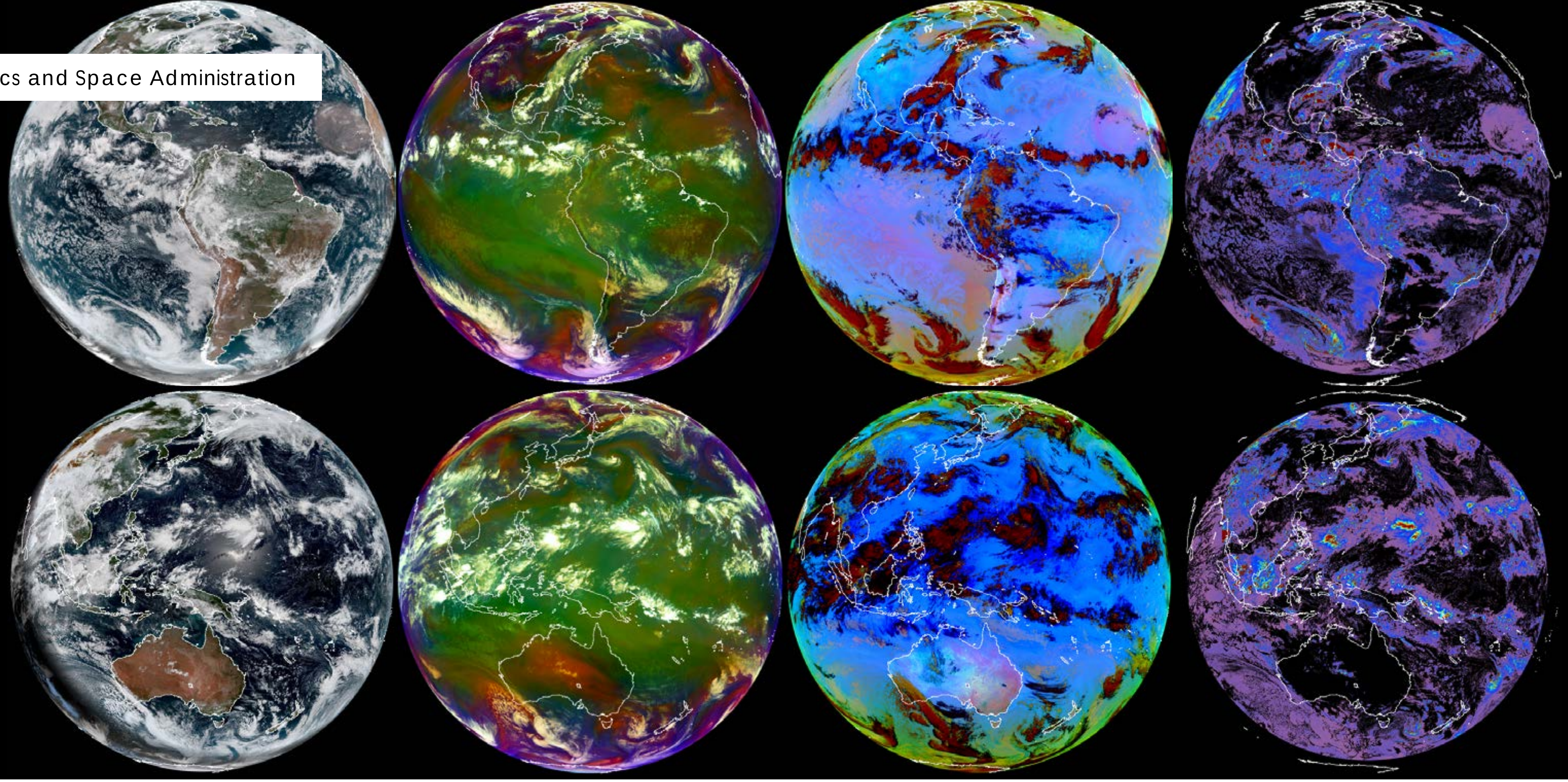
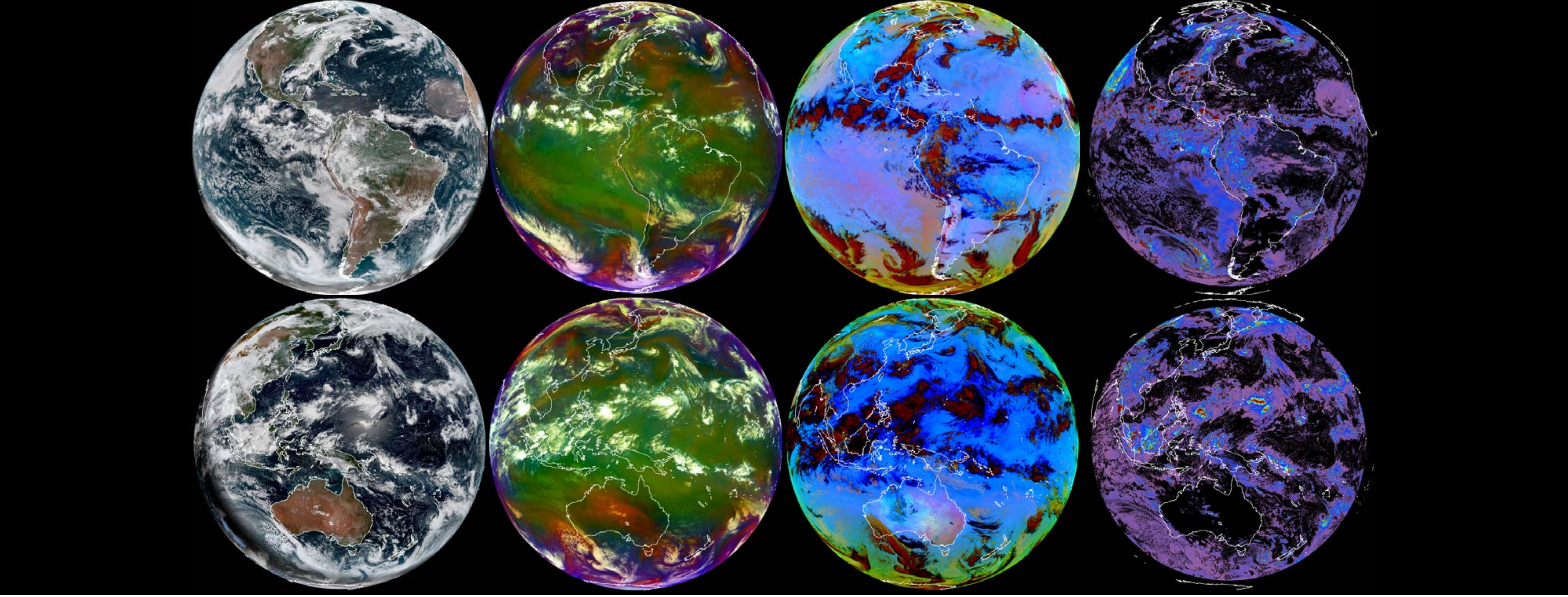
National Aeronautics and Space Administration



Aerosol Observations from the HIMAWARI, GOCI, and GEMS Satellites over Asia

Myungje Choi (Yonsei University, South Korea; choi816@yonsei.ac.kr)

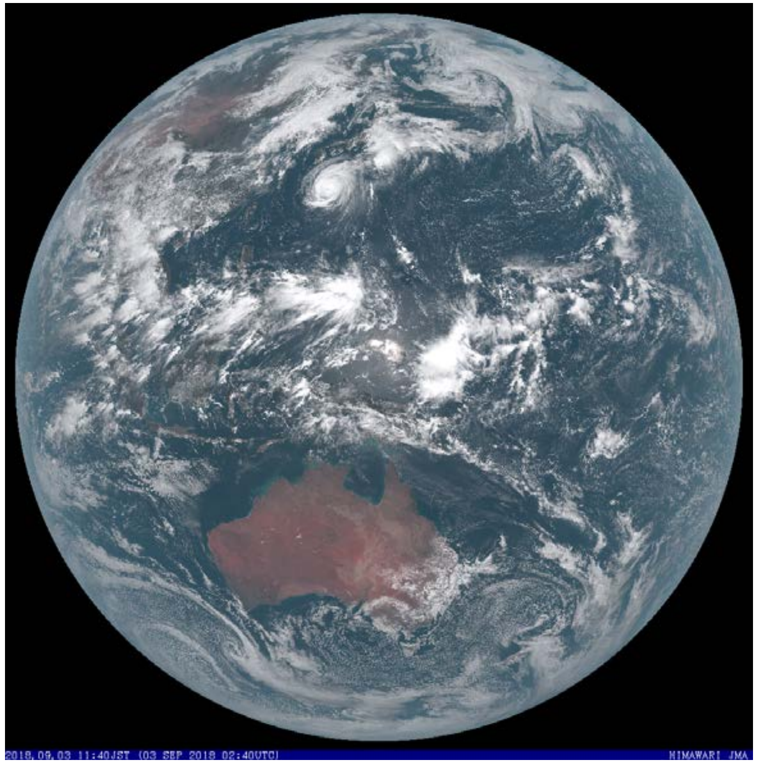
September 18, 2018



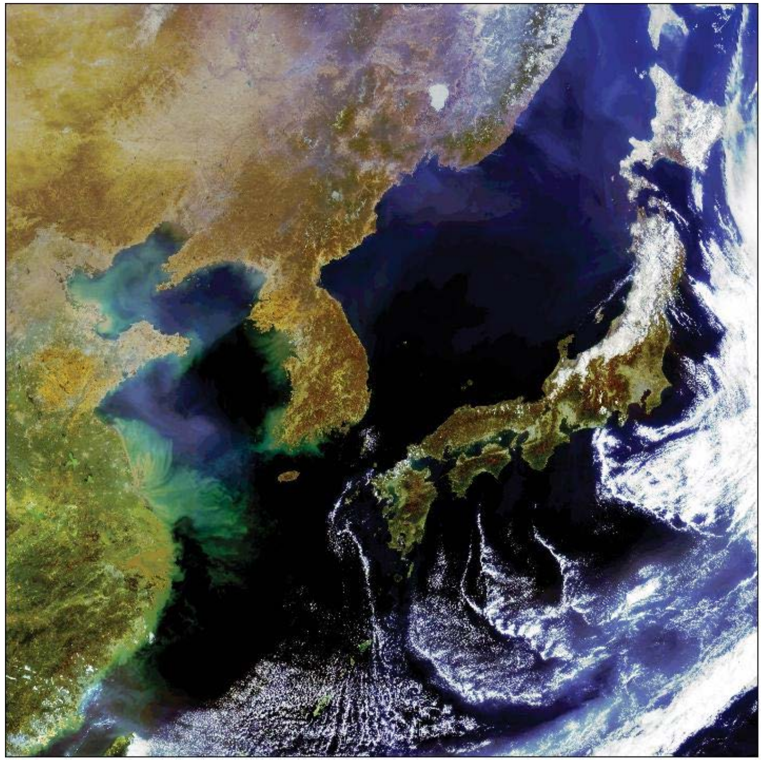
Introduction to Himawari-8, GOCI, and GEMS

Aerosol Observations From Geostationary Satellites Over East Asia

AHI/Himawari-8



GOCI/COMS



GEMS/GEO-KOMPSAT-2

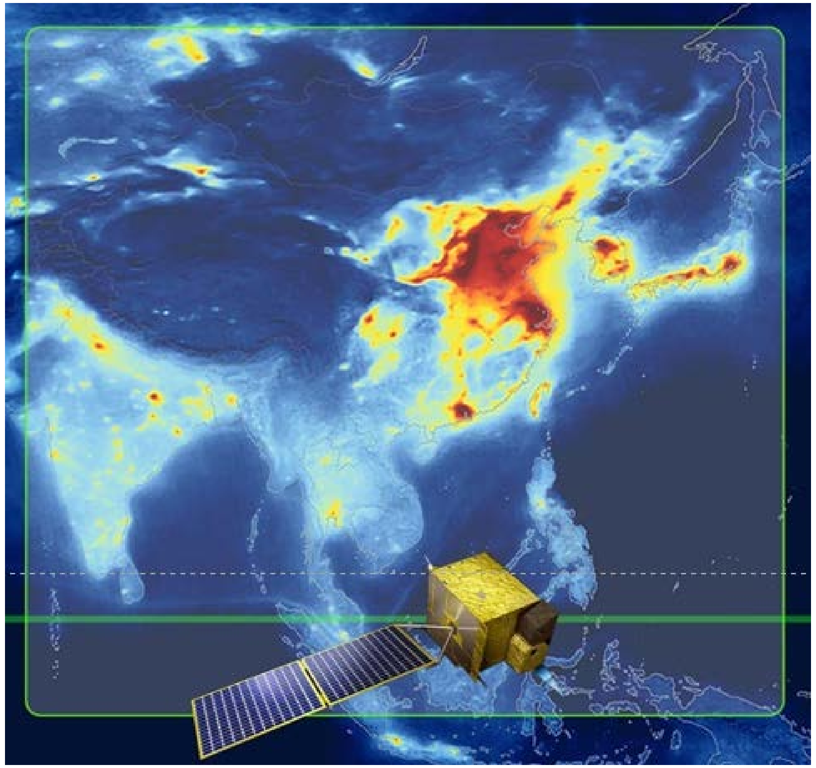
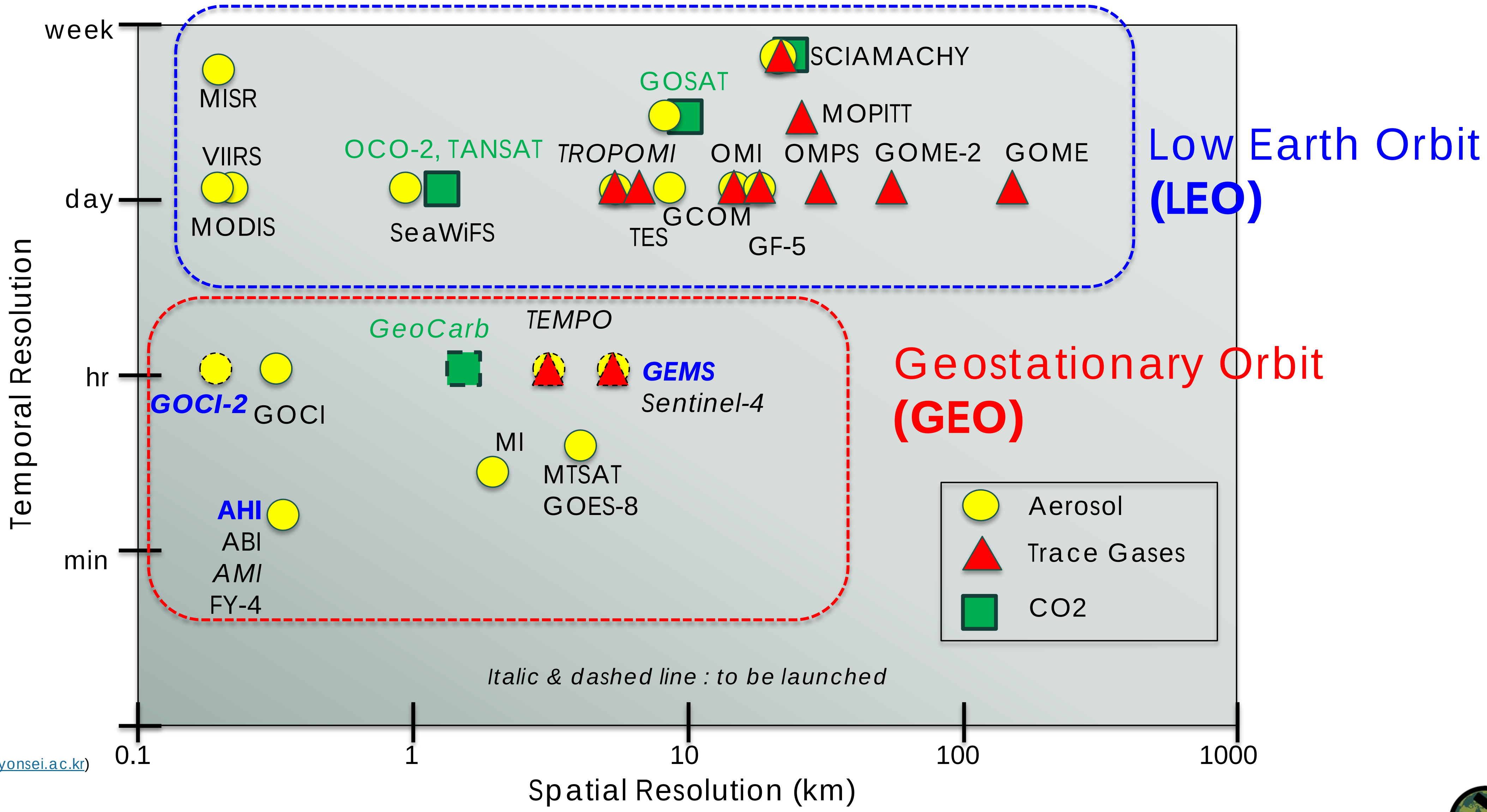


Image credit: JMA, KIOST, and NASA LaRC

Development of Satellite Remote Sensing Capability for Air Quality



Credit: Jhoon Kim (jkim2@yonsei.ac.kr)

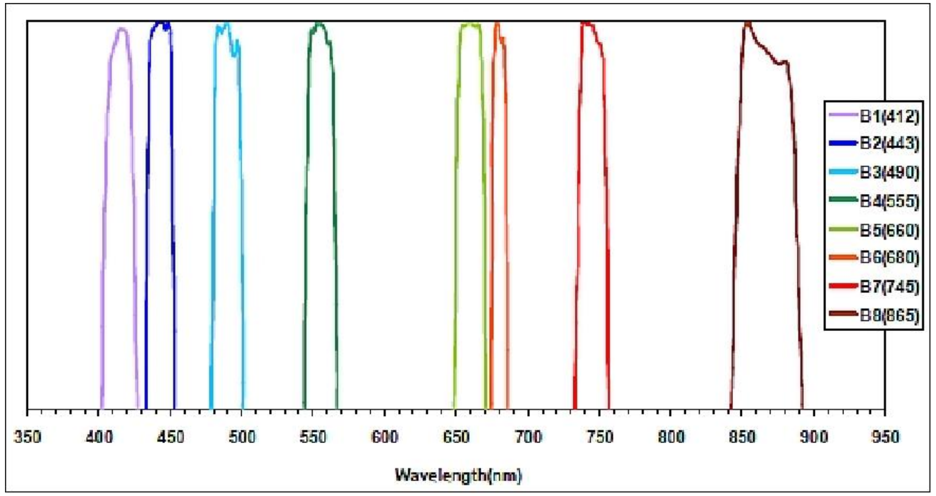
GOCI Specifications

- The instrument (Sensor): Geostationary Ocean Color Imager (GOCI)
- The satellite: COMS (Jun. 2010~ [2020](#))
- Primary objective: Ocean color measurement (Chlorophyll concentration, etc.)
- Previous/current ocean color sensors
  - CZCS, SeaWiFS, MERIS, MODIS, OLCI, etc (only LEO)
- 8 channels
  - 6 visible channels (412, 443, 490, 555, 660, and 680 nm)
  - 2 near-Infrared channels (745 and 865 nm)

COMS

GOCI Filter Wheel

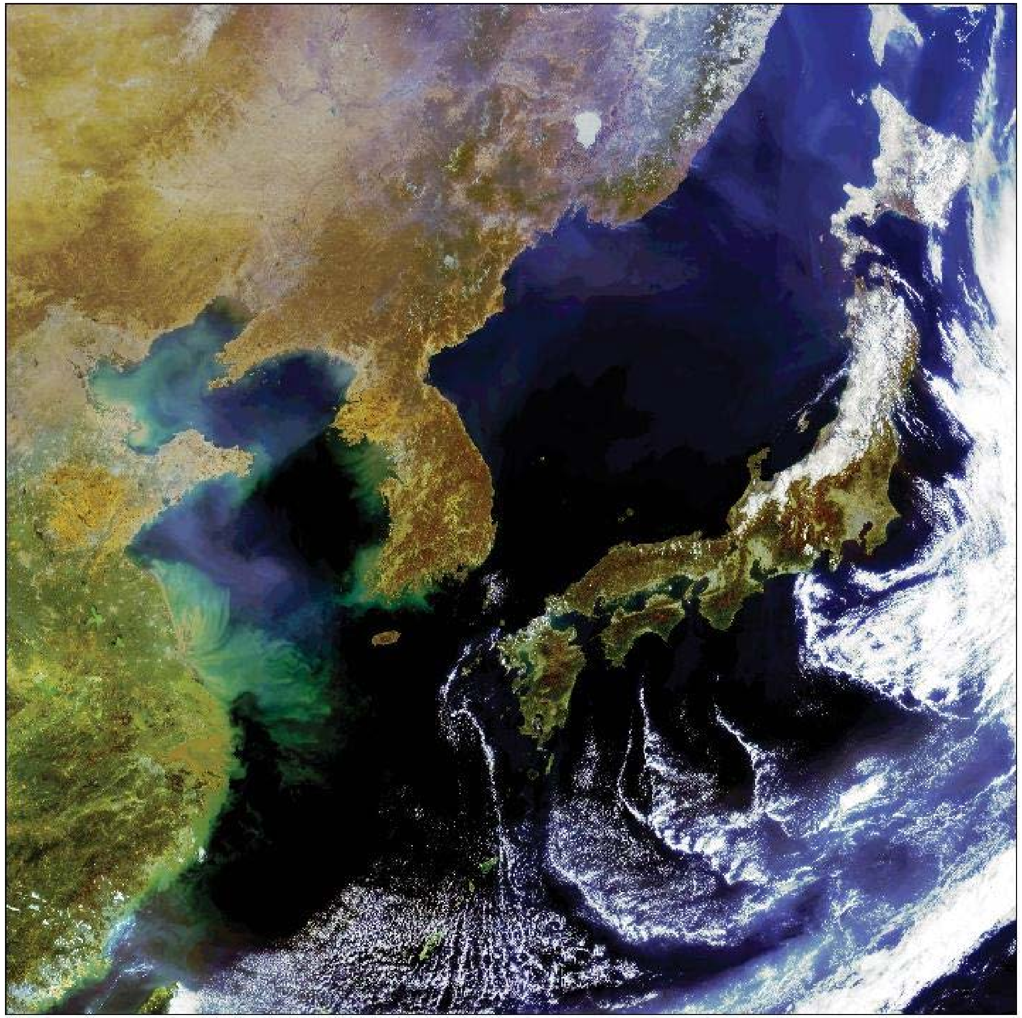
[GOCI spectral response function]



Credit: KOSC/KIOST, eoPortal (https://directory.eoportal.org/web/eoportal/satellite-missions/c-missions/coms-1)

GOCI Specifications (Cont.)

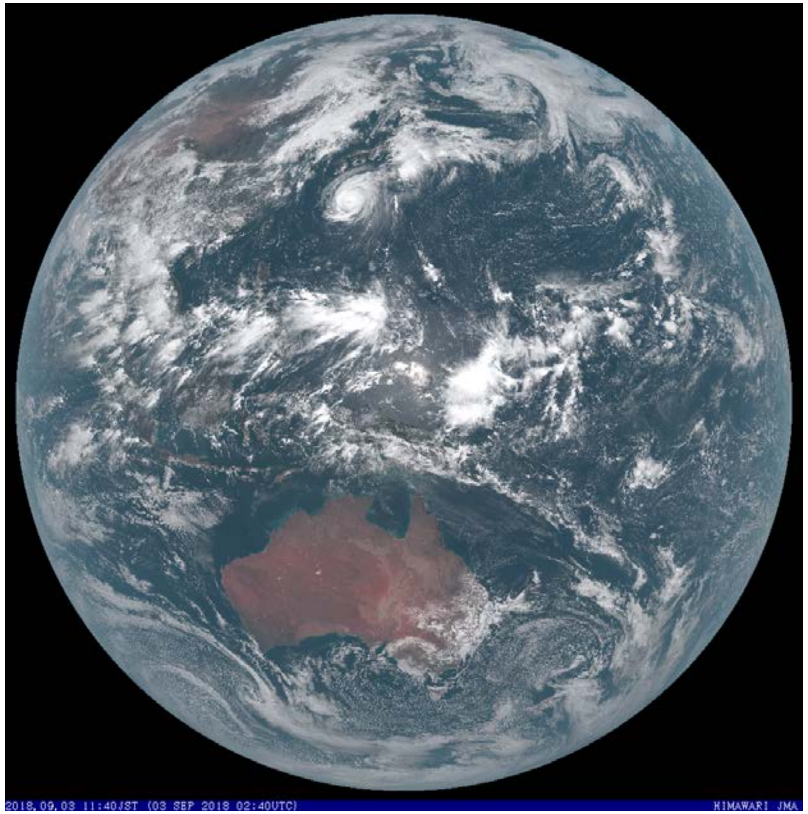
- Temporal resolution
  - 1 hour resolution (09:30 to 16:30 local time ; UTC+9)
- Spatial coverage (right figure)
  - East Asia (2,500 km × 2,500 km area including Eastern China, Korea, and Japan)
- Spatial resolution
  - 0.5 km × 0.5 km



Credit: KOSC/KIOST(http://kosc.kiost.ac.kr/)

AHI Specifications

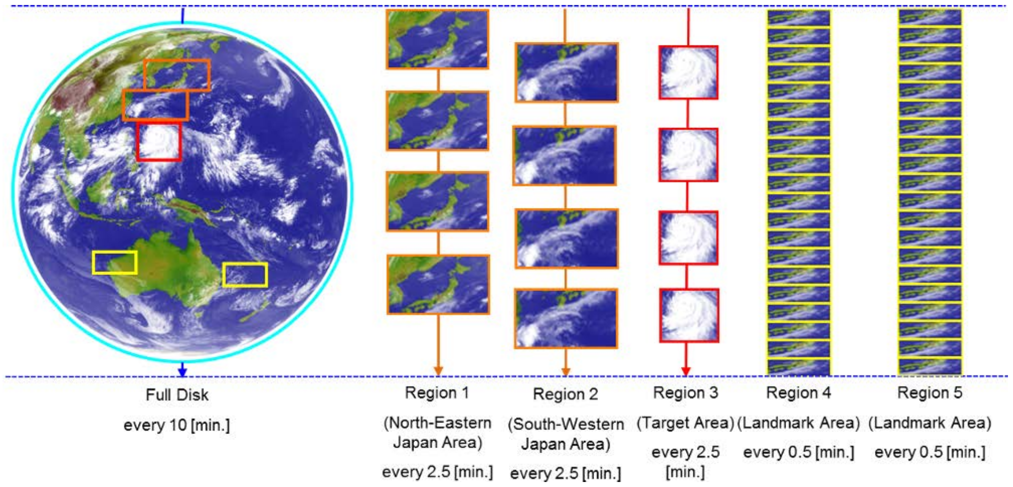
- Payload (Sensor): Advanced Himawari Imager (AHI)
- Satellite:
  - Himawari-8 (Oct 2014~)
  - Himawari-9 (Nov 2016~)
- Primary Objective: fast scanning and reporting of meteorological conditions over East Asia (e.g., Typhoons)
- Previous GEO satellite meteorological sensors over East Asia:
  - MTSAT (Japan), MI/COMS (Korea), Feng-Yun 2 series (China)
  - One broad visible channel (not suitable for high quality aerosol retrievals)
- Other similar next-generation meteorological satellite sensors:
  - ABI, operated by U.S.
  - AMI (will be) operated by Korea
  - Feng-Yun-4A (FY-41) operated by China

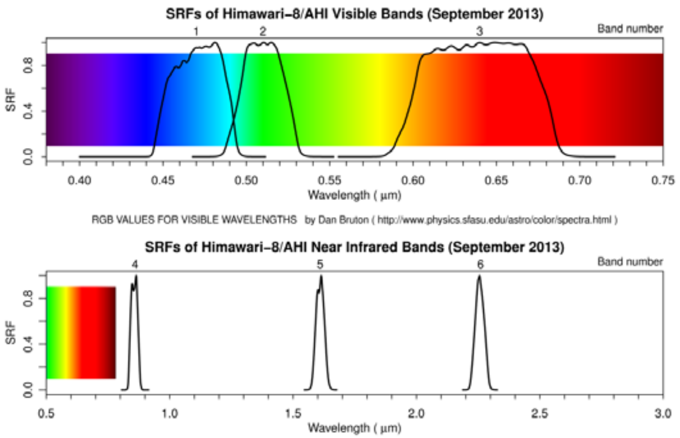


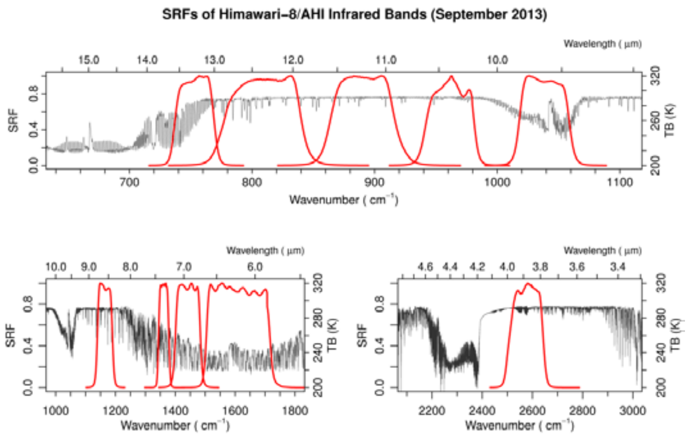
Credit: JMA (https://www.data.jma.go.jp/mscweb/en/himawari89/space_segment/spsg_ahi.html)

AHI Specifications (Cont.)

- Temporal resolution (and spatial coverage)
  - every 2.5-minutes (North-Eastern Japan, South-Western Japan, and Target Area)
  - every 10-minutes (Full-Disk; 6 times per hour × 24 hours = 144 times per day)
- 16 channels
  - 3 visible channels (0.47, 0.51, and 0.64 µm): related to aerosols
  - 1 near-Infrared (NIR) (0.86 µm) / 2 shortwave IR (SWIR) channels (1.6, and 2.3 µm): related to surface
  - 10 Infrared channels (3.9−13.3 µm): related to clouds
  - spatial resolution: 1 km, 0.5 km, and 2 km



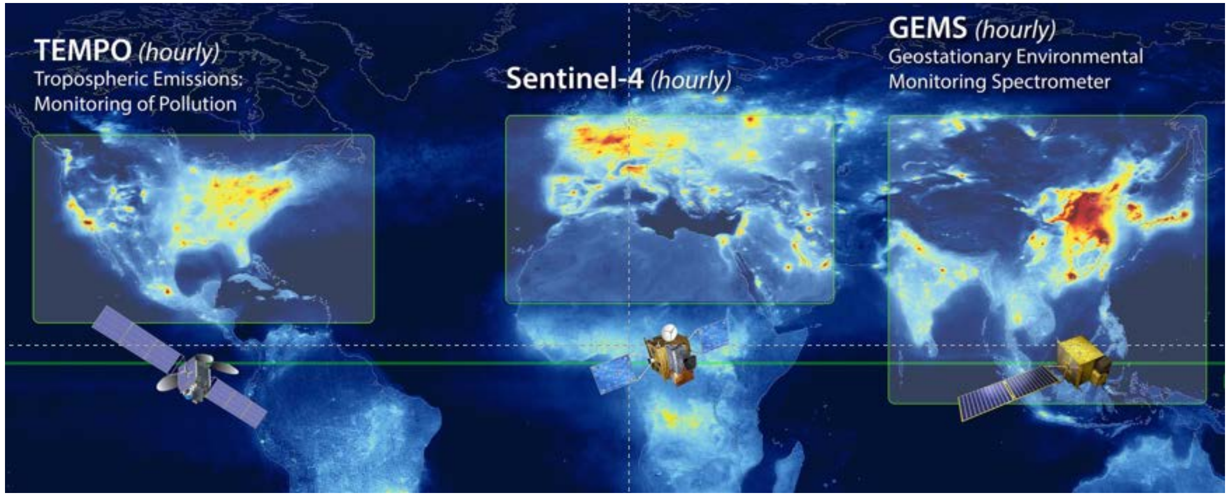




Credit: JMA (https://www.data.jma.go.jp/mscweb/en/himawari89/space_segment/spsg_ahi.html)

GEMS Specifications

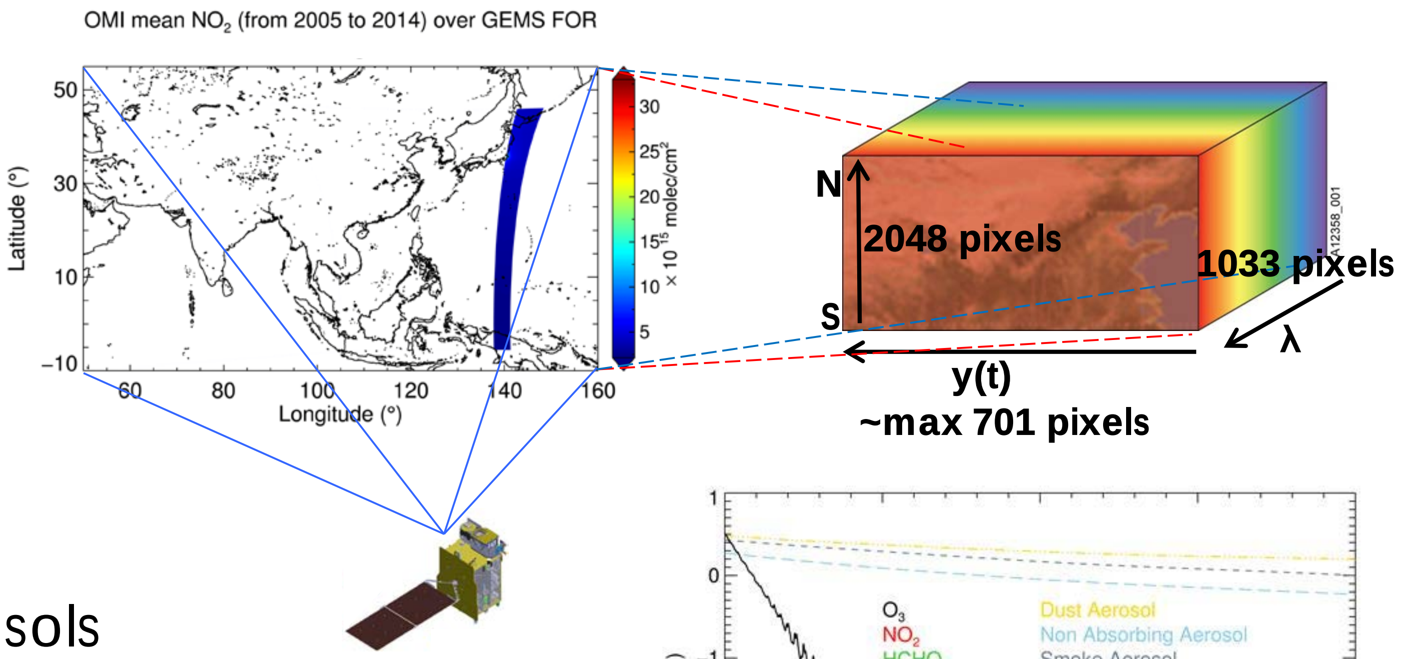
- Payload (Sensor): Geostationary Environmental Monitoring Spectrometer (GEMS)
- Satellite: GEO-KOMPSAT-2B (from late 2019 or early 2020; 10-year life span)
- Primary Objective: Air quality (aerosols and trace gases) measurement
- Other similar previous/current/planned sensors
  - SBUV, GOME, GOME-2, SCIAMACHY, OMI, OMPS, TROPOMI, etc. (LEO)
- International constellation for observing air quality with TEMPO (U.S.) and Sentinel-4 (Europe)

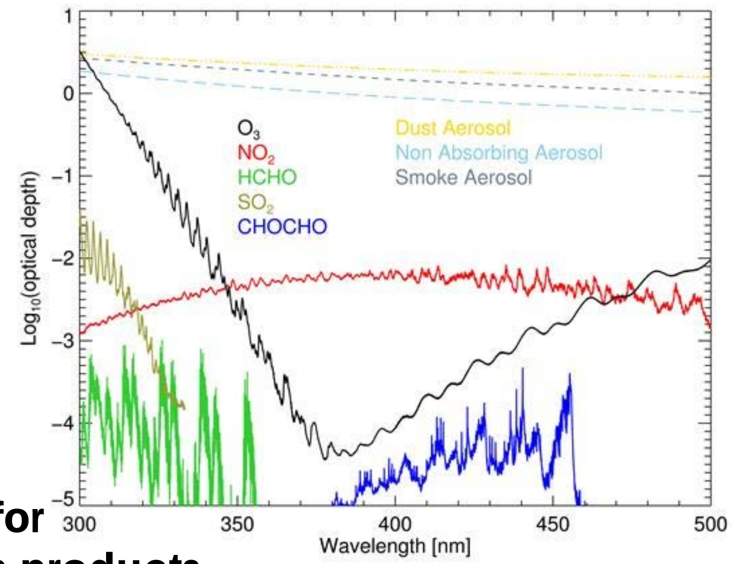


Credit: KARI, NIES, Yonsei University, Image Credit: NASA LaRC

GEMS Specifications (Cont.)

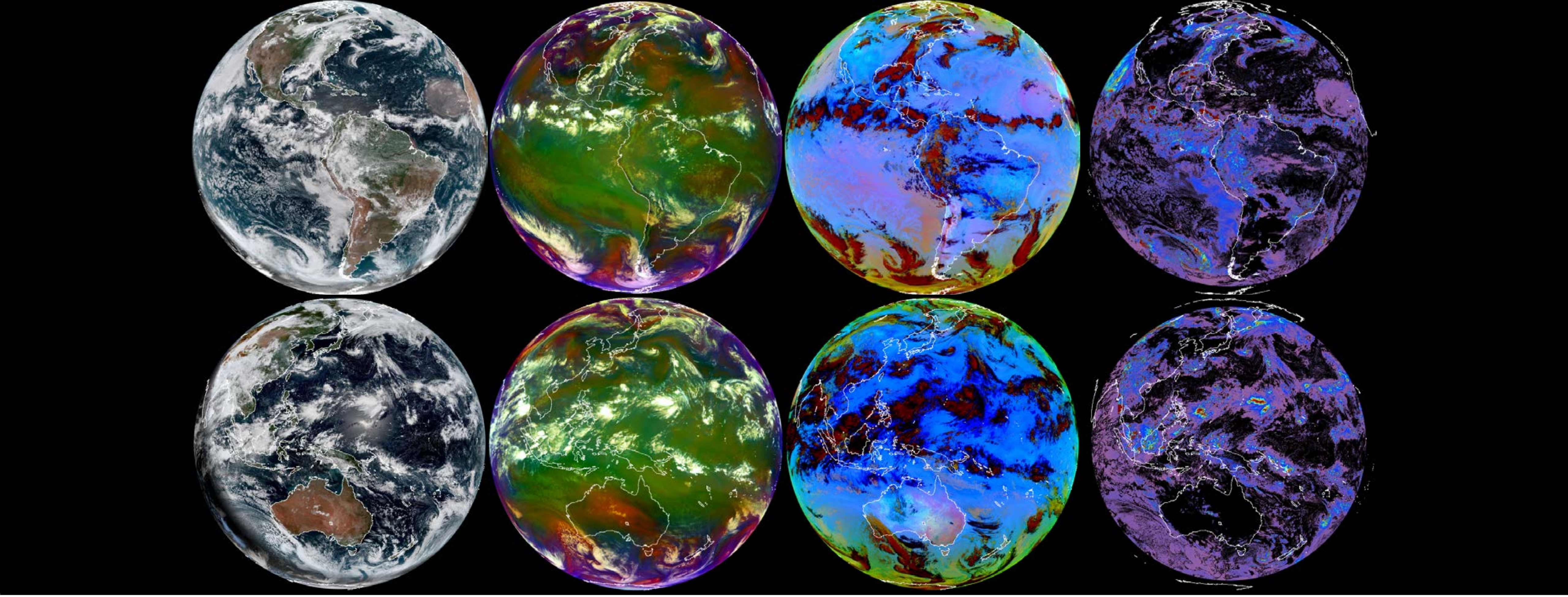
- Temporal resolution
  - 1 hour resolution during daytime (8 times per day)
- Spatial coverage (right figure)
  - East Asia (latitude: 5°S-45°N; longitude: 75-145°E)
- Spatial resolution
  - 3.5 (7)km × 8 km at Seoul for aerosols (trace gases)
- Spectral range and resolution
  - 300-500 nm with 0.6 nm resolution
  - high resolution to detect trace gases absorption





Typical optical depth for GEMS aerosol and gas products

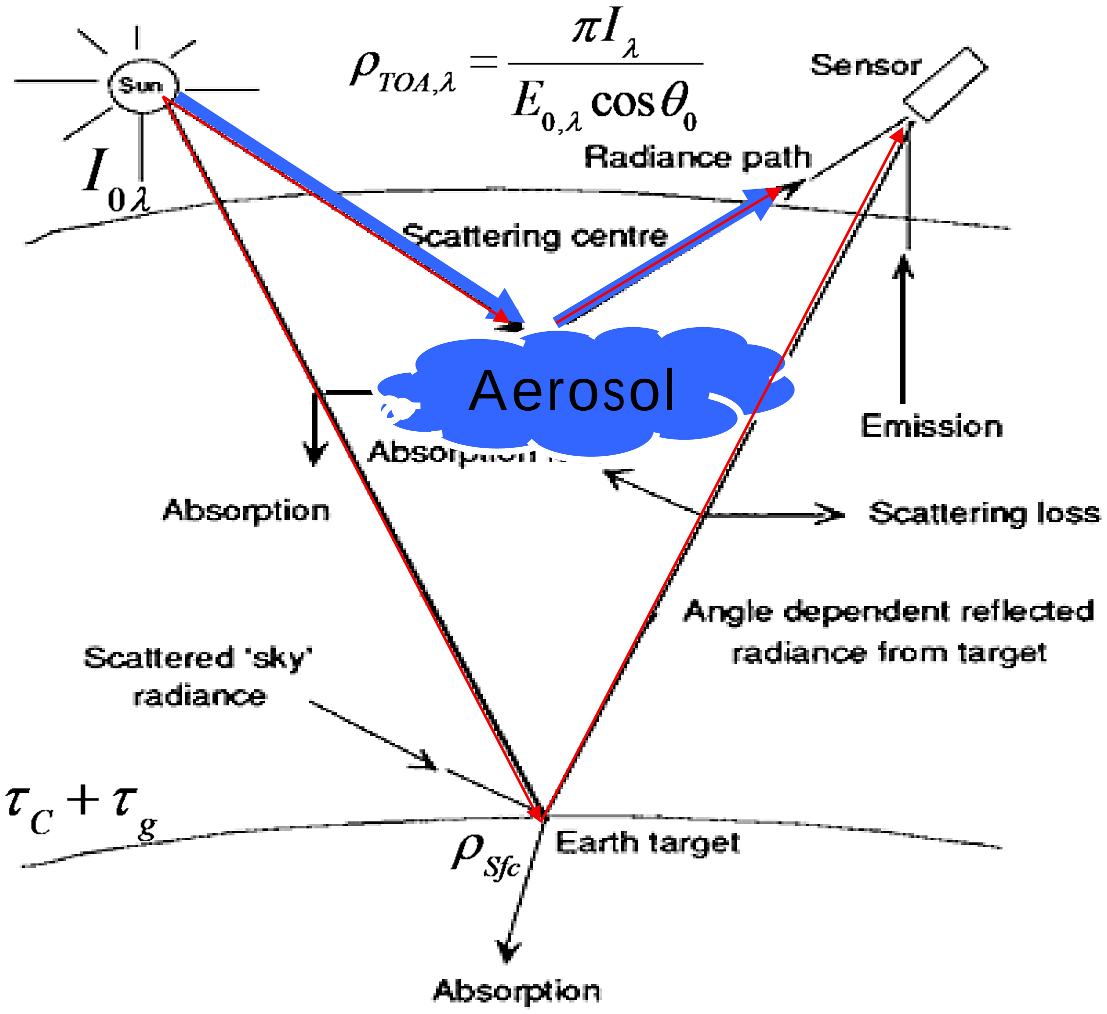
Credit: KARI, Kim et al (to be submitted), Yonsei University



Aerosol Optical Properties and Retrieval Algorithm

Principles of Aerosol Remote Sensing

$$\rho_{TOA,\lambda} = \frac{\pi I_\lambda}{E_{0,\lambda} \cos\theta_0}$$



$$I_\lambda = I_{0\lambda} \exp(-\tau_t)$$

$$\text{where } \tau_t = \tau_R + \tau_a + \tau_C + \tau_g$$

t: total
R: Rayleigh scattering
a: aerosol; C: cloud; g: gas

Rayleigh scattering

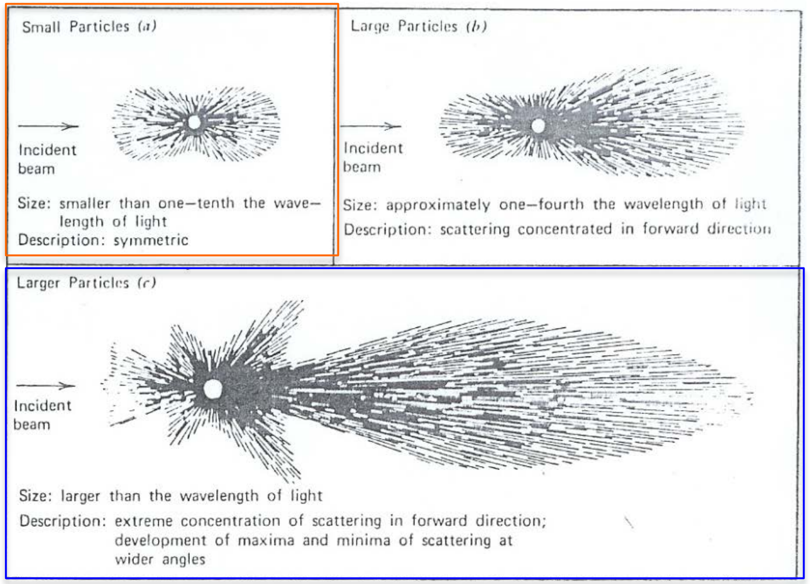


Figure 1.5 Angular patterns of scattered intensity from particles of three sizes. (*a*) Small particles, (*b*) large particles, (*c*) larger particles. From Brumberger et al. (1968).

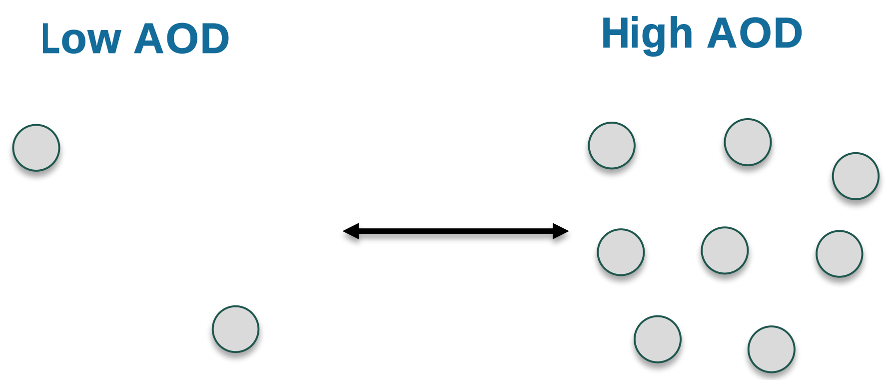
Mie scattering

$$x = \frac{2\pi r}{\lambda}$$

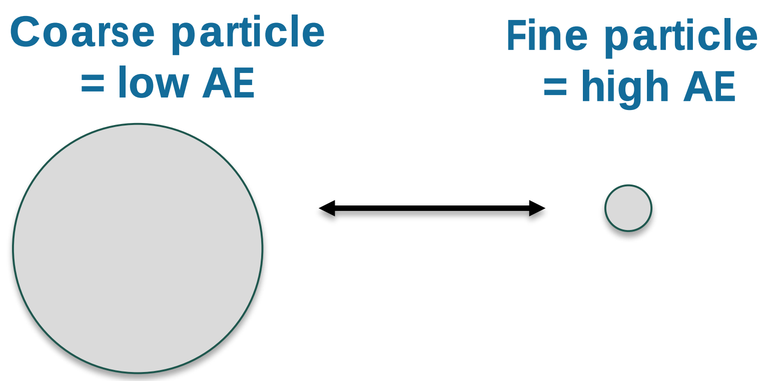
Credit: Jhoon Kim (jkim2@yonsei.ac.kr)

Definition of Aerosol Optical Properties

- **Aerosol optical depth (AOD)**
  - The degree to which aerosols prevent the transmission of light by absorption or scattering of light.
  - total column integrated value from surface to top-of-atmosphere



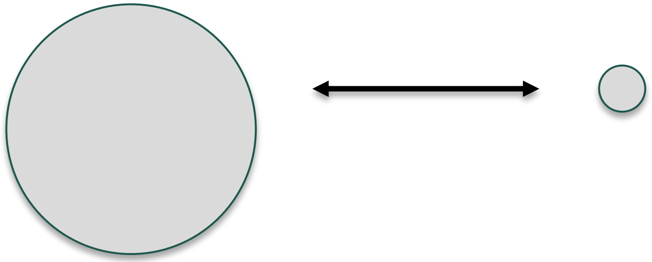
- **Ångström Exponent (AE)**
  - The spectral dependence of AOD
    It is related to the particle size
  - high AE ~2: small particle (e.g. smoke)
  - low AE ~0: coarse particle (e.g. dust)



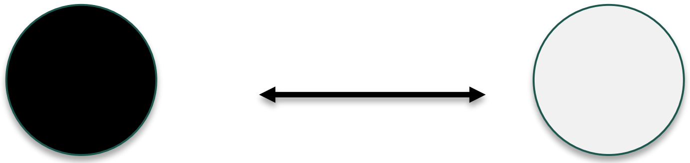
Credit: NASA GES DISC (https://disc.gsfc.nasa.gov/information/glossary), Jhoon Kim (jkim2@yonsei.ac.kr)

Definition of Aerosol Optical Properties (Cont.)

- **Fine-mode fraction (FMF)**
  - Aerosol volume size distribution: bi-modal shape (generally)
    - fine-mode: 0.1-0.25 µm
    - coarse-mode: 1.0-20 µm
  - Total AOD = coarse-mode AOD + fine-mode AOD
  - **FMF = fine-mode AOD / total AOD (range: 0.0-1.0)**



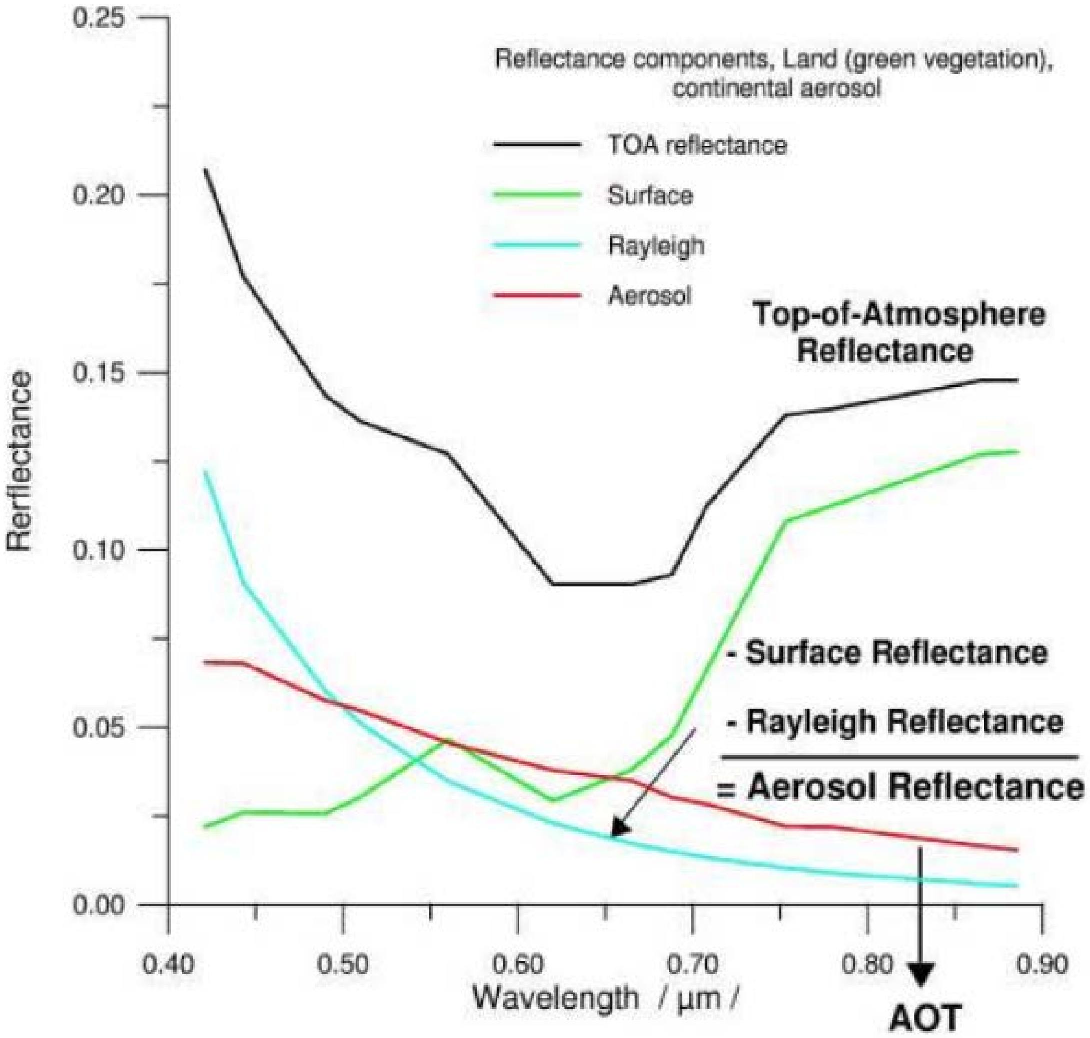
- **Single scattering albedo (SSA)**
  - The effectiveness of scattering relative to extinction for the light encountering the atmospheric aerosol particles
  - extinction coefficient = absorption coeff. + scattering coeff.
    → **SSA = scattering coeff. / extinction coeff.**
  - Scattering aerosol (high SSA): cooling
  - Absorbing aerosol (low SSA): warming



NASA GES DISC (https://disc.gsfc.nasa.gov/information/glossary)

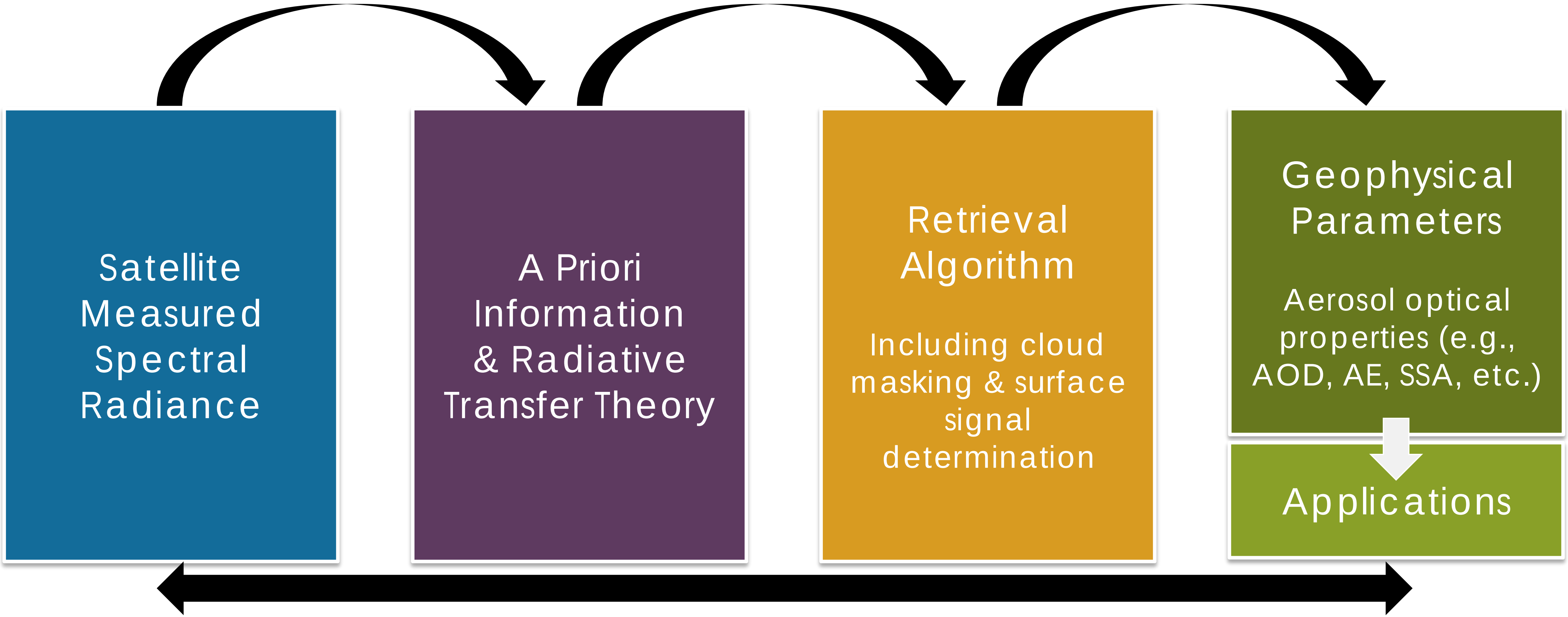
<u> No units for AOD, AE, FMF, and SSA</u>*

Top-of-Atmosphere (TOA) Reflectance Components



W. von Hoyningen-Huene et al.(2011), AMT: https://www.atmos-meas-tech.net/4/151/2011/

The Remote Sensing Process

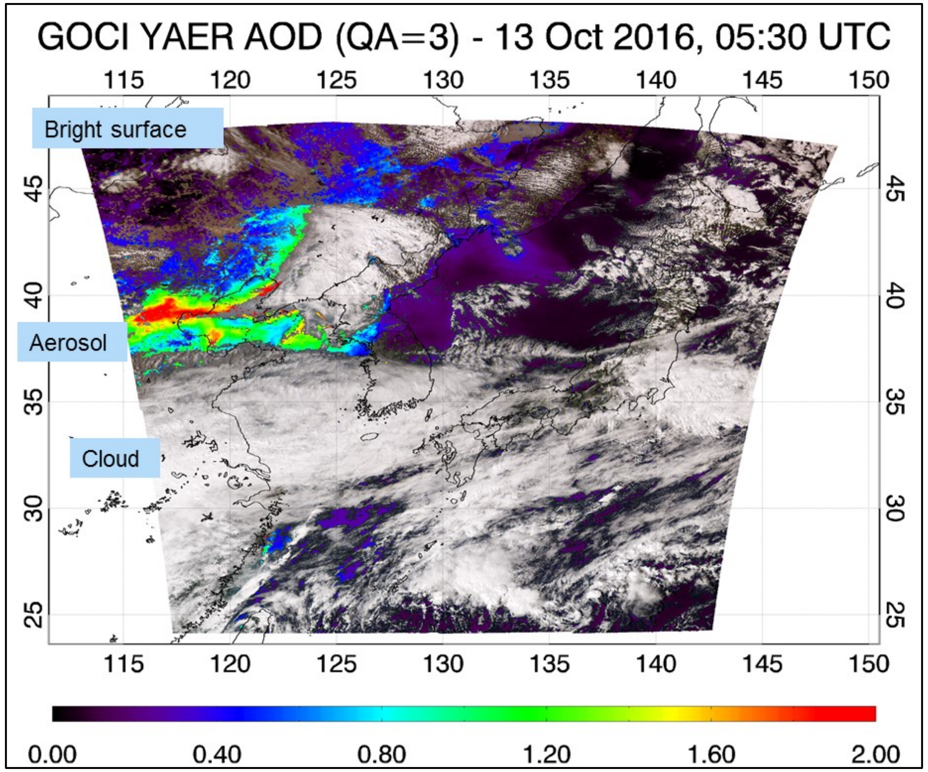


Inappropriate Pixel Masking in Aerosol Retrieval Algorithm

- The algorithm is applied to **cloud-free and snow-free** pixels over land and **cloud-free and ice-free** over ocean
- General characteristics of clouds compared to aerosols according to **VIS** (visible) and **IR** (infrared) channels:
  - Spatially inhomogeneous and bright (**VIS**): GOCI, GEMS, AHI
  - Low brightness temperature due to high altitude of clouds (**IR**): AHI
  - Sensitivity to ice-crystals or water droplets (in specific **IR**): AHI
- Bright surfaces such as **snow** or **ice** (too bright)
  - Less aerosol sensitivity (**VIS**): no retrievals
- Bright surfaces such as the **desert**
  - low surface reflectance **UV** (ultraviolet) channels

  → still high aerosol sensitivity

  → aerosols can be retrieved using GEMS



Approximation of Land Surface Reflectance

- **"Dark Target" concept**
  - based on Kaufman et al. (1997), Remer et al. (2005)
  - **Linear relationship between short-wave IR (SWIR) and visible surface reflectance**
  - real-time retrieving dark surface reflectance in visible (0.6μm) using TOA reflectance in IR (2.1μm)
  - considered different relationships according to **NDVI**
  - MODIS Dark Target products (NASA), VIIRS EDR products (NOAA)

  → **applied to AHI aerosol retrieval algorithm**

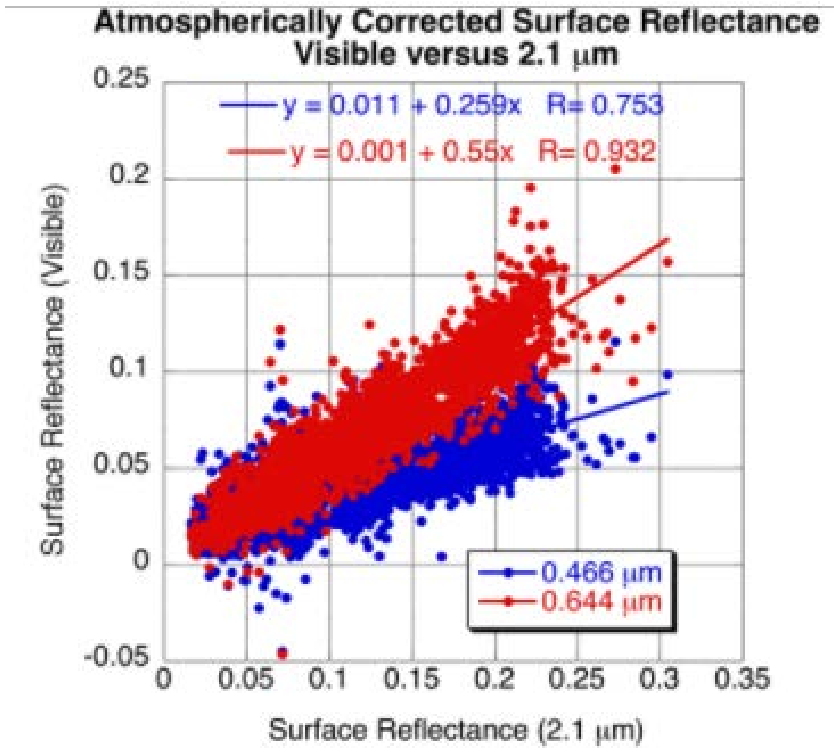


Image Credits: Levy et al. (2007) https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2006JD007811

Approximation of Land Surface Reflectance

- **The minimum reflectance from composite database**
  - based on Herman and Celarier (1997); Hsu et al. (2004)
  - pre-calculation concept (climatological dataset)
  - **composite Rayleigh-corrected reflectance and determine dark value for surface reflectance**
  - SeaWiFS/MODIS deep blue aerosol products (NASA)
  - TOMS/OMI aerosol and trace gases products (NASA)

  → **applied to GOCI, GEMS, and AHI aerosol retrieval algorithm**

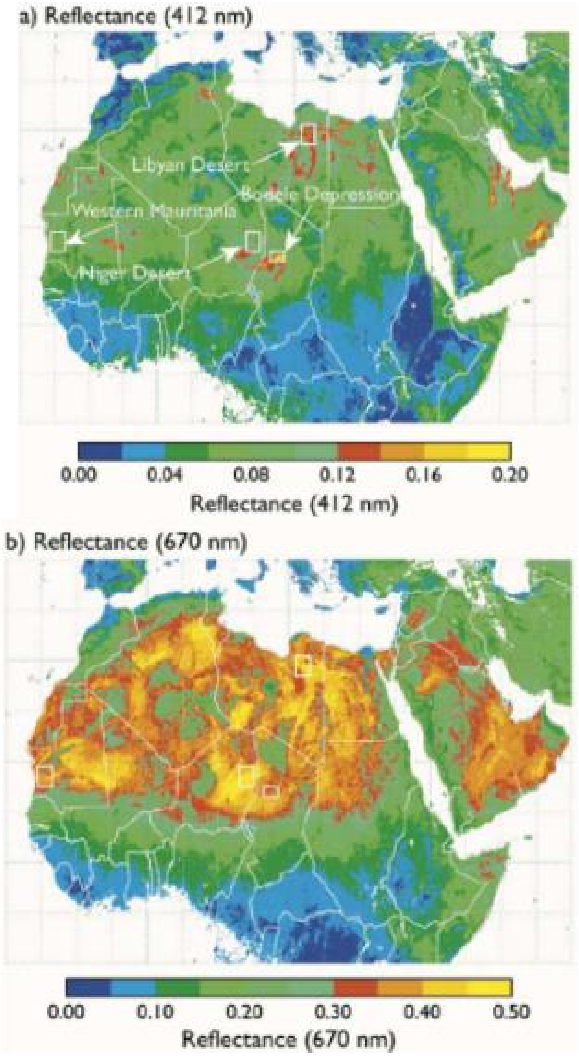
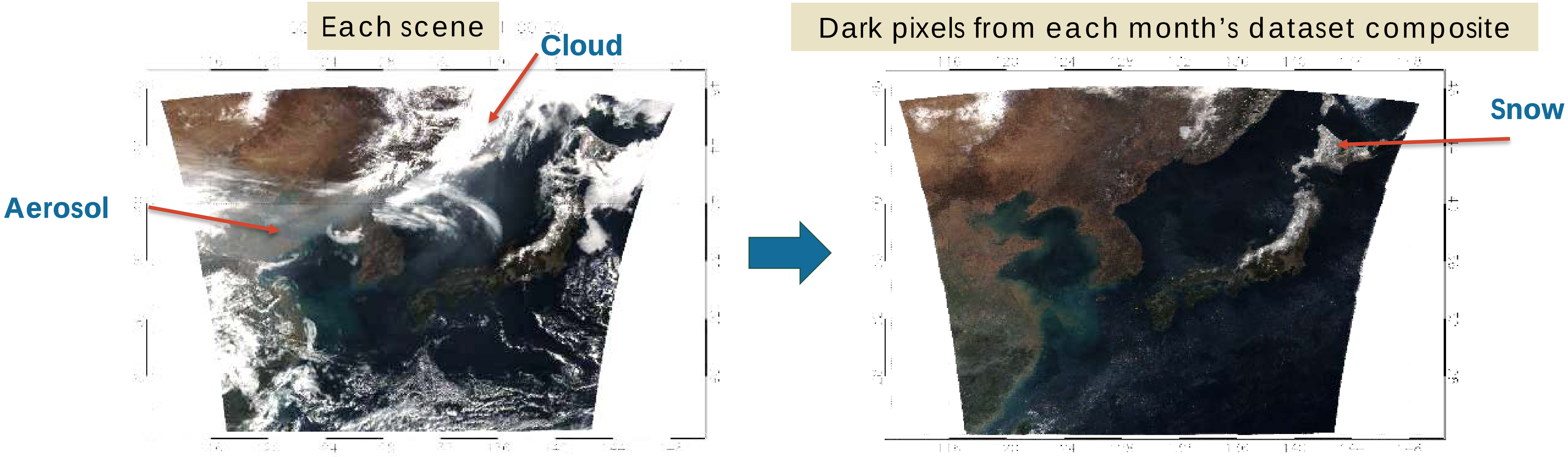


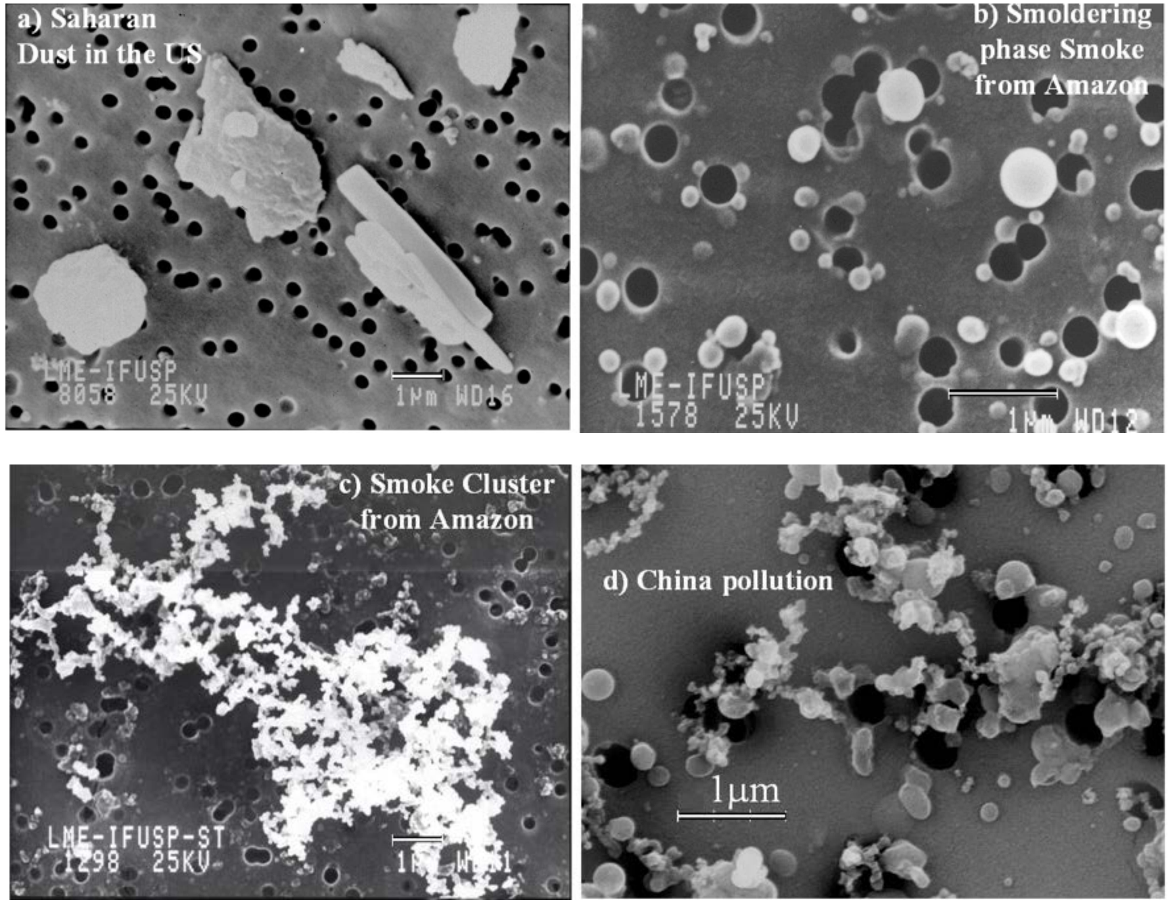
Image Credits: Hsu et al. (2004) http://ieeexplore.ieee.org/document/1273587/

Land Surface Reflectance Using the Minimum Reflectivity Technique

- Composite of one-month, same hourly scenes (Rayleigh-corrected reflectance)
  – finding a dark scene and consider it for surface reflectance



Aerosol Optical Properties



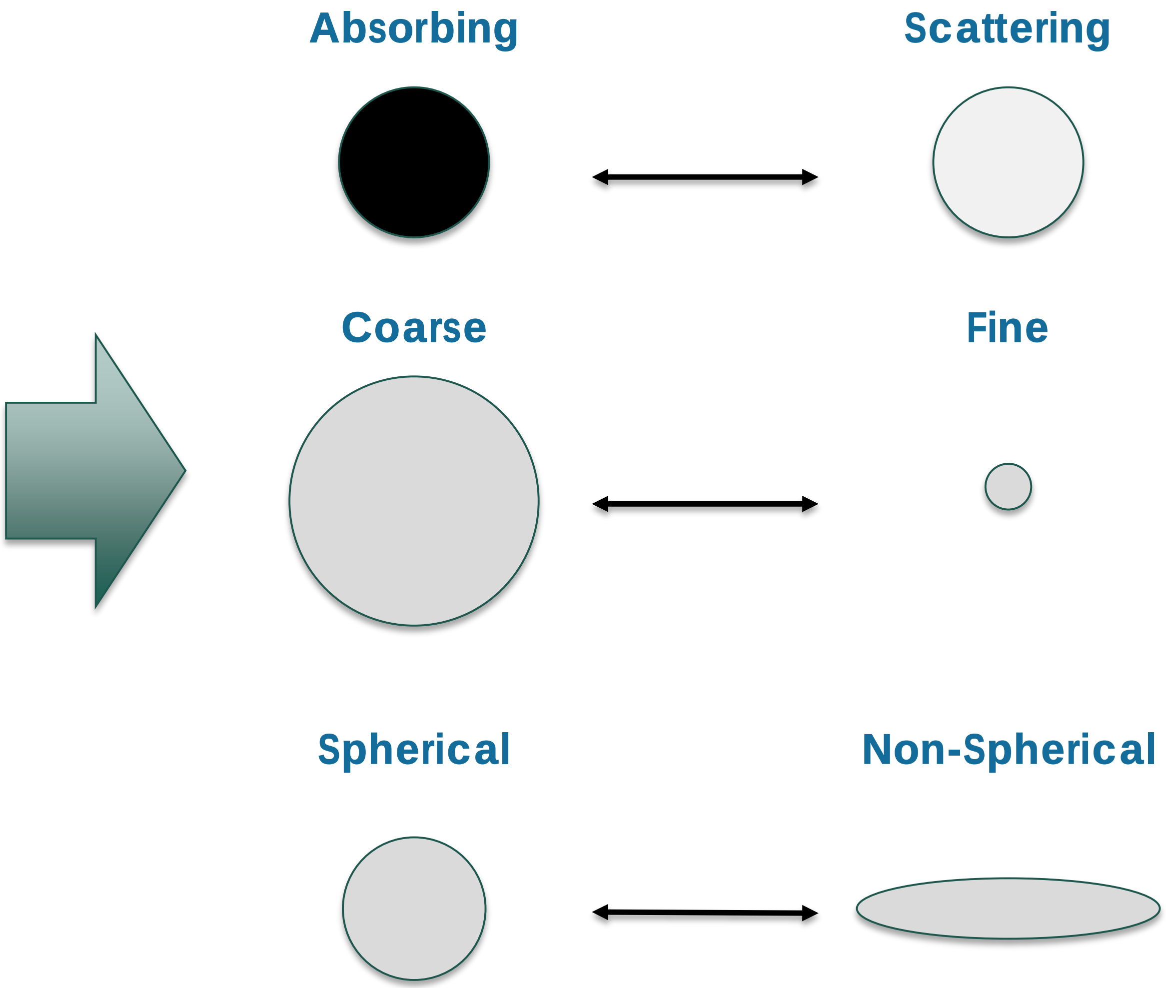
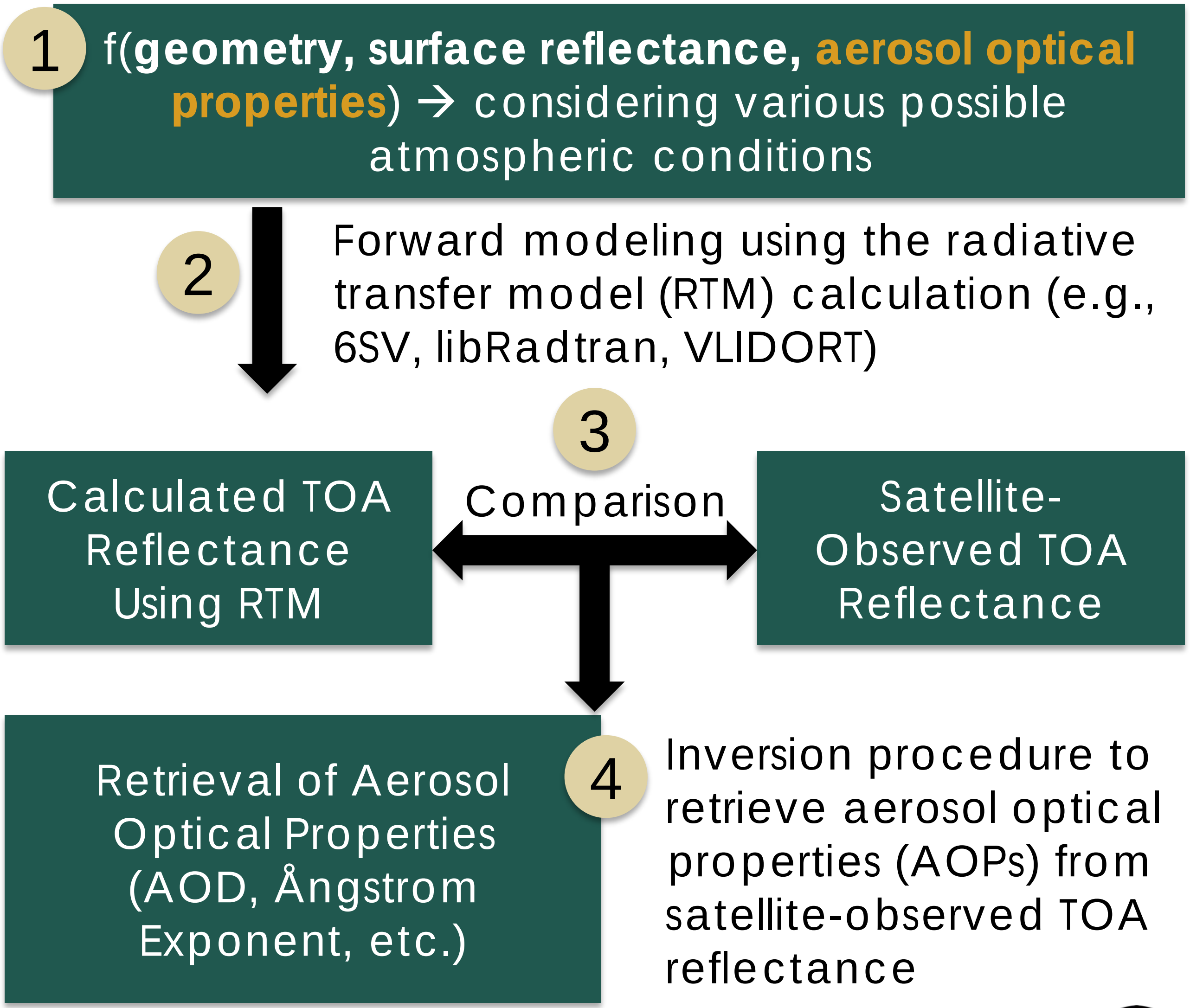


Figure in Renard et al., 2016, AMT (Courtesy of Jose Vanderlei Martins): www.atmos-meas-tech.net/9/1721/2016/

General Flow of Aerosol Retrieval Algorithm

- Aerosol optical properties (obtained from AERONET) such as
  - particle size distribution
  - refractive index
  - aerosol optical depth
  - vertical distribution
  - single scattering albedo
  - fine-mode fraction
  - phase function
  - or others
- can be used as input data for forward modeling using radiative transfer model (RTM) calculation



GOCI, AHI, and GEMS Yonsei Aerosol Retrieval Algorithm

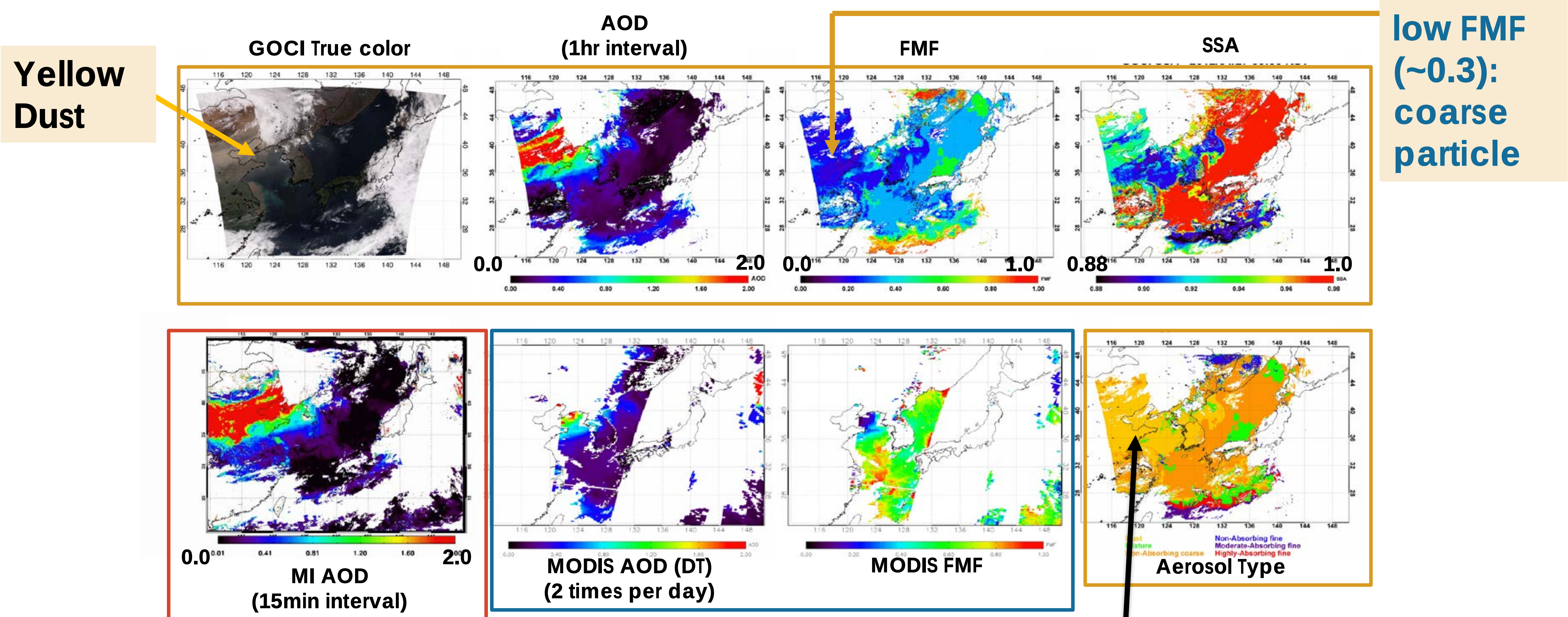
- VIS: high sensitivity for particle size

- GOCI Yonsei aerosol products
  - AOD, FMF, AE, SSA
  - 6 × 6 km^2 spatial res.
  - 1-hour temporal res.
- AHI Yonsei aerosol products
  - AOD, FMF, AE
  - 6 × 6 km^2 spatial res.
  - 10-min temporal res.

- UV: high sensitivity for absorption

- GEMS Yonsei aerosol products
  - AOD, SSA, UV aerosol index, and aerosol layer height
  - 3.5 x 8 km^2 spatial res.
  - 1-hr temporal res

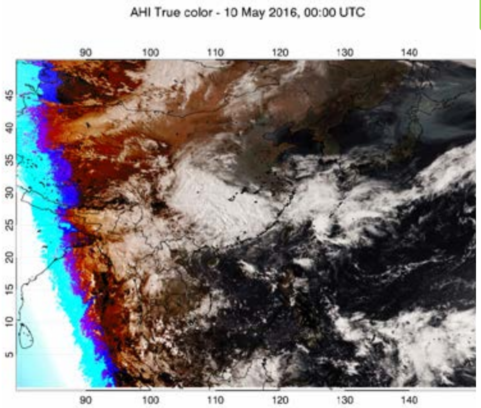
Dust Case (Apr 27, 2012): GOCI Aerosol Retrieval Results



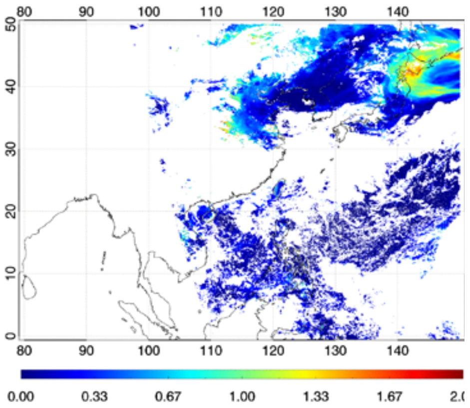
	HA, fine	MA, fine	NA, fine	Mixture	Dust	NA/Coarse
FMF	0.6 ~ 1.0	0.6 ~ 1.0	0.6 ~ 1.0	0.4~0.6	0.1~0.4	0.1~0.4
SSA	0.85~0.90	0.90~0.95	0.95~0.99	0.85~0.99	0.85~0.95	0.95~0.99

Smoke Case (May 19, 2016): AHI Yonsei Aerosol Retrieval Results

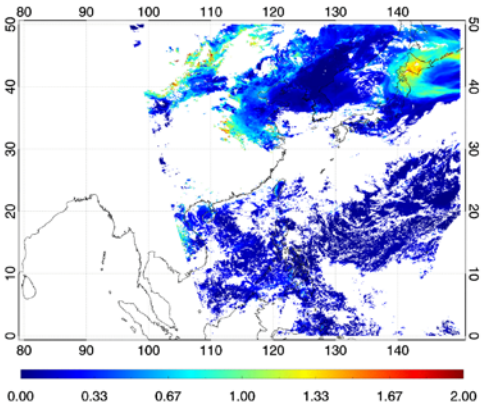
AHI RGB image



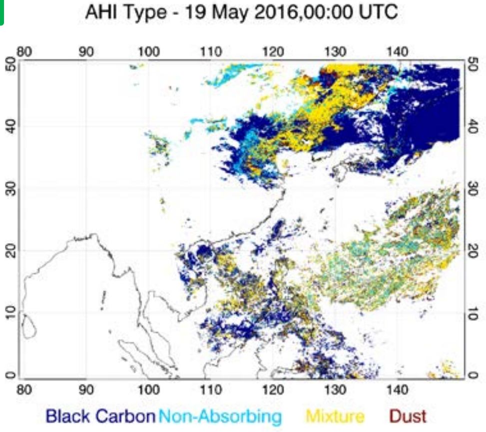
AHI AOD MRMver (composite method)

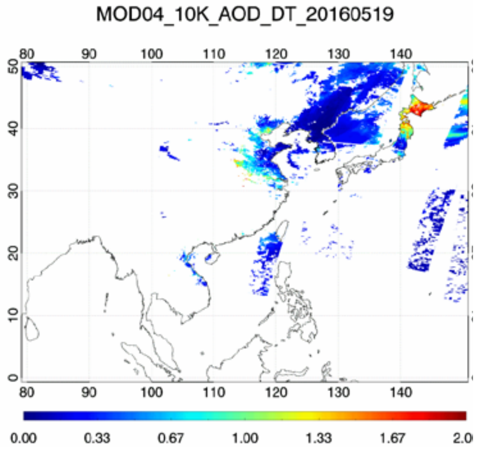


AHI AOD ESRver (Dark-Target method)

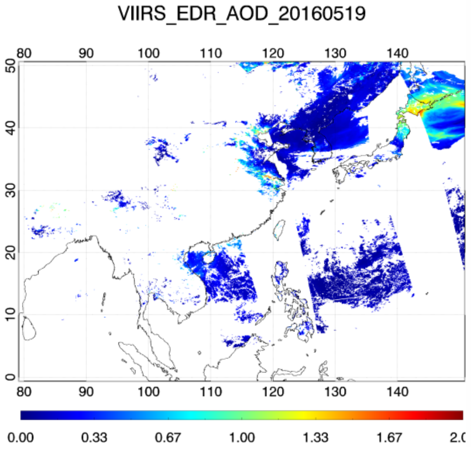


AHI aerosol type

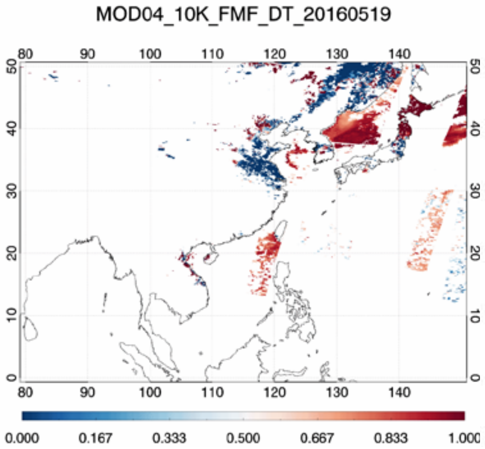




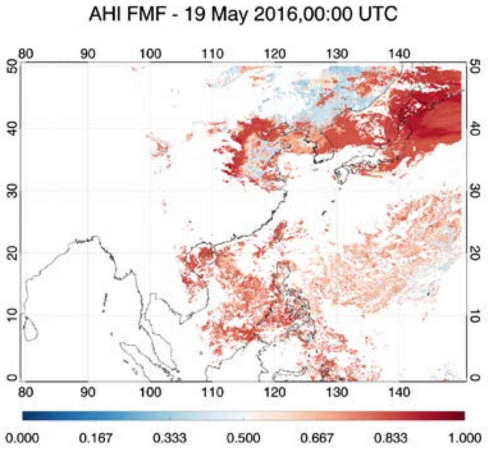
MODIS AOD (Terra,Aqua)



VIIRS AOD (Suomi NPP)



MODIS FMF (Terra,Aqua)

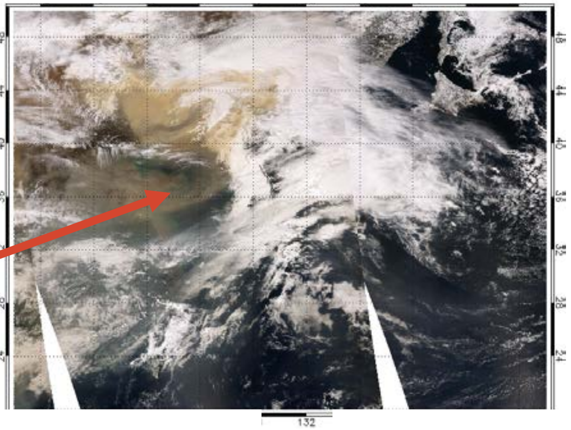


AHI YAER FMF

Dust Case (March 31, 2007): GEMS Aerosol Retrieval Results

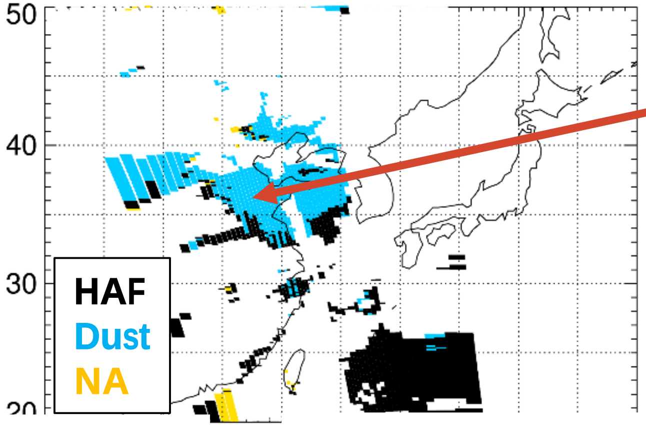
* Simulated with OMI L1B Data (as proxy data for GEMS)

MODIS RGB



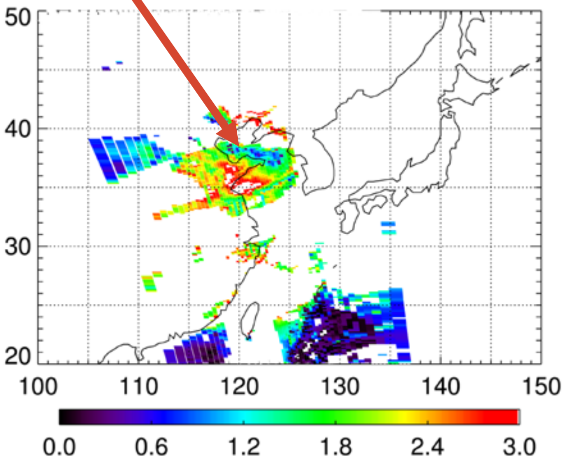
Dust plumes over ocean

Aerosol Type

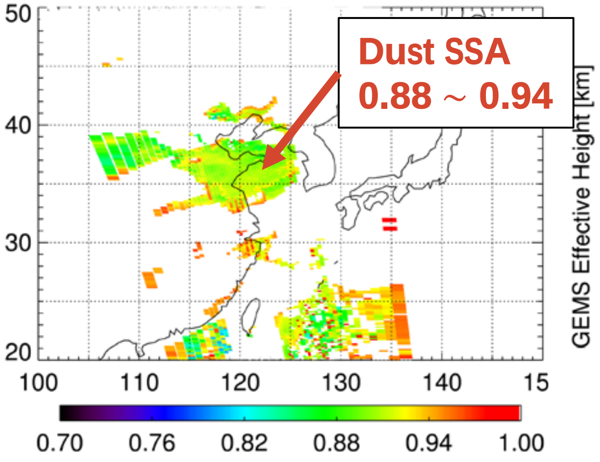


Detected Dust aerosol type

AOD 443nm

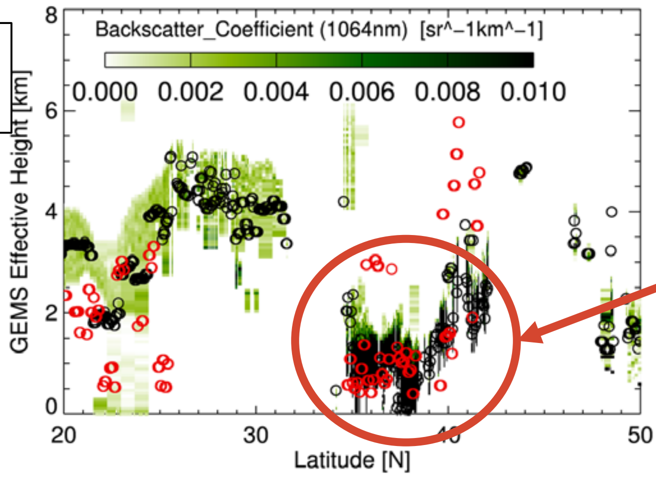


SSA 443nm



Dust SSA 0.88 ~ 0.94

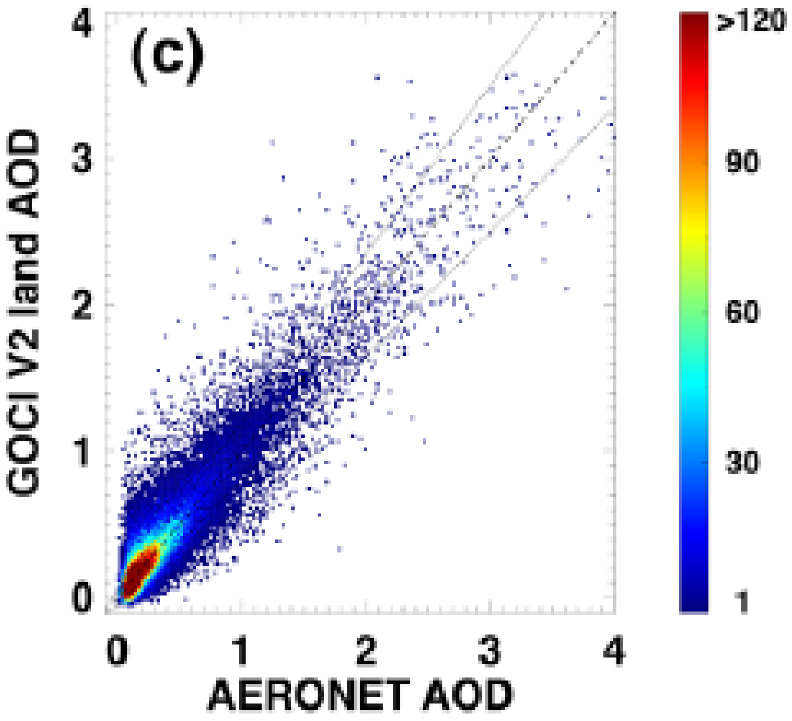
Aerosol Effective Height



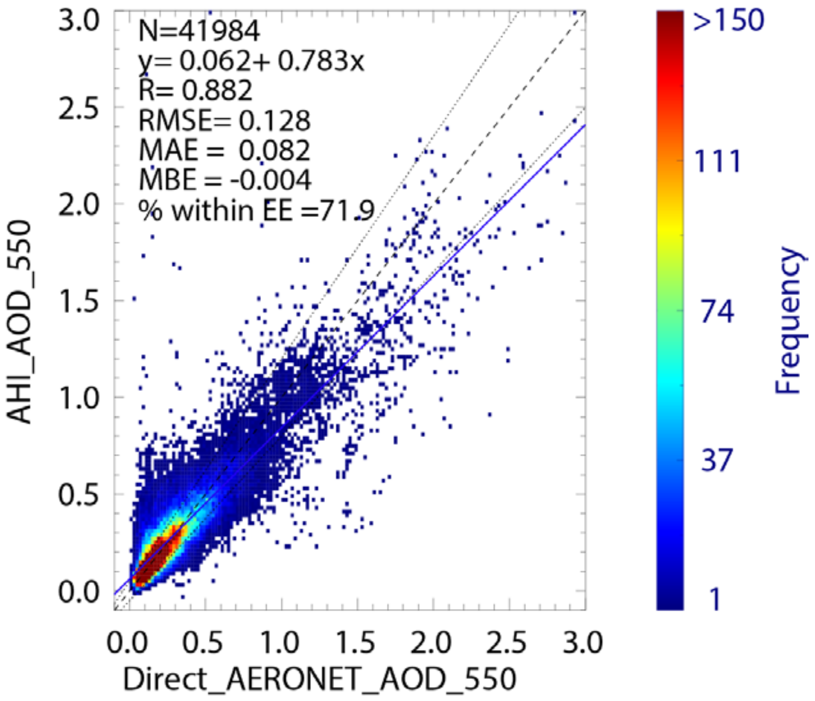
GEMS Height (Red Circle)
CALIOP Height (Black Circle)

Validation of GOCI, AHI, and GEMS Aerosol Optical Properties Using AERONET Measurements: AOD (*R*: 0.8-0.9)

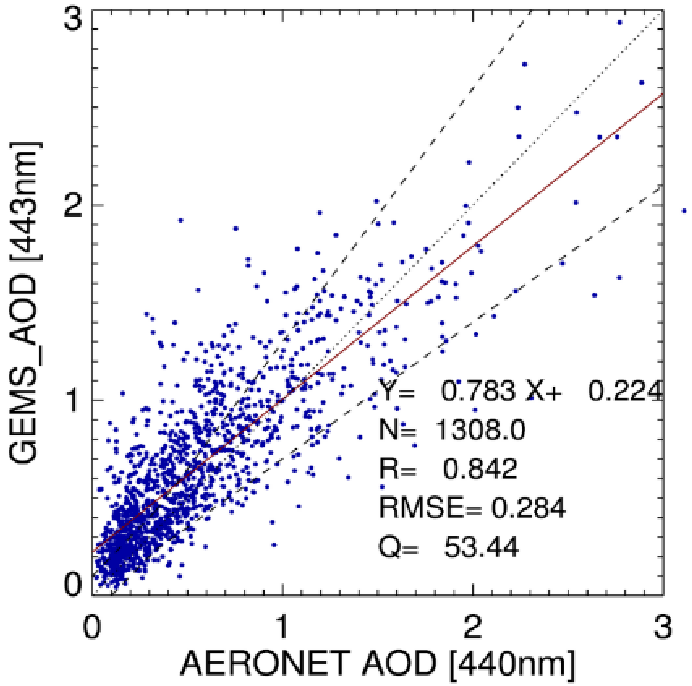
GOCI



AHI



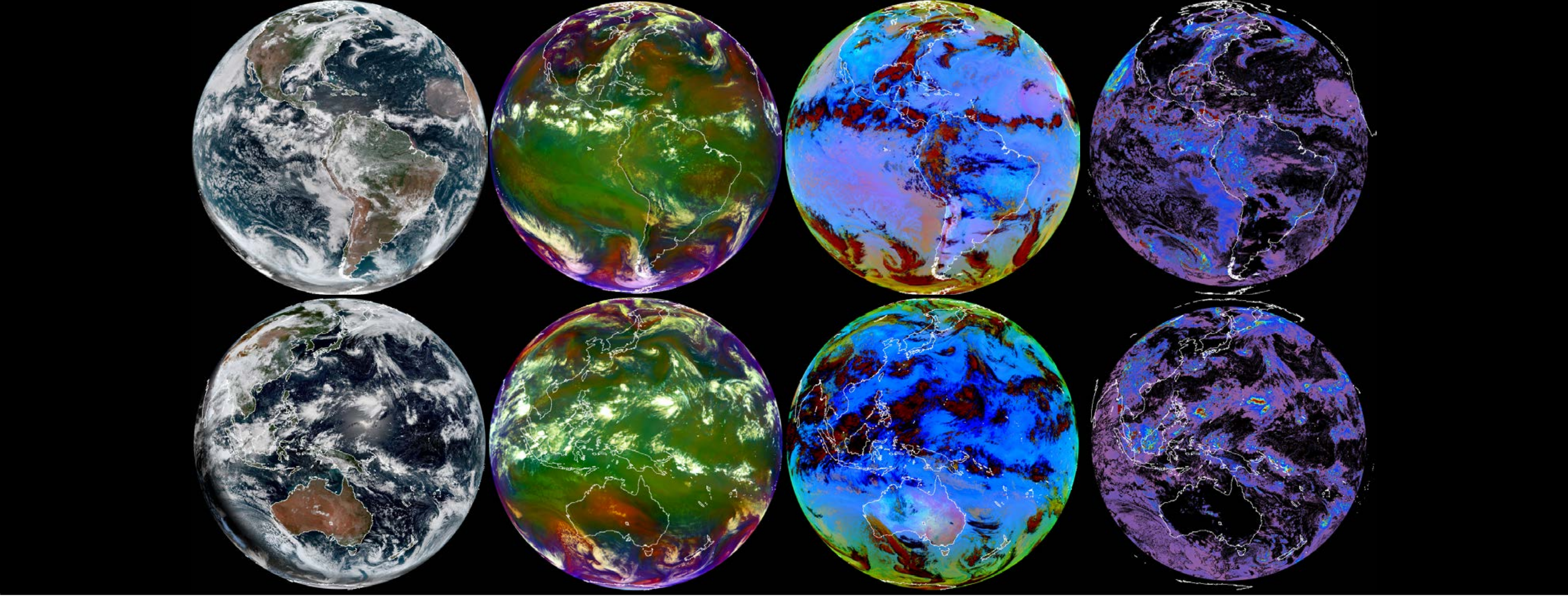
GEMS



Assumptions and Limitations of the Aerosol Retrieval Algorithm

- Aerosol retrieval from limited satellite measurement is an ill-posed problem
  - Real atmospheric status is a combination of unknown variables, but satellite measurements provide limited information
  - Amount of Unknown information > Degree of Freedom of satellite measurement

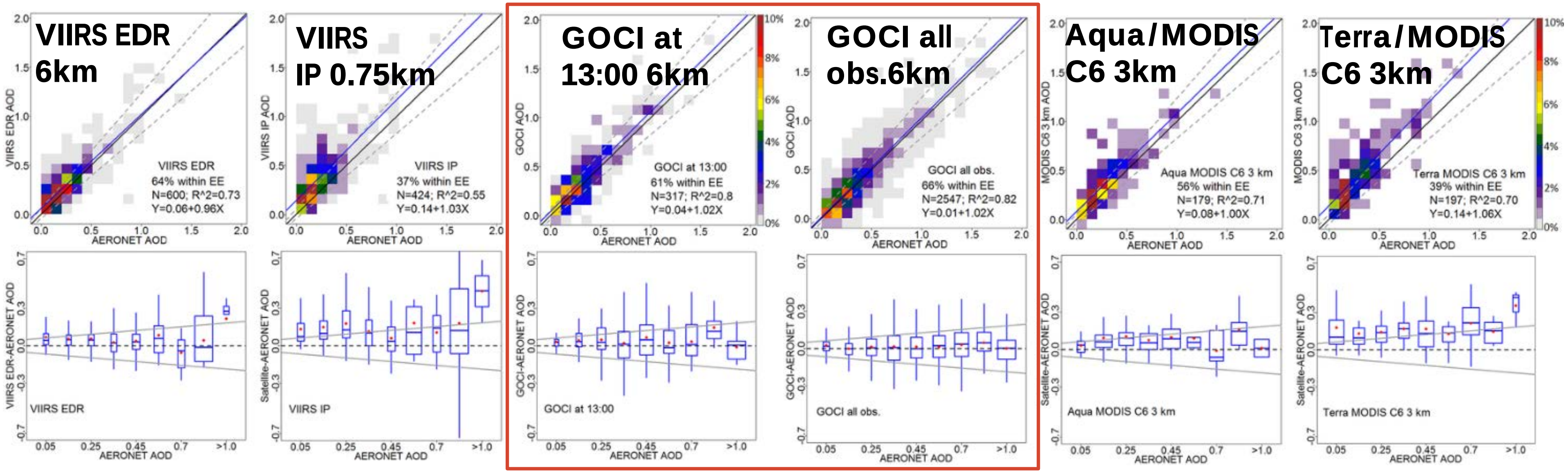
- Thus, a priori information and accurate Radiative Transfer Theory/Model are required to retrieve high-quality aerosol information from satellites.
  - Assumption of aerosol vertical distribution (gaussian or exponential), representative types (dust, sea-salt, black carbon, etc.), particle shape (spherical, or non-spherical).
  - Assumption of surface reflectance (Lambertian, or BRDF)
  - Other atmospheric composition status (gas profile, temperature profile)



Practical Uses of Geostationary Aerosol Datasets and Their Application to Air Quality Studies

Evaluation of GEO and LEO AOD Products Together

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



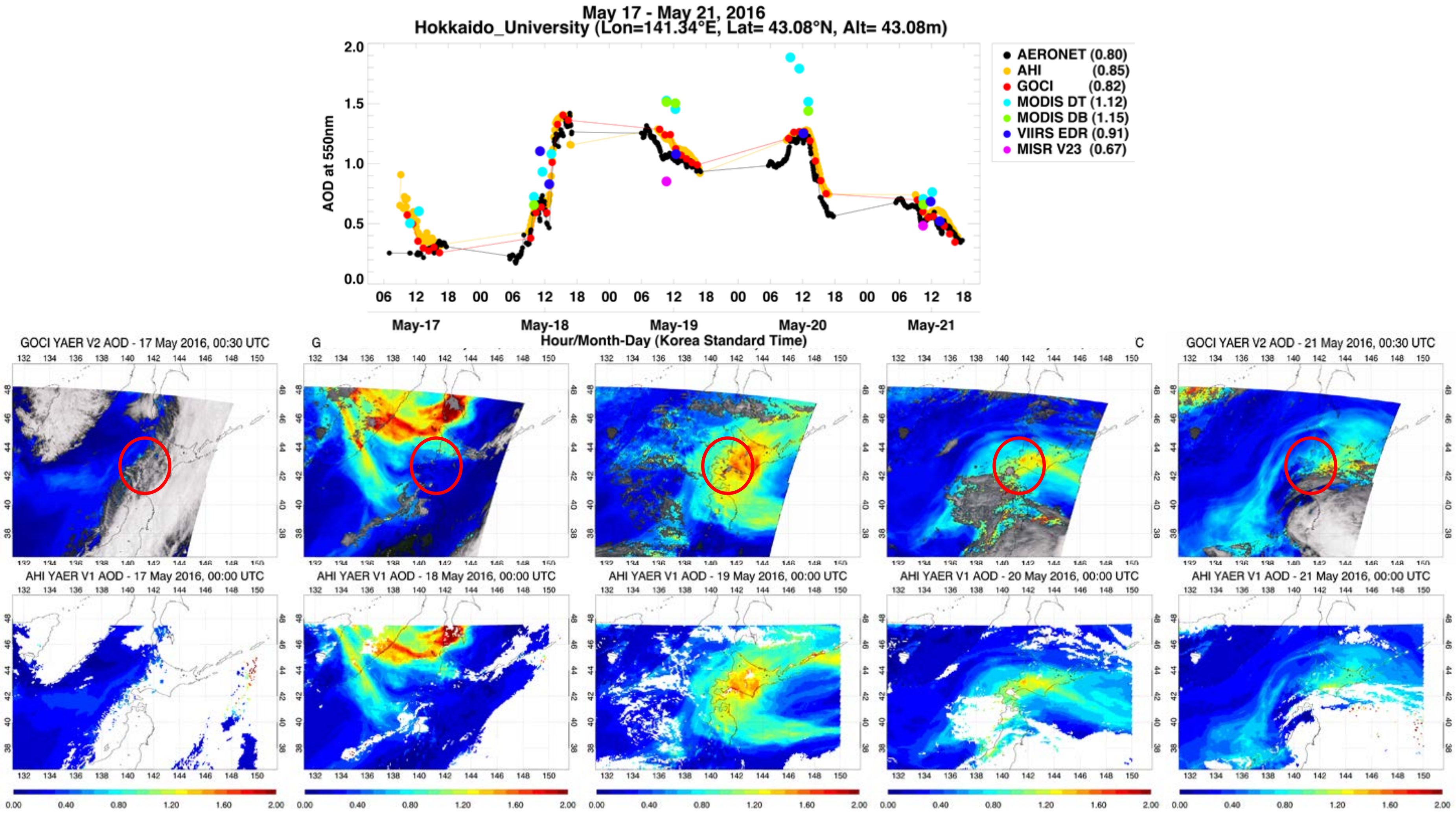
GOCI AOD shows less bias, and matches better with AERONET than other products

	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

Xiao et al. 2016, ACP: http://www.atmos-chem-phys.net/16/1255/2016/

Strength of Geostationary Orbital Measurements:

Detection of Highly Variable Aerosol Transportation

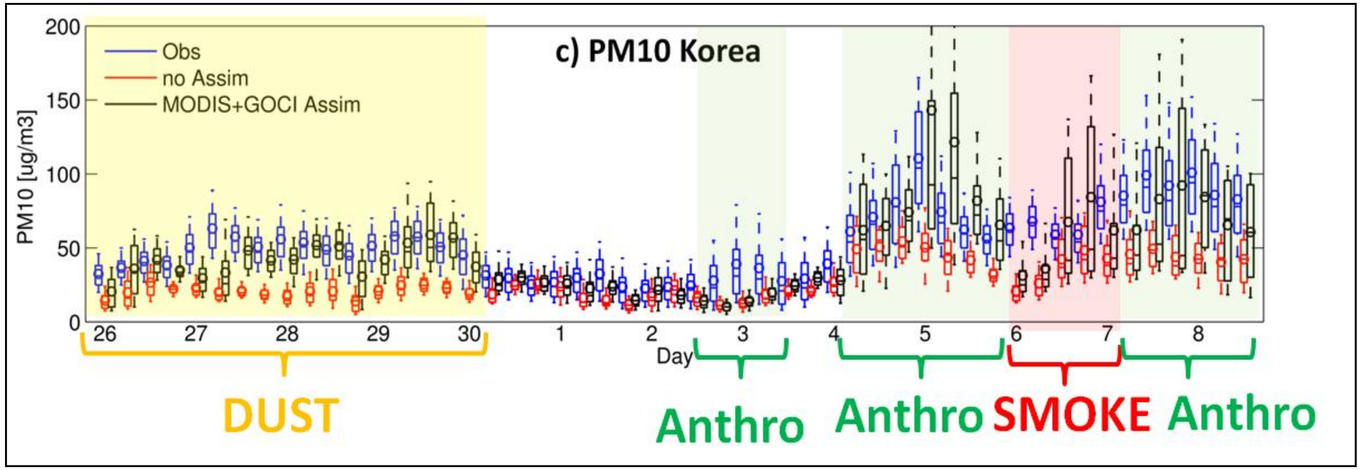


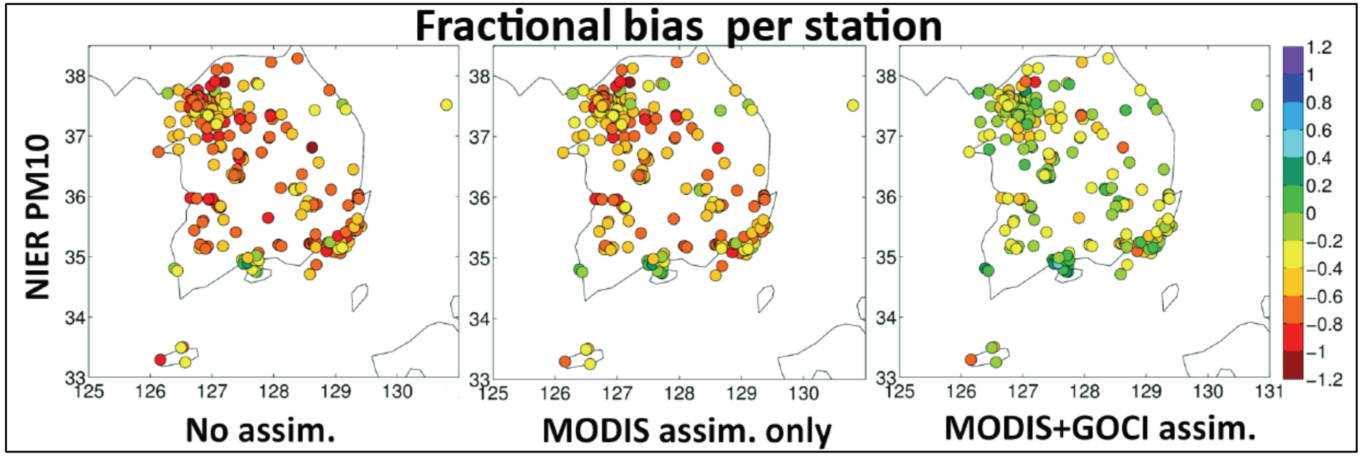
Credit: Jhoon Kim
(jkim2@yonsei.ac.kr)

Data Assimilation of GOCI & MODIS AOD with WRF-Chem

Application to PM_{10} (with Univ. of Iowa & NCAR)

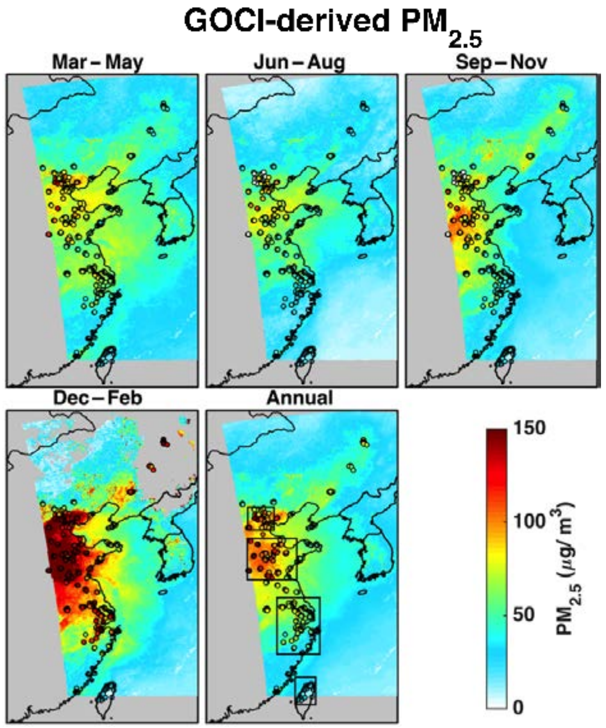
- GOCI can provide hourly AOD images, thus it can be assimilated with Chemical Transport Model **multiple times** during the daytime.
  - (3-hour interval assim. In this study)
- During 2012 DRAGON-NE Asia campaign
  - GOCI+MODIS assimilation results show less bias in PM_{10} than MODIS-only assimilation or no-assimilation results

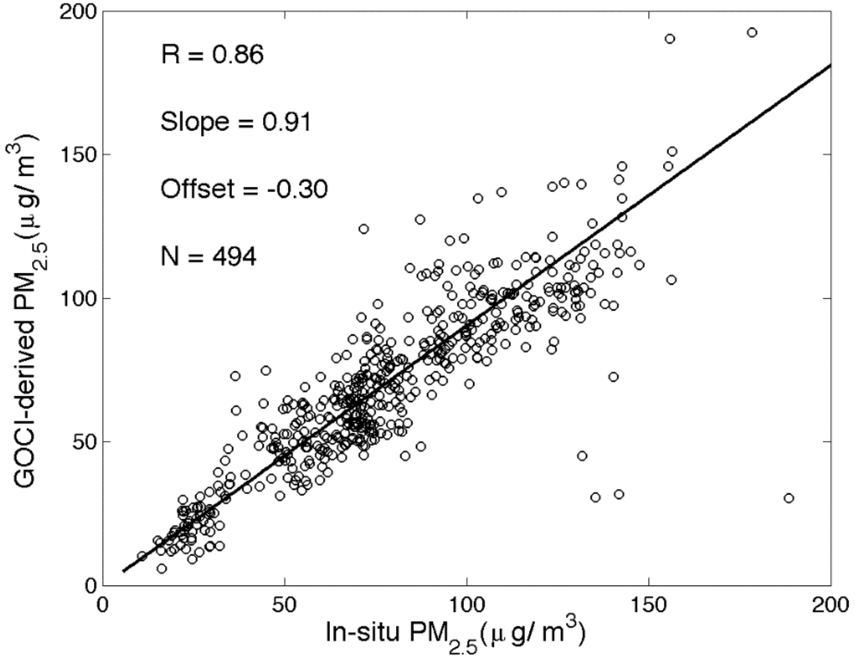




Saide et al., 2014, GRL: https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1002/2014GL062089

Estimation of Ground-Level $PM_{2.5}$ from GOCI AOD and GEOS-Chem (with Dalhousie Univ.)





- In Situ $PM_{2.5}$ is better represented by GOCI-derived $PM_{2.5}$ (slope = 0.91) than by GEOS-Chem (slope =0.53)
- AOD adjustment in GEOS-Chem

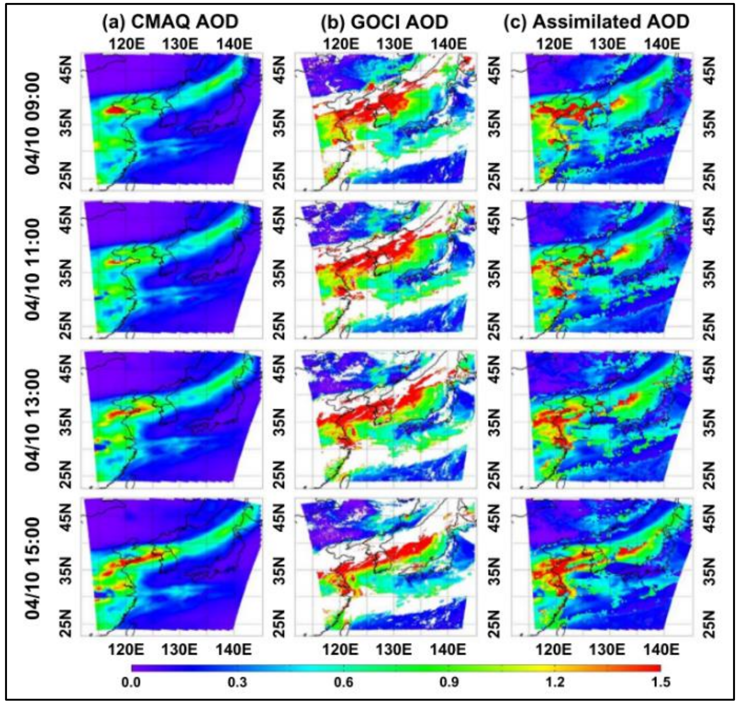
Xu et al., 2015, ACP: https://www.atmos-chem-phys.net/15/13133/2015/

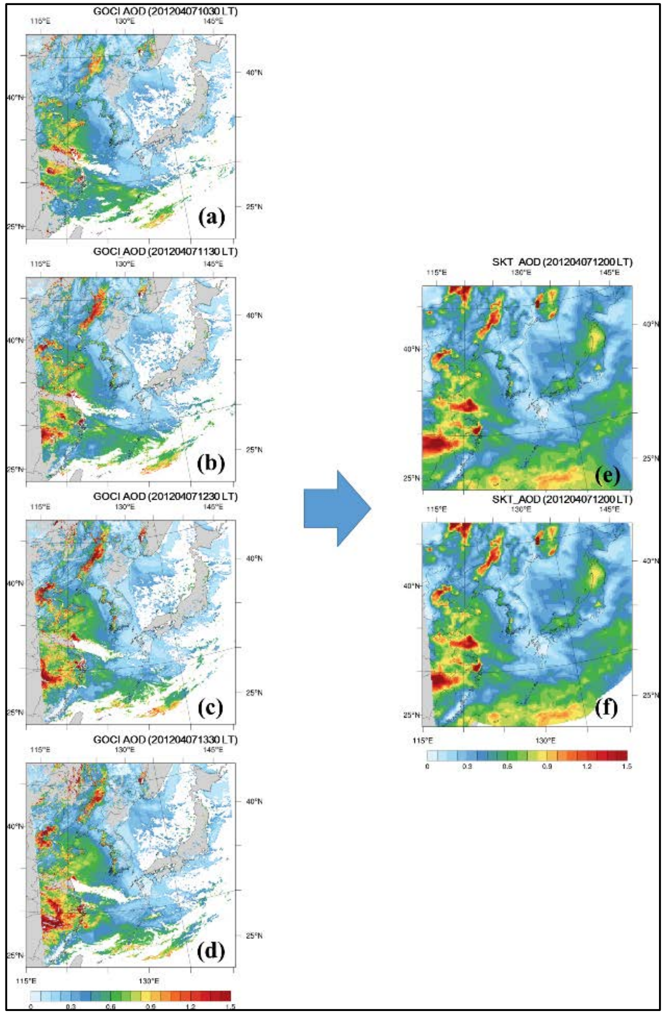
Data Assimilation of GOCI AOD with CMAQ

Application to PM_{10} (GIST)

- Investigation of AOD data assimilation techniques with the Chemical Transport Model (CTM)

Optimal Interpolation





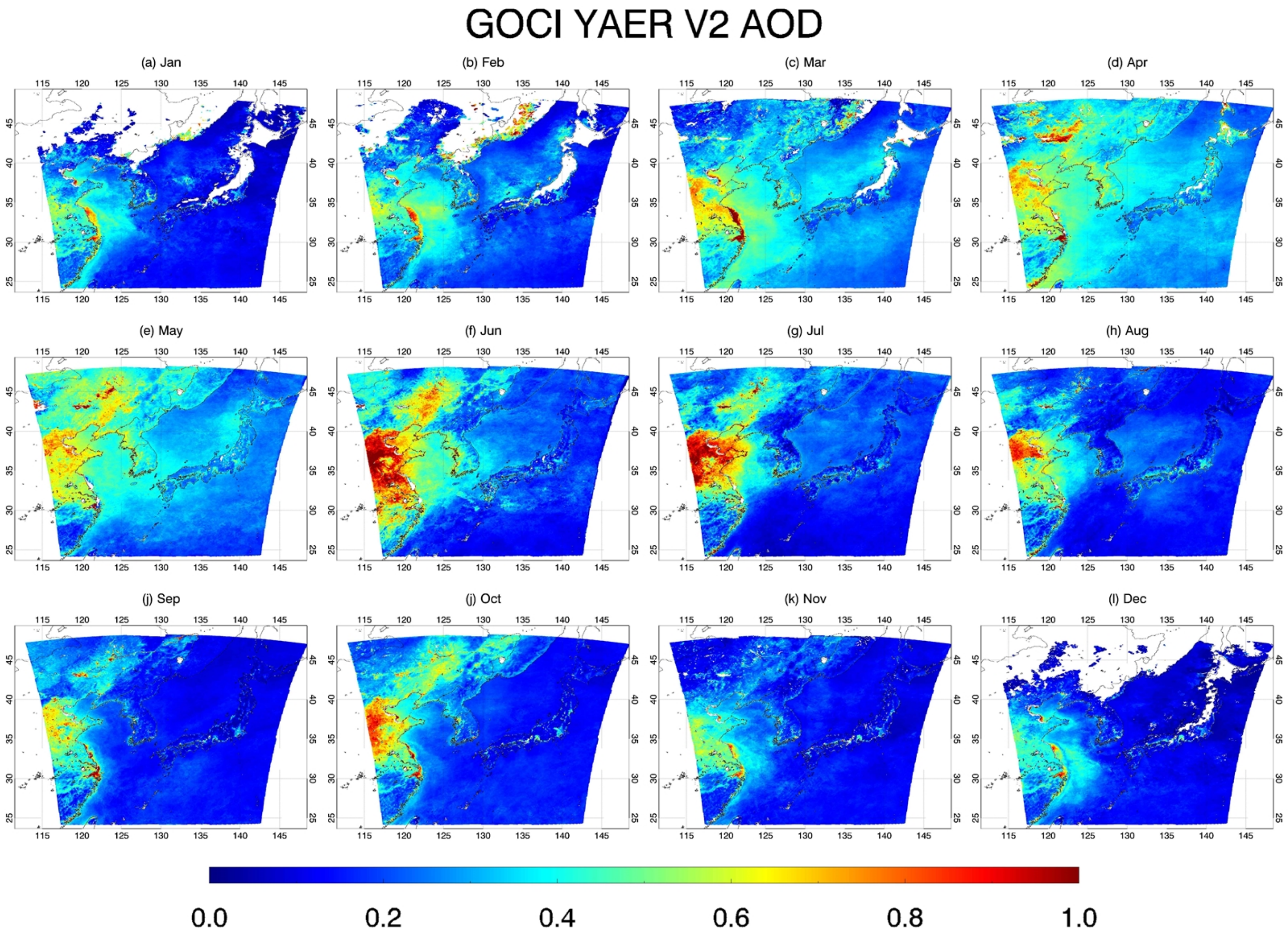
“Gap-filling method” to fill the empty data for model time and cloud-masked area

Left: Park et al., 2014, ACP: https://www.atmos-chem-phys.net/14/659/2014/ ;

Right: Lee et al., 2016, GMD: https://www.geosci-model-dev.net/9/17/2016/

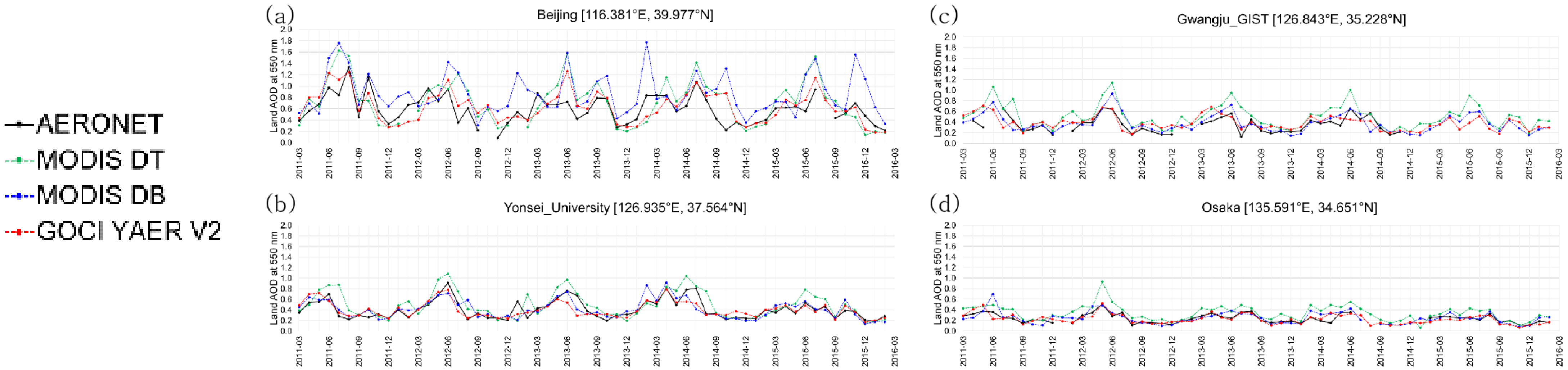
High Spatial Distribution: GOCI Monthly Mean AOD (5-year)

- Spatial distribution is well matched with MODIS results (Kim et al. 2007; Levy et al. 2013; Hsu et al. 2013) and VIIRS results (Liu et al. 2014)
- **However, GOCI can provide climatological value as high-spatial resolution (original 6 × 6 km2 Level 2 resolution)**



Myungje Choi PhD thesis, 2017, Yonsei University: http://dcollection.yonsei.ac.kr/public_resource/pdf/000000501619_20180904212027.pdf

Monthly Mean Land AOD (1°x 1° Lat/Lon) at AERONET Sites



- Daily mean AERONET AOD is calculated from the all-points (~minutes) measurement, and daily mean GOCI AOD is from eight measurements, but only one or two in MODIS
  - More samples in GOCI can provide reasonable daily/monthly AOD
  - This can be less affected by sampling issues for climatological analysis

	R			RMSE		
	DT	DB	GOCI	DT	DB	GOCI
Beijing	0.66	0.58	**0.71**	0.32	0.41	**0.21**
Yonsei_Univ	0.78	0.76	**0.81**	0.18	0.12	**0.10**
Gwangju_GIST	0.80	0.72	**0.61**	0.22	0.13	**0.14**
Osaka	0.83	0.72	**0.82**	0.14	0.08	**0.05**

Myungje Choi PhD thesis, 2017, Yonsei University: http://dcollection.yonsei.ac.kr/public_resource/pdf/000000501619_20180904212027.pdf

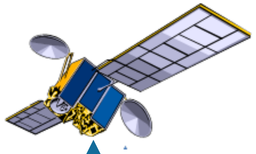
Primary Satellite Data to Support Air-Quality Field Campaign

KORUS-AQ

(1 May – 14 June 2016)

Ministry of Environment
National Institute of Environmental Research

KORUS-AQ combined assets from the Korean and U.S. atmospheric science communities and their supporting organizations (NIER, NASA, Universities, etc.) to implement an integrated observation system for improving our understanding of Air Quality



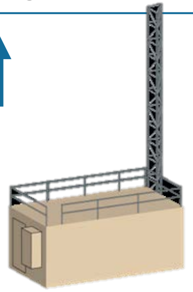
GOCI, MI, Himawari-8, MODIS, OMI, MOPITT...
- ✓ Broad spatial coverage for key atmospheric components (aerosols, ozone, precursors)

NASA DC-8 (HSRL, 4STAR...)
LaRC King Air (GeoTASO, MOS)
Hanseo King Air

Model evaluation and improvement, chemical process understanding, Satellite Cal/Val and observing strategies

Operational air quality forecasts, regional and global models of atmospheric composition

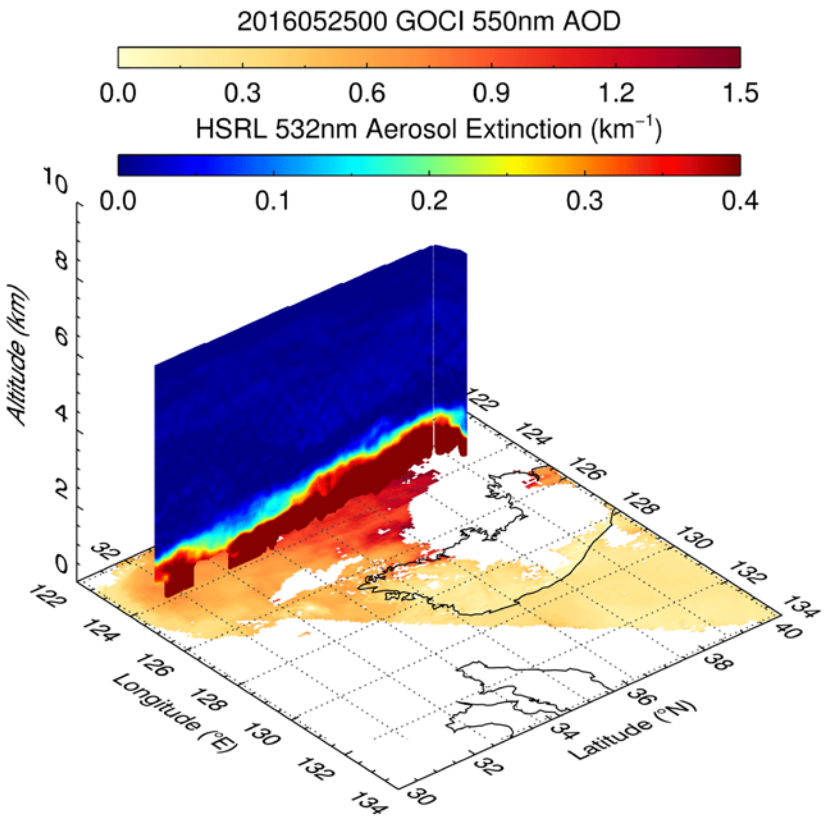
KORUS-OC

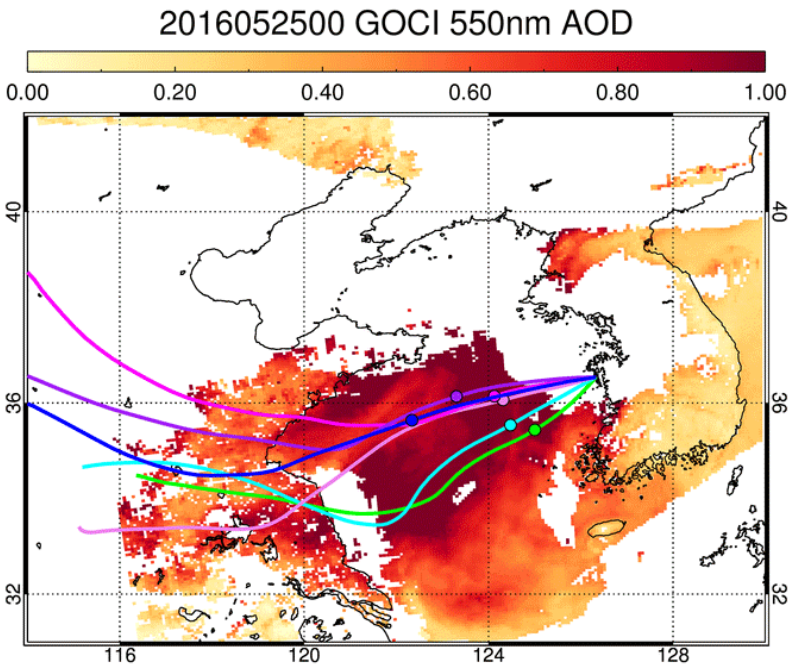


Air quality network, research sites, research vessels including in situ and remote sensing observations (**AERONET, Pandora, Lidar**)

Credit: James Crawford (J.H.CRAWFORD@larc.nasa.gov)

Detection of Aerosol Transportation: Case of May 25, 2016

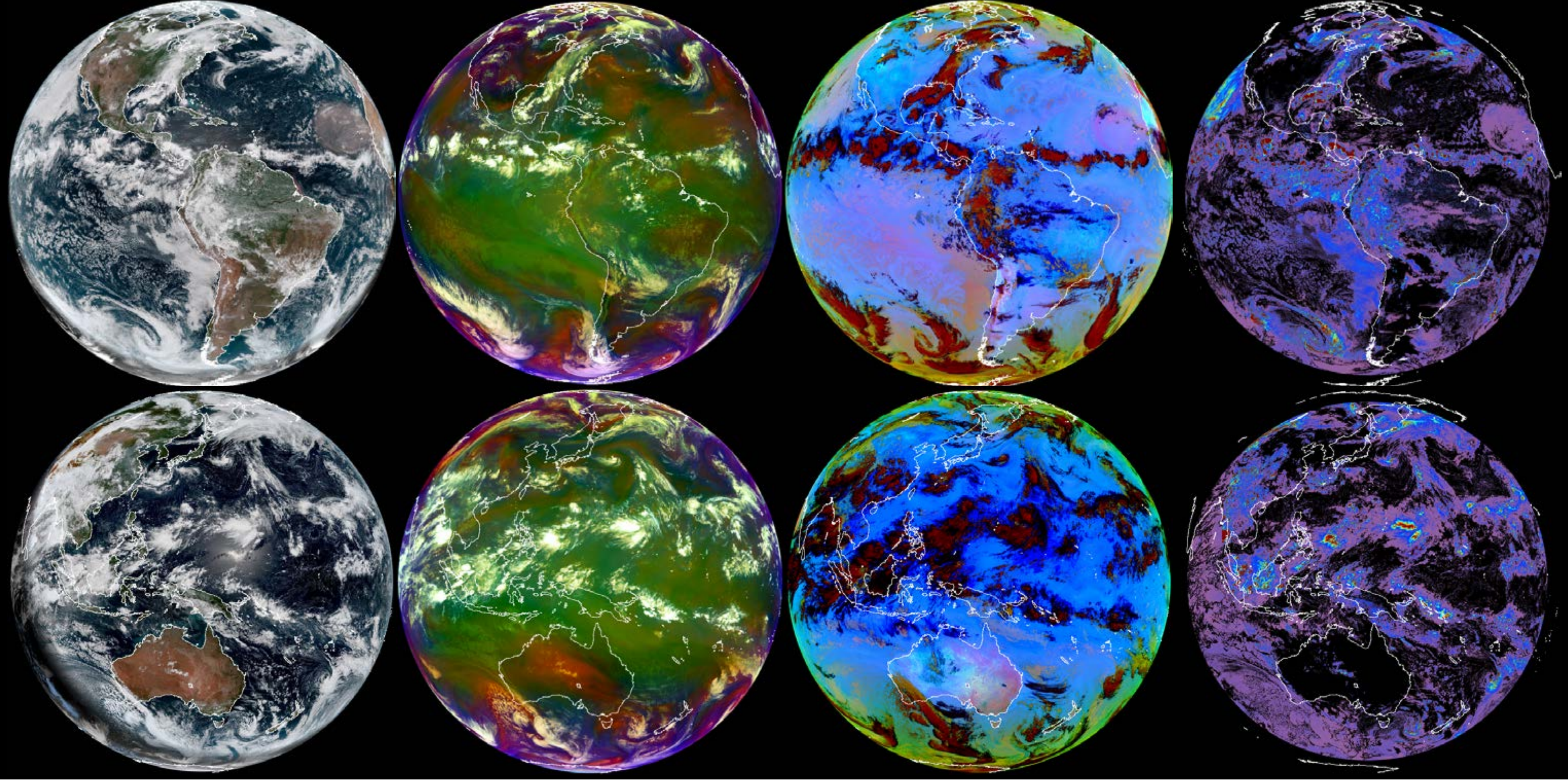




Anmyon (36.54N,126.33E)
GOCI AOD with NOAA HYSPLIT
Backward trajectory modeling

- Hourly GOCI AOD can be matched several times with HSRL airborne lidar measurements → providing 3-D aerosol distribution over the Yellow Sea

Credit: Jhoon Kim (jkim@yonsei.ac.kr)



Additionally Available Air Quality Datasets From Geostationary Satellites Over East Asia in the Near Future

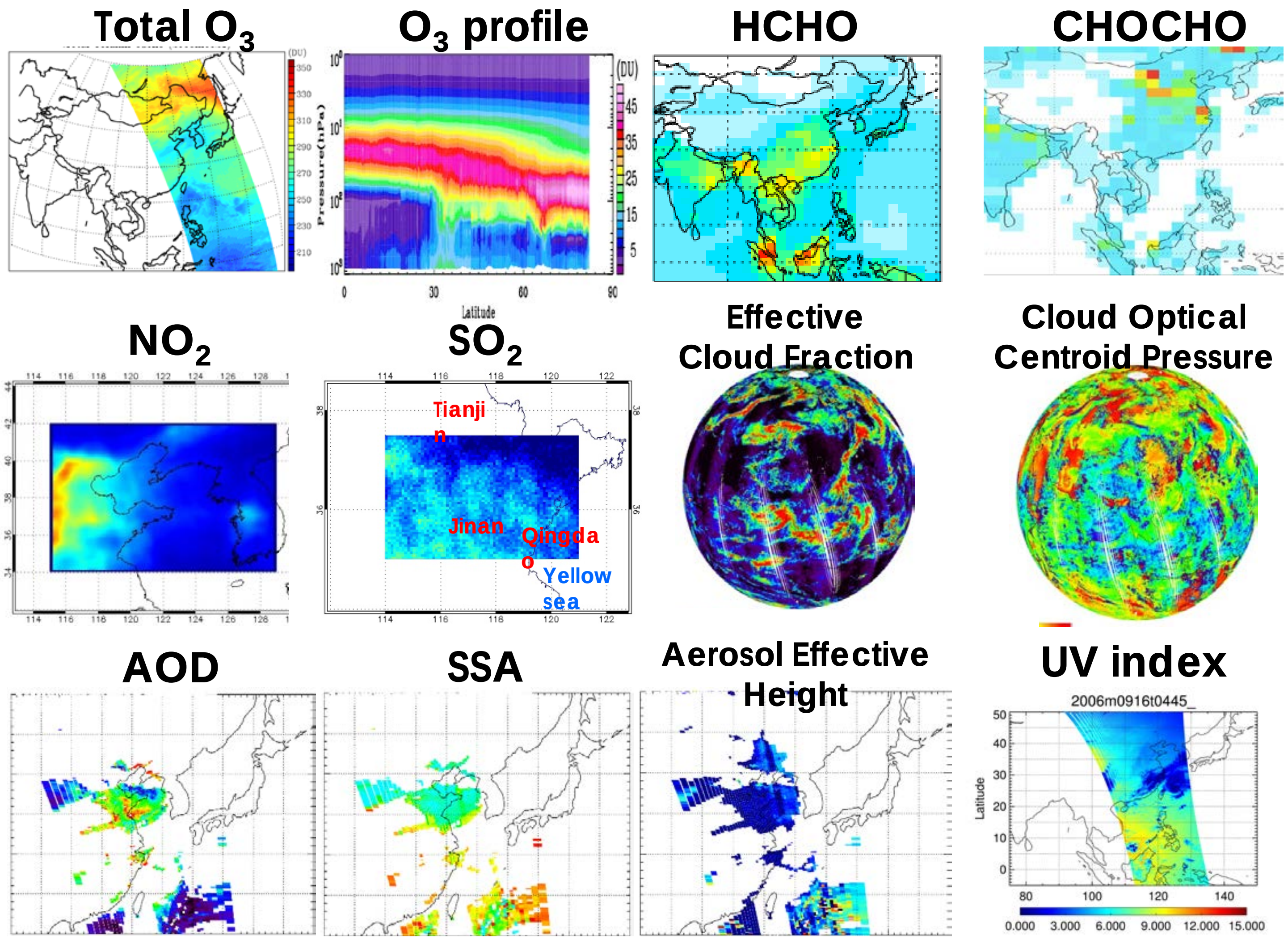
AMI, GOCI-II, and GEMS Onboard GEO-KOMPAST (GK)-2A/2B

Satellite in Orbit	GEO-KOMPSAT-2A	GEO-KOMPSAT-2B	
Payload	**AMI (~ABI)**	**GEMS(~TEMPO)**	**GOCI-2**
Channels (㎛)	*16 channels (0.47~13.31)*	*1000 channels (0.3~0.5) Scanning UV-VIS Spectrometer*	*12 channels + 1 wideband (0.380~0.865) VIS, NIR*
Temporal resolution	within 10 min (FD)	1 hour (8 times/day) (30min imaging + 30min rest)	1 hour (10 times/day (Local) + 1 times (FD))
Spatial resolution	1km (<0.856㎛, VIS) 0.5km (=0.64㎛, VIS) 2km (>1.38㎛, IR)	Gas : 7(NS)x8(EW) km Aerosol : 3.5(NS)x8(EW) km	250m (@130°E) 1km (FD)
Spectral resolution	-	<0.6nm (3 samples) (spectral sampling < 0.2nm)	12 narrow bands (10 ~ 40 nm)
Field of regard (FOR)	**Full Disk**	5,000km(N/S) × 5,000km(E/W) N/S: 45°N ~ 5°S, E/W: 75°E ~ 145°E (E/W, Selectable)	2,500km(N/S) × 2,500km(E/W)
Baseline products	- Scene & Surface Analysis - Cloud & Precipitation - *Aerosol* & Radiation *: (AOD, Asian Dust detection, Particle Size)* - Atmospheric condition & Aviation	O_3 (Column, Profile), NO_2, SO_2, HCHO, *Aerosols (AOD, SSA, ALH)*, UVI, CHOCHO	- Water quality variable - Marine Environmental products - *Atmospheric Properties* *: AOD, dust detection, aerosol type..* - Land variable

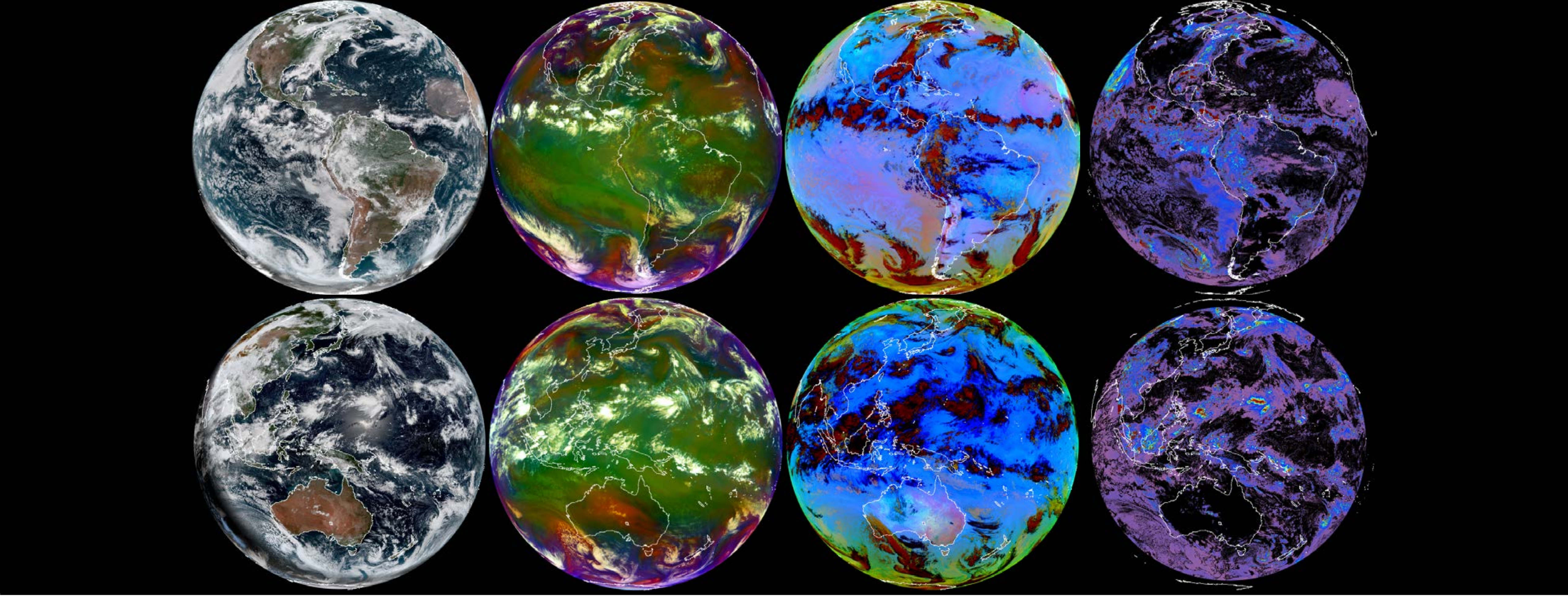
Credit: Jhoon Kim (jkim2@yonsei.ac.kr)

GEMS Aerosol, Trace Gases, and Application Products

- GEMS will provide column amounts of atmospheric trace gases and aerosols.
- Synergy of hourly measurements of aerosols and trace gases from GEMS will be key to understanding highly varying air quality status comprehensively.



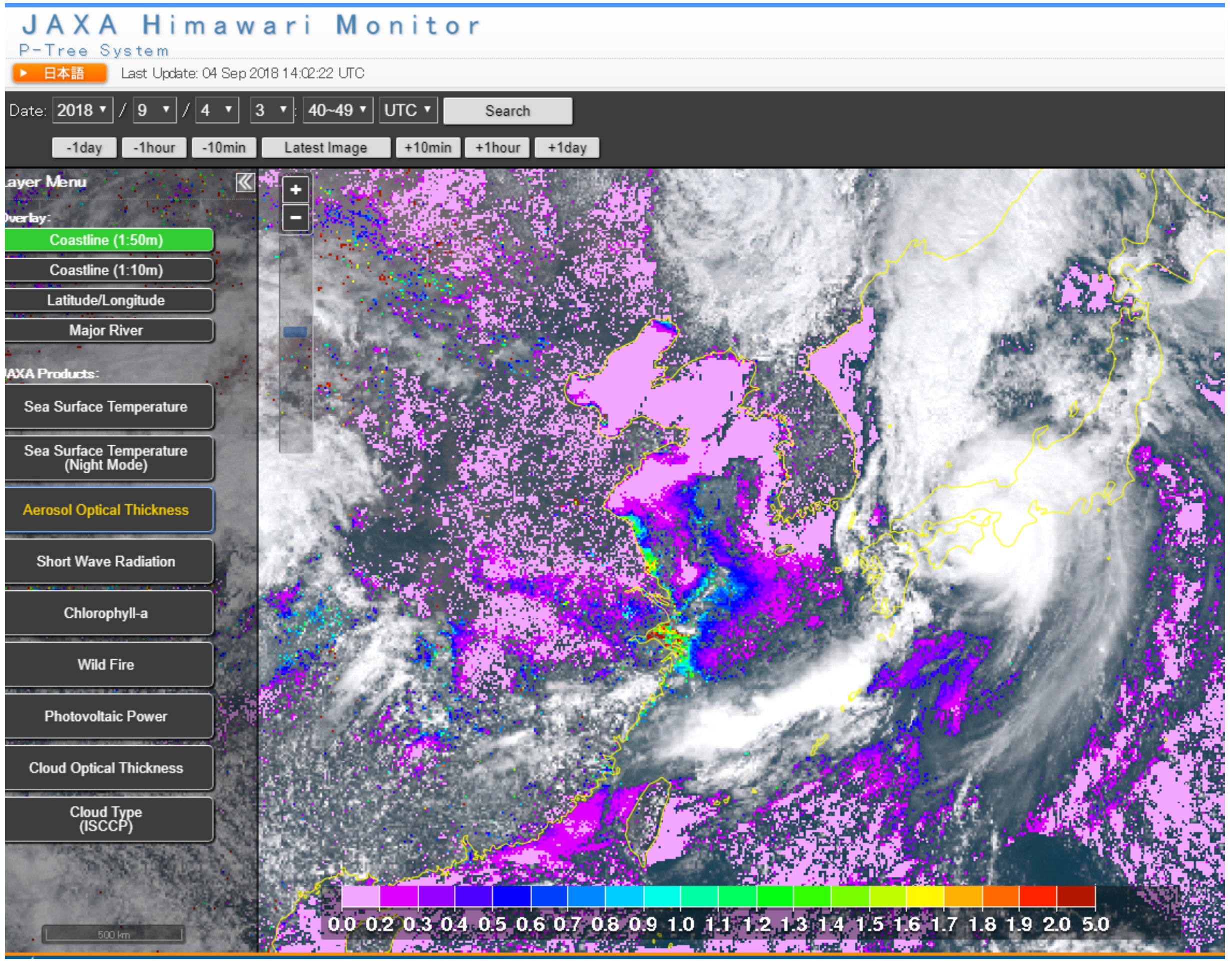
Credit: Jhoon Kim (jkim2@yonsei.ac.kr) and GEMS Science Team



How to Access Those Datasets

AHI/Himawari JAXA Official Aerosol Product

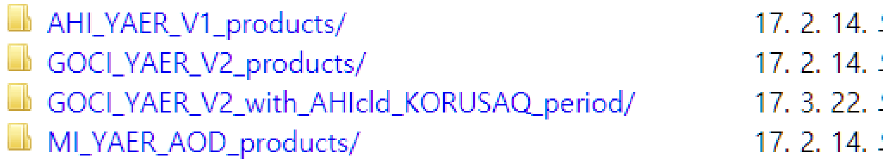
- http://www.eorc.jaxa.jp/ptree/
  - ftp service is also available for Level 1B radiance and Level 2 aerosol data

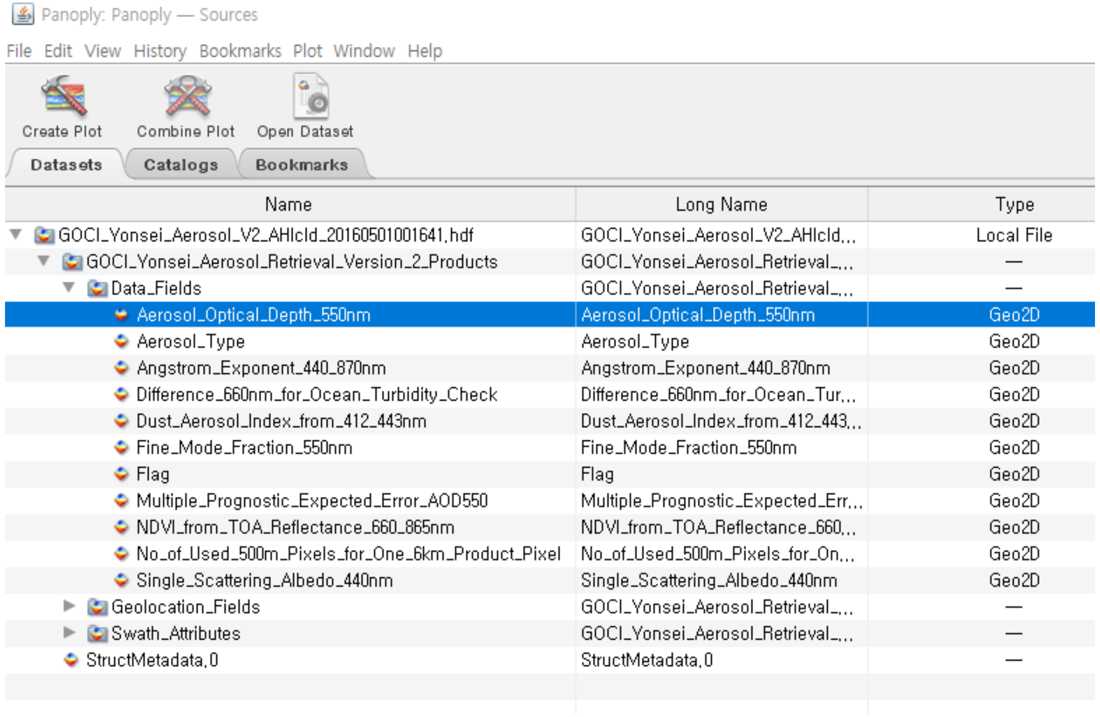


GOCI and AHI Yonsei Aerosol Products

- Specific period (KORUS-AQ campaign; May-June 2016) are freely available at these links:
  - https://www-air.larc.nasa.gov/missions/korus-aq/index.html
  - ftp://ftp-air.larc.nasa.gov/pub/KORUSAQ/SATELLITE_AOD/

- GOCI (March 2011 ~ current) and AHI (2016, Mar 2018~) Yonsei aerosol data and images are also available through the ftp server operated by Prof. Jhoon Kim's Lab
  - To get data, please contact to Prof. Jhoon Kim (jkim2@yonsei.ac.kr), Hyunkwang Lim (raul105@yonsei.ac.kr), or Seoyoung Lee (tjdud9207@yonsei.ac.kr)



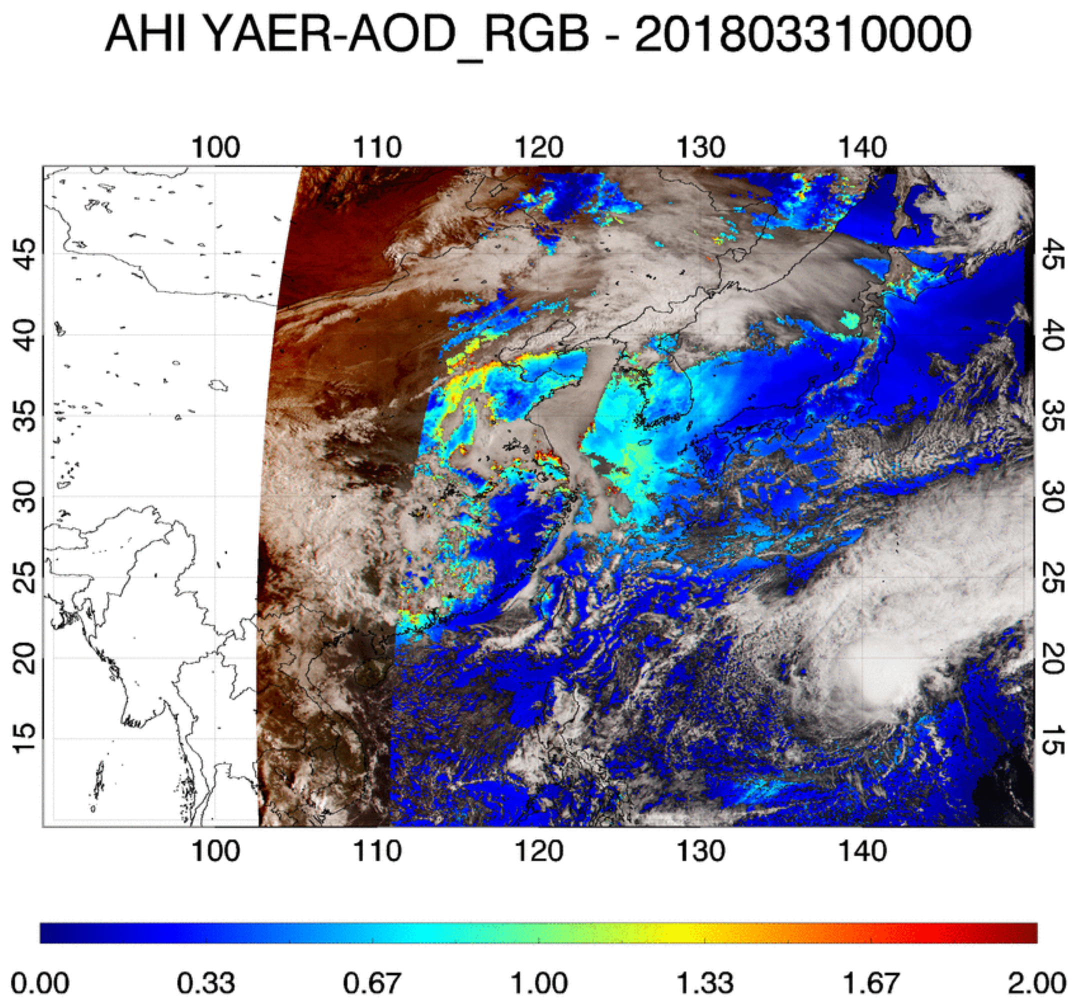


*After the launch of GEO-KOMPSAT-2B, GEMS and GOCI-II aerosol products also will be available through Prof. Jhoon Kim's Lab.

GOCI and AHI Yonsei Aerosol Products

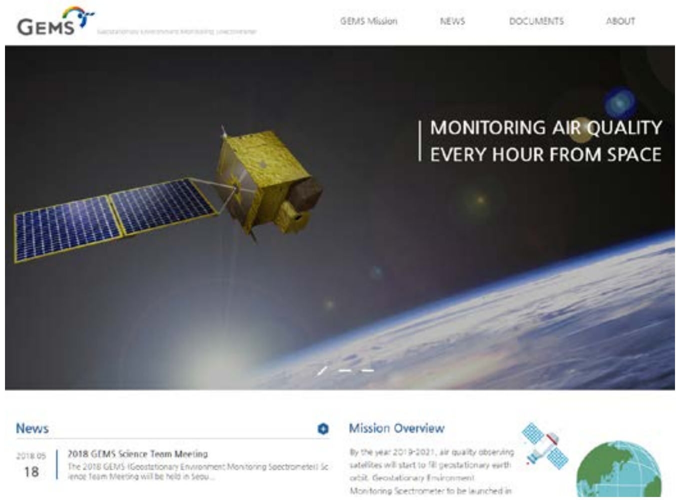
- Daily GOCI and AHI AOD animation is available at this google drive link
  - https://drive.google.com/drive/folders/1ZgOkozWYks-mB0xLDPZXVVgfXiilcZ3l?usp=sharing
  - if it's not working, please contact to Seoyoung Lee (tjdud9207@yonsei.ac.kr)

- GOCI and AHI aerosol data format: hdf4
  - "Panoply" is a useful tool to plot images: https://www.giss.nasa.gov/tools/panoply/download/



Other Useful Homepages

- GOCI official homepage by KOSC/KIOST: http://kosc.kiost.ac.kr/eng
- GEMS Science Team homepage: http://gems1.yonsei.ac.kr/
  - more details can be found with presentation files and lectures
- Jhoon Kim's Lab homepage: http://atrad.yonsei.ac.kr
  - Email: jkim2@yonsei.ac.kr
- **We welcome collaboration opportunities!**



GOCI, AHI, and GEMS Yonsei Aerosol Retrieval Algorithm Papers

- GOCI
  - Lee et al., 2010, RSE: https://doi.org/10.1016/j.rse.2009.12.021
  - Lee et al., 2012, ACP: https://www.atmos-chem-phys.net/12/7087/2012/
  - Choi et al., 2016, AMT: www.atmos-meas-tech.net/9/1377/2016/
  - Choi et al., 2018, AMT: https://www.atmos-meas-tech.net/11/385/2018/
- AHI
  - Lim et al., 2018, RS: http://www.mdpi.com/2072-4292/10/5/699
- GEMS
  - Kim et al., 2018, RS: http://www.mdpi.com/2072-4292/10/2/162
- MI (previous generation of the meteorological satellite)
  - Kim et al., 2014, RSE: https://doi.org/10.1016/j.rse.2013.12.003
  - Kim et al., 2016, ACP: https://doi.org/10.5194/acp-16-1789-2016
- Other air quality application studies using GOCI aerosol product
  - Pang et al., 2018, AE: https://doi.org/10.1016/j.atmosenv.2018.02.011
  - Jeon et al., 2016, GMD: https://www.geosci-model-dev.net/9/3671/2016/
  - Hyer et al., 2018, JCSDA News Letter: https://doi.org/10.7289/V5/Q-JCSDA-59-2018