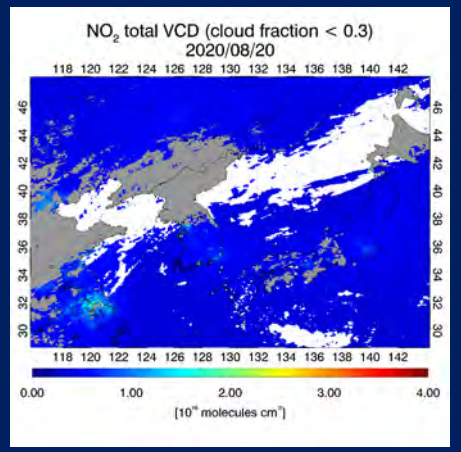
GEMS SCD



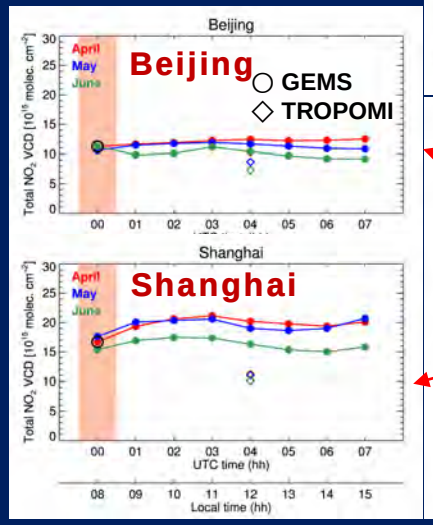
GEMS VCD



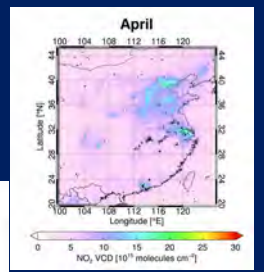
TROPOMI VCD



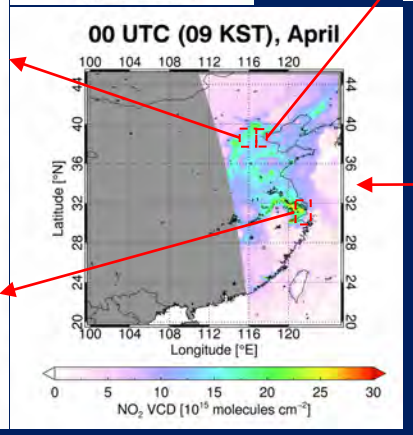
Results: Average NO_2 Period : April–June 2021

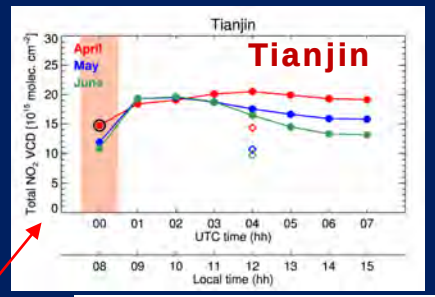


TROPOMI

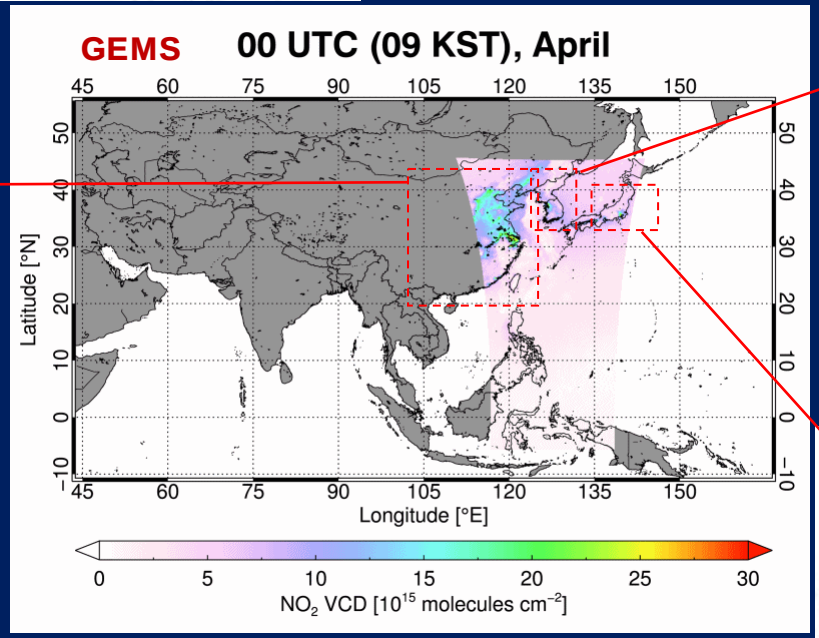


GEMS

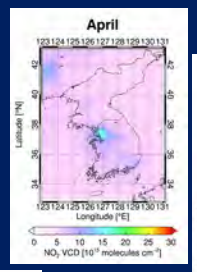




GEMS



TROPOMI



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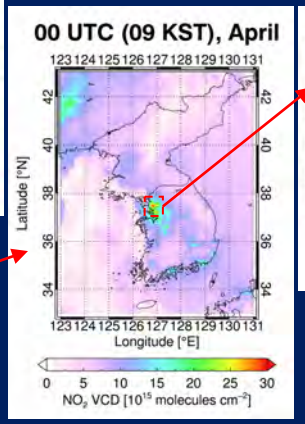

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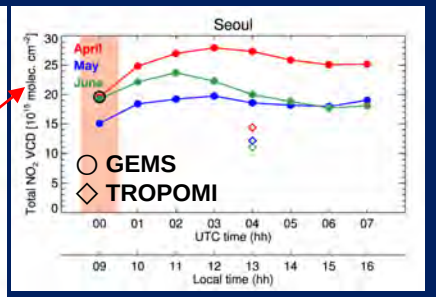
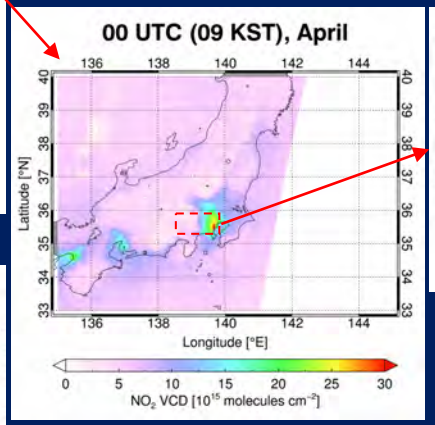
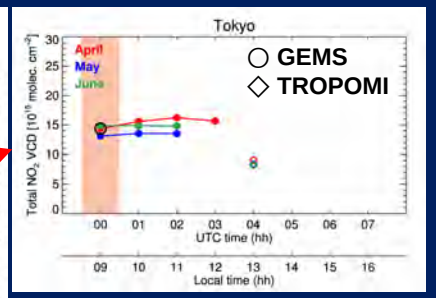


GEMS



Tokyo



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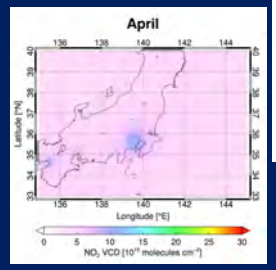
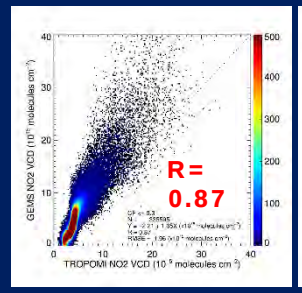
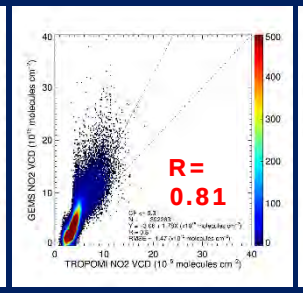


GEMS whole domain validation (total column)

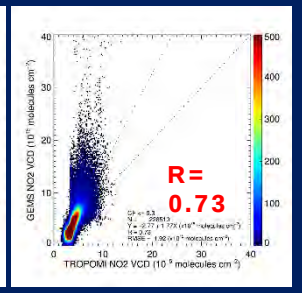
April



May



June

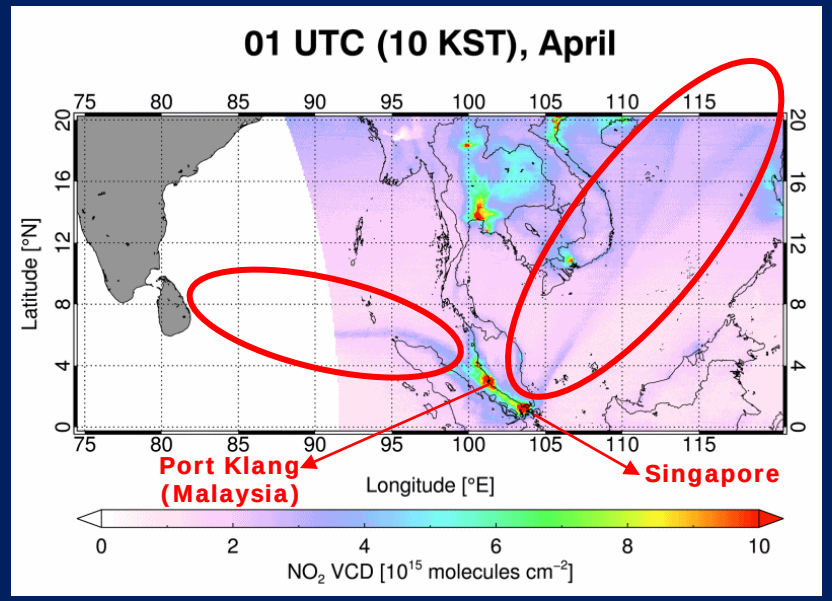


- ✓ NO_2 diurnal cycle observed from space
- ✓ GEMS NO_2 > TROPOMI NO_2 (total column)

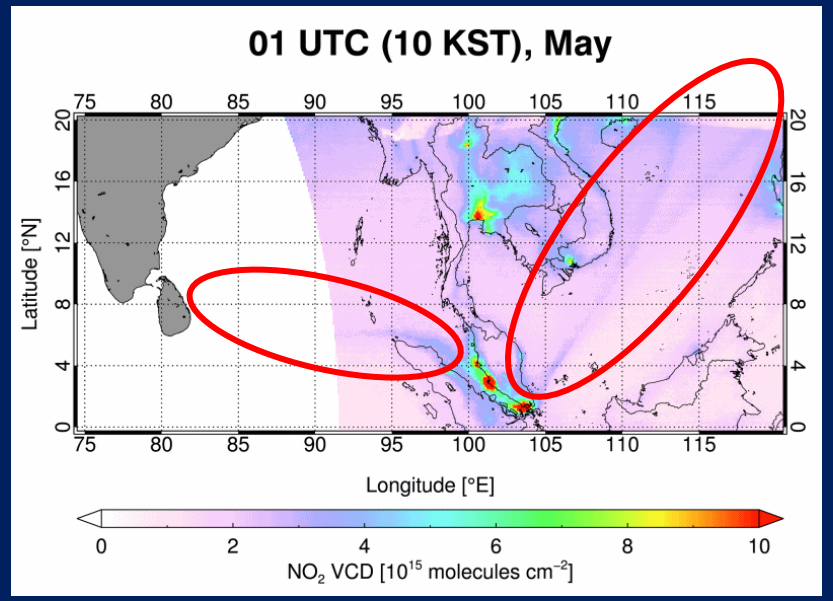
[Courtesy of Hanlim Lee (PKNU)]

Results: Average NO_2 – Ship emissions

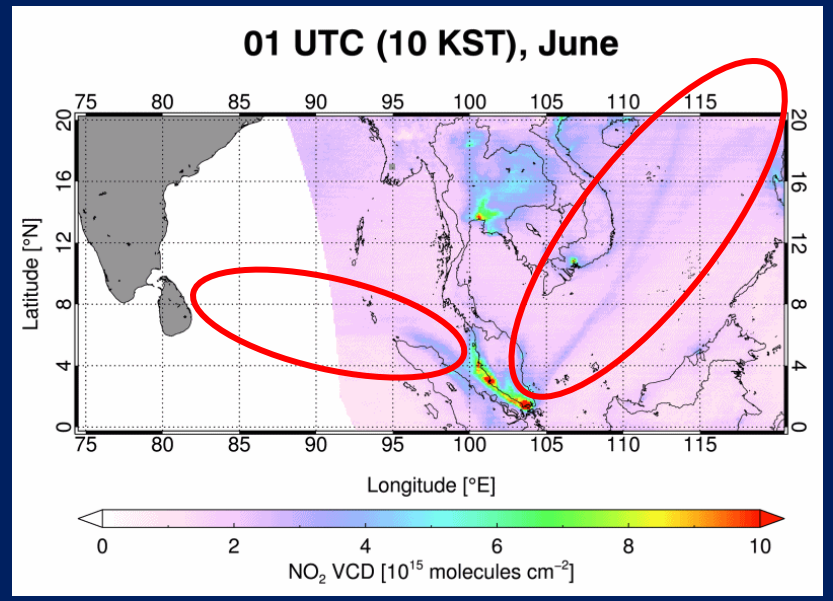
April



May



June

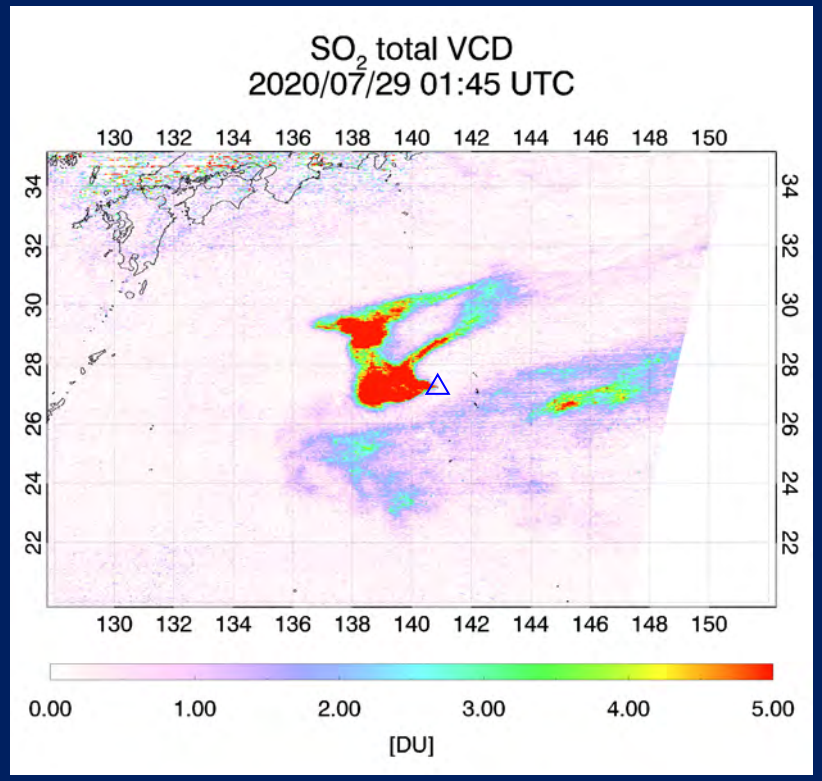


- ✓ Ship tracks from/to Singapore and Malaysia (Port Klang) are clearly detected.
- ✓ Ship-emitted NO_2 columns are typically large in the morning.

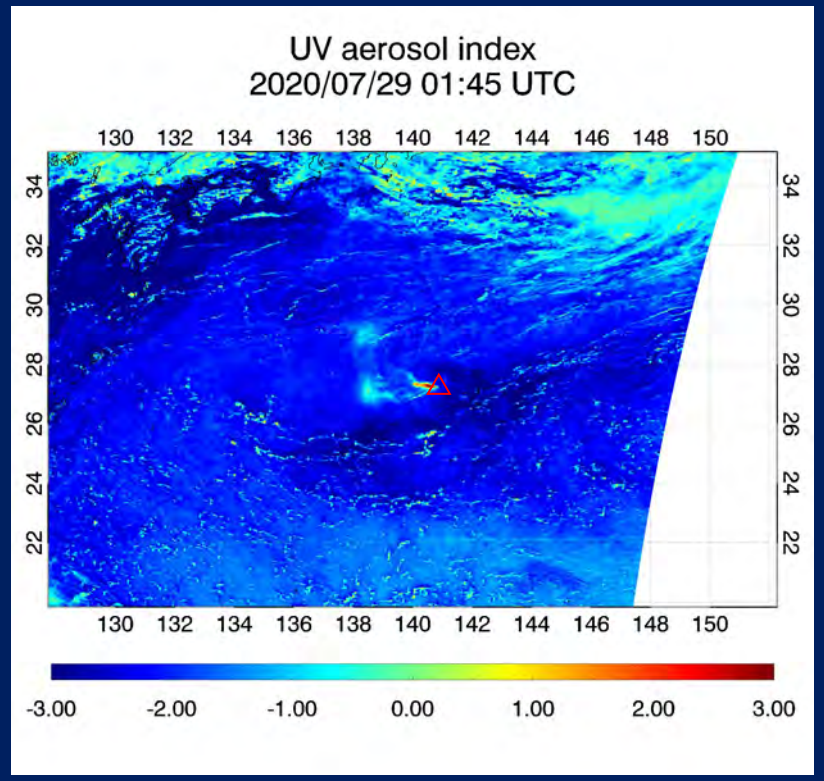
[Courtesy of Hanlim Lee (PKNU)]

Results: Volcanic SO_2 & Aerosols

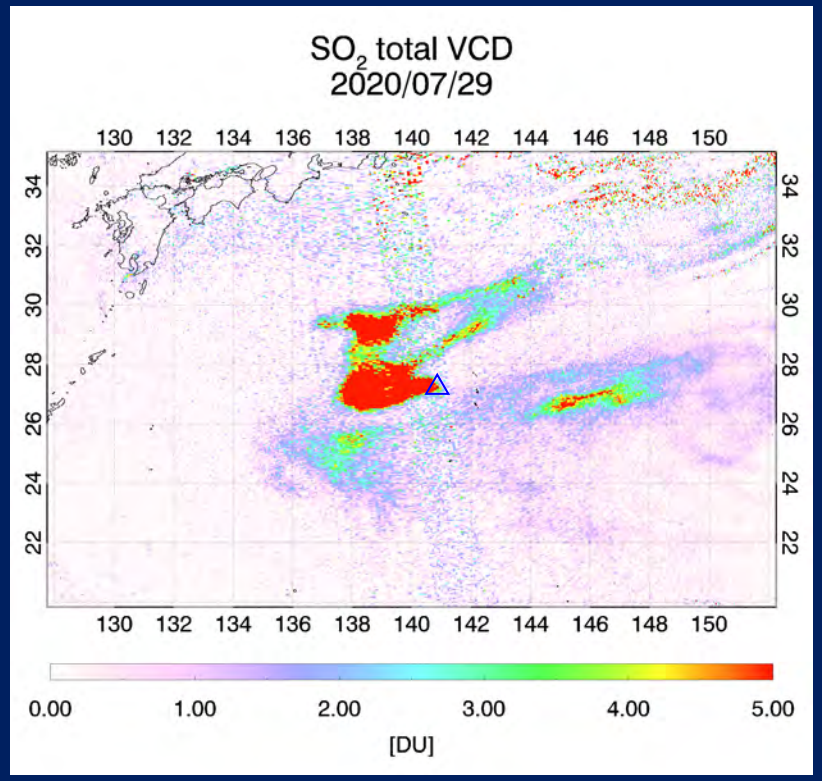
GEMS SO_2



GEMS UV aerosol index

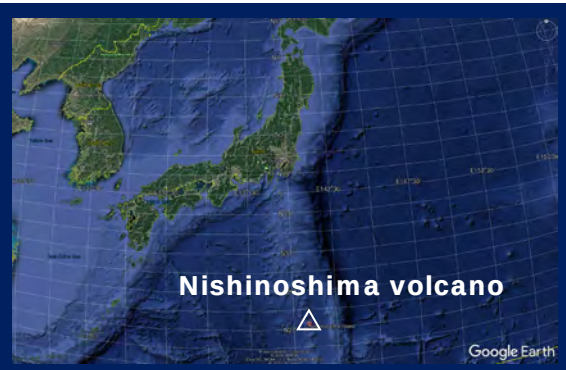


TROPOMI SO_2



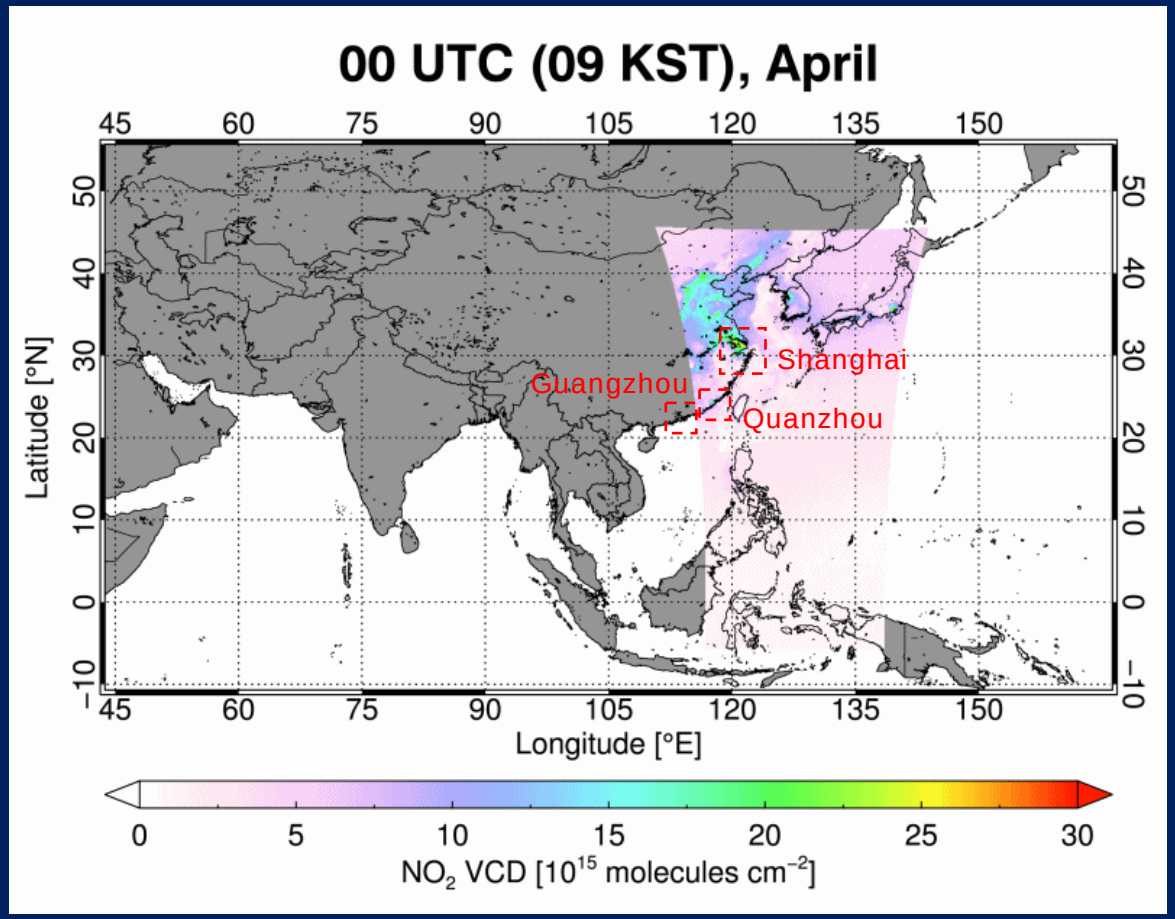
[Courtesy of Hanlim Lee (PKNU)]

Volcanic eruption at Nishinoshima Island, Japan

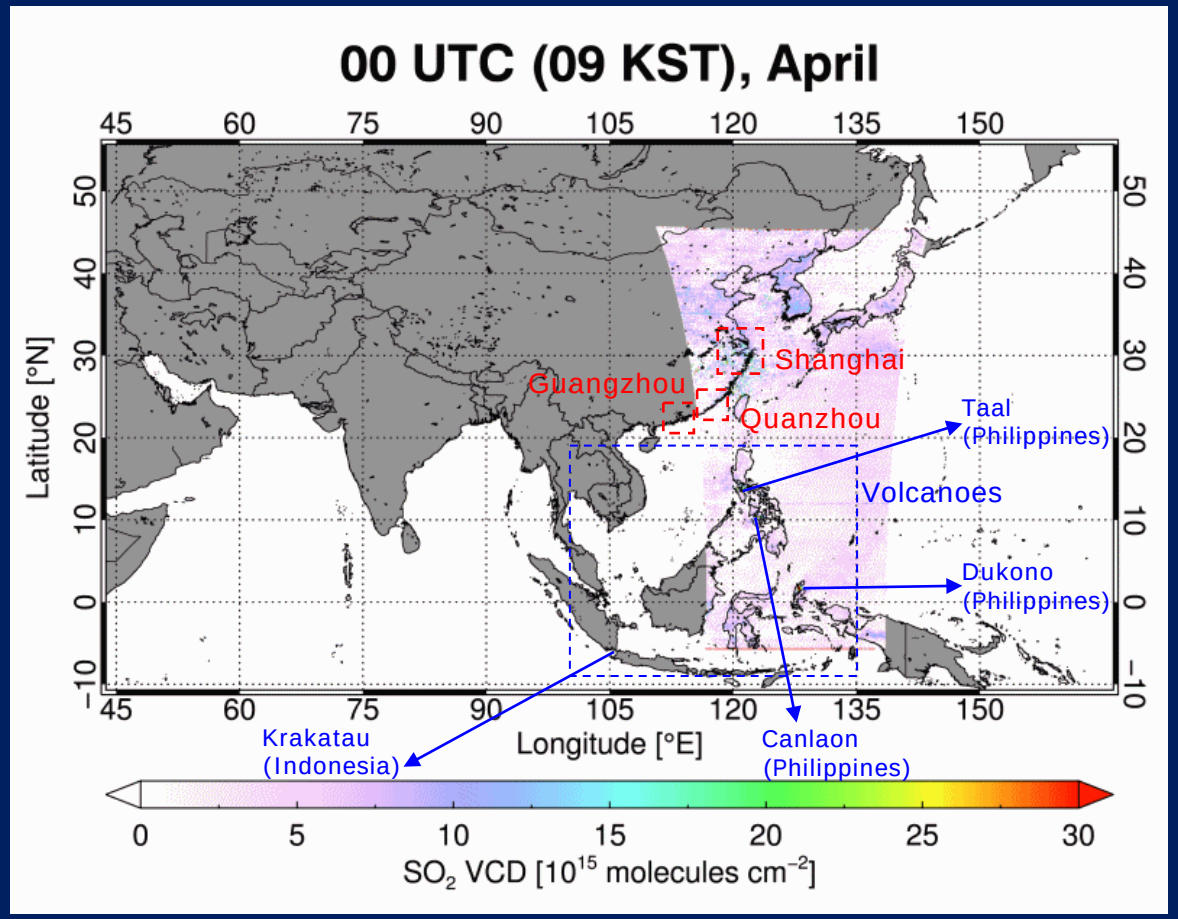


Results: Average SO_2 Period : April–June 2021

NO_2



SO_2

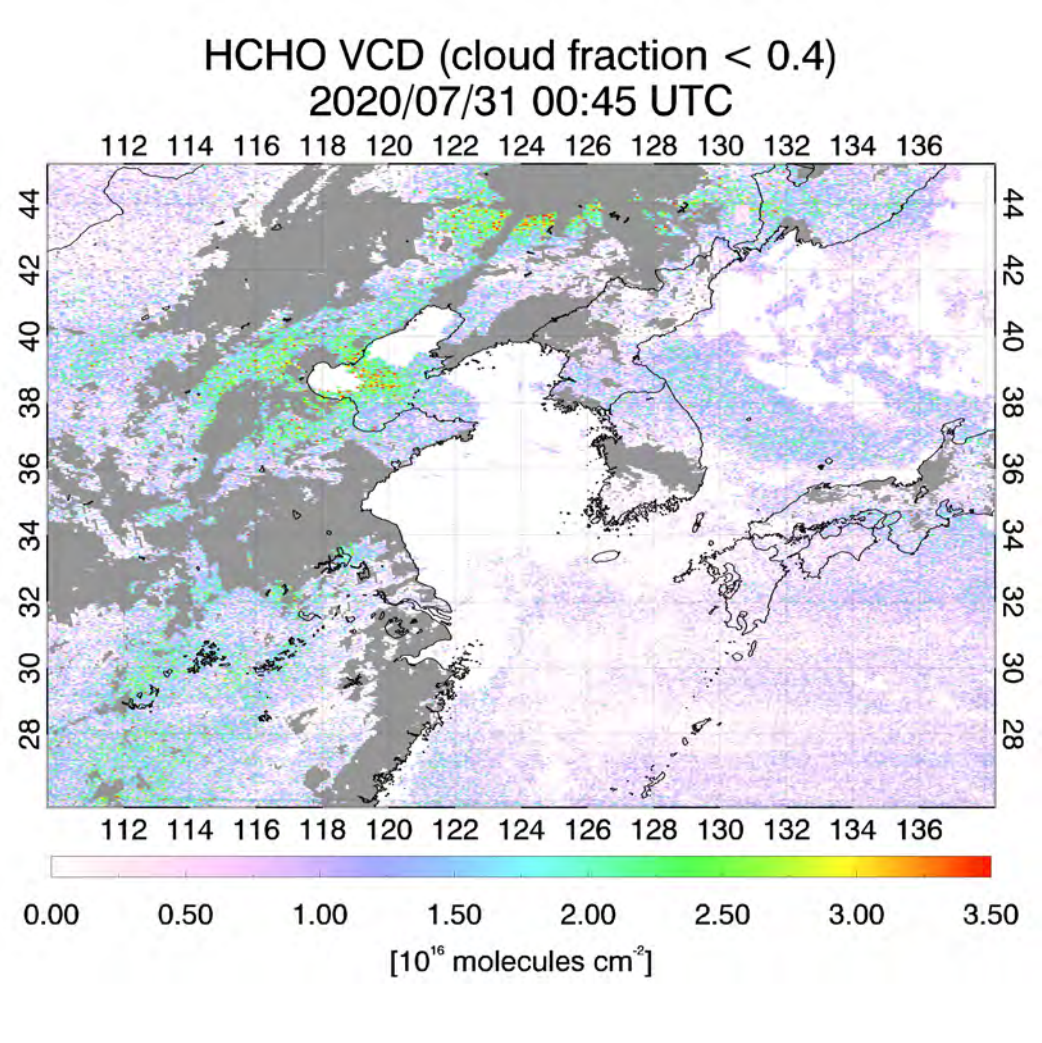


- ✓ Both volcanic and anthropogenic SO_2 sources are detected.
- ✓ GEMS retrievals demonstrate diurnal variations of simultaneous NO_2 & SO_2 emissions

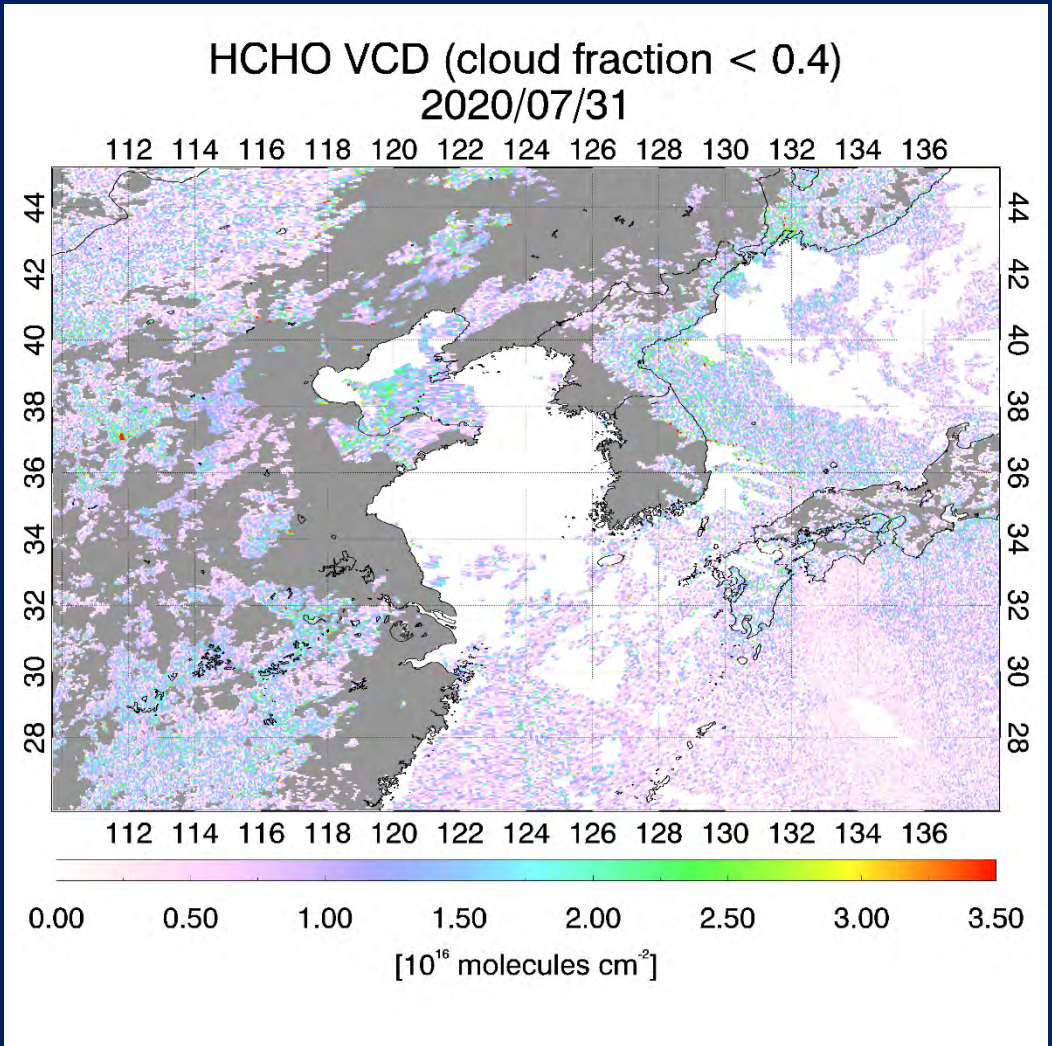
[Courtesy of Hanlim Lee (PKNU)]

Results: HCHO

GEMS HCHO



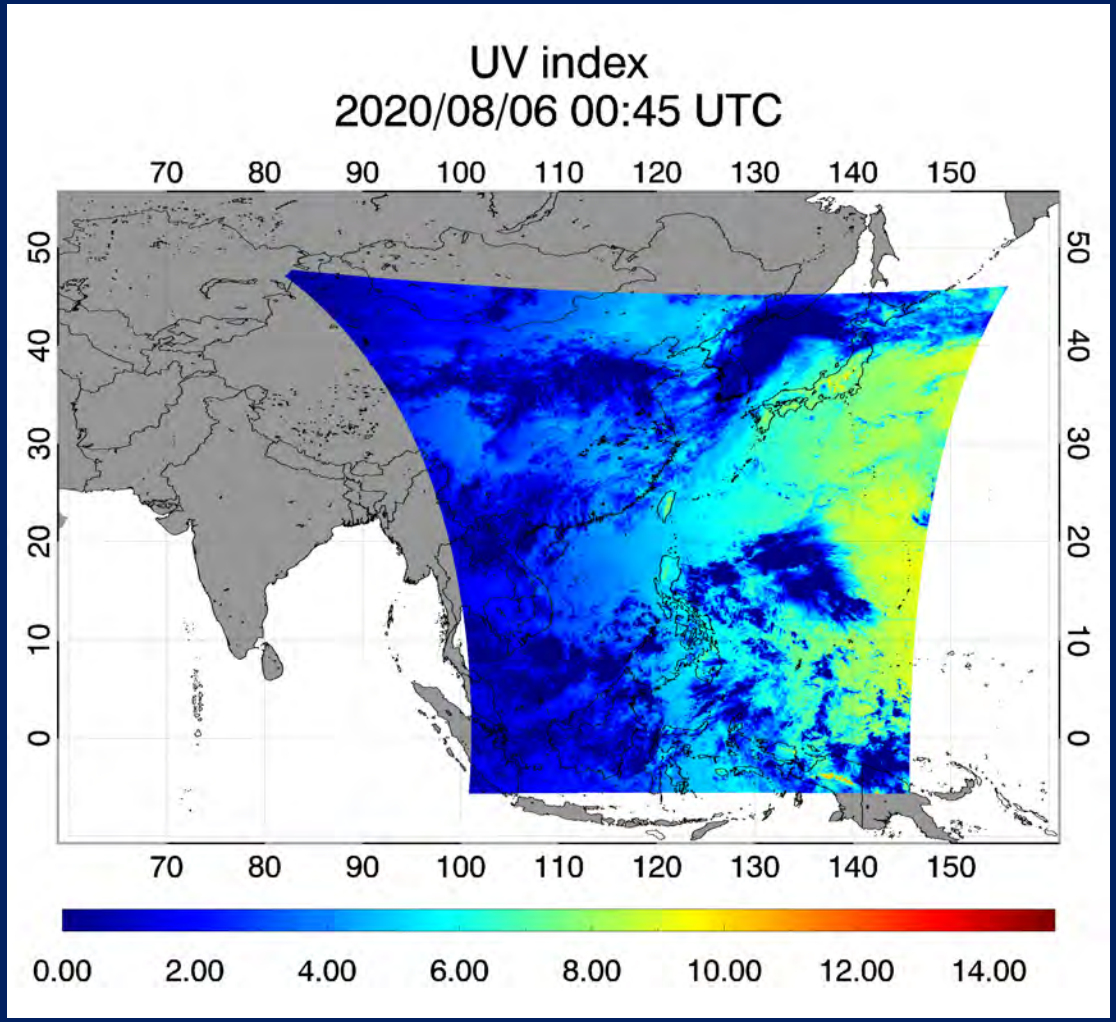
TROPOMI HCHO



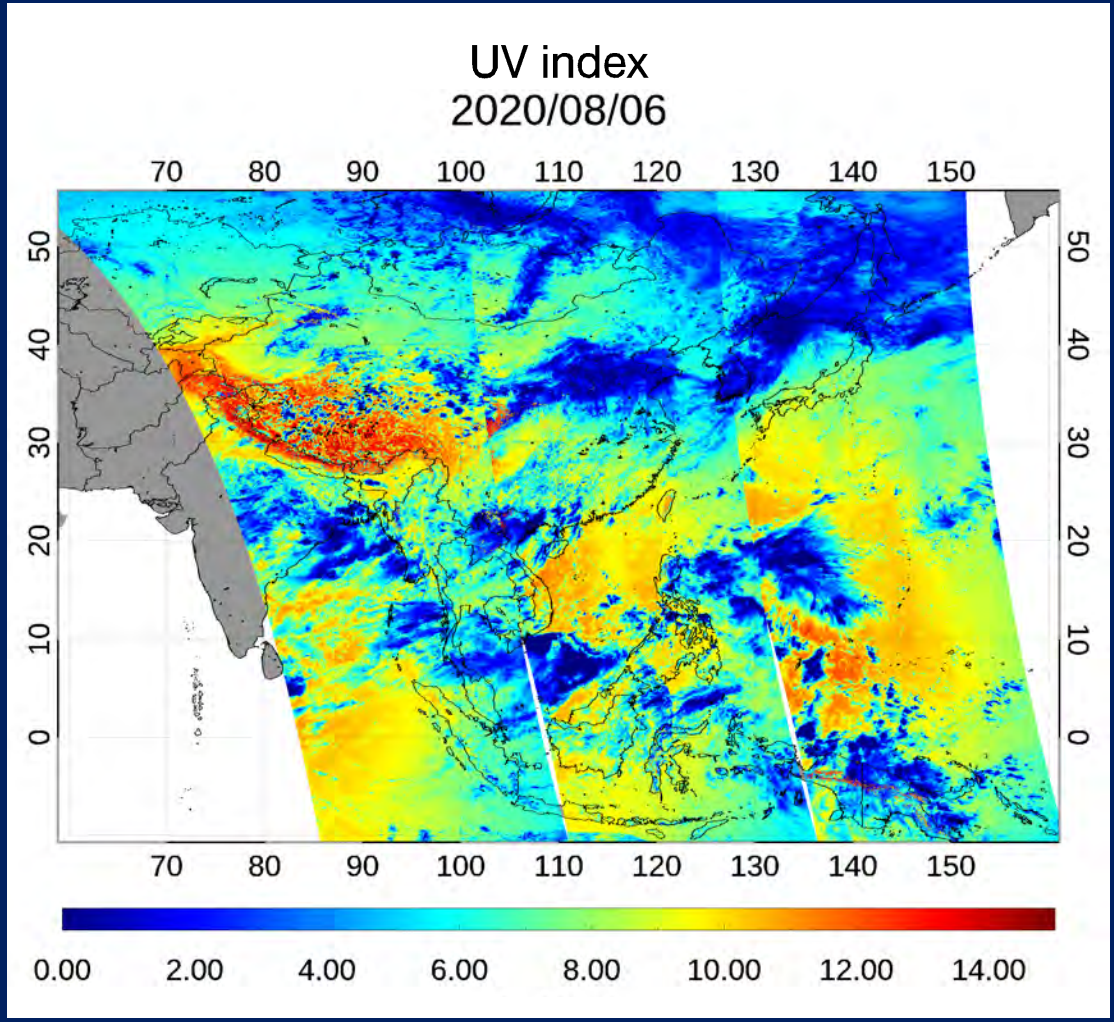
[Courtesy of Rokjin Park (SNU)]

Results: UV index

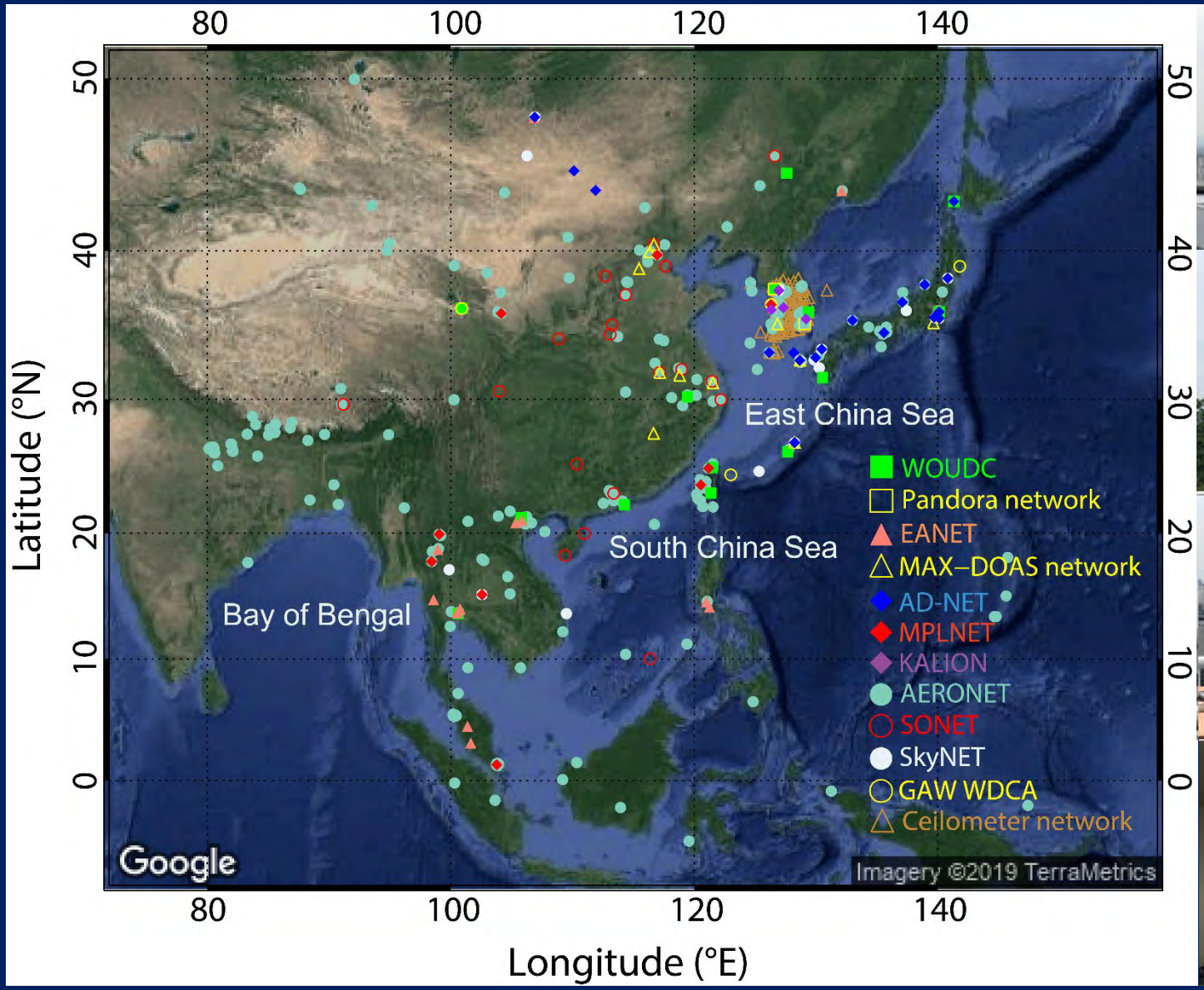
GEMS UV index

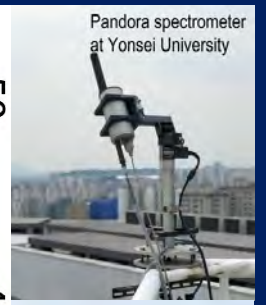


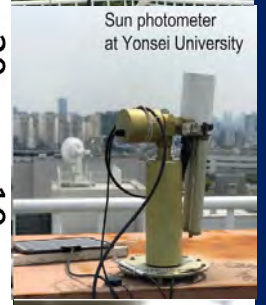
TROPOMI UV index

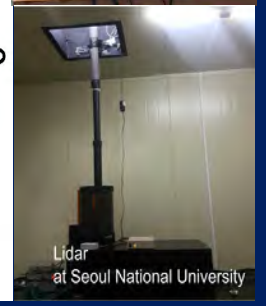


GEMS validation network





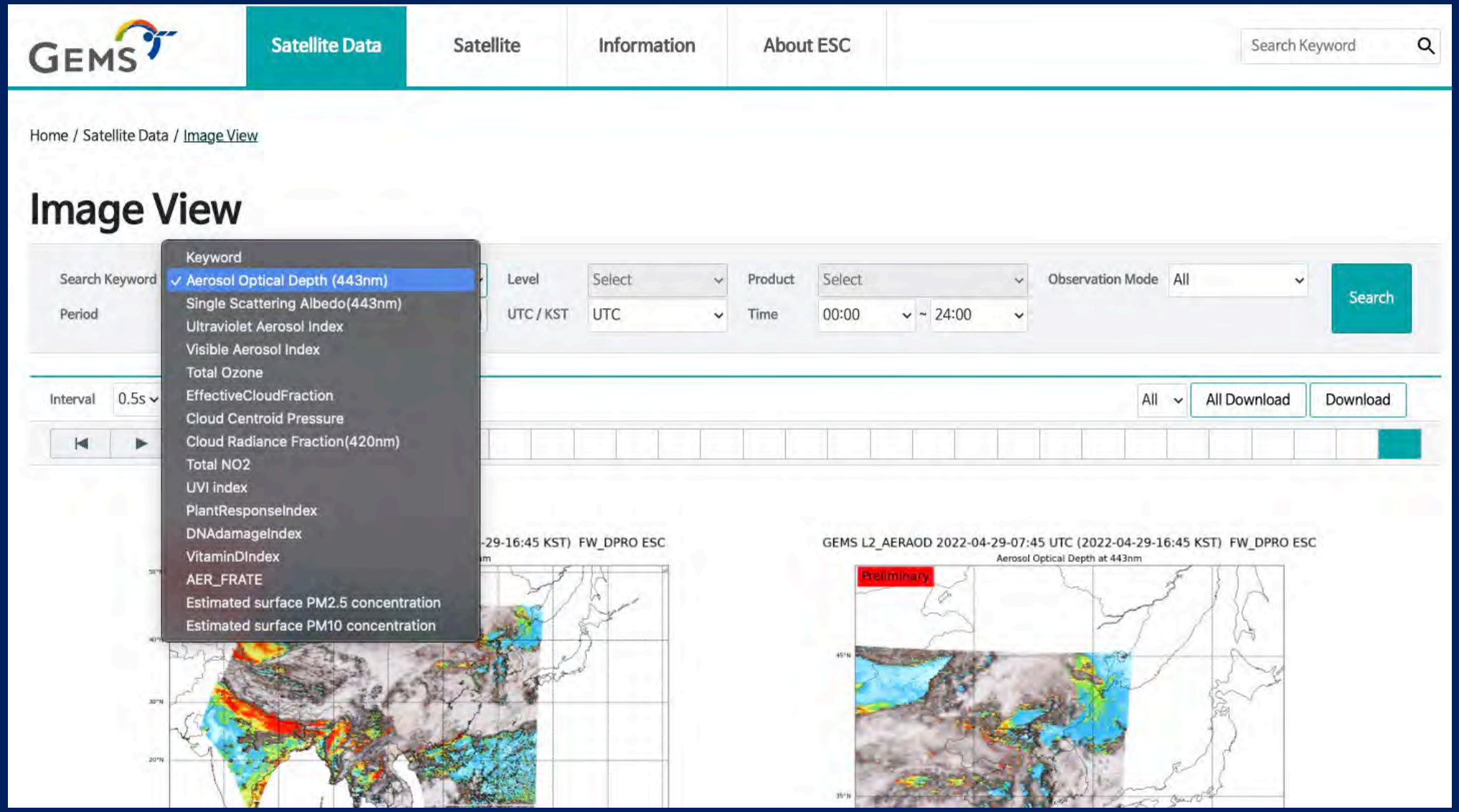




[Kim et al. (BAMS 2020)]

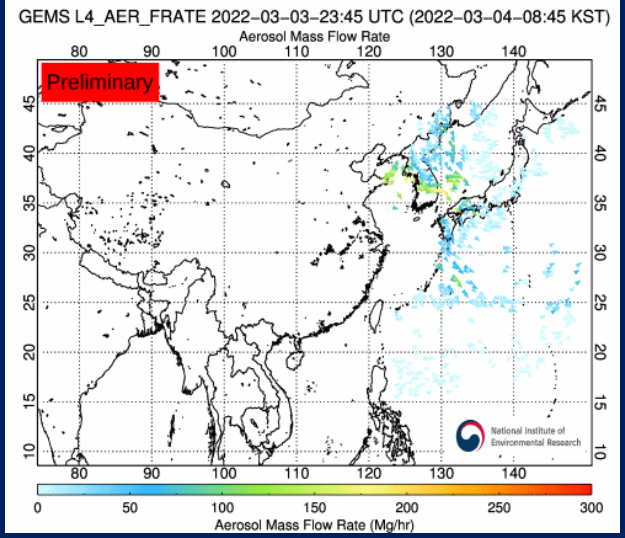
GEMS images open to the public

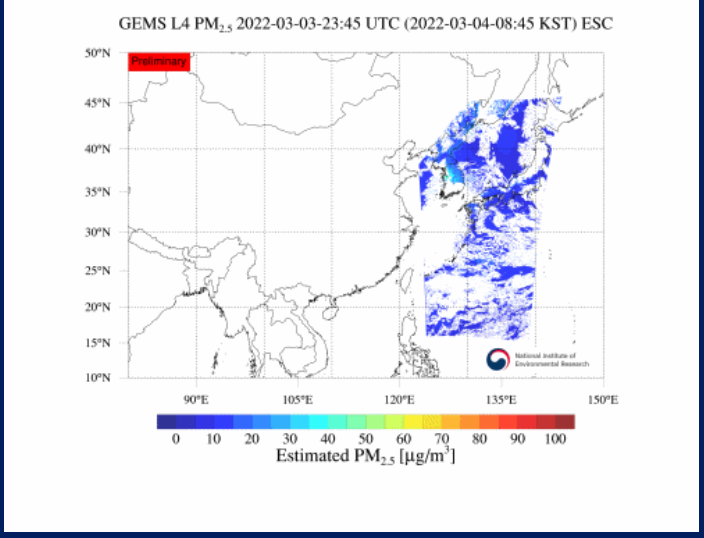
NIER website> https://nesc.nier.go.kr/product/view



Summary and implications

- Several considerations are required for satellite air quality applications, including clouds, spatial resolution, and sensitivity.
- As a part of the geostationary air quality constellation, GEMS has been successfully operating since its launch in Feb 2020, capturing diurnal variations of aerosols and trace gases (O_3, NO_2, SO_2, HCHO, and CHOCHO).
- Continuous validation of GEMS observations is essential to improve the data quality.
- High spatiotemporal coverages of GEMS will provide advantages in applications.





[NIER website (https://nesc.nier.go.kr/product/view)]

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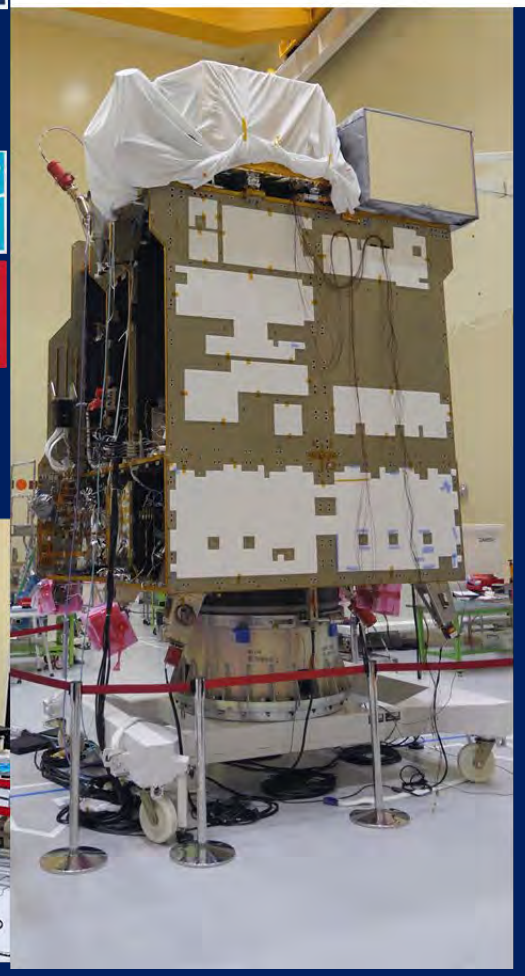

Thank you!