Enhancement of Retrieving Aerosol Optical Properties by measuring polarization over Asia

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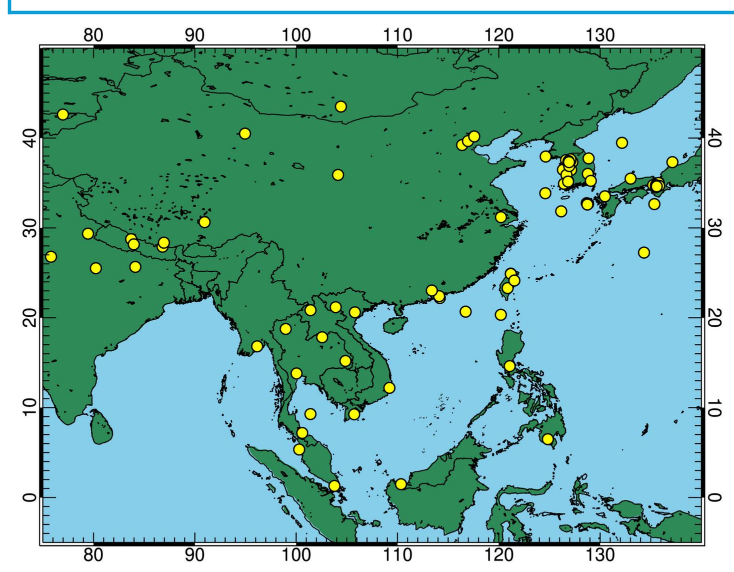
Abstract

Currently, the majority of satellite-based aerosol retrievals are conducted using data from passive sensors that measure radiances (e.g., MODIS, VIIRS, MISR). Additional polarization measurements provide more information contents on aerosols, including complex refractive indices and particle size. We analyzed the benefit of measuring polarization for obtaining optical characteristics of aerosols over East Asia, where various types of aerosols prevail. We analyzed the POLDER-3 aerosol products by comparing them with the VIIRS retrievals in this study. In the future, we aim to utilize recent polarimetric instruments such as the HARP2, SPEXone onboard the PACE, and BusanSat-B. The enhanced aerosol information from these polarimeters can provide reliable aerosol models for the GEMS validation/analysis studies. We expect that this research will contribute to a better understanding of the aerosol characteristics in East Asia.

Data



Data Sources
- POLDER3 L2
- VIIRS L2
- AERONET

Data Period
: Mar-May, 2012

Data Region
:Asia

Figure 1. GEMS observation area and AERONET locations (Yellow dot) of 83 sites during DRAGON Campaign over Asia.

Validation of VIIRS and POLDER3 Data

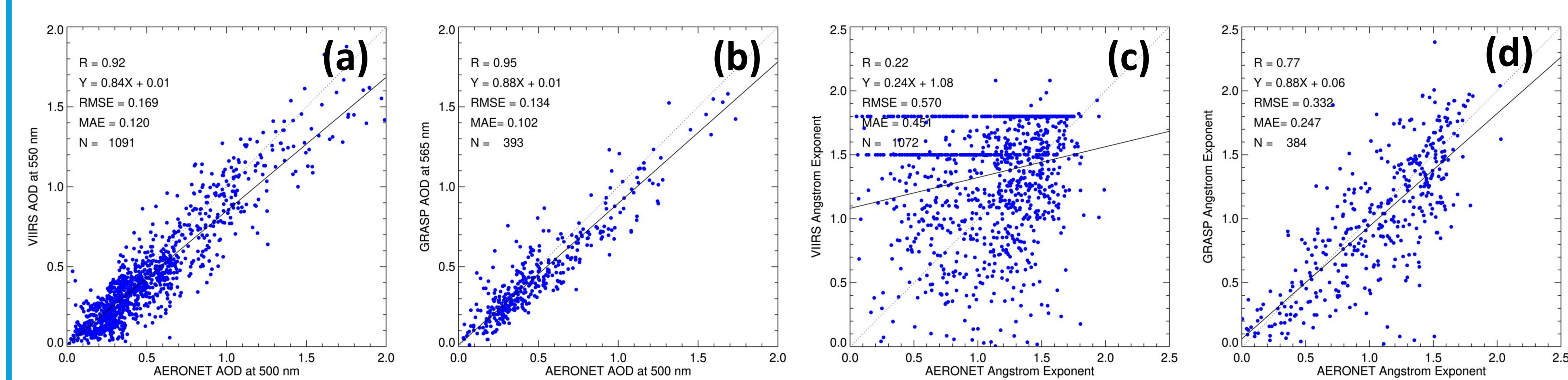


Figure 2. Scatterplots comparing VIIRS and POLDER data with AERONET properties. (a) Comparison with VIIRS Aerosol Optical Depth, (b) Comparison with POLDER-3 Aerosol Optical Depth, (c) Comparison with VIIRS Angstrom Exponent, (d) Comparison with POLDER-3 Angstrom Exponent. Overall, the aerosol properties observed by POLDER-3 which measures polarization, generally demonstrates high accuracy.

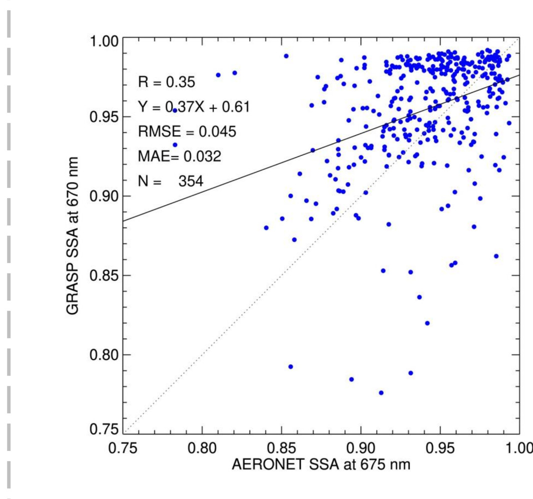


Figure 3. Scatterplots comparing POLDER-3 and AERONET Single Scattering Albedo at 670nm.

BusanSat-B

PolCube is a modified version of the PolCube is a modified version of the PolCam lunar instrument, that has been optimized for Earth-Science observations of aerosol, ocean, and thin cloud optical Properties (Stamnes et al., 2021).

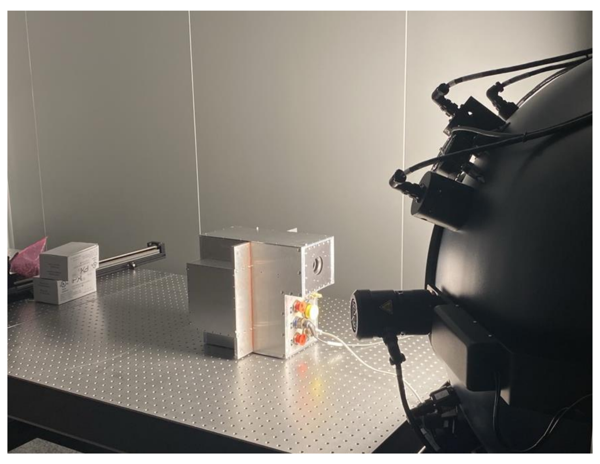
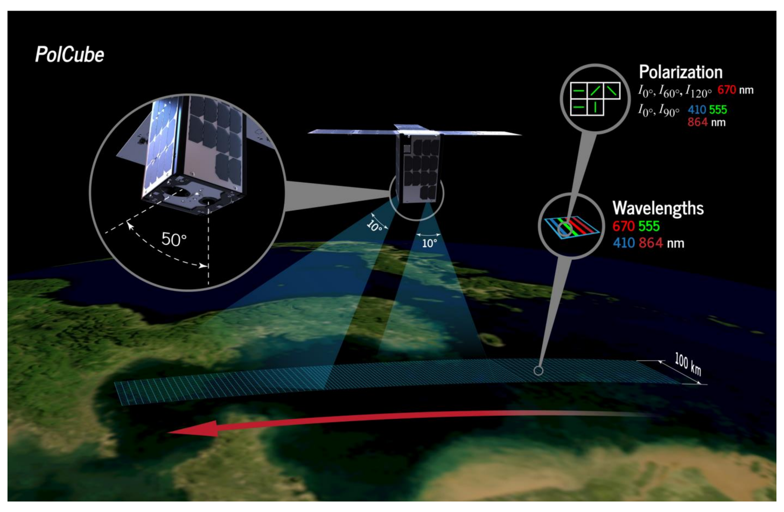


Figure 4. Calibration of the Airborne PolCube using an integrating sphere.



PolCube CubeSat polarimeter	
Instrument type	Multi-angle multi-spectral pushbroom imaging polarimeter
Measurement technique	Spectral filters and wire-grid polarizers
Detector	Teledyne e2v Onyx EV76C664 CMOS
Channel center wavelengths	410, 555, 670, 865 nm
Channel FWHM bandwidths	20, 20, 20, 20 nm
Channel VZA	57°, 52°, 0°, −5°
Measurements per VZA	Intensity (I) and Degree of Linear Polarization (DoLP)
No. VZA per channel	4
No. measurements per channel	8 (4 VZA × {I, DoLP})
No. measurements per ground pixel	32 (8 measurements per channel × 4 channels)
Polarization states per channel per VZA	$\{I_{0°}, I_{90°}\}$ at 410, 555, 865 nm; $I_{0°}, I_{60°}, I_{120°}$ at 670 nm
No. polarization states per ground pixel	36 (24 states at 410, 555, 865 nm + 12 states at 670 nm)
Radiometric uncertainty (1σ)	2%
DoLP uncertainty (1σ)	0.5%
Super-pixel ground resolution at nadir	0.39 × 0.31 km (567 km orbit altitude)
Effective multi-angle super-pixel ground resolution	0.65 × 0.96 km (567 km orbit altitude)
FOV	2 cameras with 10° FOV each
Swath	100 km
Power	10 W average (14 W peak)
Mass	4 kg
Volume (including spacecraft bus)	19 U
Communication bandwidth	30 Mbps
Expected lifetime	1 year

Figure 5. (Right panel) Image of the PolCube CubeSat polarimeter over Yellow Sea, (Left panel) Summary of PolCube CubeSat instrument capabilities and spacecraft specifications (Stamnes et al., 2021).

Flight of Airborne PolCube

Before the launch of BusanSat-B, an airborne version of PolCube conducted observations over Incheon and Busan from May 8 to 10, 2024. As major port cities in Korea, Incheon and Busan experience deteriorating air quality due to a complex interplay of factors, making it essential to monitor air quality in these regions.

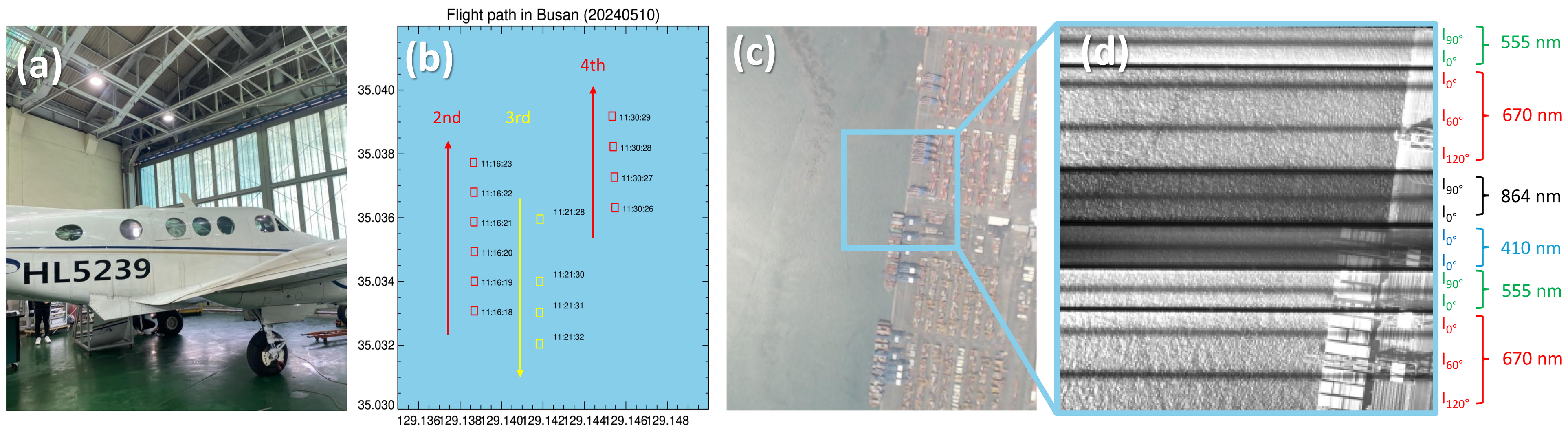
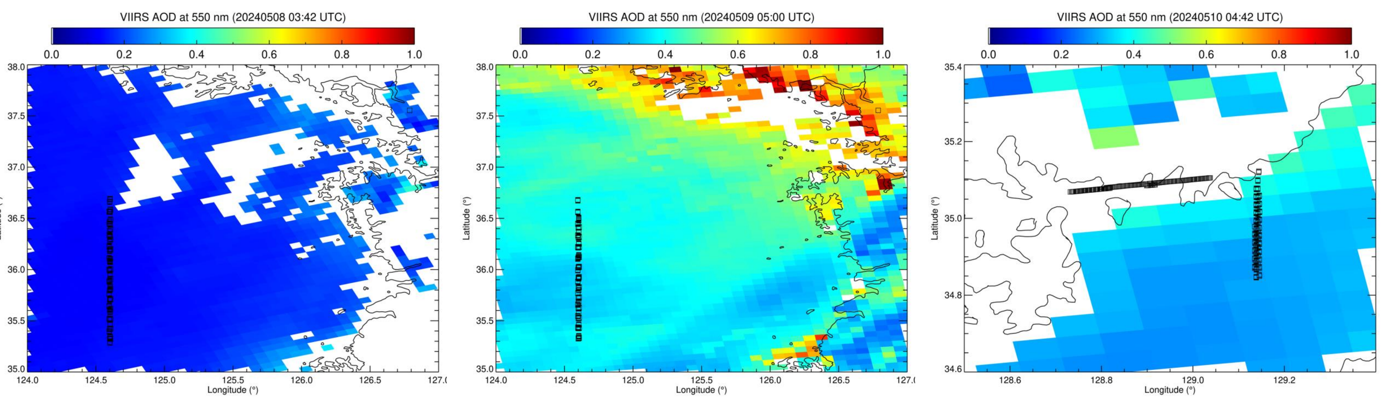
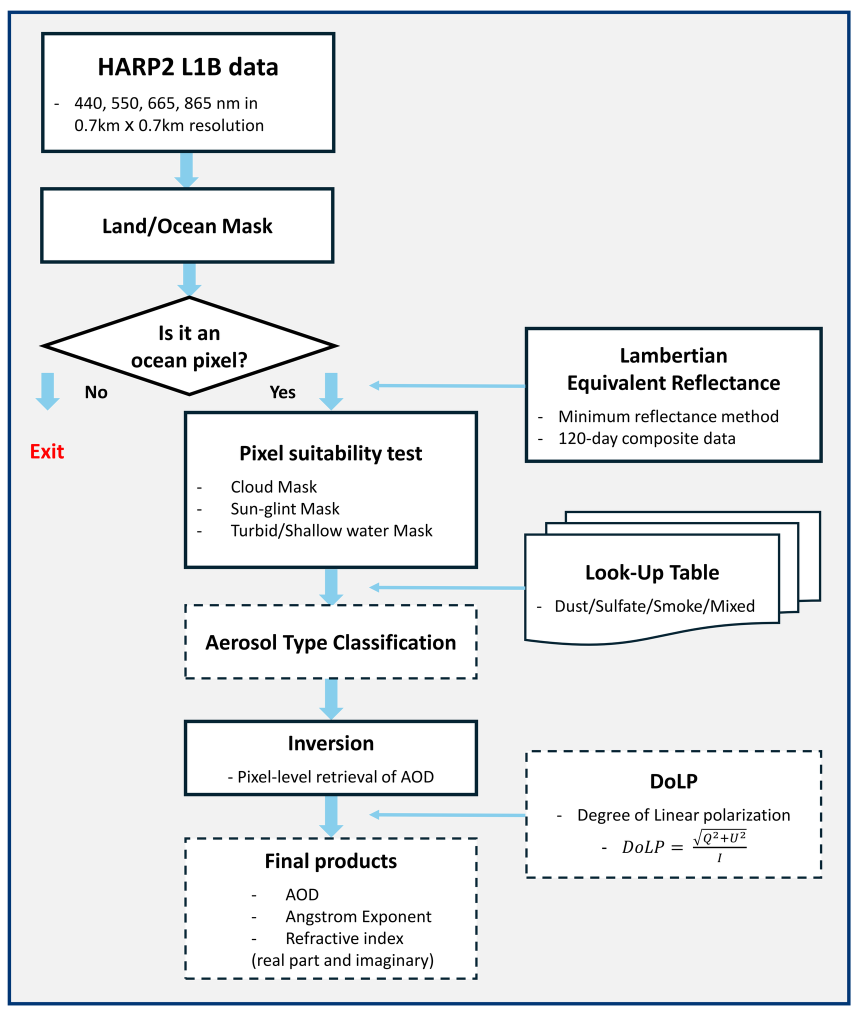


Figure 6. (a) Airborne equipped with the airborne PolCube, (b) Flight path over ocean near Busan (May 8-9, 2024), (c) A photo taken by a webcam during a flight in Busan, (d) Observations of the airborne PolCube in Busan (May 10, 2024).

Figure 7. Air quality measurements during the flight period based on VIIRS AOD data for the flight regions. (Left panel) VIIRS AOD shows low values in Incheon on May 8, 2024. (Middle panel) VIIRS AOD shows higher values in Incheon on May 9, 2024, compared to those on May 8. (Right panel) VIIRS AOD reveals high values in Busan on May 10, 2024.



Aerosol Retrieval Algorithm over Ocean & Initial Result



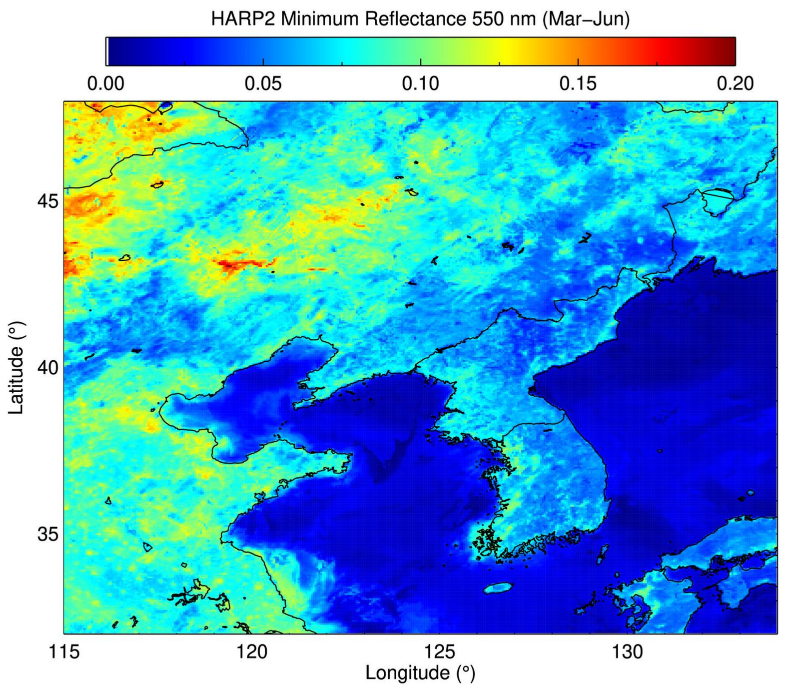


Figure 8. Minimum Lambertian Equivalent Reflectance at 555nm from HARP2. Due to, HARP-2 has a short swath and heritage, we considered compositing approximately 120 days of data for the test.

Figure 9. Flowchart of aerosol algorithm over the ocean from HARP2.

Adding polarimetry to the multi-angle observations allows for the retrieval of aerosol optical depth, Angstrom exponent, parameters of size distribution, measures of aerosol absorption, complex refractive index and degree of non-sphericity of the particles. (Remer et al., 2019)

Table 1. Dimensions of Look-Up Table for Dust model.

Name	Count	Entries
Wavelength	4	440, 550, 665, 865 nm
SZA	19	0, 5, 10, 15, … , 88 (5.0° step)
VZA	19	0, 5, 10, 15, … , 88 (5.0° step)
RAA	37	0, 5, 10, 15, … , 180 (5.0° step)
AOD	10	0.0, 0.2, 0.4, 0.6, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0
Albedos	8	0.0, 0.01, 0.03, 0.05, 0.1, 0.3, 0.5, 1.0

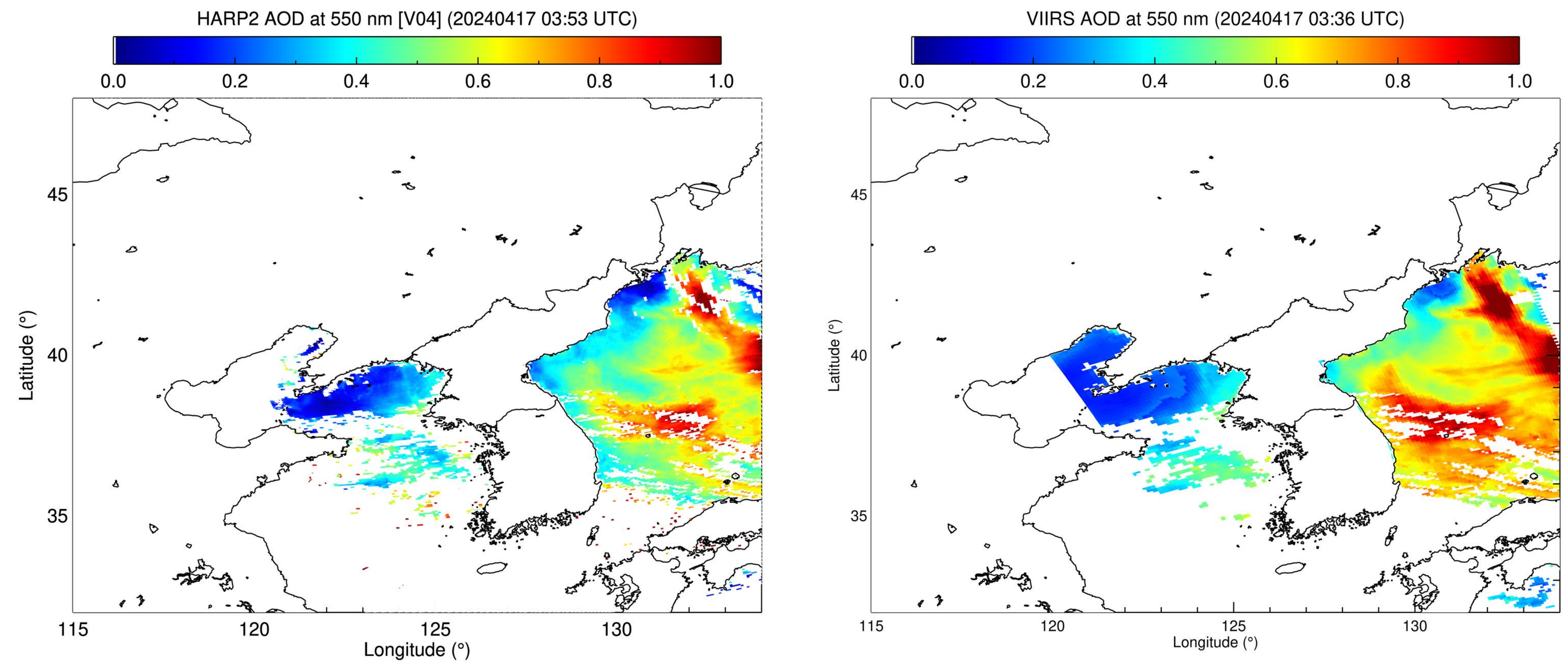


Figure 10. (Left panel) HARP2 AOD at 550 nm on April 17, 2024, processed according to the solid black line in the Figure 7 flowchart. In this case, only the Dust model was selected to retrieve the AOD (Right panel) VIIRS AOD at 550 nm on April 17, 2024.

Future works

- The airborne observation was successfully completed, and the collected radiance and polarization data are currently being analyzed.
- The next step involves developing an algorithm to derive aerosol properties from BusanSat-B data, utilizing a vector radiative transfer model that simulates polarization. The overlapping observational areas of BusanSat-B, GEMS, and TEMPO will enable synergistic research outcomes.
- After developing the algorithm for oceanic regions, We will focus on creating an algorithm for the land.
- Currently, We are using a Look-Up Table (LUT) method for retrieving aerosol properties. However, the primary goal is to use an iterative method expected to enhance aerosol properties' accuracy.

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