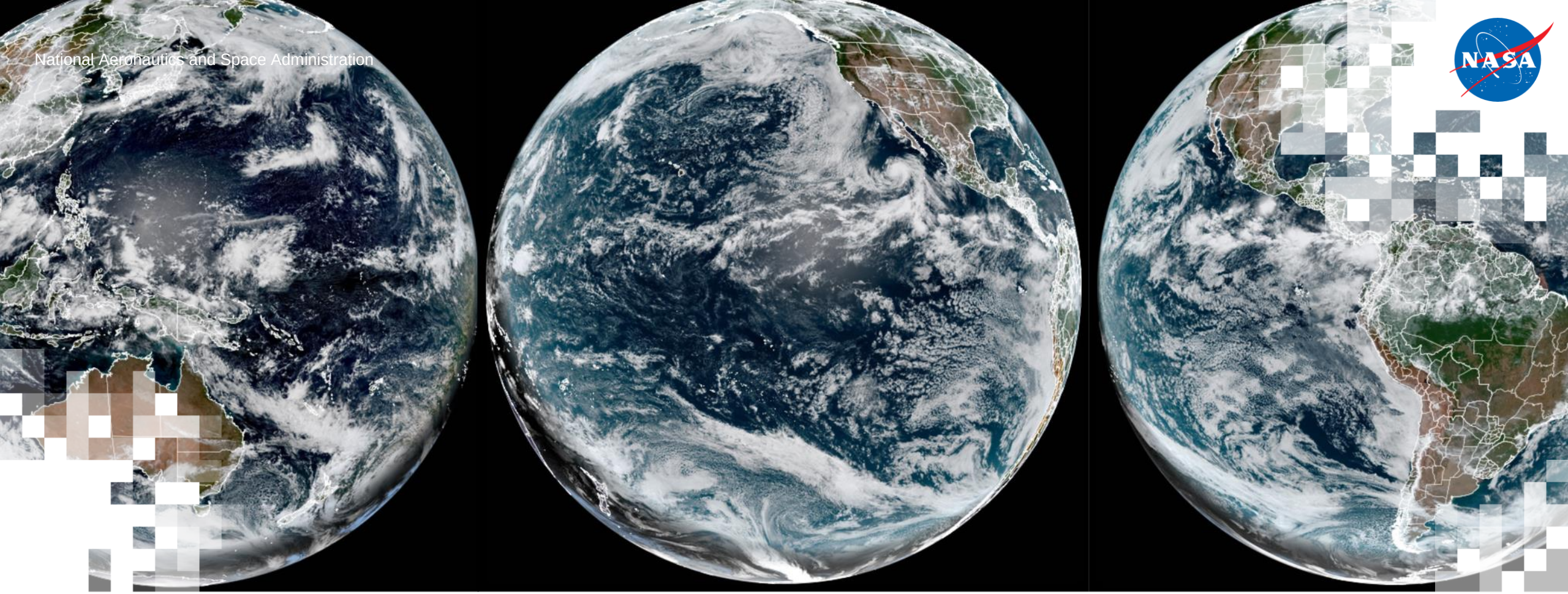


Accessing and Analyzing Air Quality Data from Geostationary Satellites

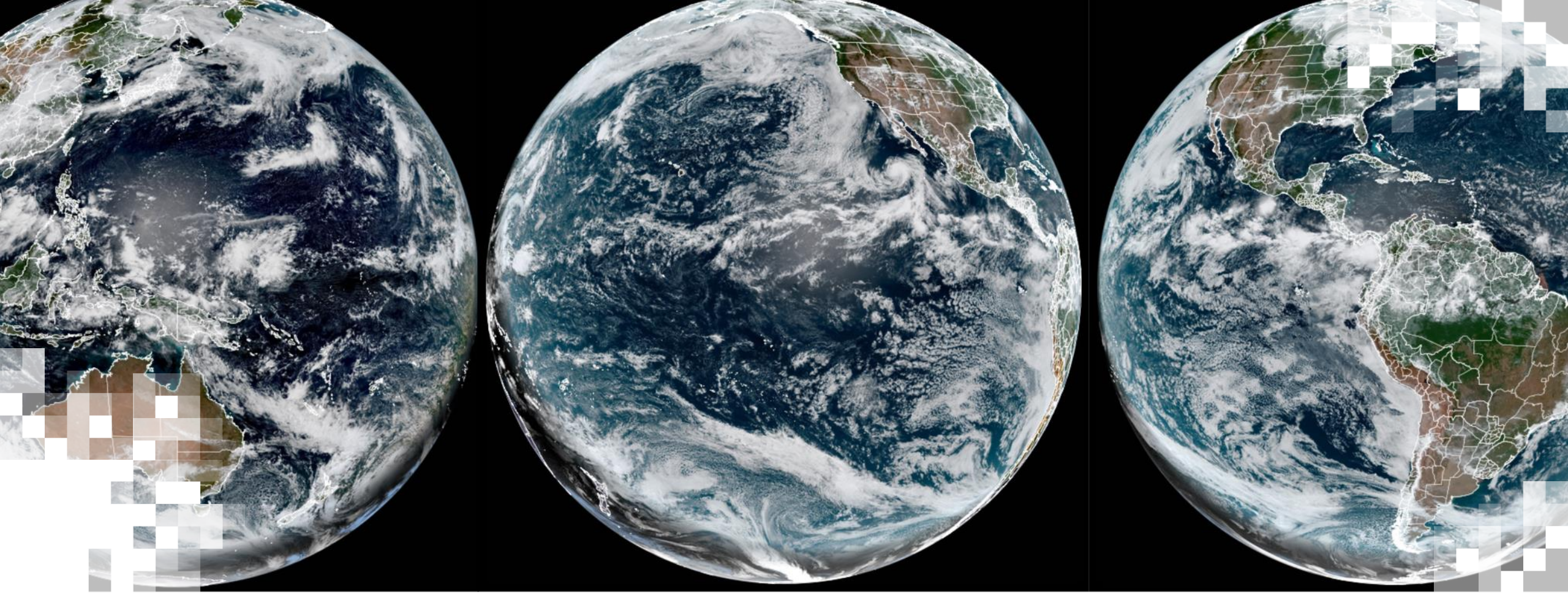
Sujung Go (UMBC/NASA GSFC; sujung.go@nasa.gov), Jhoon Kim, and the GEMS Science Team

Air Quality Products from GEMS – October 25, 2022

Learning Objectives

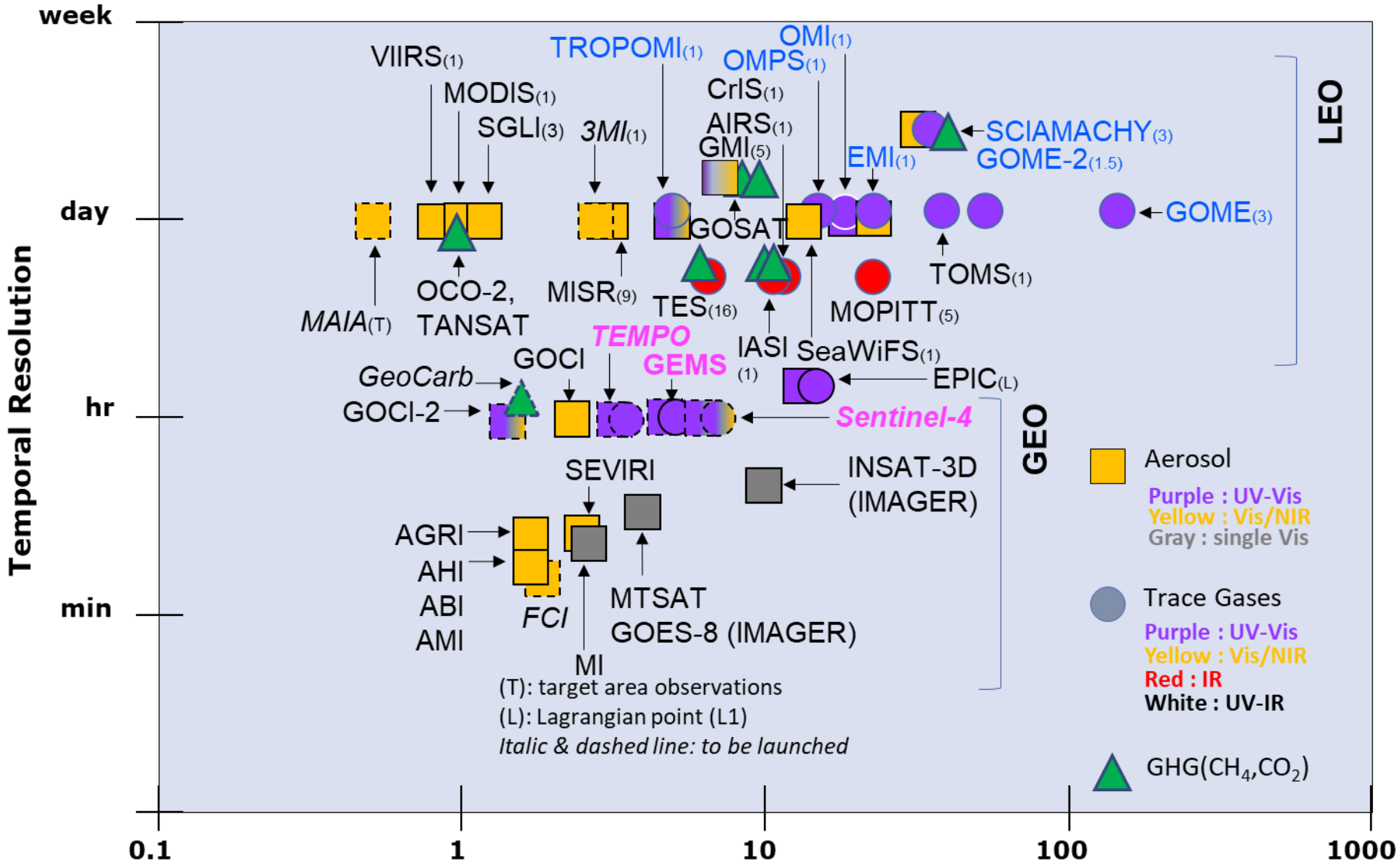
By the end of this session, participants will:

- Understand Air Quality Mission GEMS
- Understand the GEMS air quality datasets, retrieval algorithms, validation
- Locate and access GEMS air quality datasets
- Have sample python Jupyter Notebooks to read, map and extract GEMS datasets



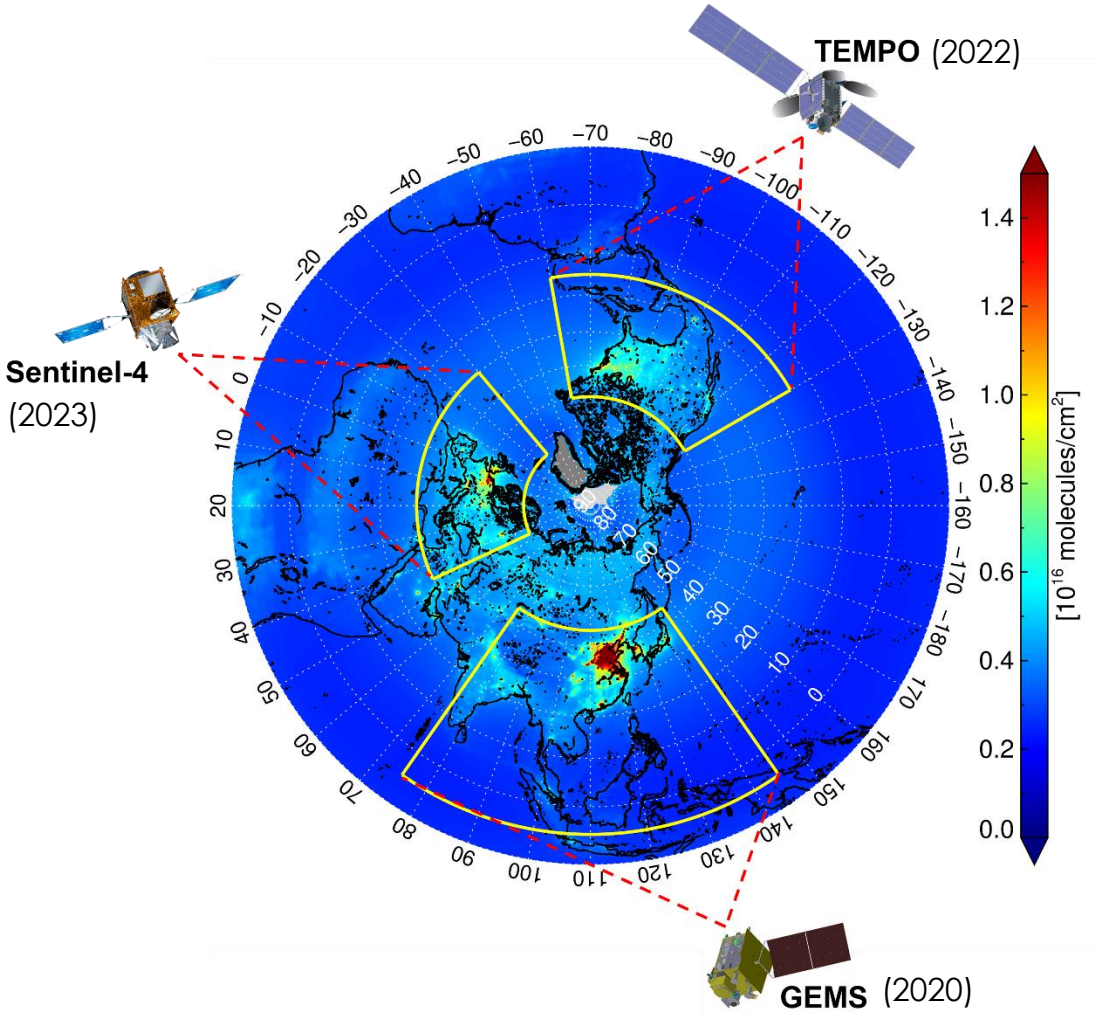
1. Introduction to the GEMS Mission

Satellite Remote Sensing for Aerosols & Gases



[Kim et al. (BAMS 2020)]

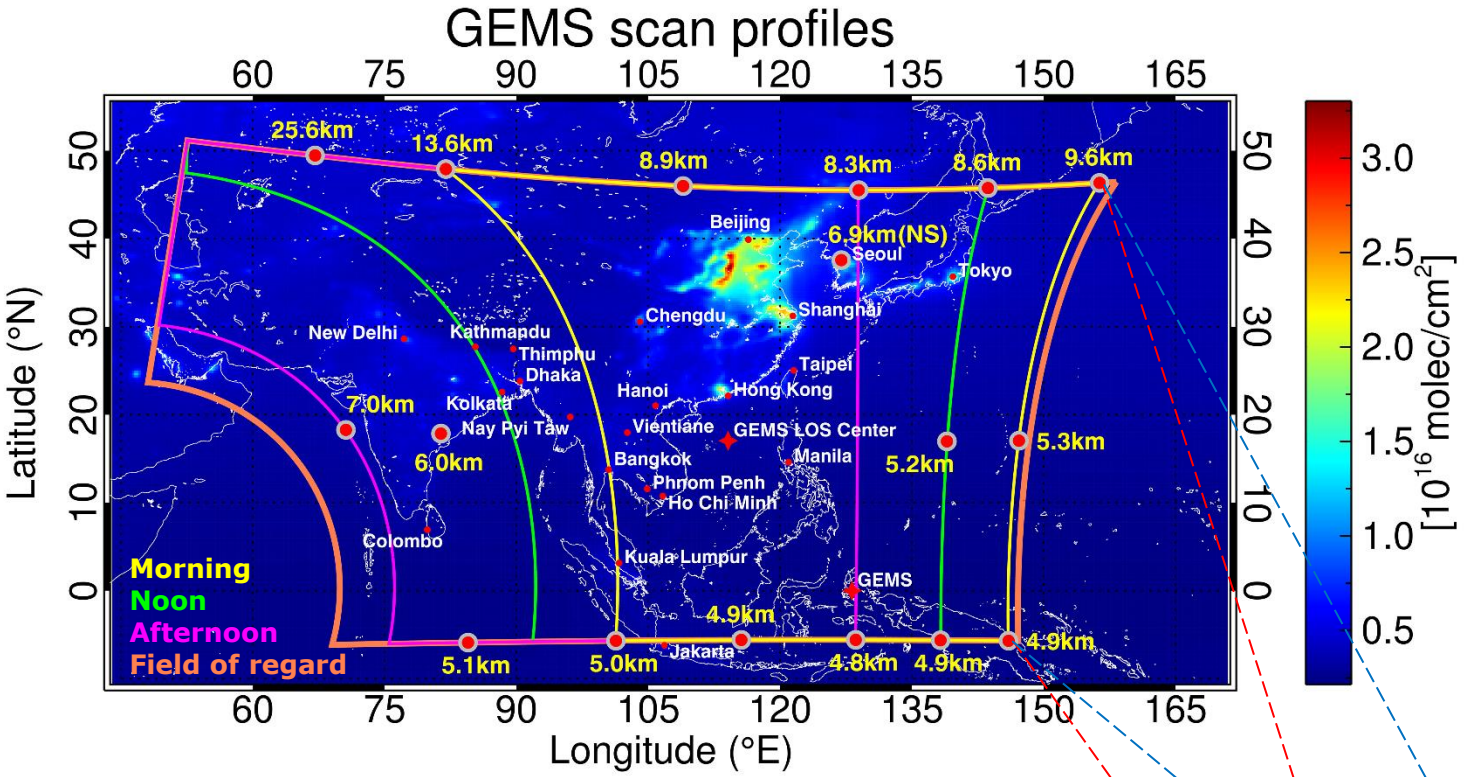
Geostationary Air Quality Constellation

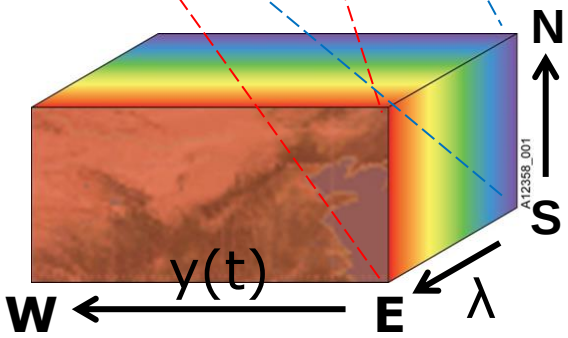


	Sentinel-4	TEMPO	GEMS
Domain	Europe	North America	Asia-Pacific
Revisit	1 hour	1 hour	1 hour
(Planned) Launch	~2023	2022	2020
Payload	UV–Vis–NIR 305–500 nm 750–775 nm	UV–Vis 290–490 nm 540–740 nm	UV–Vis 300–500 nm
Products	O_3, trop. O_3, NO_2, SO_2, HCHO, AAI, AOD, height-resolved aerosol	O_3, trop. O_3, 0-2km O_3, NO_2, HCHO, SO_2, CHOCHO, BrO, IO, HONO, AOD, AAI	O_3, trop O_3, NO_2, SO_2, HCHO,CHOCHO, AOD, AAI, AEH, (BrO, IO ..)
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

[Kim et al. (BAMS 2020)]

GEMS: Geostationary Environment Monitoring Spectrometer





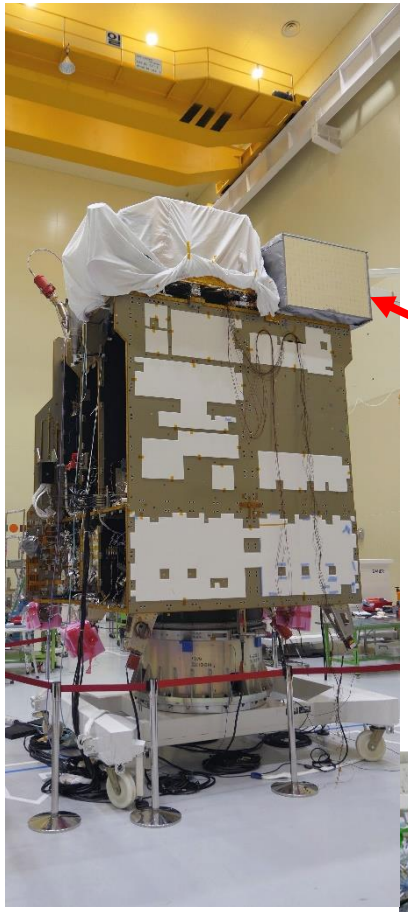
[Kim et al. (BAMS 2020)]

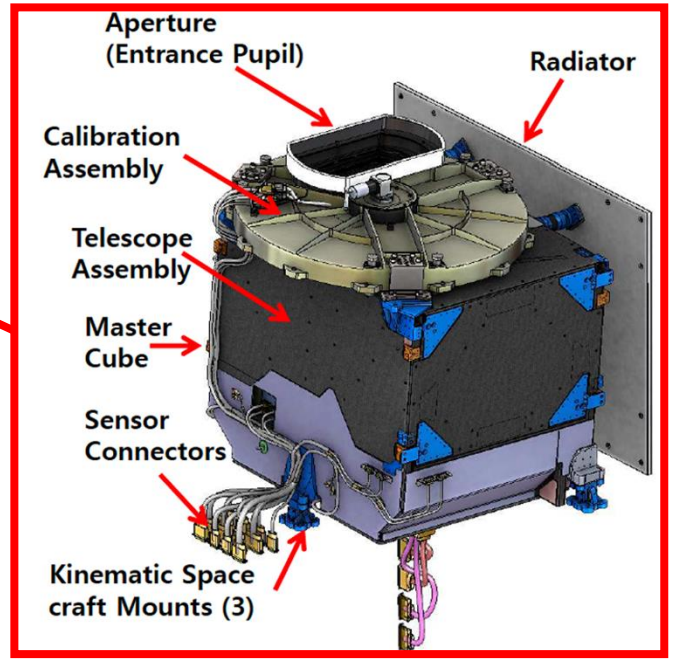
- GEMS (Geostationary Environment Monitoring Spectrometer), on board the GEO-KOMPSAT2B (Geostationary Korea Multi-Purpose Satellite), is a geostationary, scanning, ultraviolet-visible spectrometer.
- It is designed to monitor trans-boundary pollution events for the Korean peninsula and the Asia-Pacific region.

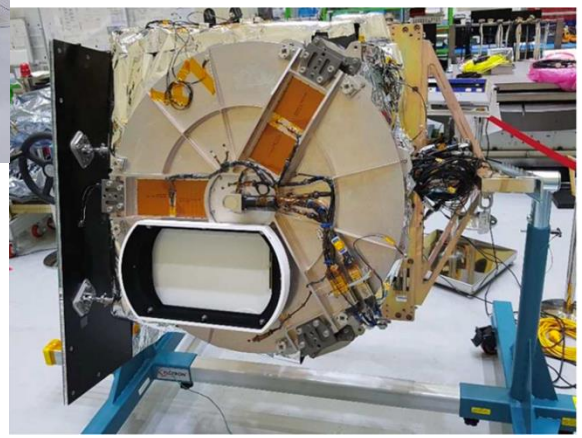
2048 N-S x 695 E-W x 8 times/day
= 11,386,880 spectra/day
= 227,737,600 data/day

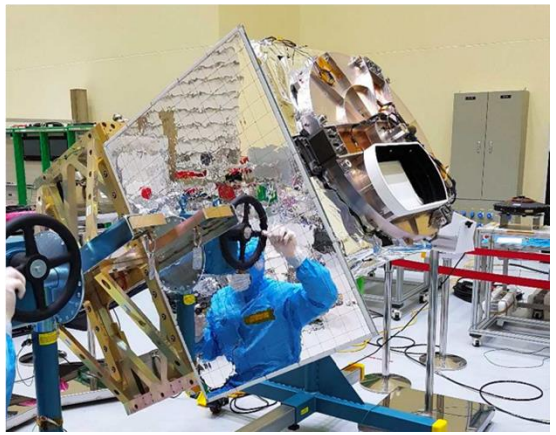
	UV – VIS	
Wavelength Range	300 – 500 nm	
FWHM	< 0.6 nm	
Temporal Resolution	1 hour	
Spatial Sampling @ Seoul [km^2]	3.5 x 8 km^2 (Aerosol)	7 x 8 km^2 (Trace-gas)

GEMS Instrument Specification





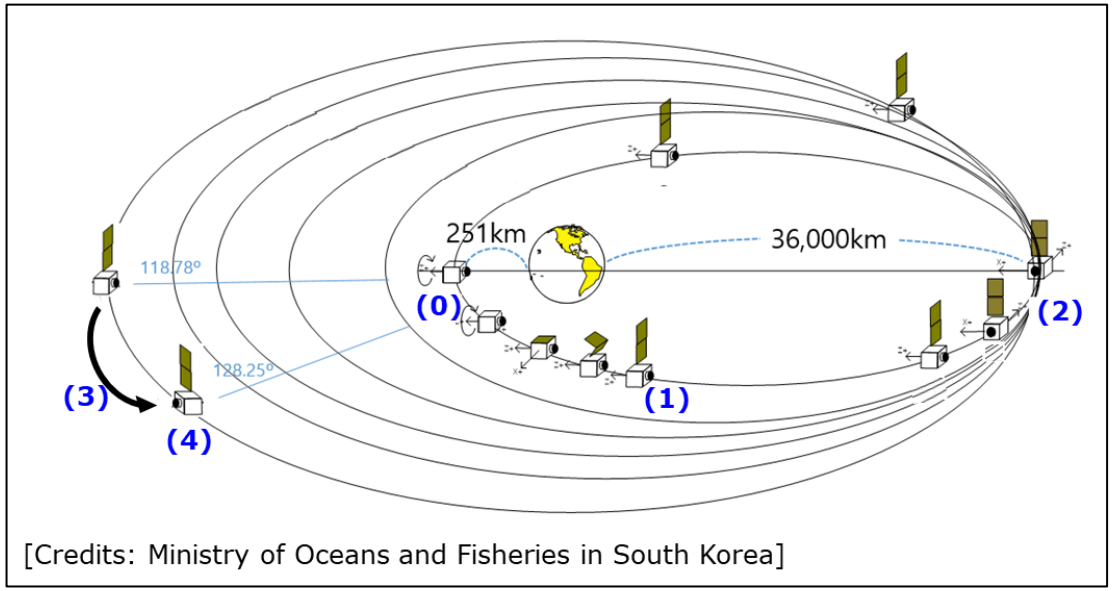




System Attributes	Requirements
Lifetime	>10 years
Reliability	> 0.85 at end of life
Field of regard	> 5000 km (N/S) × 5000 km (E/W) N/S range: 45°N–5°S E/W range: selectable between 75°E and 145°E Orbital position:116.2°E <position<128.2°E
Duty cycle/imaging time	Eight images during the daytime (30 min imaging + 30 min rest) × 8 times day^{-1}
Ground sampling distance	< 7 km (N/S) at Seoul GSD area < 56 km^2 at Seoul (Aspect Ratio less than 1:3)
Spectral range	300 to 500 nm
Spectral resolution	< 0.6 nm
Spectral sampling	< 0.2 nm
Signal-to-noise ratio	> 720 at 320nm > 1500 at 430nm
Data quantization	≥ 12 bits
MTF (instrument level)	> 0.3 in N/S direction at Nyquist frequency > 0.3 in E/W direction at Nyquist frequency
Imaging navigation	1 pixel
Pointing stability	48 $\mu rad^2\ s^{-1}$
Pointing accuracy	0.02°
Radiometric calibration accuracy	< 4% (including standard lamp uncertainty)
Spectral calibration accuracy	< 0.02 nm
Spectral calibration stability	< 0.02 nm (within daytime observations)
Polarization factor	< 2% (310-500nm) No inflection point within 20 nm for all the wavel engths range
Spectral feature	<0.05% (within 3 nm)
Stray light	<2% (310–350 nm)

Timeline Since Launch

No.	Date (KST)	Activity
0	2020.02.19	Transfer orbit injection (GK-2B launch)
1	2020.02.19	Solar array deployment
2	2020.02.20 – 2020.02.26	Liquid apogee engine firing
3	2020.02.26 – 2020.03.06	Moving from 118.78°E to 128.25°E
4	2020.03.06	GK-2B arrived successfully in orbit
5	2020.03.10	GEMS initial operation monitoring
6	2020.03.23	GEMS power on
7	2020.03.31	GEMS outgassing
8	2020.04.07	GEMS outgassing monitoring
9	2020.04.21	First GEMS measurements for Sun/Earth/LED
10	2020.04.23~	Daily operation (in-orbit test)
11	2020.04.28	Solar measurements with reference diffuser



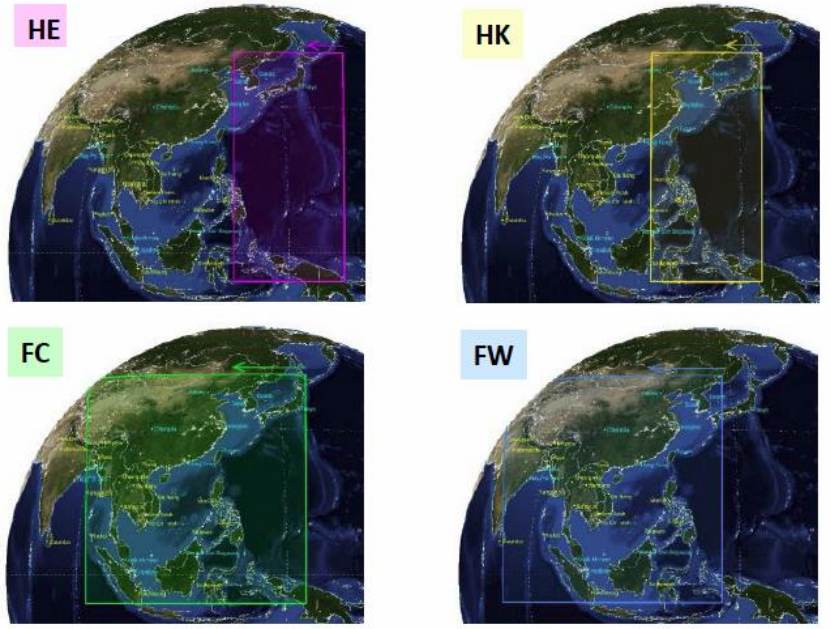
[Credits: Ministry of Oceans and Fisheries in South Korea]

[Courtesy of KARI & NIER]

No.	Date (KST)	Activity
12	2020.08.31	GEMS power reset
13	2020.09.22	Solar measurements with reference diffuser
14	2020.12.20	Solar measurements with reference diffuser

GEMS E-W Scan Operation Scenario

Obs. No.	1	2	3	4	5	6	7	8	9	10	11	Total Obs. No.
UTC	23:00	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	
KST	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	
Jan	X	X	HE	HK	FC	FW	FW	FW	X	X	X	6
Feb	X	X	HE	HK	FC	FW	FW	FW	FW	X	X	7
Mar	X	HE	HK	FC	FC	FW	FW	FW	FW	X	X	8
Apr	HE	HK	FC	FC	FC	FW	FW	FW	FW	FW	X	10
May	HE	HK	FC	FC	FW	FW	FW	FW	FW	FW	X	10
Jun	HE	HK	FC	FC	FW	FW	FW	FW	FW	FW	X	10
Jul	HE	HK	FC	FC	FW	FW	FW	FW	FW	FW	X	10
Aug	HE	HK	FC	FC	FW	FW	FW	FW	FW	FW	X	10
Sep	HE	HK	FC	FC	FW	FW	FW	FW	FW	FW	X	10
Oct	X	HE	HK	FC	FC	FW	FW	FW	FW	X	X	8
Nov	X	X	HE	HK	FC	FW	FW	FW	X	X	X	6
Dec	X	X	HE	HK	FC	FW	FW	FW	X	X	X	6



		Longitude	Scan Width
HE	Half East	152.000	3.80500
HK	Half Korea	142.000	3.80500
FC	Full Central	142.000	7.61000
FW	Full West	133.000	7.61000
X	No observation		

[Source: https://nesc.nier.go.kr/satellite/operation?page=1&limit=10]

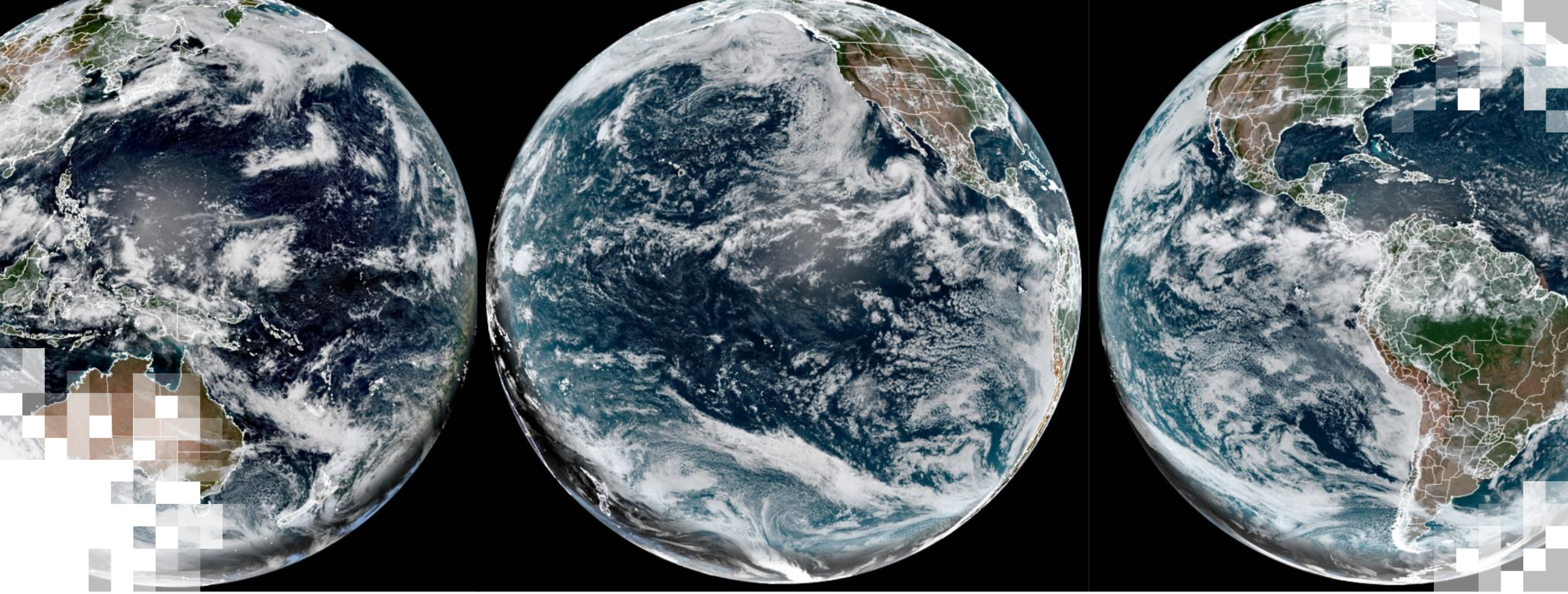
Baseline Level-2 Products of GEMS

Product Group	Product	Importance
Aerosol	1) Aerosol Optical Depth	Air Quality Climate Public Health
	2) Single Scattering Albedo	
	3) UV·VIS Aerosol Index	
AEH	4) Aerosol Effective Height	
Cloud	5) Effective Cloud Fraction	Retrieval Climate
	6) Effective Cloud Pressure	
	7) Cloud Radiance Fraction	
SFC	8) Surface Reflectance	Retrieval Environment
O3T	9) Total Ozone	Oxidant Pollutant O_3 layer
O3P	10) Tropospheric Ozone Profile	
	11) Stratospheric Ozone Profile	

Product Group	Product	Importance
HCHO	12) Formaldehyde	VOC Proxy
CHOCHO	13) Glyoxal	
NO_2	14) Tropospheric Nitrogen dioxide	O_3 & Aerosol Precursor
	15) Stratospheric Nitrogen dioxide	
SO_2	16) Sulfur dioxide	Aerosol Precursor Volcano
UVI	17) UV Index	Public Health
	18) Plant Response Index	
	19) DNA Damage Index	
	20) Vitamin D Synthesis Index	

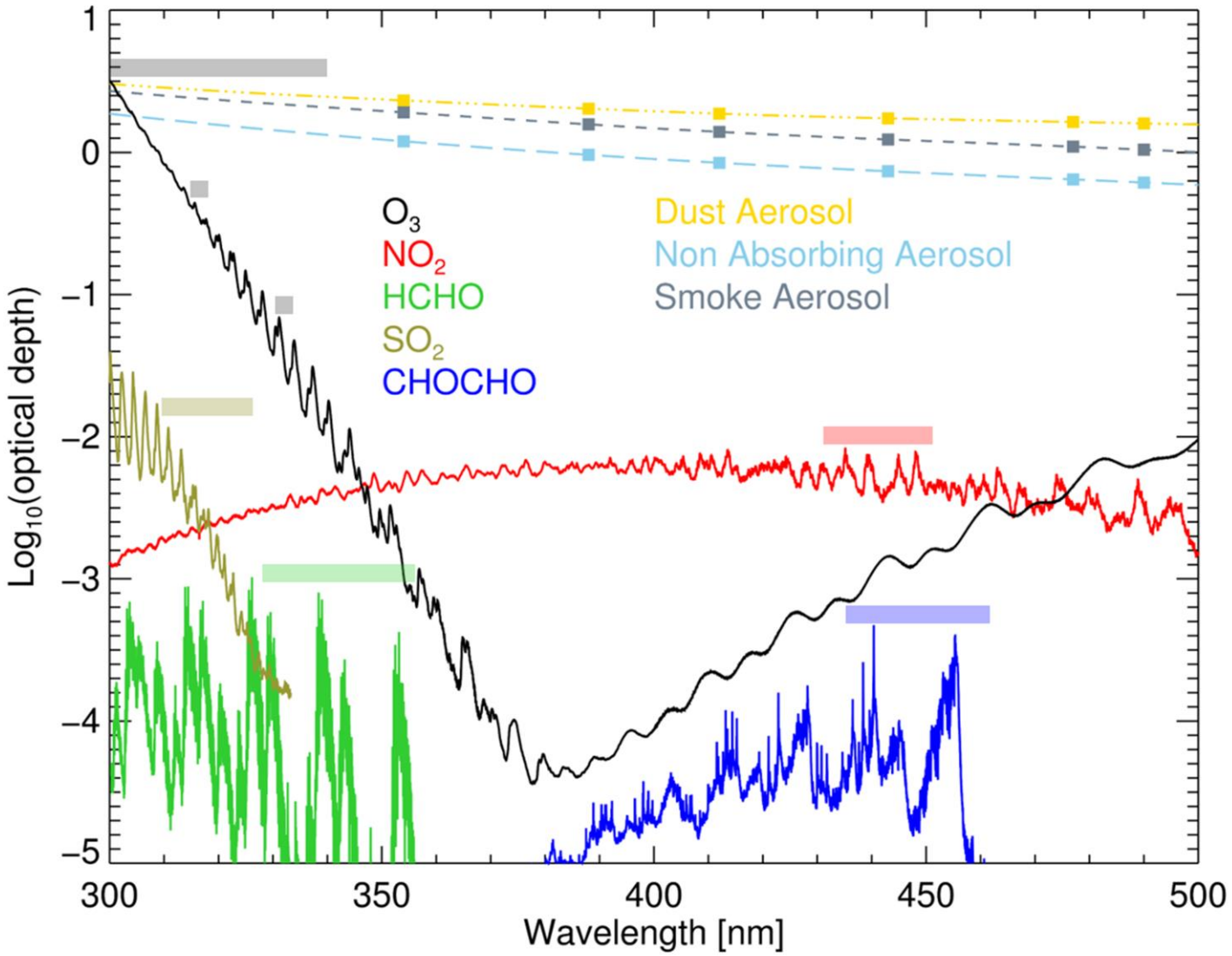
*Additional products of H_2O, BrO, HONO under development.

Data released as of September 2022



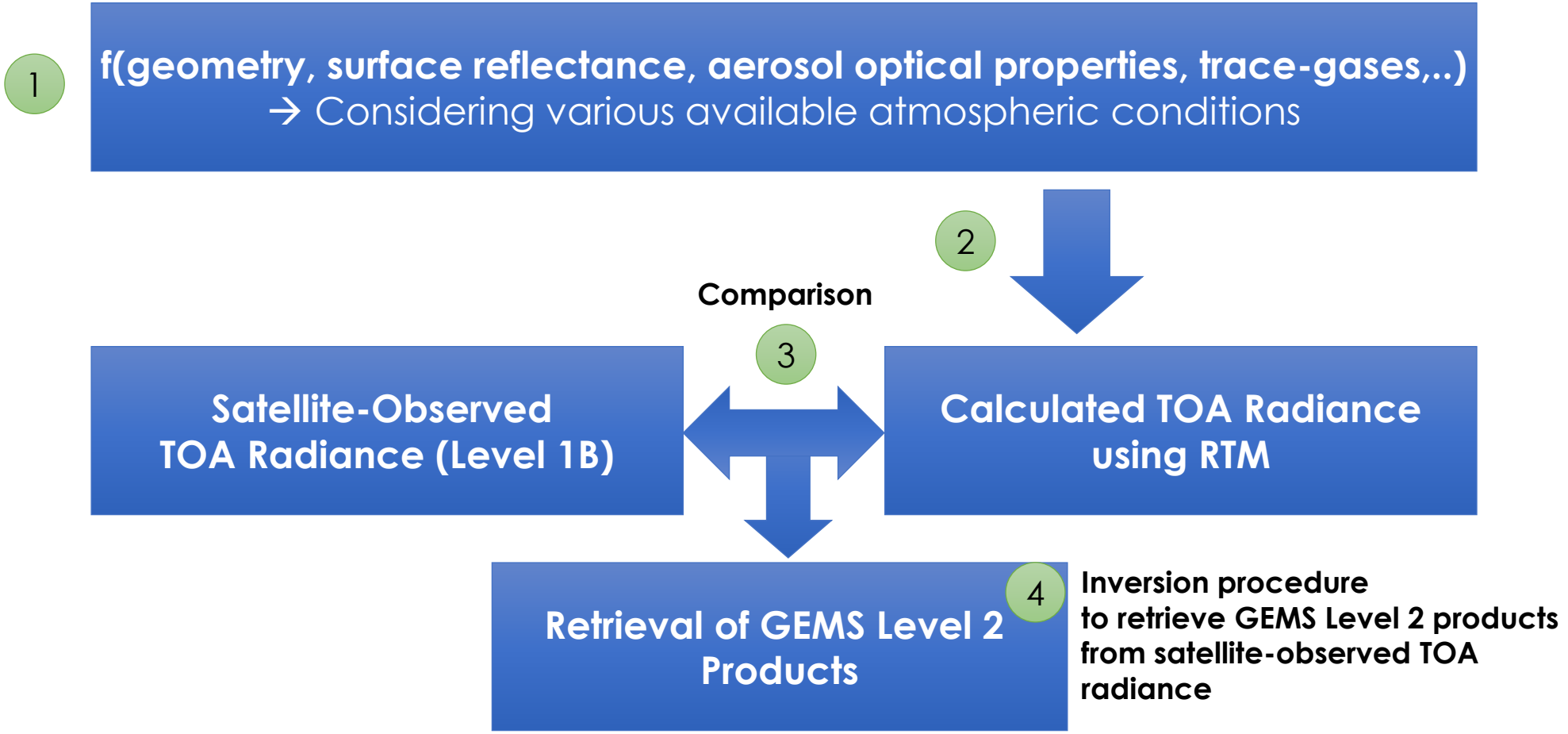
2. GEMS Air Quality Datasets – Algorithms & Validation

Optical Depths of Air Pollutants

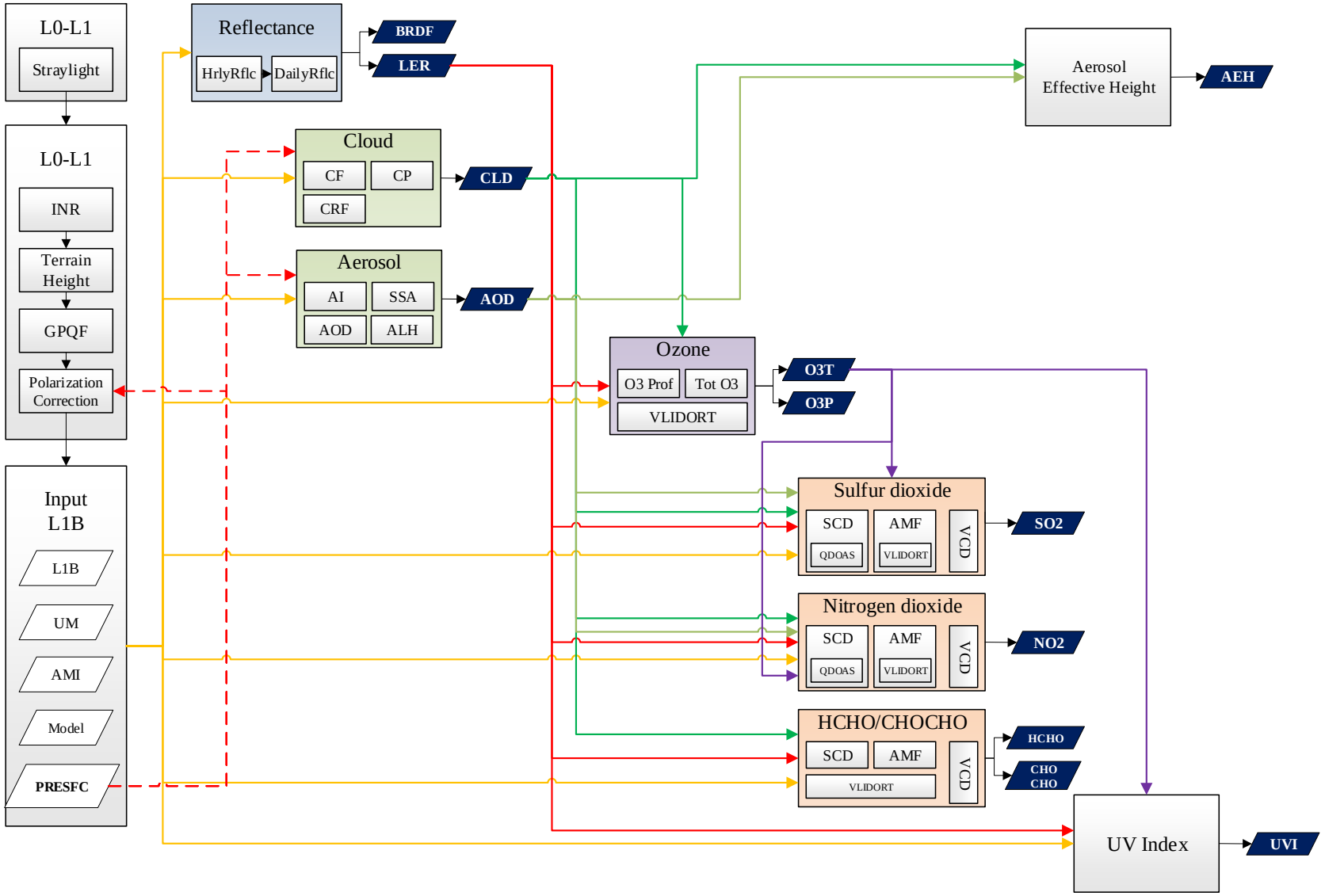


[Kim et al. (BAMS 2020)]

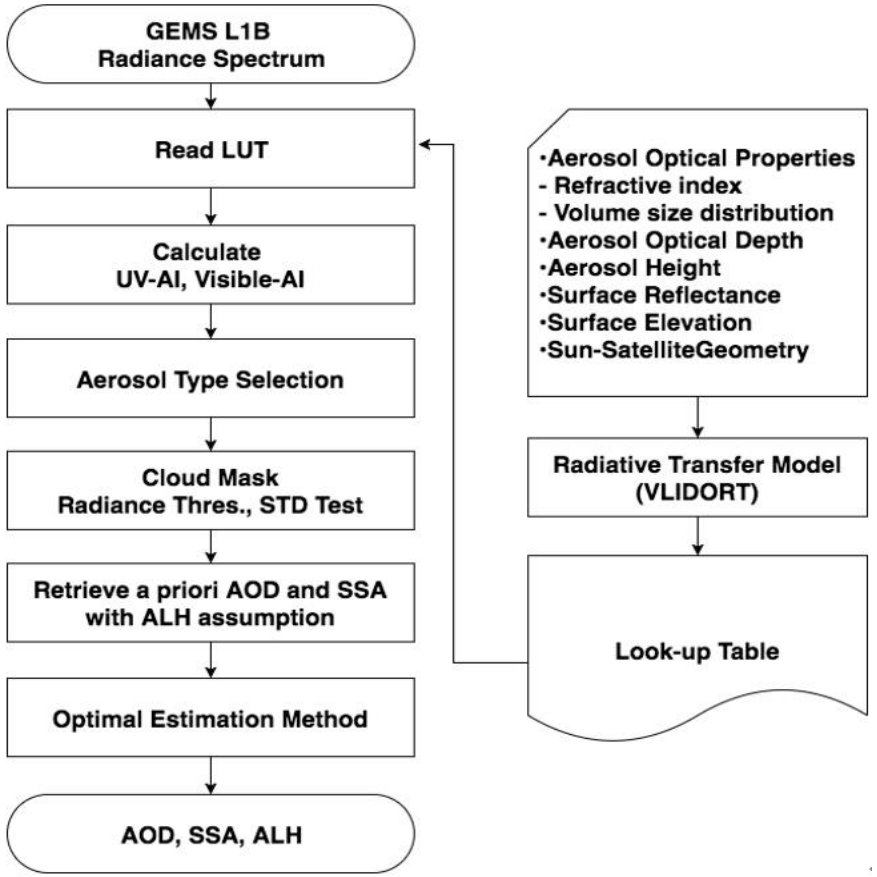
General Concept of Retrieving Level 2 Products from Satellite Measurement Datasets



GEMS Algorithm Flow Chart



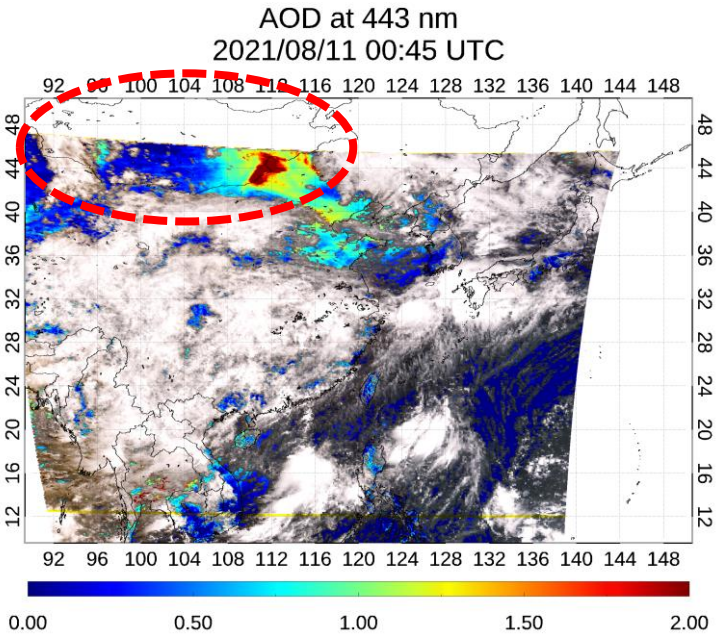
Aerosol Product- AOD (Aerosol Optical Depth)



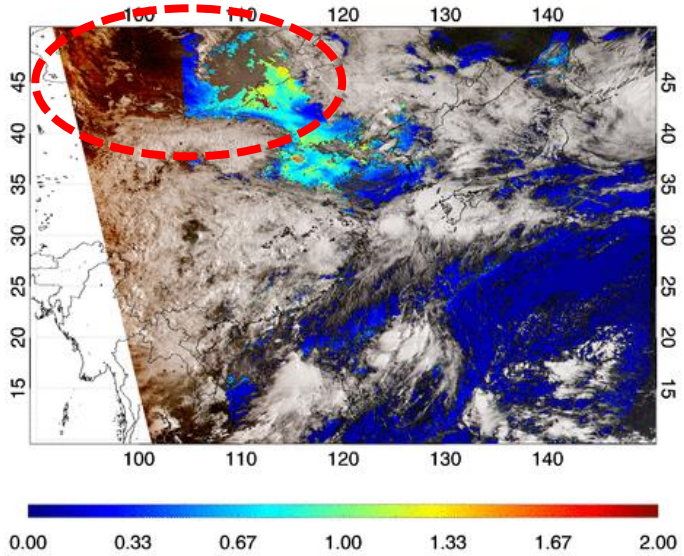
- Major Products: AOD, SSA, and ALH
- Channels: 354, 388, 412, 443, 477, 490 nm
- Methods: 2-channel method + Optimal Estimation

(Torres et al., 2013; Kim et al., 2018; Go et al., 2020a,b)

GEMS



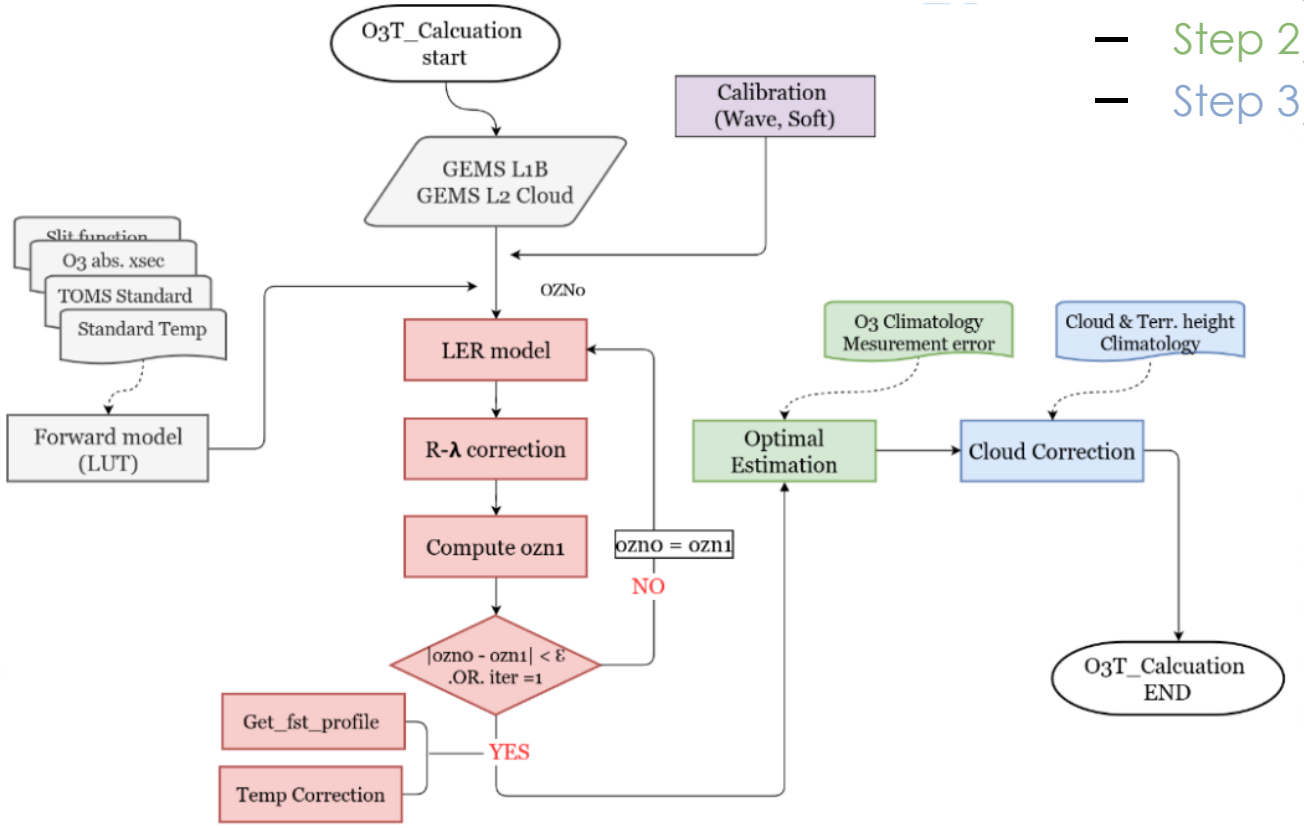
AHI

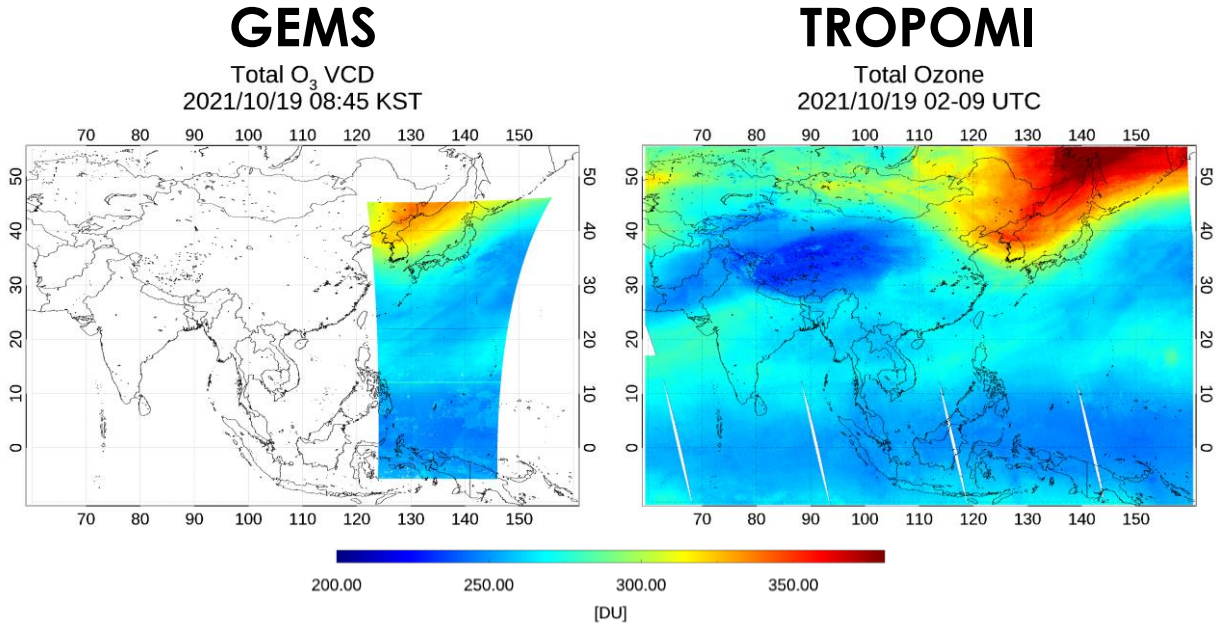


Lim et al. (RS 2018, AMT 2021)

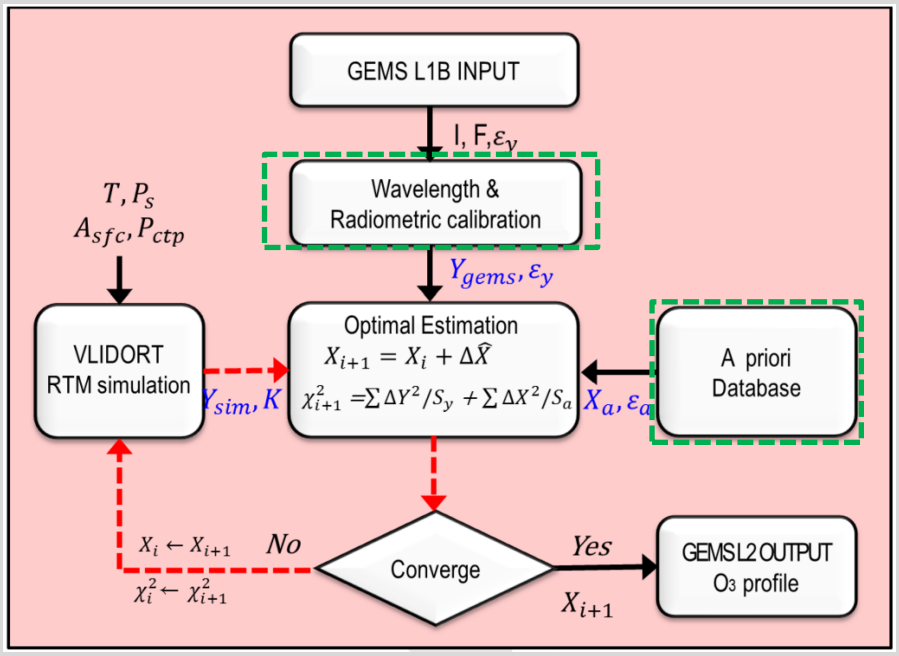
Ozone Product- O3T (Total Ozone)

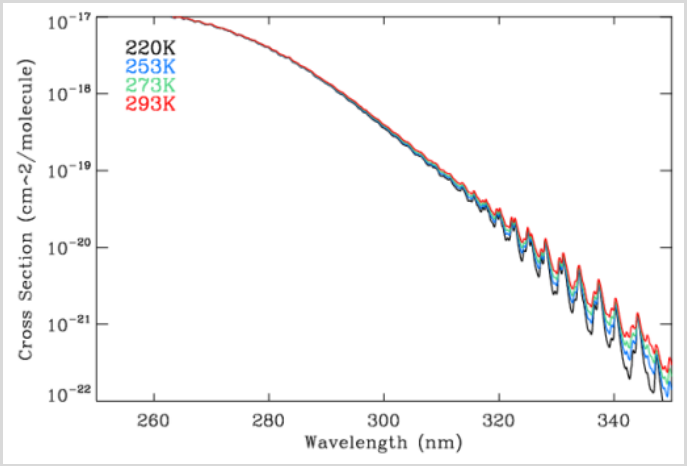
- Inversion Methods:
  - Step 1) TOMS Algorithm (Dave and Mateer (1967), Dave (1977))
  - Step 2) Optimal Estimation (Rodgers (2000))
  - Step 3) Effects of Clouds and Terrain Height Correction

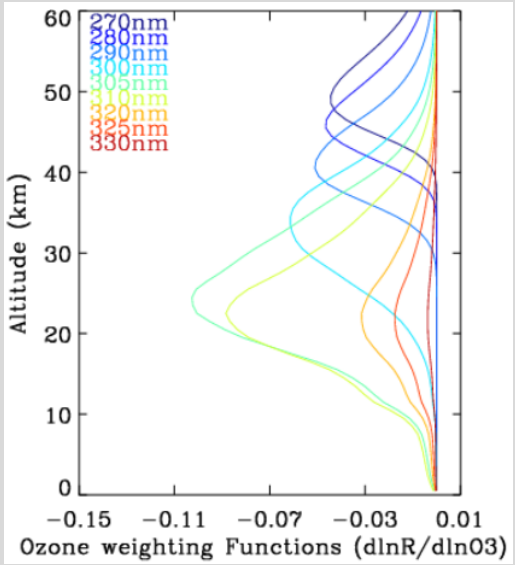




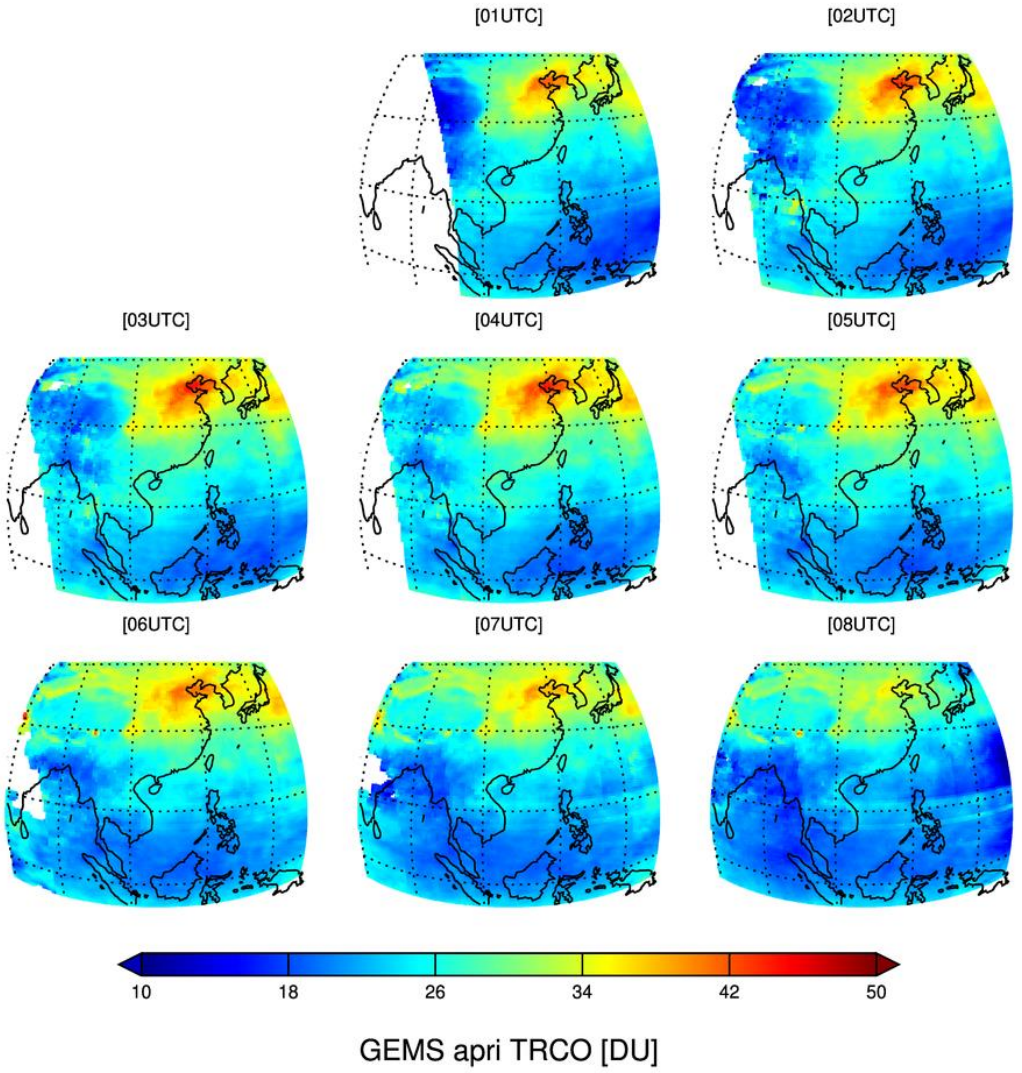
Ozone Product - O3P (Ozone Profile)



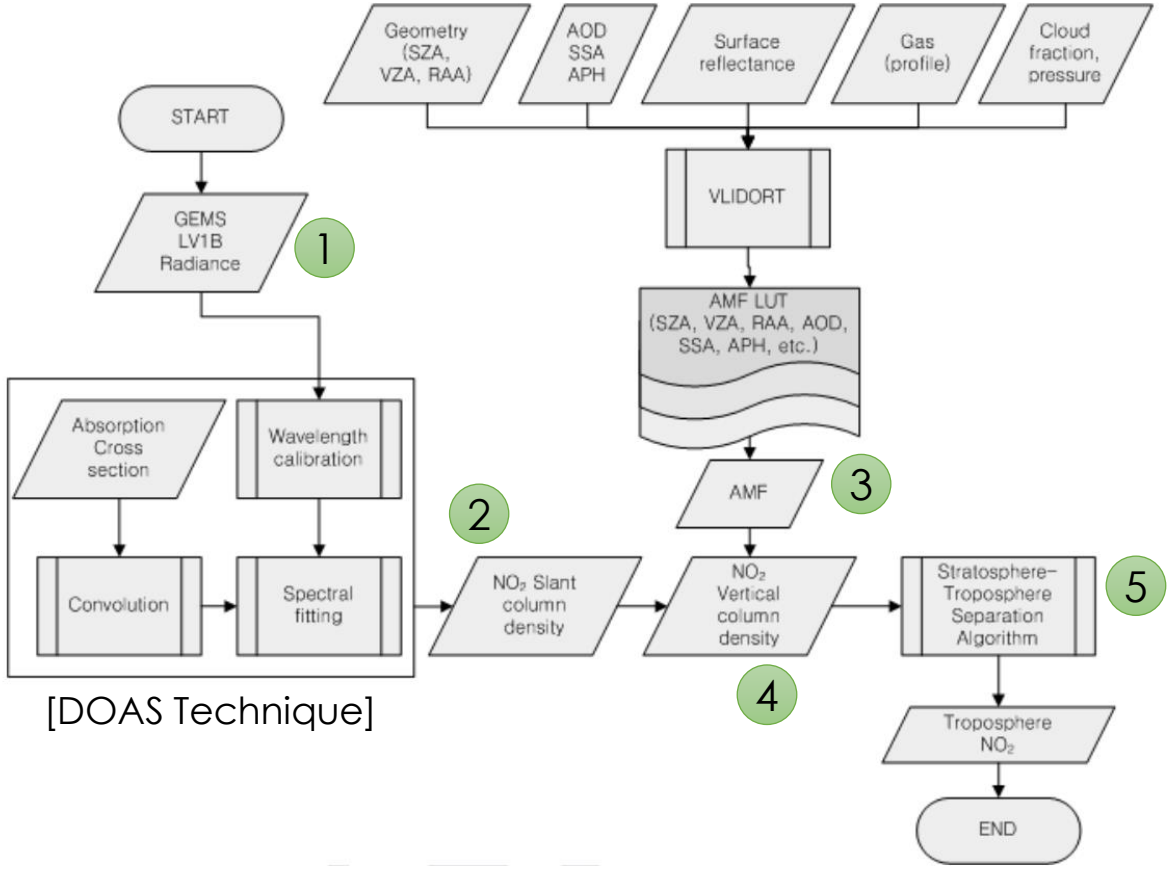




- Huggins Ozone Bands (300-340nm)



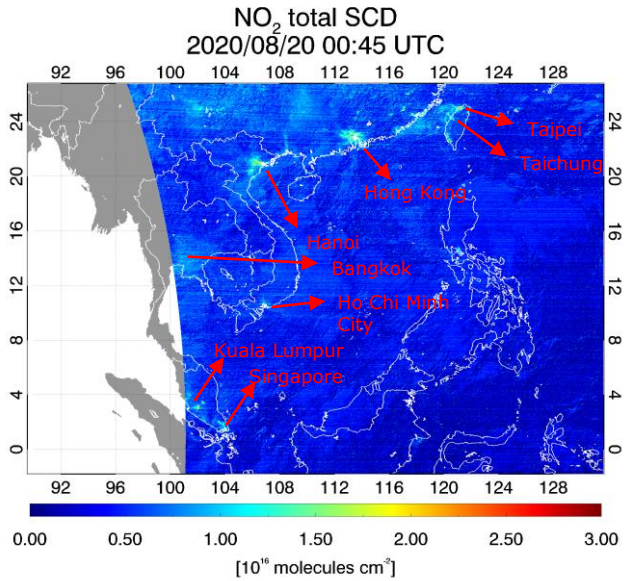
Nitrate Product - NO_2 (Nitrogen Dioxide)



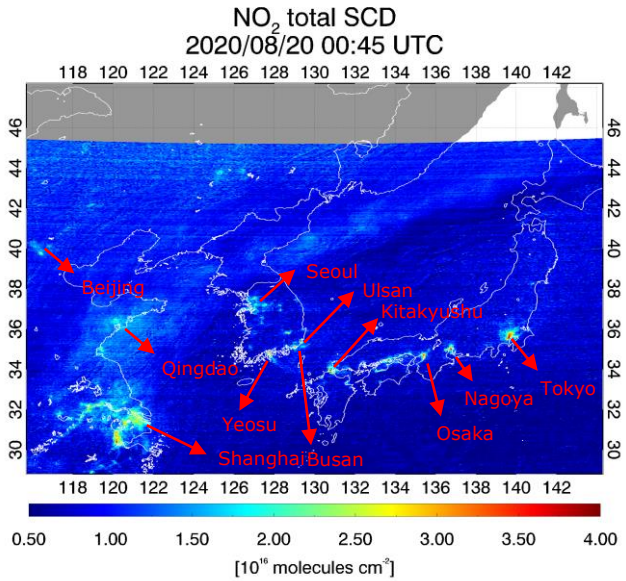
[DOAS Technique]

- Fitting Windows: 432-450 nm
- Inversion Algorithms (NO_2, SO_2, HCHO):
  1) Spectral Radiance Measurements from GEMS
  2) Spectral Fitting of Slant Column Density (SCD)
  3) Air Mass Factor (AMF) Correction
  4) Calculate Vertical Column Density (VCD)
  5) NO2: Stratosphere-Troposphere Separation (Based on Bucsela et al., 2013)

GEMS SCD

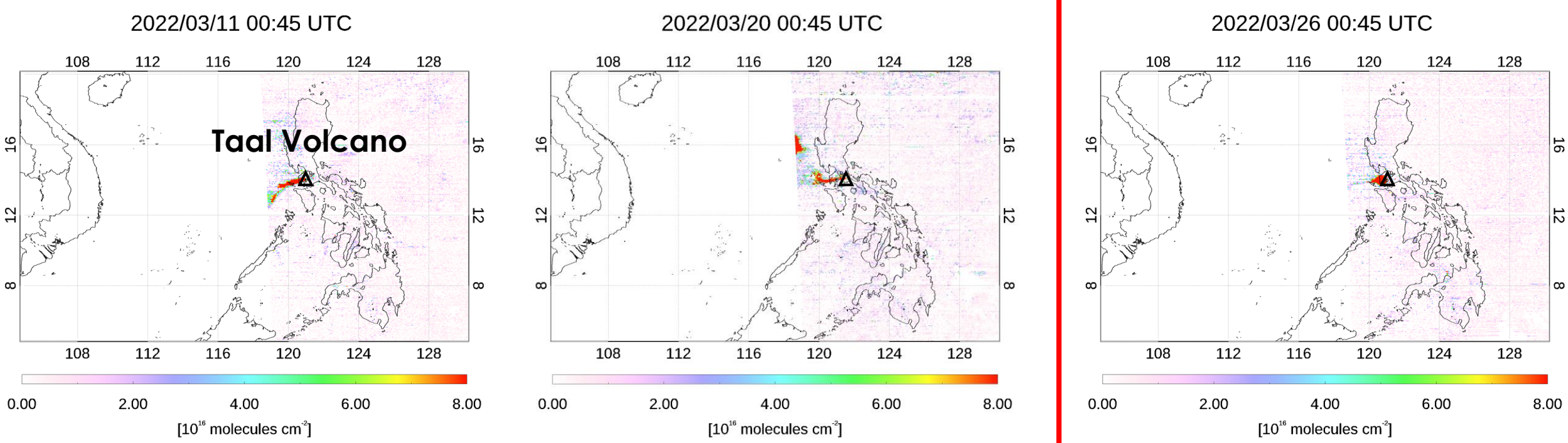


GEMS SCD



Sulfate Product - SO_2

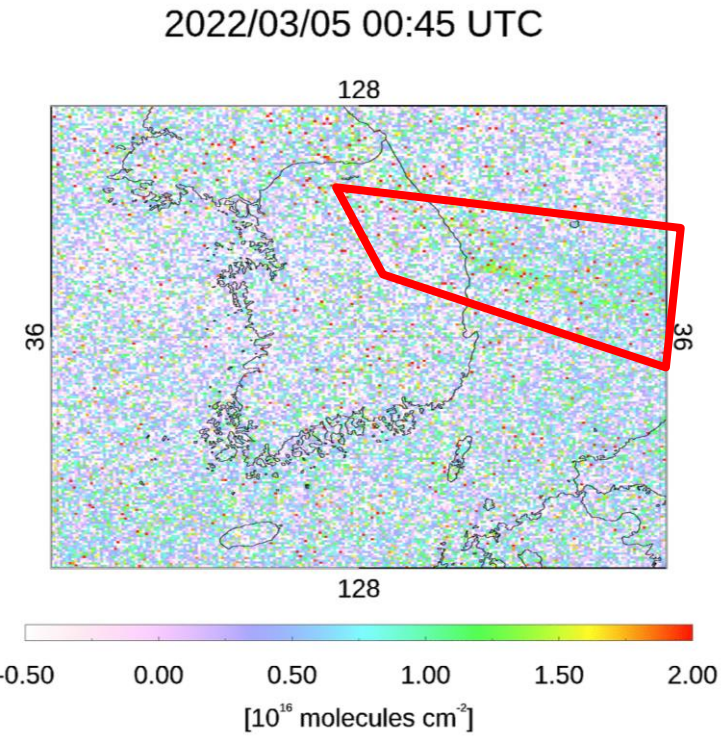
- Slant Column Retrieval: PCA (Li et al., 2013) and DOAS Method (Platt, 1994).
- Fitting Windows: 308-324nm
- Taal Volcano is located ~65 km south of Manila. A large-scale volcanic eruption occurred on March 26, 2022.
- GEMS captured SO_2 emitted from Taal volcano spreading to the Indochina Peninsula through the western coastal region of the Philippines.



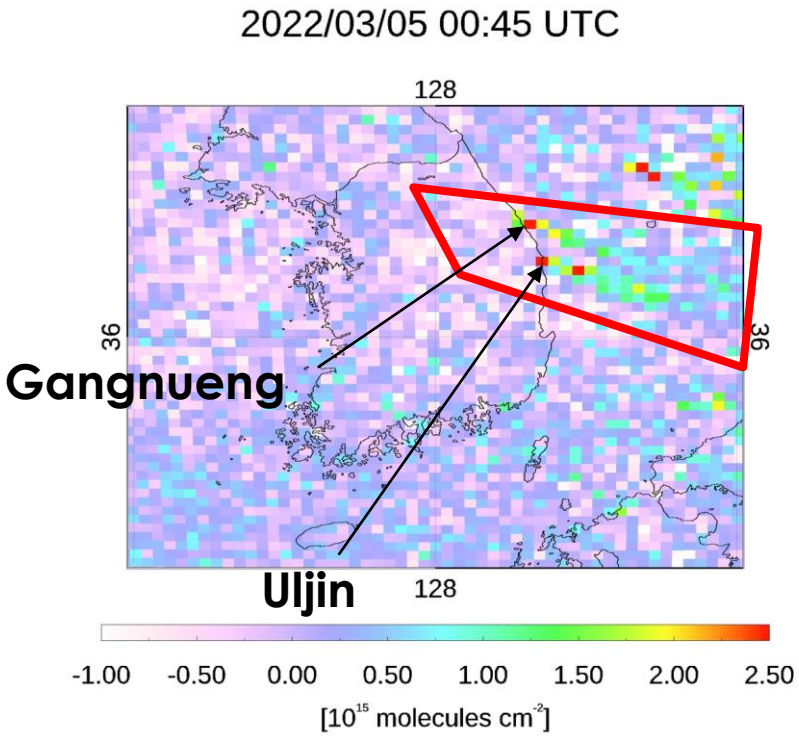
VOC Products - Formaldehyde (HCHO) and Glyoxal (CHOCHO)

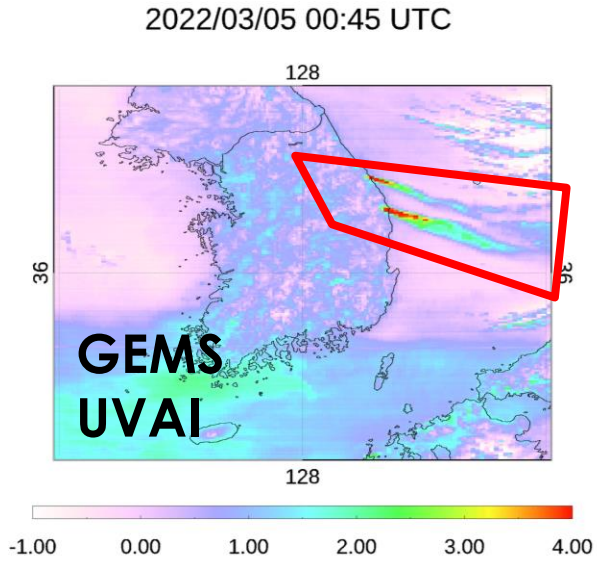
- Slant Column Retrieval: Basic Optical Absorption Spectroscopy (BOAS)
- Fitting (calibration) Window of HCHO : 328.5–356.5 nm (325.5–358.5 nm)
- Fitting (calibration) Window of CHOCHO : 435.0–461.0 nm (433.0–463.0 nm)
- Large wildfires in Uljin and Gangnueng, South Korea on March 5, 2022

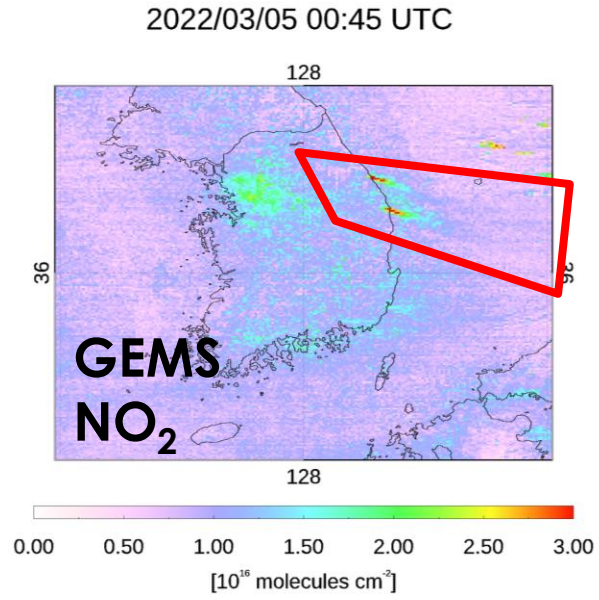
GEMS HCHO



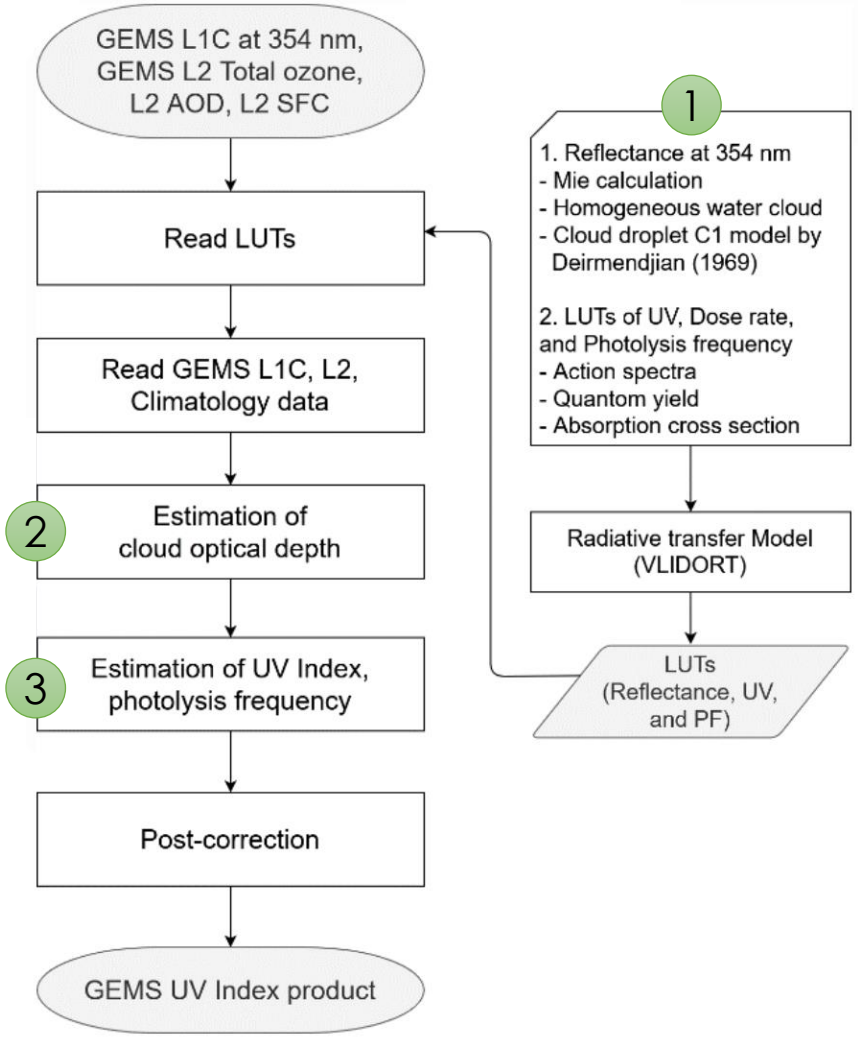
GEMS CHOCHO





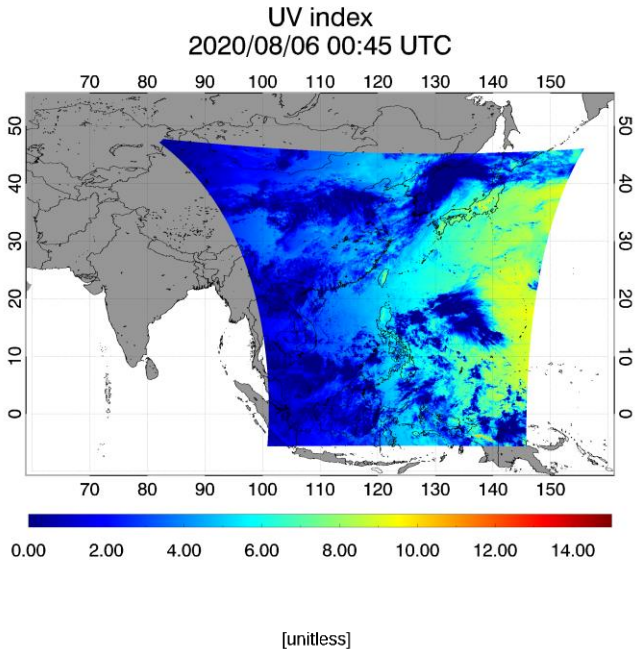


UV Index Product

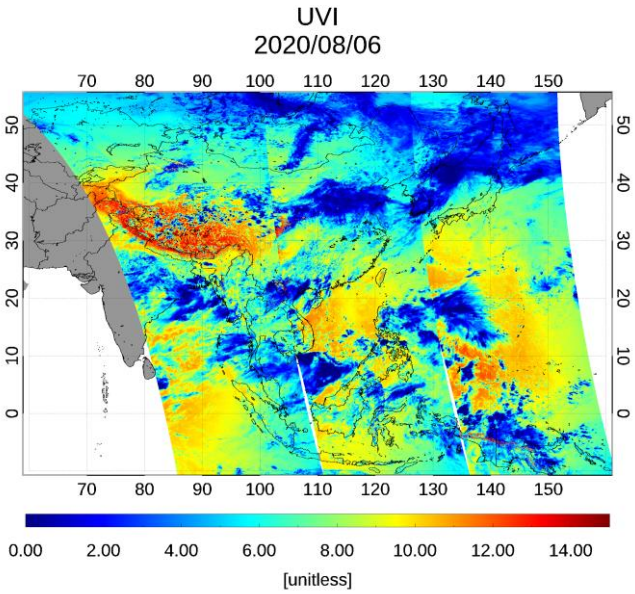


- Major Products:
  - UV Index
  - Plant Response Index
  - DNA Damage Index
  - Vitamin D Synthesis Index

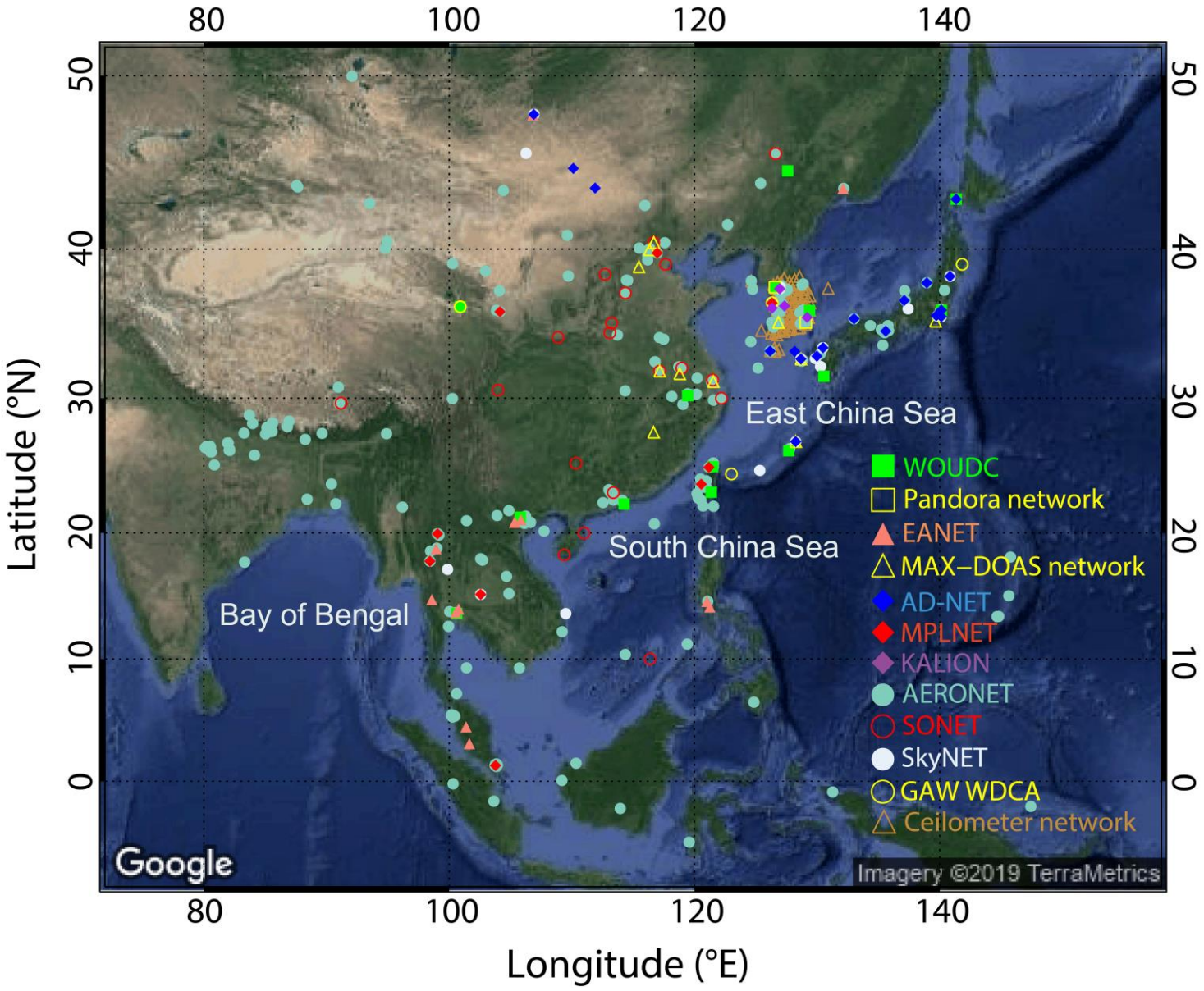
GEMS UV Index

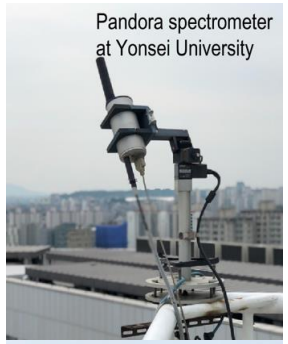


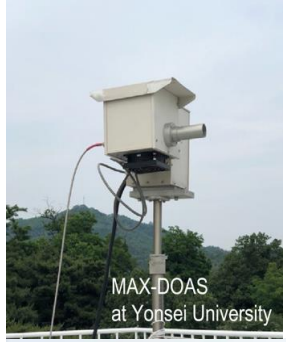
TROPOMI UV Index

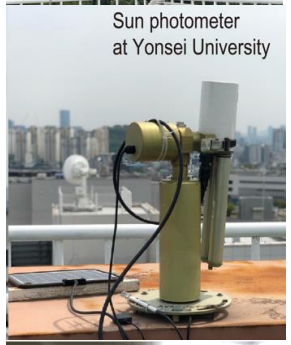


Validation Results of GEMS Level-2 Products





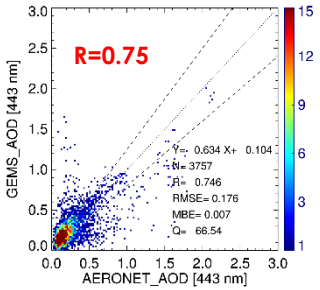




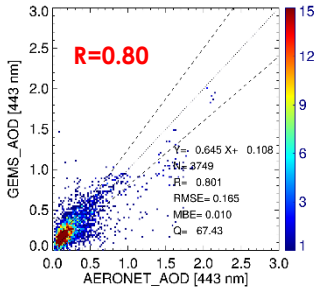
Validation Results of GEMS Level-2 Products Period: August–October 2020

AOD Versus AERONET

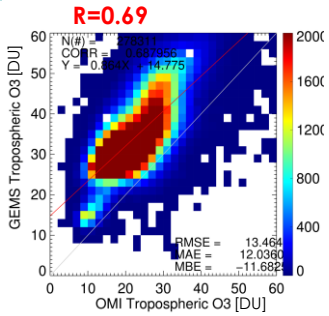
GEMS domain



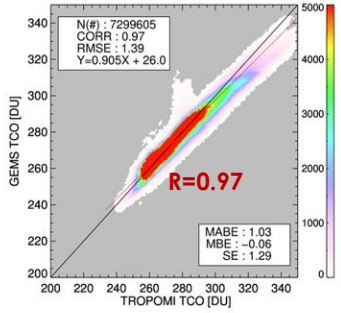
East Asia domain



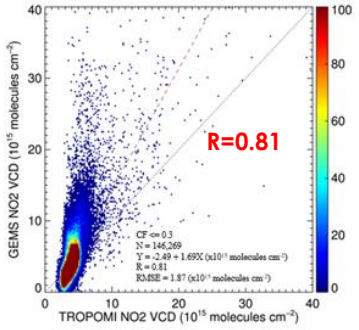
Trop. O_3 Versus OMI



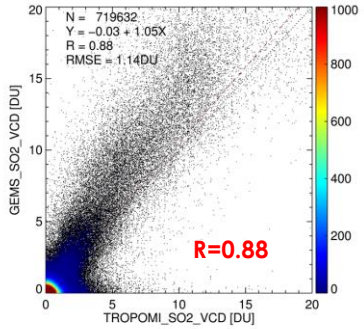
Total O_3 Versus TROPOMI



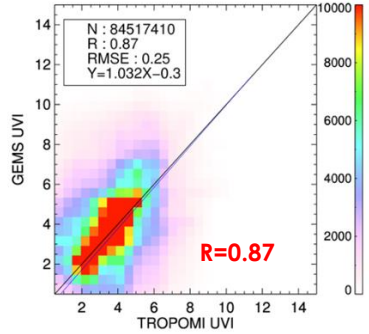
NO_2 Versus TROPOMI



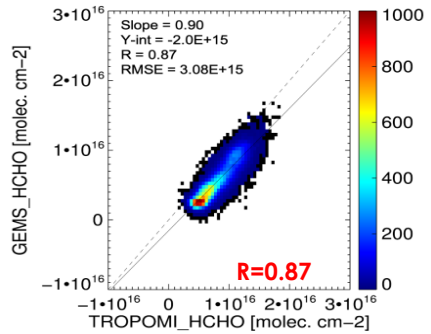
SO_2 Versus TROPOMI



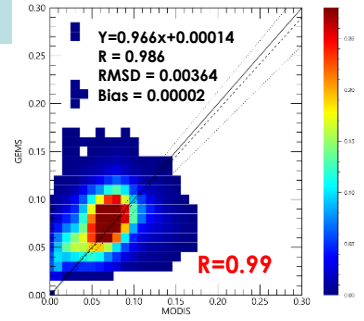
UVI Versus TROPOMI



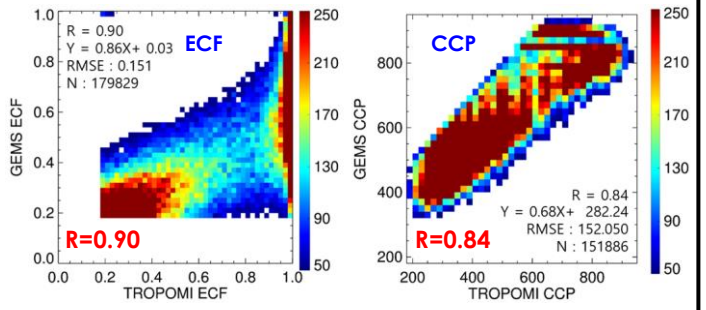
HCHO Versus TROPOMI



Surface albedo Versus MODIS

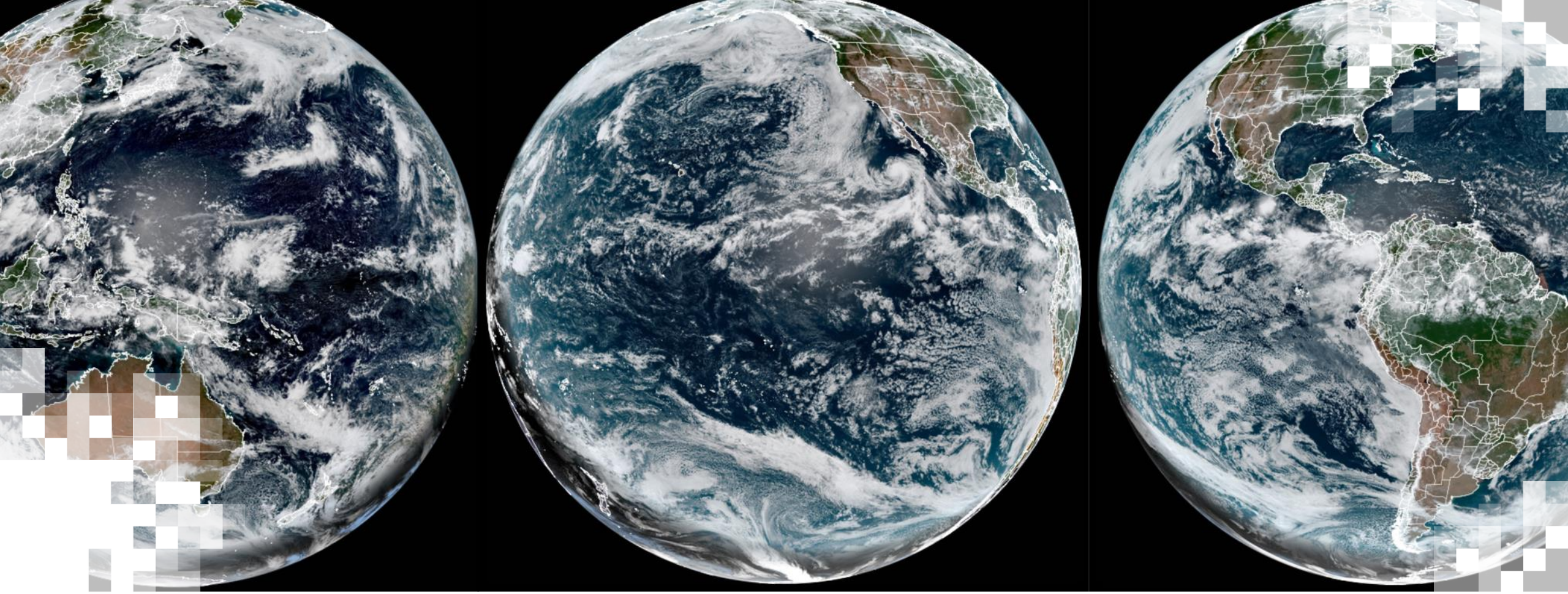


Cloud Versus TROPOMI



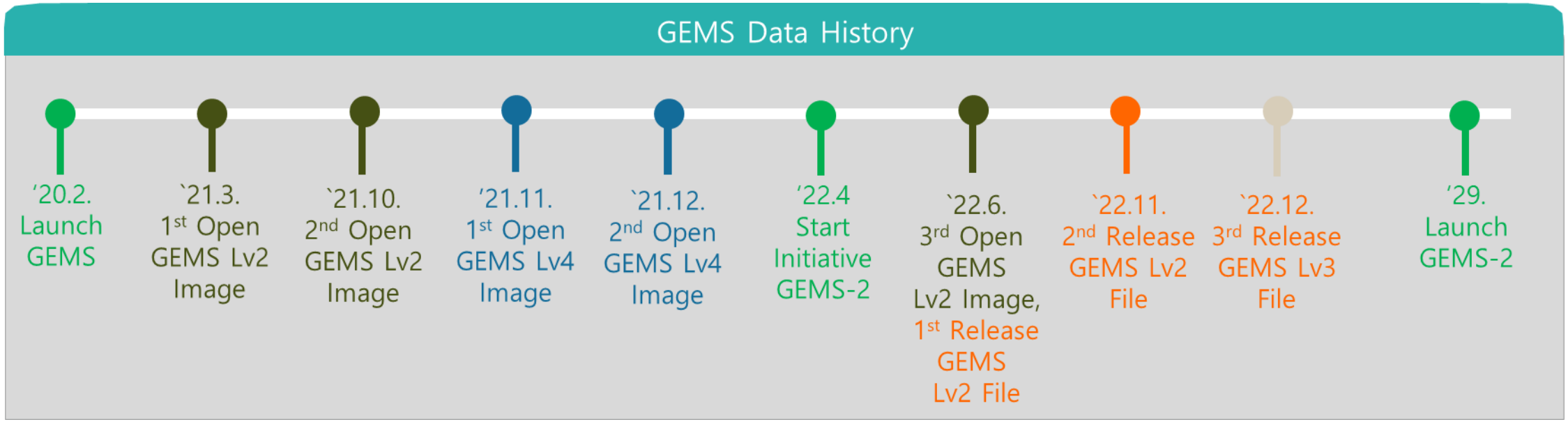
Validation Results of GEMS Level-2 Products

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



3. GEMS Air Quality Data Access

GEMS Data Release Plan



Credit: NIER

- ✓ 1st Release ('22.6.) Lv2 file product: Cloud, AOD, O3T, UVI, SO2
- ✓ 2nd Release ('22.11.) Lv2 file product: AEH, O3P, SFC, HCHO, Glyoxal, NO_2 (troposphere, total)
- ✓ 3rd Release ('22.12.) Lv3 file product: NO2 (around the Korea Peninsula)

※ Data will be downloadable from the ESC website: https://nesc.nier.go.kr

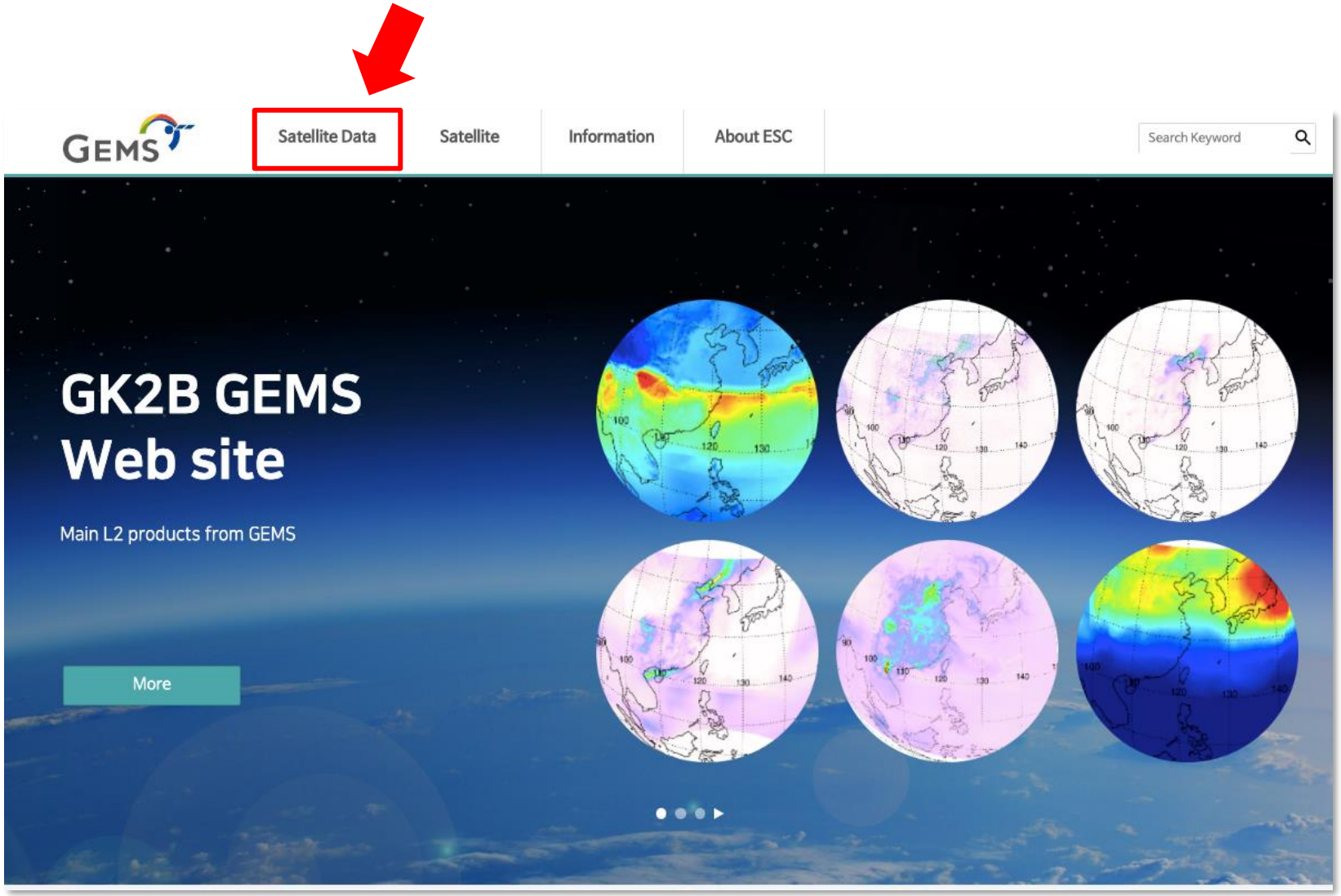
☞ L1C: Only offline (HDD) distribution (due to the large file size of ~8Gb per one hourly scan)

How to Access GEMS Data (1)

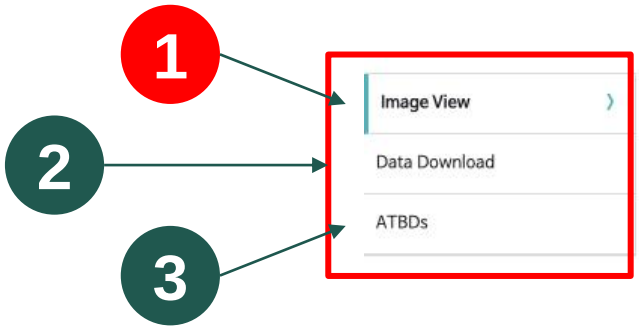
Step 1. Go to the National Institute of Environmental Research (NIER)-Environmental Satellite Center website: https://nesc.nier.go.kr/

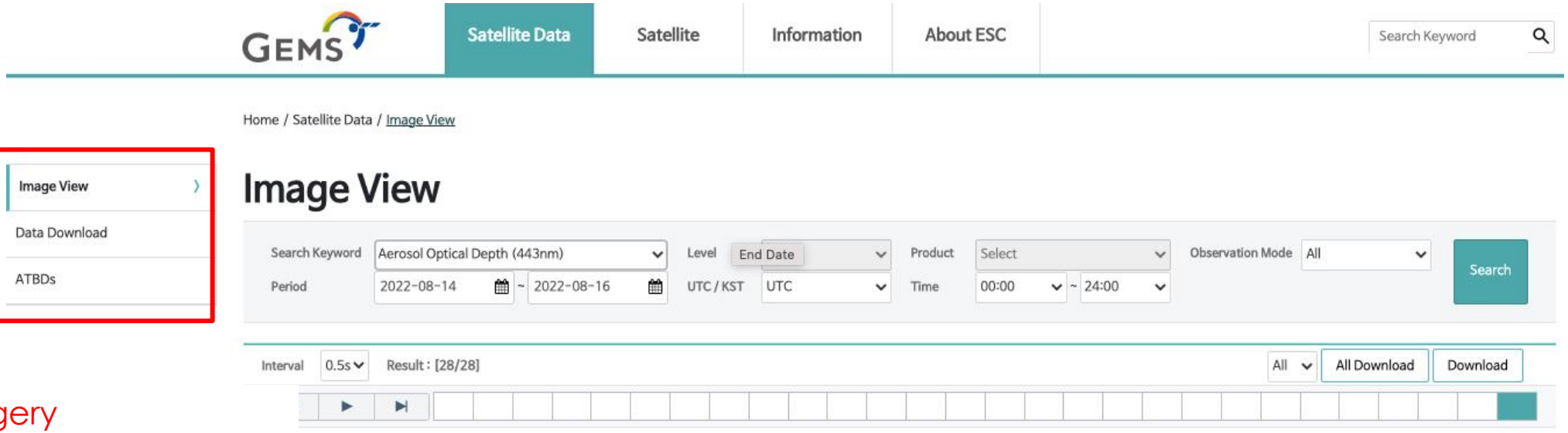
Step 2. Click the 'Satellite Data' tab.

Note: You can find the instrument detail and products for GEMS on the 'Satellite' tab.

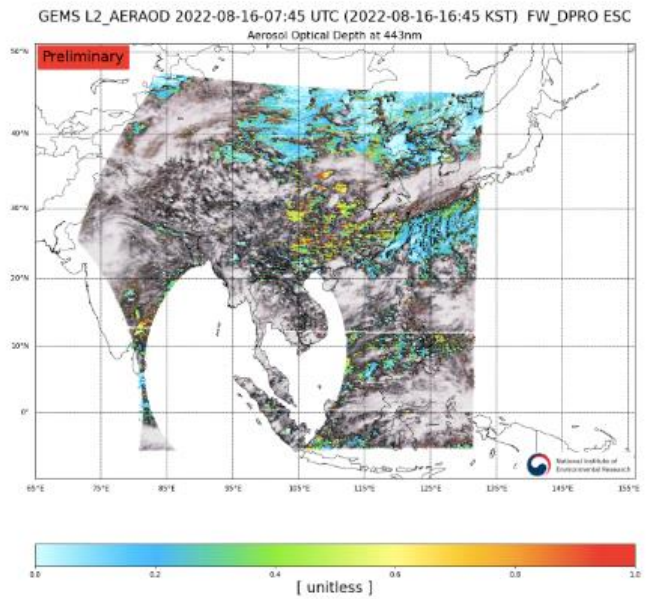


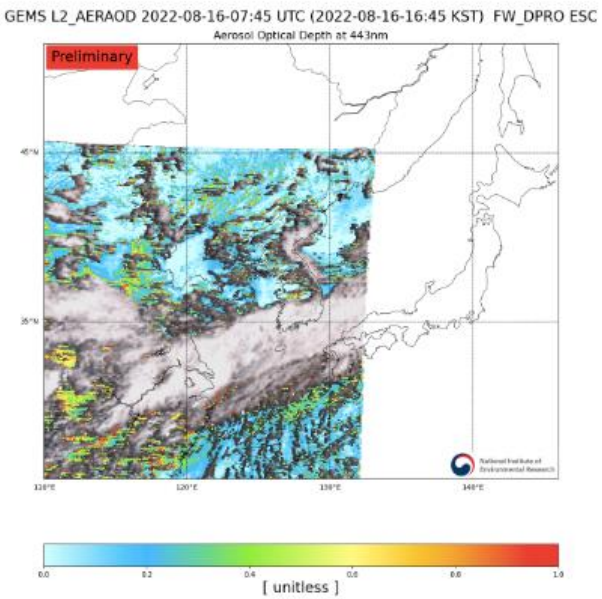
How to Access GEMS Data (2)



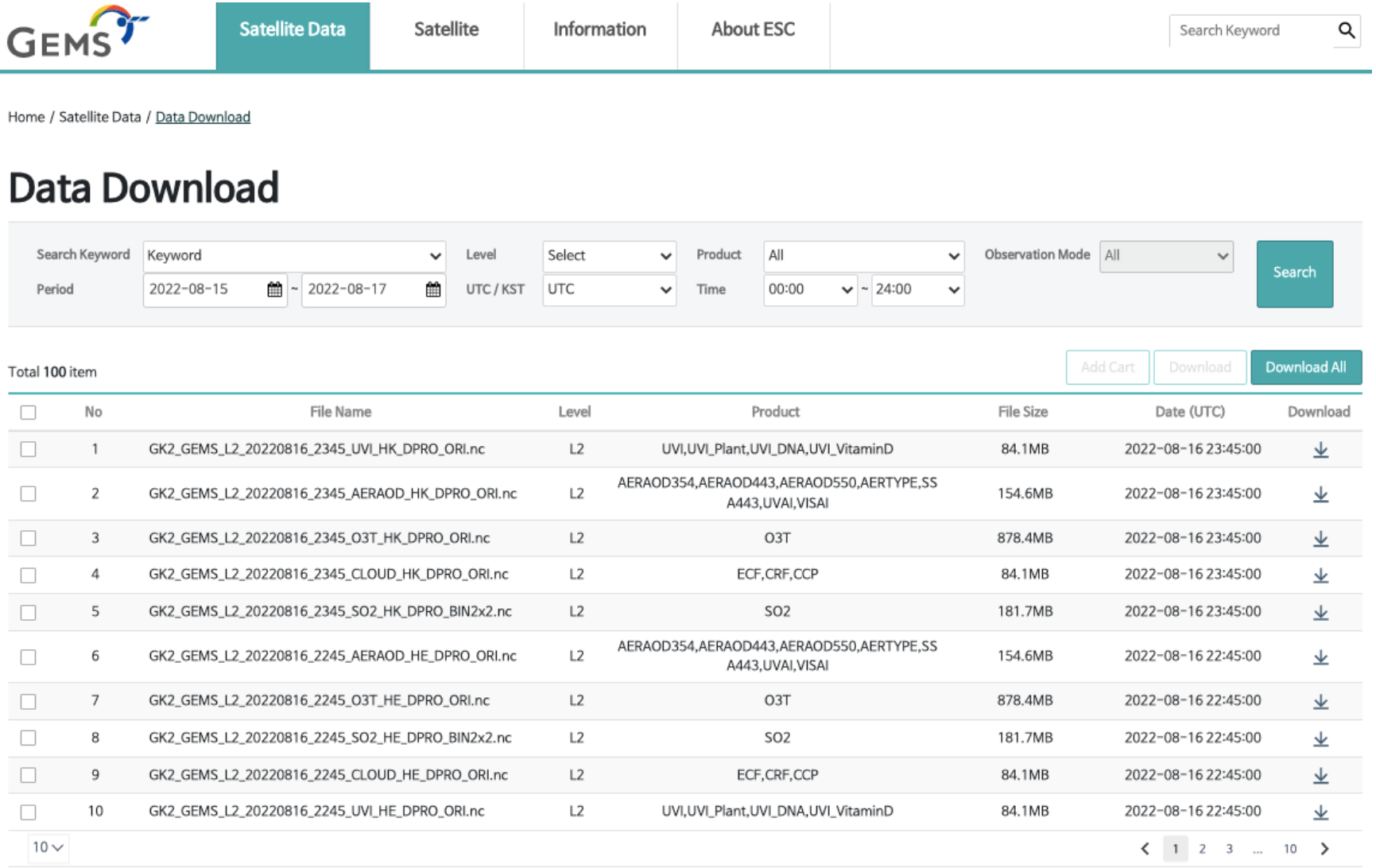


1. View GEMS Imagery
   - Begin by selecting the product of interest from the search bar, such as AOD, SSA, O3T, etc.
   - Use the temporal search options to filter the data by time and date.
   - You can see the image of the field of regards of GEMS and the zoomed-in area around the Korean Peninsula.
2. Download GEMS Data
3. Download ATBDs for GEMS





How to Access GEMS Data (3)

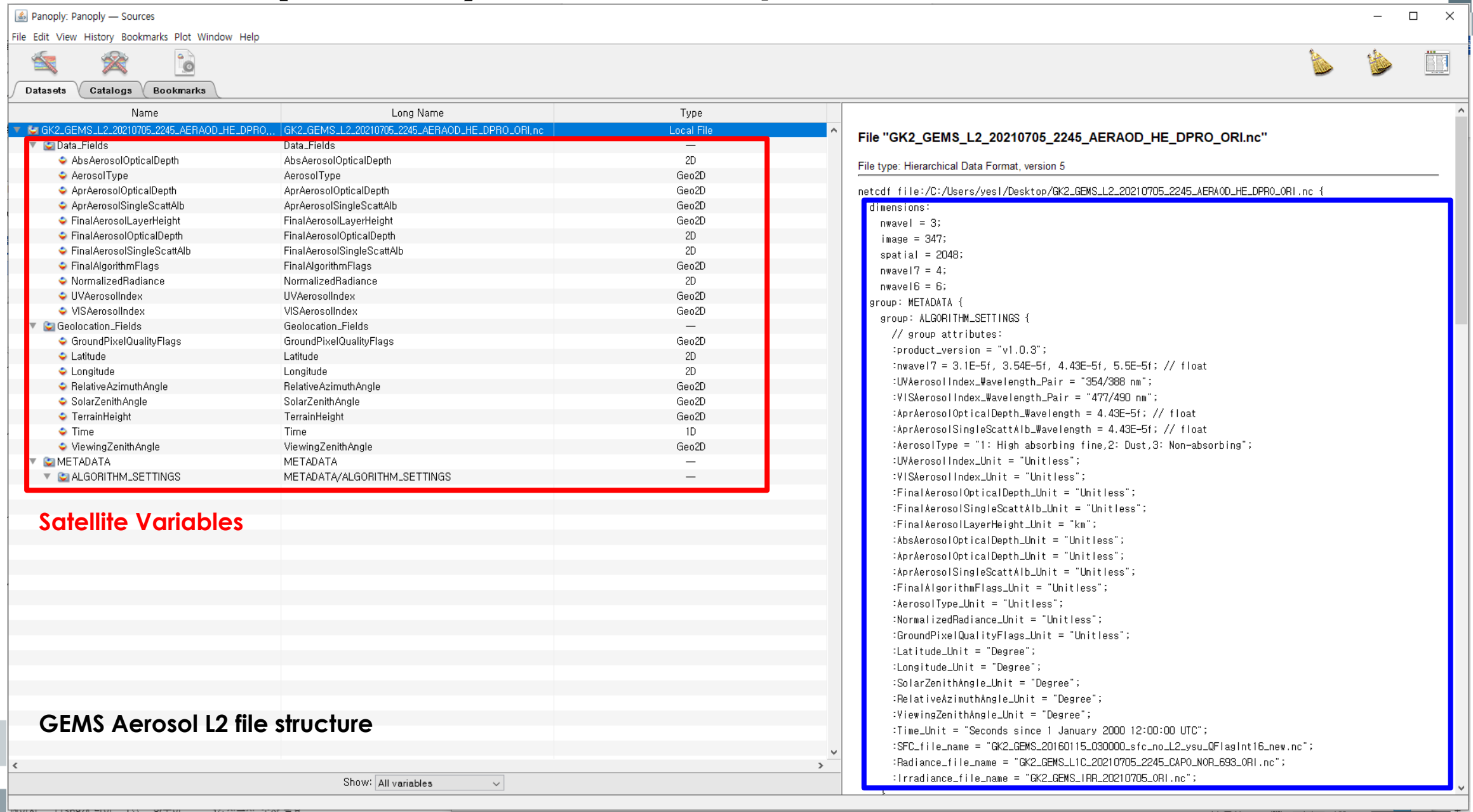


1. View GEMS Imagery
2. Download GEMS Data
   - Use the temporal search options to filter the data by time and date.
   - Click the Download button to begin downloading GEMS data.
   - You can download multiple files using checkboxes.
3. Download ATBDs for GEMS

GEMS NetCDF4 File Naming Conventions

- **SAT_Instrument_Level_ Date_Time_ALG_Area_ProcessType.Extension**
- i.e., GK2_GEMS_L2_20210705_2245_AERAOD_HE_DPRO_ORI.nc
  - SAT: Satellite name, GK2B (GEO-KOMPSAT 2B: Geostationary Korea Multi-Purpose Satellite)
  - Instrument: Instrument name, GEMS
  - Level: Data processing level, L2
  - Date: Observation date
  - Time: Start time of GEMS observation
  - ALG: Algorithm name
  - Area: GEMS scan area
  - Process Type: L2, including (DPRO: Daytime processing, NPRO: Night-time processing, RPRO: Re-processing)
  - Extension: File format, NC (NetCDF4 file)

GEMS AERAOD (Aerosol) Data Description



GEMS AERAOD (Aerosol) Data Description – Quality Flag

National Institute of Environmental Research
Republic of Korea

Geostationary Environment Monitoring Spectrometer (GEMS)

User's Guide

Aerosol

October 2020

National Institute of Environmental Research
Republic of Korea

quality of retrieval is reliable. If bits are 1, 10, 11, or 12, the quality of retrieval is less reliable.

Table 2. Quality flags for the GEMS Aerosol L2 file.

Bits	Definition	Note	Description
0	Reliable (AOD, SSA, ALH)	Good	(0, Good; 1 : have issue) AOD > 0.2 & ALH AK > 0.2
1	Less reliable (AOD, SSA, ALH)	Suspect	AOD < 0.2 or ALH AK < 0.2
2	Out-of-bounds SSA or AOD at 443 nm.	Bad	AOD < –0.05 or AOD > 3.6 or SSA < 0.82 or SSA > 1.0
3	OE fitting error	Bad	Fitting error during optimal estimation.
4	Normalized radiance above threshold	Bad	High normalized radiance
5	Surface albedo above threshold	Bad	High surface albedo
6	Cloud masking	Cloud	Presence of clouds
7	Solar zenith angle above threshold (69°) or viewing zenith angle above threshold (69°).	Bad	SZA > 69° or VZA > 69°
8	Sun-glint angle below threshold over water	Bad	Sun glint angle < 30°
9	Terrain height high	Suspect	Terrain height > 2 km
10	Previous L2 SFC (-5day) are used	Suspect	Absence of L2 SFC information
11	OMI climatology used for surface albedo	Suspect	Absence of L2 SFC information
12	Previous irradiance used	Suspect	Absence of L1C irradiance
13	AMI cloud-masking used	Cloud	Cloud masking using AMI L2 Cloud product.

Table 3. The example of a quality flag of 2561.

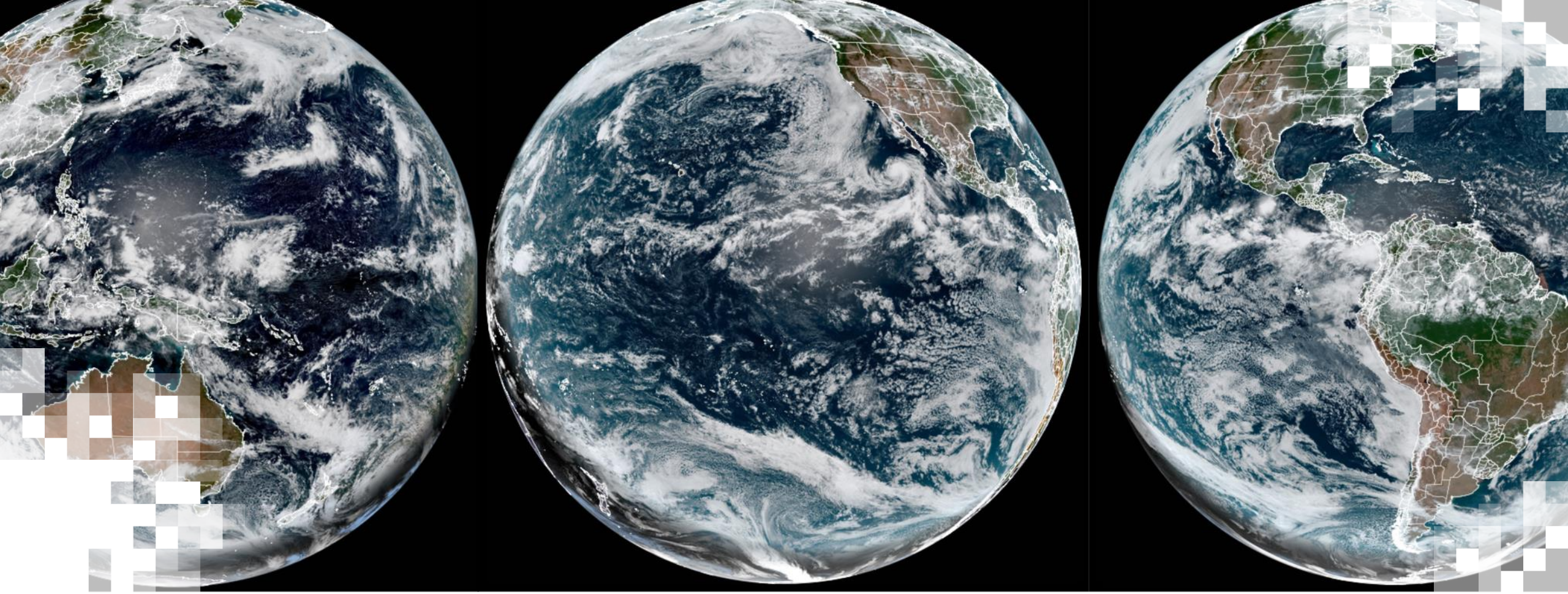
Bits	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	0	0	1	0	1	0	0	0	0	0	0	0	0	1
	$2^0 + 2^9 + 2^{11} = 1+512+2048 = 2561$													

2.2.9 NormalizedRadiance

Normalized radiance [steradian^{-1}]

8

※ User guide will be downloadable from the ESC website: https://nesc.nier.go.kr



4. Python Jupyter Notebooks Exercise to Read, Map, and Analyze GEMS Data


APPLIED REMOTE SENSING TRAINING PROGRAM
TRAIN - EMPOWER - ADVANCE

Thank You!