High-Resolution Aerosol Monitoring over Africa Using Deep Learning-Based MTG FCI AOD Estimation

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NEED
Sparse ground monitoring limits aerosol and $PM_{2.5}$ assessment over Africa.

APPROACH
Collocate cloud-screened FCI reflectance, geometry, and albedo with AERONET AOD_{500} and train TabM model.

PRODUCT
Generate sub-hourly FCI-estimated AOD_{500} data over the Africa domain.

1. WHY FCI AOD OVER AFRICA?

AOD-Mediated Pathway Toward $PM_{2.5}$ Estimation

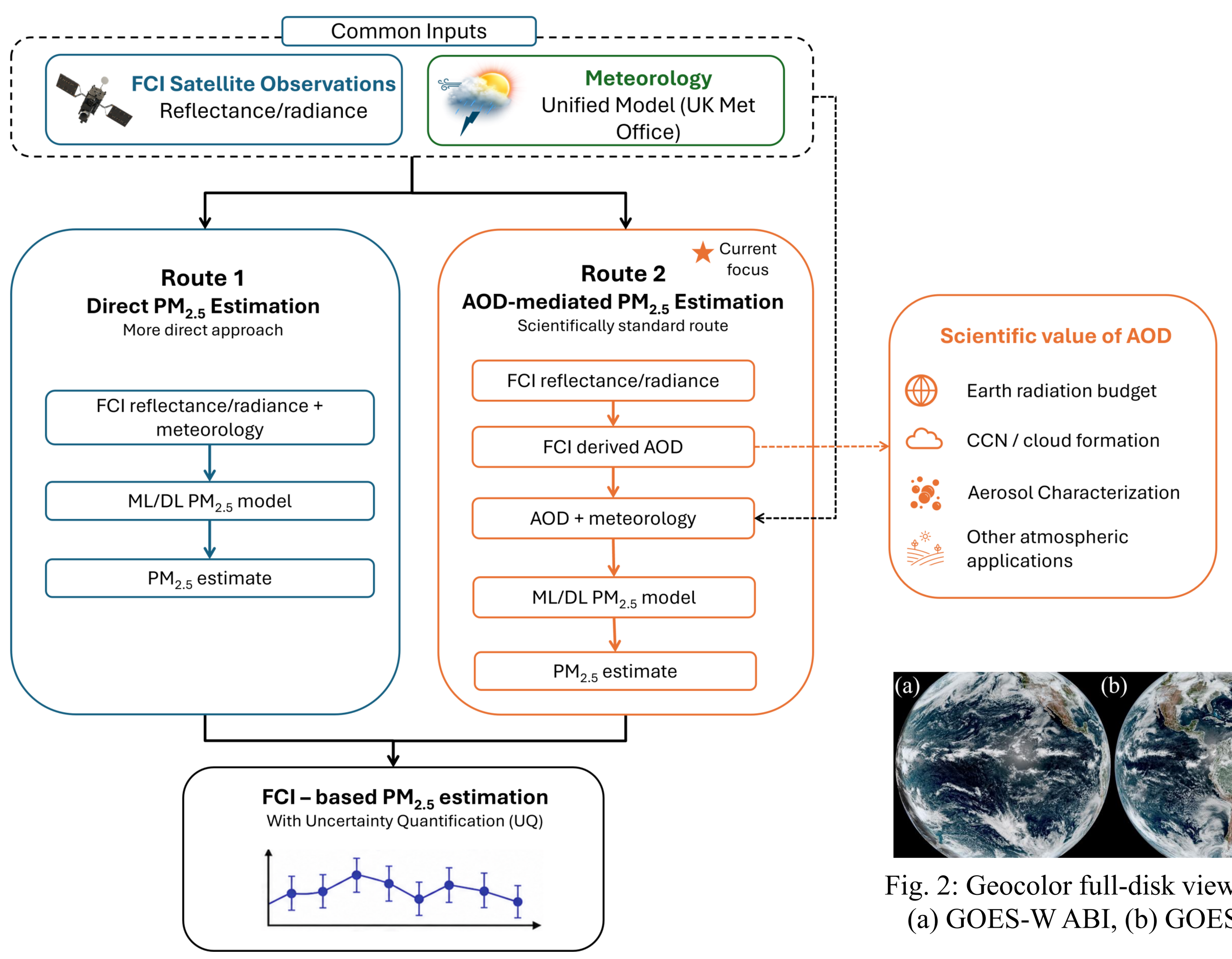


Fig. 1: AOD-mediated pathway linking FCI observations to future $PM_{2.5}$ estimation.

Motivation

Sparse monitoring: Ground observations are limited across Africa.
High variability: Dust and biomass burning drive strong aerosol gradients.
FCI opportunity: Geostationary Flexible Combined Imager (FCI) observations support frequent daytime monitoring.
AOD pathway: AOD_{500} provides a physical bridge toward $PM_{2.5}$ estimation.

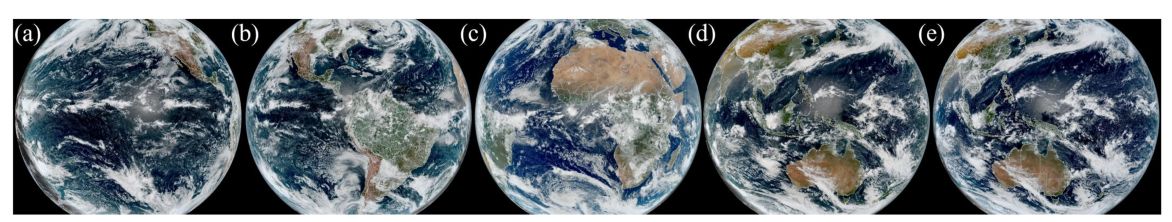
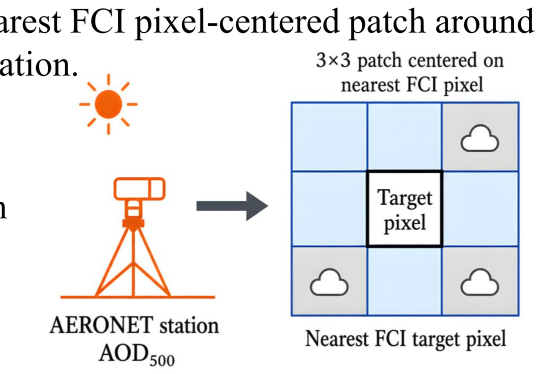


Fig. 2: Geocolor full-disk views from major geostationary imagers showing near-global coverage: (a) GOES-W ABI, (b) GOES-E ABI, (c) MTG-I FCI, (d) GK2A AMI, and (e) Himawari AHI.

FCI–AERONET Collocation

Target: AERONET AOD_{500} observations.
FCI predictors: VIS/NIR reflectance, geometry, cloud-screened pixels, and visible albedo (2 km).
Spatial match: nearest FCI pixel-centered patch around each AERONET station.
Temporal match: AERONET observations within ±10 min of each FCI timestamp.



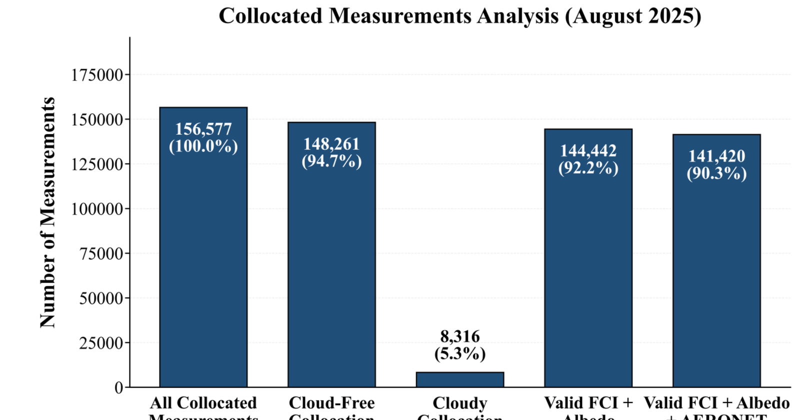


Fig. 3: Summary of August 2025 FCI–AERONET collocations after cloud screening and predictor-quality filtering.

2. TABM-BASED AOD ESTIMATION

TabM Architecture for FCI-Based AOD Estimation

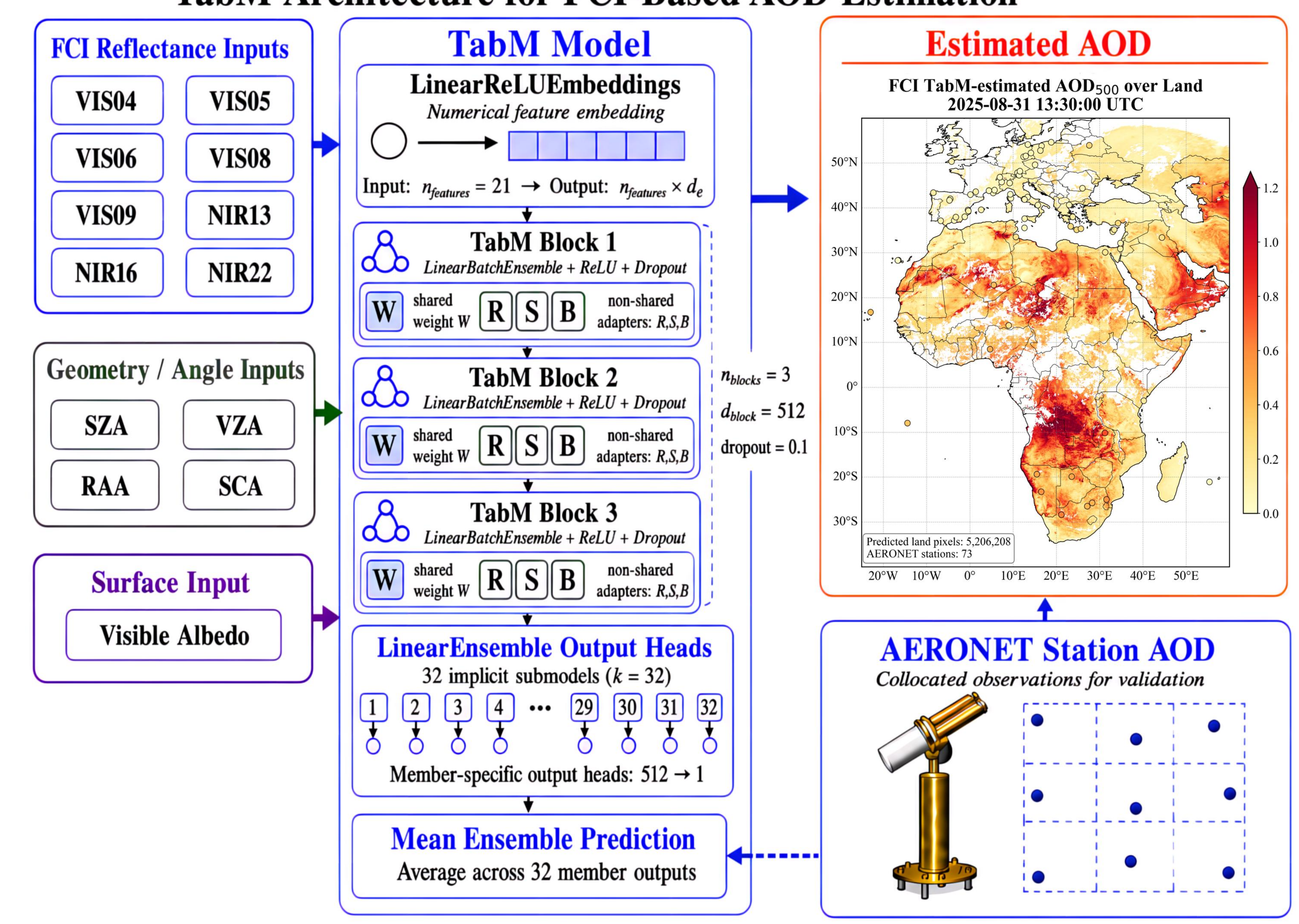


Fig. 4: TabM model structure for estimating AOD_{500} from FCI reflectance, geometry, and surface predictors.

Why TabM Model?

- **Tabular deep learning:** Learns nonlinear relationships among FCI reflectance, geometry, and surface predictors.
- **Numerical embeddings:** Transform continuous satellite variables into richer feature representations.
- **Parameter-efficient ensemble:** Uses 32 implicit ensemble members to improve stability and generalization.
- **Final AOD estimate:** Averages ensemble-member outputs to produce the FCI-derived AOD_{500} prediction.

3. MODEL VALIDATION

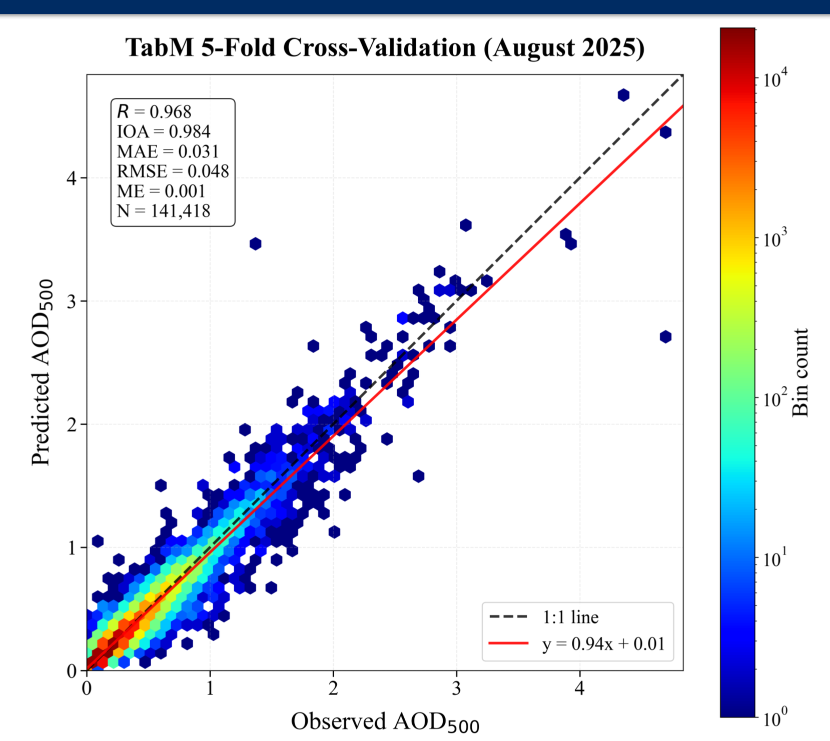


Fig. 5: Hexbin density comparison of AERONET-observed and TabM-predicted AOD_{500} from 5-fold cross-validation.

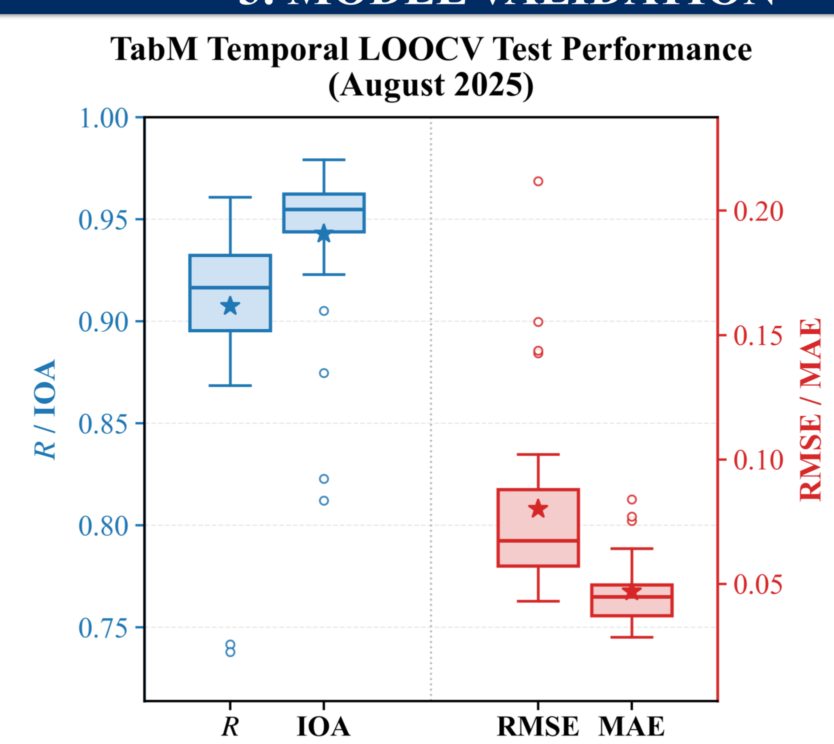


Fig. 6: Boxplots of daily test performance metrics from temporal leave-one-day-out cross-validation.

Validation Highlights

High agreement: Estimated AOD_{500} closely follows AERONET observations in 5-fold CV.

Consistent retrieval pattern: The highest sample density follows the 1:1 line across the dominant AOD range.

Stable temporal skill: Temporal LOOCV shows high R and IOA across most held-out days.

Low overall bias: Near-zero ME indicates minimal systematic overestimation or underestimation across the collocated dataset.

4. DAILY AOD MAPPING AND VIIRS BENCHMARKING

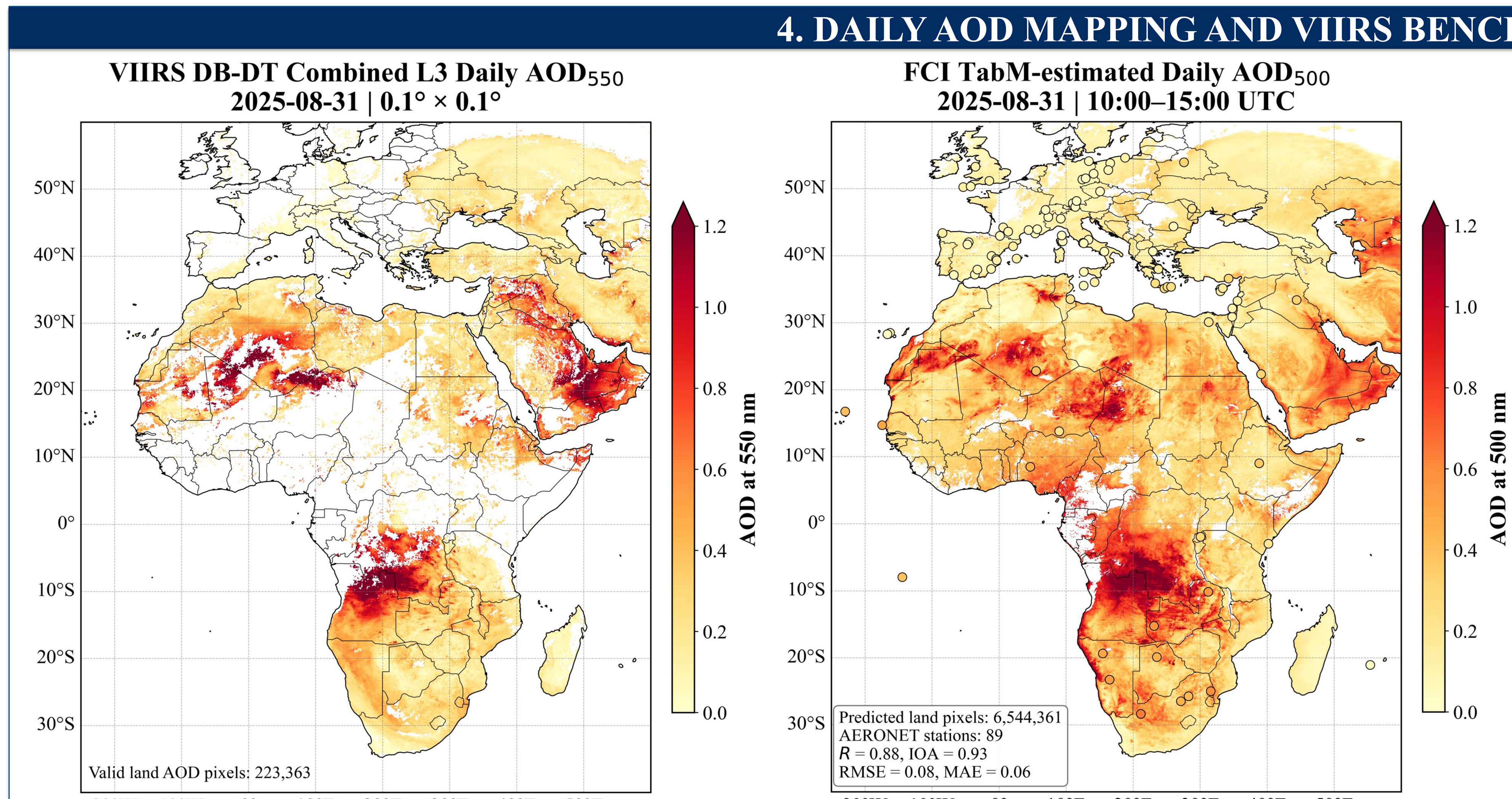


Fig. 7: Daily AOD comparison between Suomi-NPP VIIRS DB-DT AOD_{550} (left) and FCI TabM-estimated AOD_{500} (right) over Africa on test date 2025-08-31.

Inferences

- FCI captures major aerosol plumes across the Sahara, Sahel, and southern-central Africa at finer-scale
- Elevated AOD in southern-central Africa is consistent with biomass-burning influence
- VIIRS shows broadly similar high-AOD regions, supporting spatial consistency.
- Differences are expected from AOD wavelength, temporal sampling, cloud screening, and spatial resolution.
- Geostationary high spatial-temporal resolution provides a strong pathway toward future $PM_{2.5}$ estimation over Africa.

5. KEY CONTRIBUTIONS

- **Geostationary AOD capability:** Demonstrates high-resolution (2 km), sub-hourly AOD_{500} estimation over Africa using MTG-I FCI.
- **Physics-informed pathway:** Uses AOD as an interpretable bridge from FCI reflectance to future $PM_{2.5}$ applications.
- **Multi-level evaluation:** Combines AERONET validation, temporal holdout testing, and VIIRS benchmarking.

6. HAQAST RELEVANCE

- **Data-sparse regions:** Supports aerosol monitoring where ground observations are limited.
- **Applied air quality:** Provides a foundation for satellite-driven $PM_{2.5}$ estimation over Africa.
- **Decision support:** Sub-hourly geostationary sampling can help track daytime aerosol evolution.

7. NEXT STEPS

- **Seasonal extension:** Expand training and validation beyond August 2025.
- **Uncertainty analysis:** Quantify prediction confidence using ensemble-based diagnostics.
- **$PM_{2.5}$ modeling:** Integrate meteorology and available surface $PM_{2.5}$ observations.

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Reference: Park, S., Sayeed, A., Seo, J., Henderson, B. H., Naeger, A. R., & Gupta, P. (2025). Hour by hour PM2.5 mapping using geostationary satellites. ACS ES&T Air, 2(9), 1816–1830. doi.org/10.1021/acsestair.4c00365