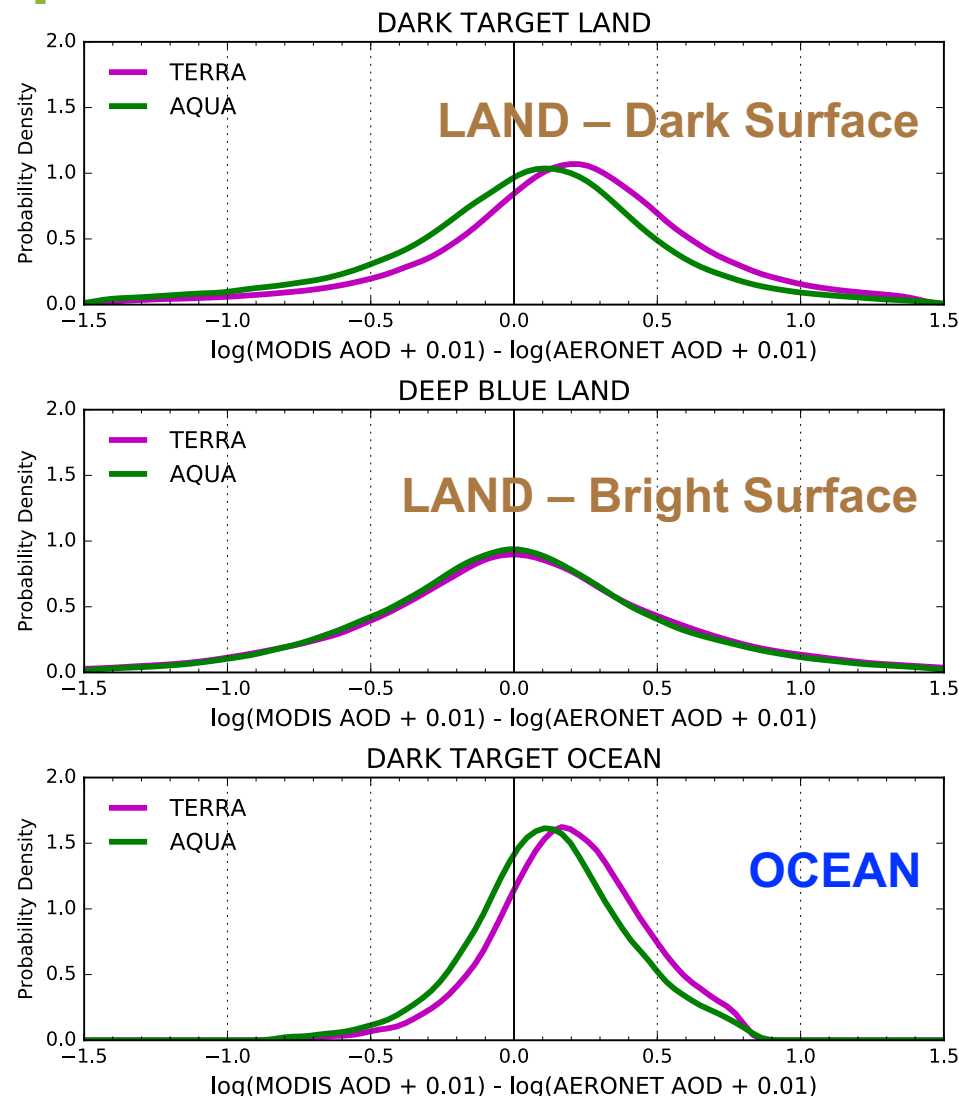


GEOS Neural Network Retrieval for AOD Data Assimilation

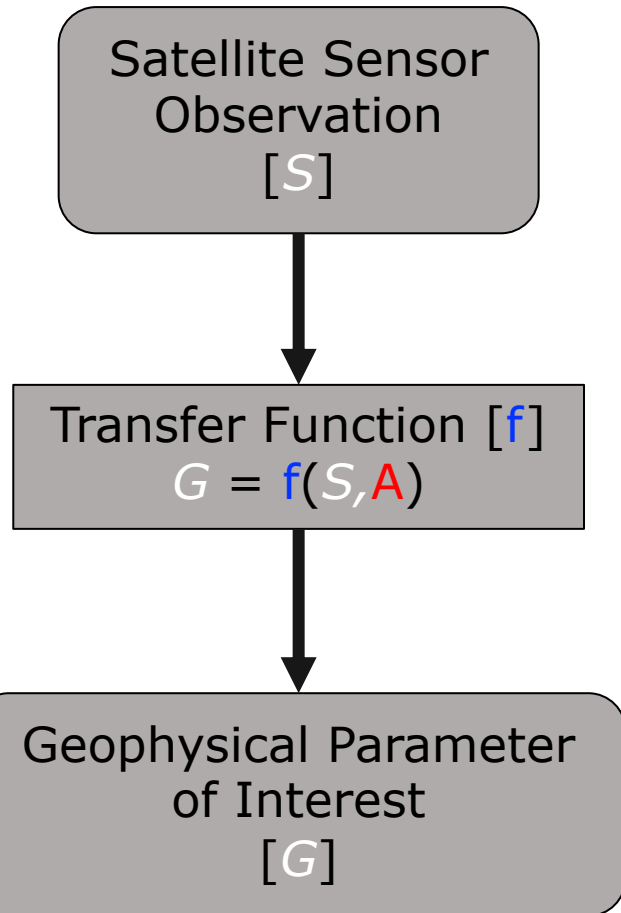
Patricia Castellanos, Arlindo da Silva
Dark Target & Deep Blue Teams
NASA Goddard Space Flight Center

Comparison of MODIS DT & DB AOD Retrievals



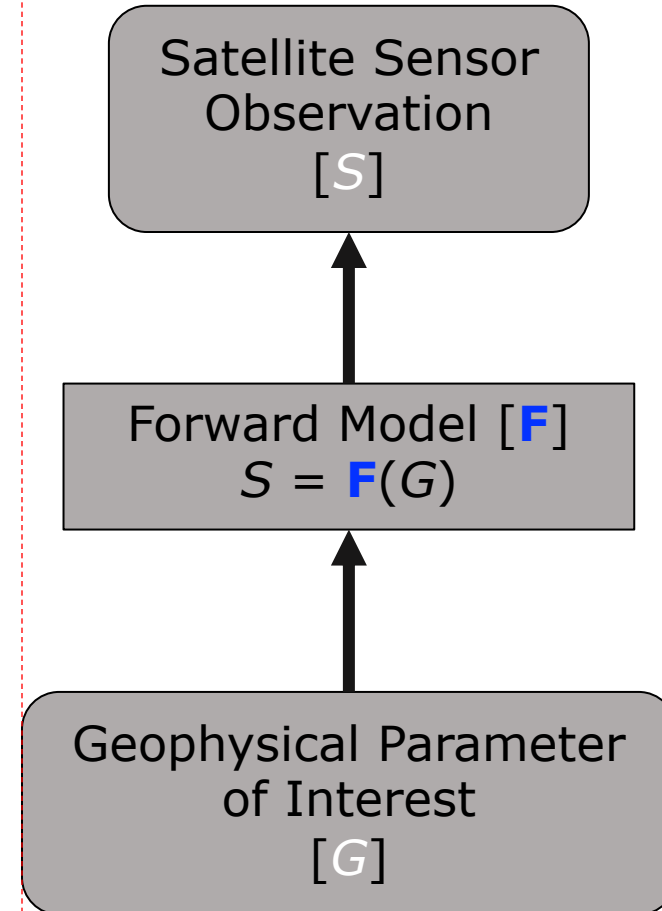
- Biases between datasets can propagate in the model forecast and lead to **artificial time variability**.
- The AOD data assimilation problem requires a **homogenized AOD observing** system across different platforms

Empirical Retrievals



- f is a continuous function that maps S to G
- Represent f with a mathematical function that contains a set of empirical parameters, A
- A are determined from a training dataset of pairs of G and S observations.
- Training empirically captures physical relationships and tunes away calibration issues.

Physically Based Retrievals



- F is a physical model derived from first principles (e.g. radiative transfer model)
- F is not easily inverted
- The objective of the retrieval algorithm is to search for a G^* that minimizes $\|S - F(G)\|$
- Product quality affected by calibration issues.

L1 Reflectances

Read directly from
DT & DB Level 2
Files

Generate L2 Reflectance

- ☐ Cloud mask
- ☐ Quality control

Collect Relevant Ancillary Data

- ☐ Surface reflectance
- ☐ Aerosol speciation (GEOS forecast)

Machine Learning
Algorithm trained
with AERONET
observations

Do Retrieval

AOD

MODIS Over Land Algorithm

All procedures applied to individual boxes of 20 x 20 pixels at 500 m resolution (10 km at nadir)

- Ensure angles and reflectance values are valid. If not: **report Fill values and EXIT**
- Identify and mask (discard) all water, cloudy and snow/ice pixels.
- Identify "dark target pixels" that have $0.01 \leq \rho_{2.13} \leq 0.25$
- Discard brightest 50% and darkest 20% of pixels defined with $\rho_{0.66}$... leaving a maximum of 120 pixels

Are there
at least 12 (10%)
dark target pixels?

yes

no

Procedure A

Set QAC=0,1,2 or 3 (based on # of pixels)

- For all identified 'dark' pixels, Calculate mean $\rho_{0.47}, \rho_{0.66}, \rho_{2.1}, \rho_{1.2}$
- Calculate $NDVI_{SWIR}(\rho_{2.1}, \rho_{1.2})$
- Assume surface reflectance relationships:
 $\rho_{0.66}^s = f(\rho_{2.12}^s, NDVI_{SWIR}, \Theta); \rho_{0.47}^s = g(\rho_{0.66}^s, \Theta)$
- Select fine model aerosol type LUT (function of geography and season)
- Select coarse model aerosol LUT (dust)
- Correct lookup tables for elevation
- Interpolate lookup tables on geometry

Do Inversion

For 13 values of η
(-0.1, 0.0, 0.1, ..., 0.9, 1.0, 1.1) ...
Find $\tau_{0.55}$ and $\rho_{2.1}^s$ such that
 $\rho_{0.47}^{MODIS} - \rho_{0.47}^{TOA} = 0$,
where $\rho_{\lambda}^{TOA} = \eta(\rho_{\lambda}^{fine}) + (1-\eta)(\rho_{\lambda}^{coarse})$
Choose η such that
 $\rho_{0.66}^{MODIS} - \rho_{0.66}^{TOA} = \epsilon$ is minimized

Primary products: $\tau_{0.55}, \eta, \rho_{2.1}^s, \epsilon$

- Calculate $\tau_{\lambda}, \rho_{\lambda}^s, \alpha, M_C, \tau_{\lambda}^{fine}$
- If $\eta = -0.1$ set $\eta = 0.0$; If $\eta = 1.1$ set $\eta = 1.0$
- If $\tau_{0.55} < 0.2$, then set $\eta = \text{Fill}$
- If $\epsilon > 0.25$, then set QAC = 0

Is $\tau_{0.55} < 0.0$?

yes

no

Procedure B

Set QAC=0

Identify and count pixels where
 $\rho_{2.13} > 0.25$ and $\rho_{2.13} \leq 0.25$ $G(\mu, \mu_0) < 0.40$

Is $N \geq 12$?

yes

no

Report Fill values & error codes
EXIT

- Assume surface reflectance relationships:
 $\rho_{0.66}^s = f(\rho_{2.12}^s, NDVI_{SWIR}, \Theta); \rho_{0.47}^s = g(\rho_{0.66}^s, \Theta)$
- Assume Continental aerosol model (only)
- Correct lookup table for elevation
- Interpolate lookup table on geometry

Do Single Channel Retrieval

Find $\tau_{0.55}$ and $\rho_{2.1}^s$ such that
 $\rho_{0.47}^{MODIS} - \rho_{0.47}^{TOA} = 0$,
where $\rho_{\lambda}^{TOA} = \rho_{\lambda}^{Continental}$

Primary products: $\tau_{0.55}, \rho_{2.1}^s$

- Calculate $\tau_{0.47}, M_C$
- Set $\eta, \tau_{0.66}, \tau_{2.1}, \alpha, \tau_{\lambda}^{fine} = \text{Fill}$

If $\tau_{0.55} \leq 0.0$ then set $\alpha = \text{Fill}, M_C = 0, \tau_{\lambda}^{fine} = 0$
If $-0.1 < \tau_{0.55} \leq -0.05$, then set $\tau_{\lambda} = -0.05$
If $\tau_{0.55} \leq -0.10$, then set $\tau_{\lambda}, \alpha, M_C, \tau_{\lambda}^{fine} = \text{Fill}$

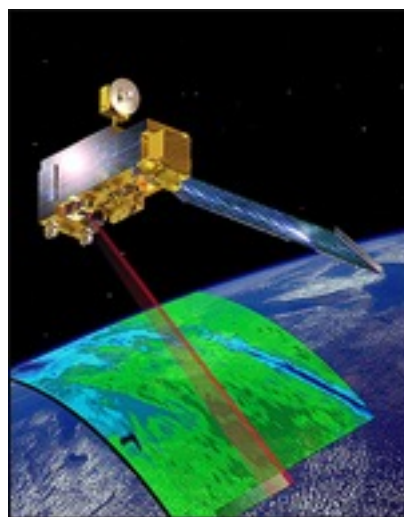
Report: $\tau_{\lambda}, \rho_{\lambda}^s, \alpha, M_C, \tau_{\lambda}^{fine}, QA$, etc **EXIT**

Observations

Satellite Sensor Observation:

MODIS MOD04 /MYD04 Level 2 Reflectance

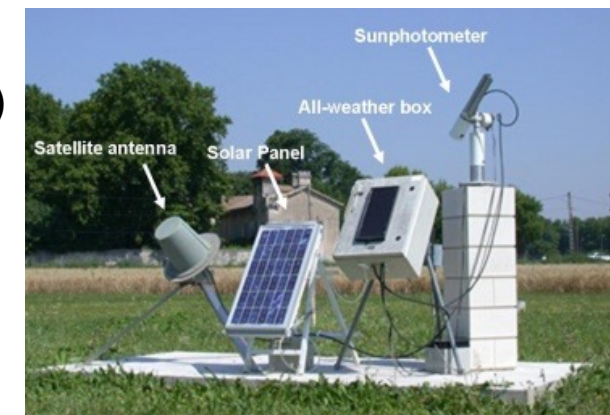
- Cloud masked, quality controlled, 10 km data
- Deep Blue Land
 - 3 channels over bright surfaces
 - 412 nm, 470 nm, and 670 nm
- Dark Target Land
 - 9 channels over dark surfaces
 - 412-2100 nm
- Dark Target Ocean
 - 7 channels over ocean
 - 470-2100 nm



Geophysical Parameter of Interest:

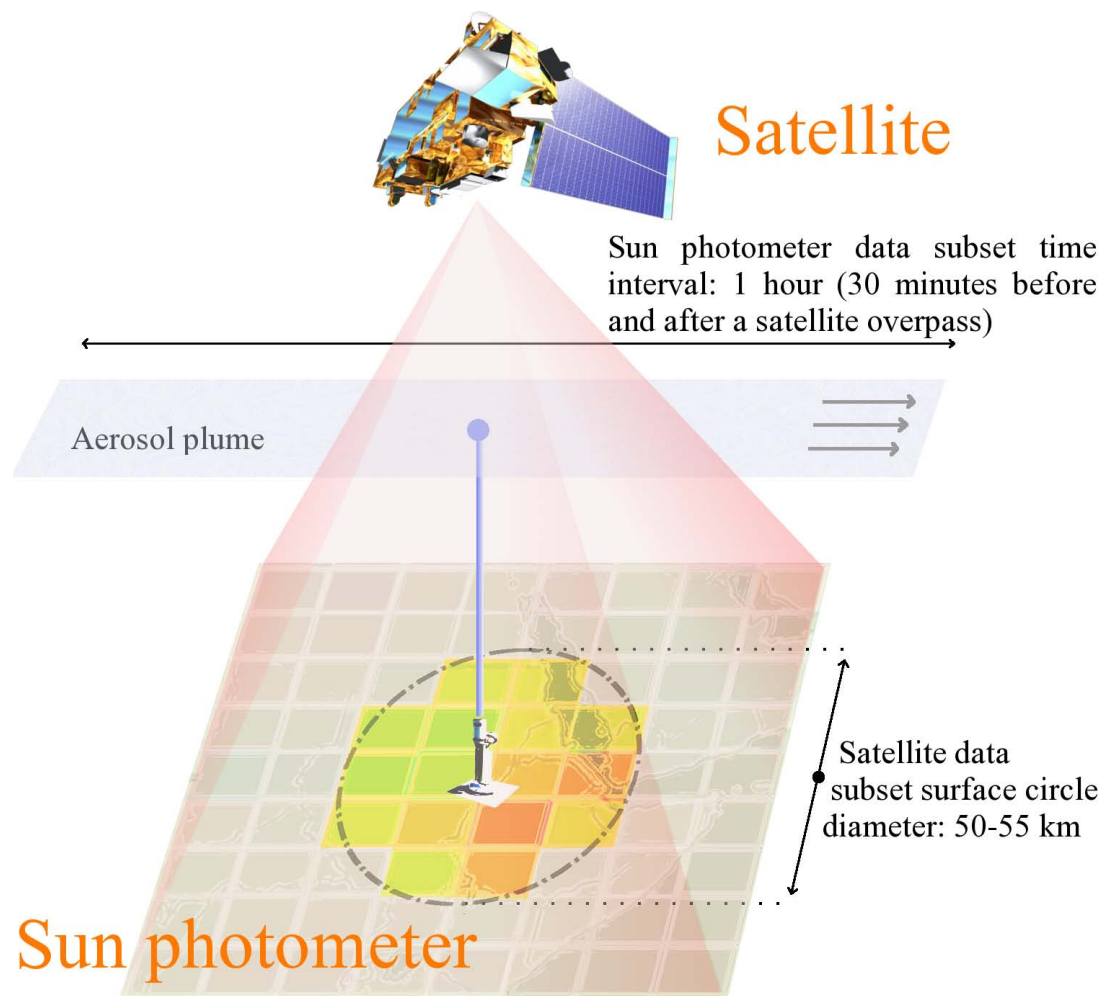
440, 470, 550, 670, 870 nm AOD

- Aerosol Robotic Network (AERONET) observations of AOD
 - Global network of sunphotometers
 - 15 minute sampling
 - Low uncertainty (± 0.01)



aeronet.gsfc.nasa.gov

MODIS-AERONET Data Pairs



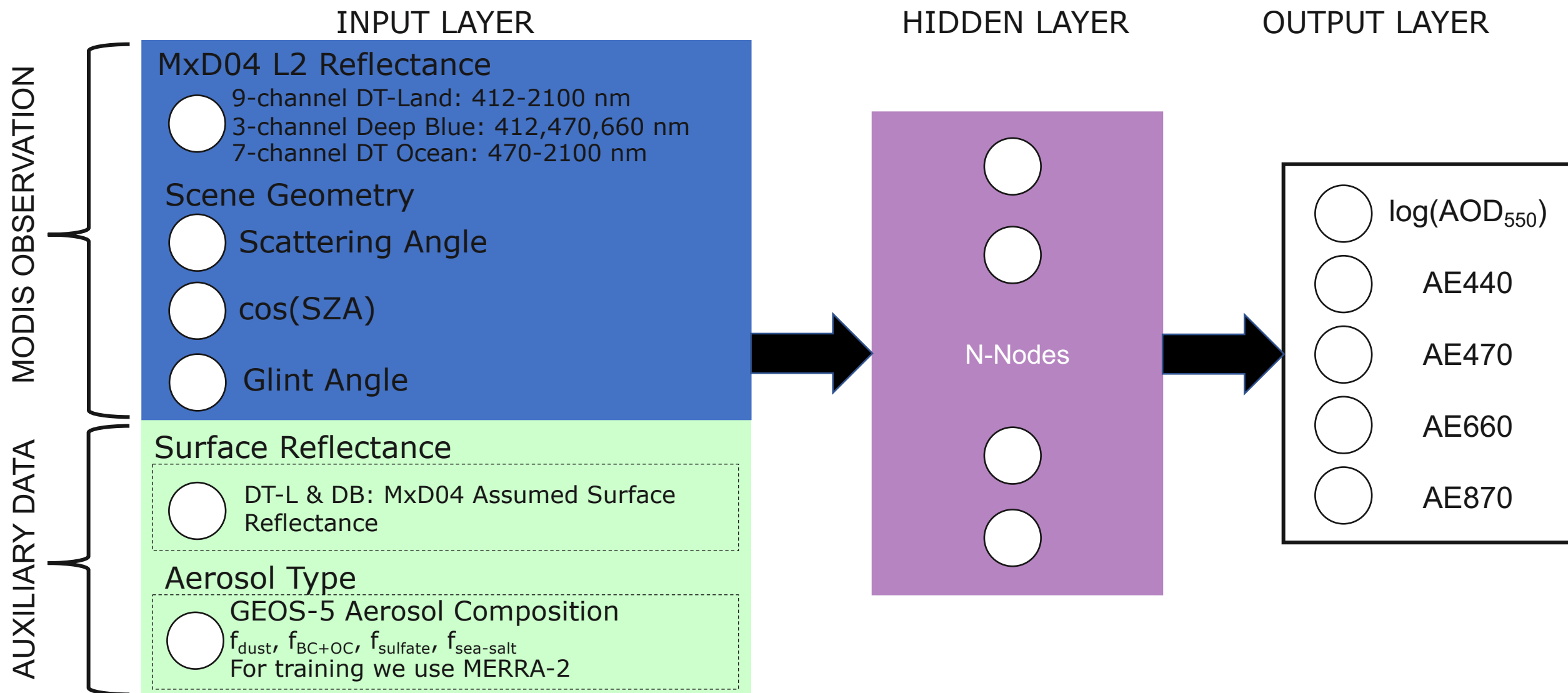
Petrenko, et al. AMT (2012)

- 20 years of data (2000-2021)

Additional Data Screening

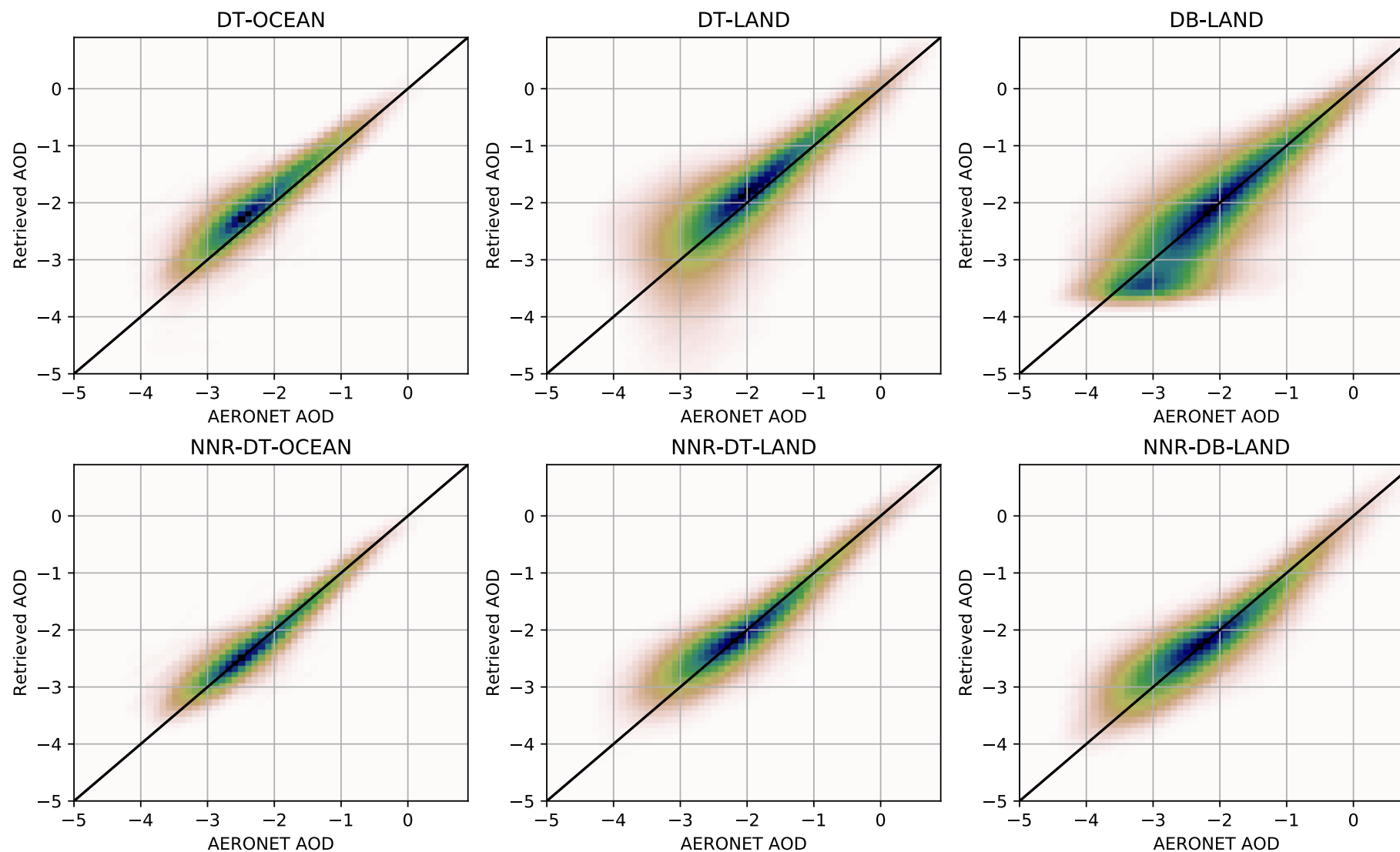
- Outlier removal
- Cloud Fraction < 0.7
- Used MERRA-2 to “balance” the dataset by aerosol type
 - Dust
 - Smoke (Black Carbon + Organic Carbon)
 - Sea Salt
 - Sulfate

GEOS NNR for AOD



550 nm AOD

DT & DB

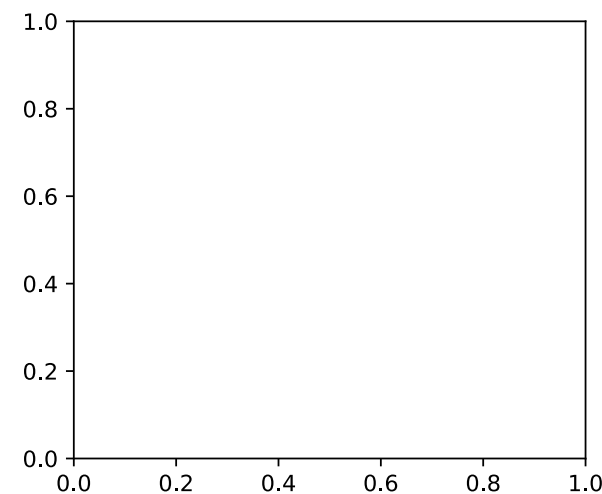
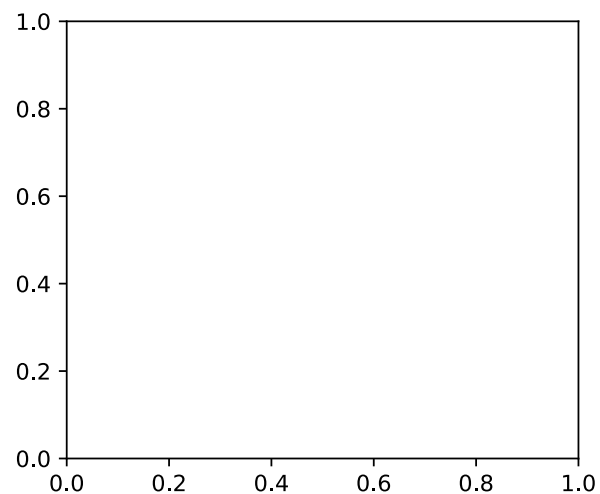
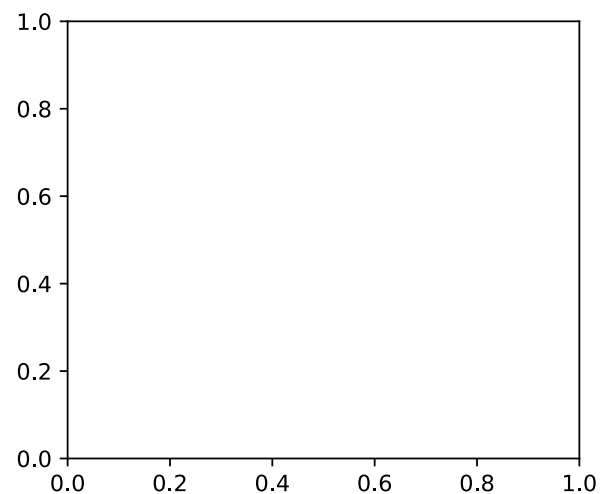


NNR

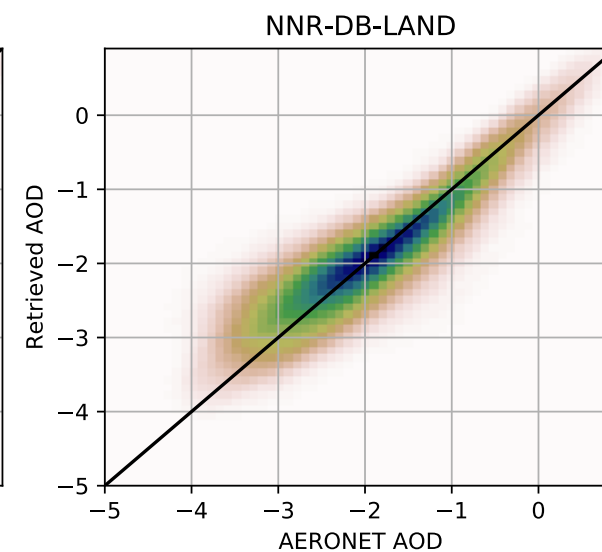
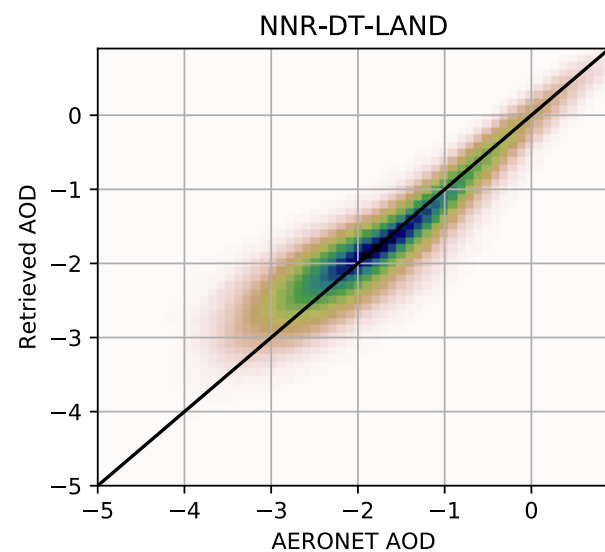
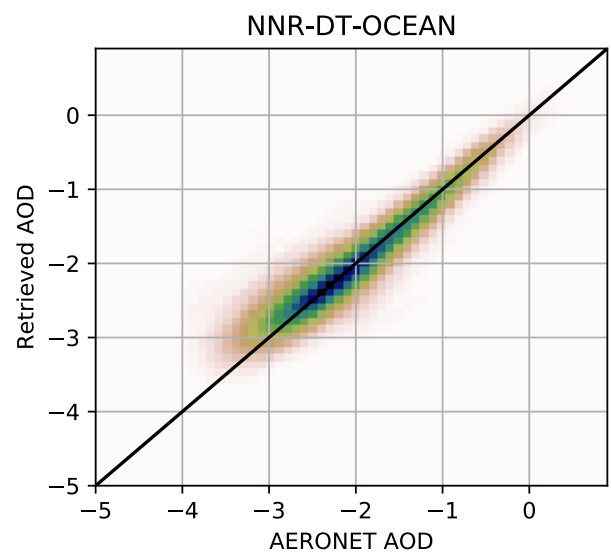


440 nm AOD

DT & DB →

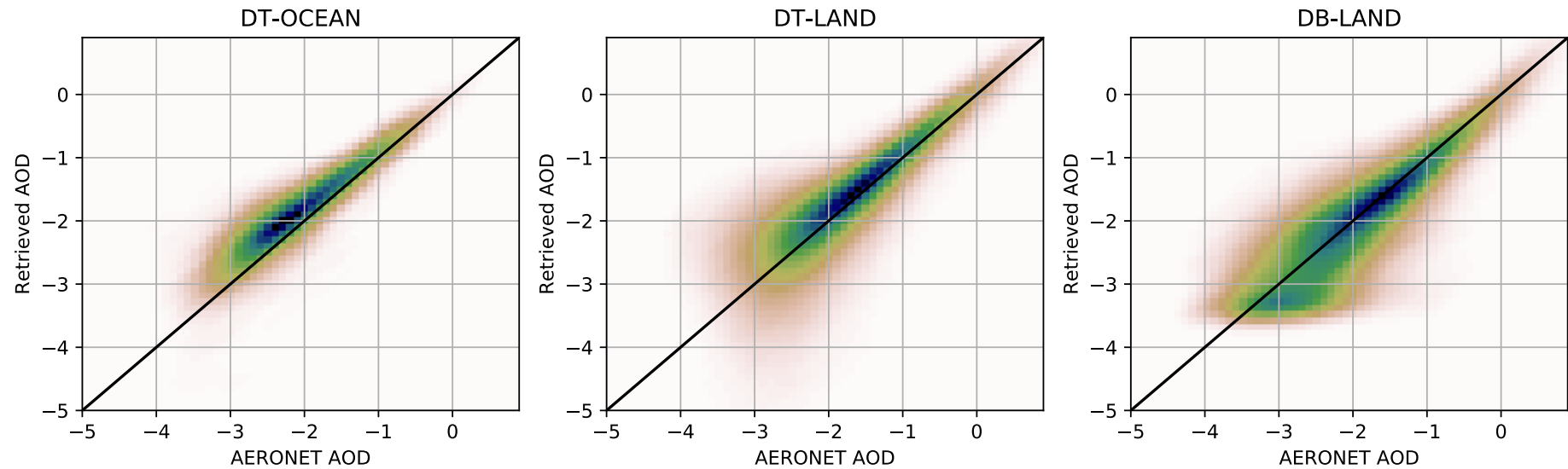


NNR →

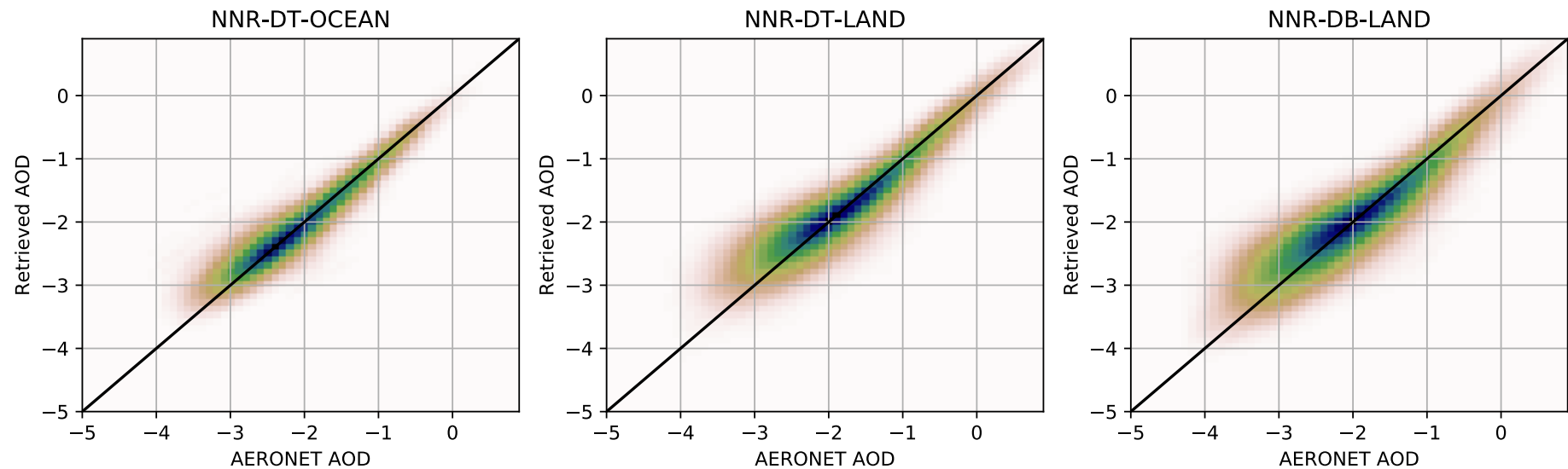


470 nm AOD

DT & DB →

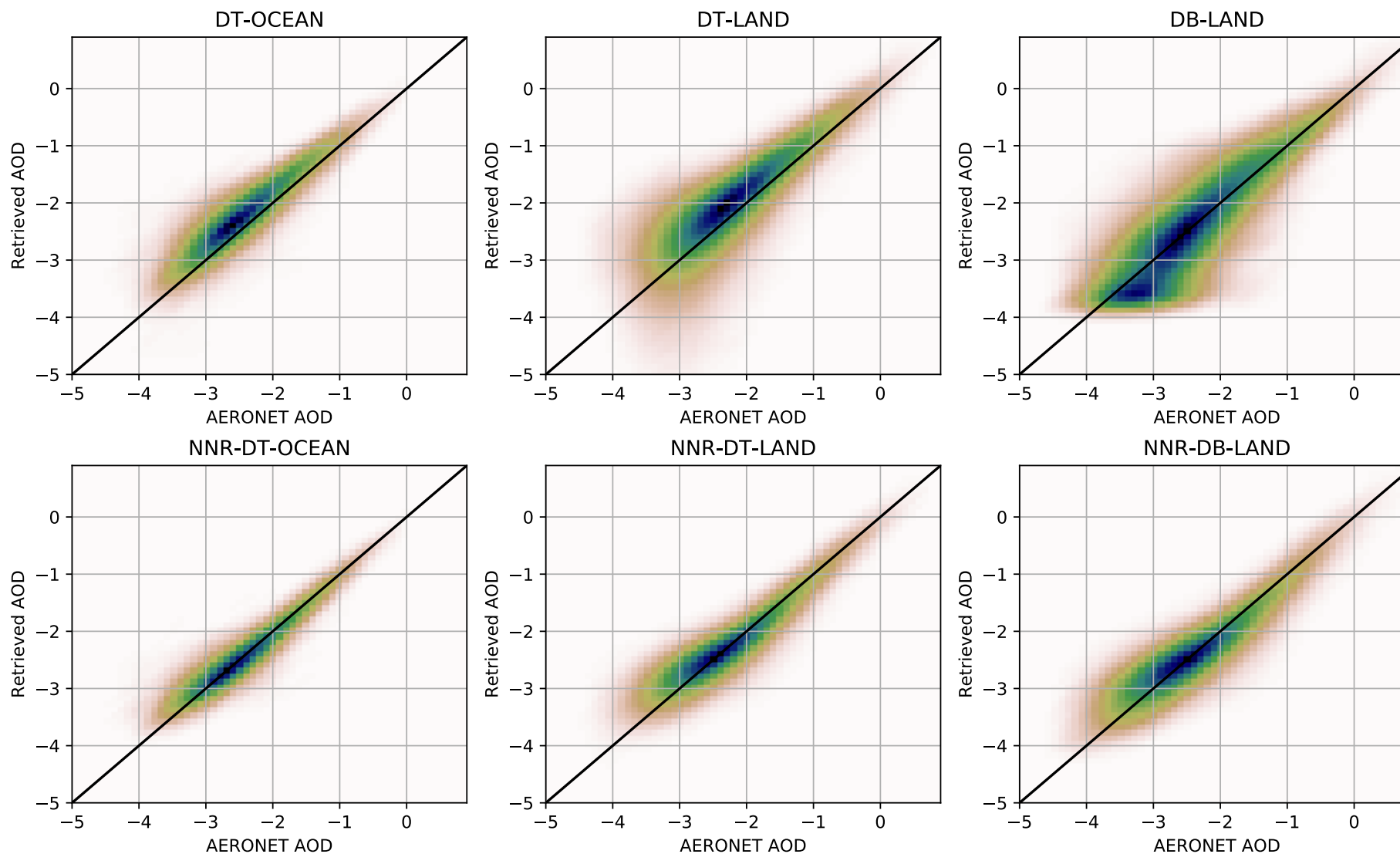


NNR →



660 nm AOD

DT & DB

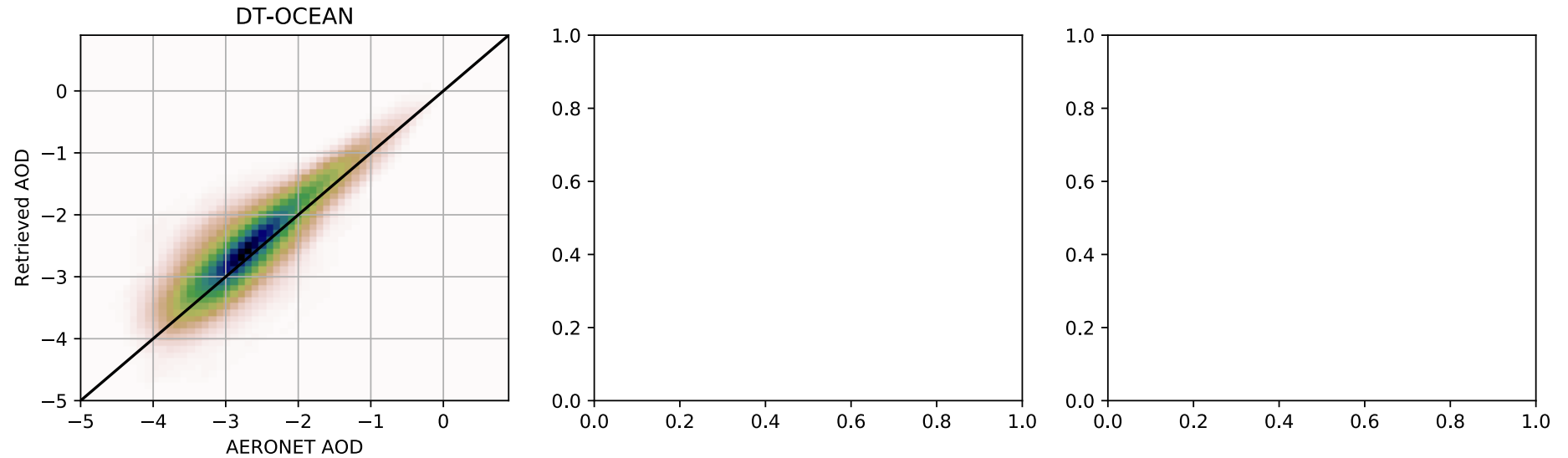


NNR

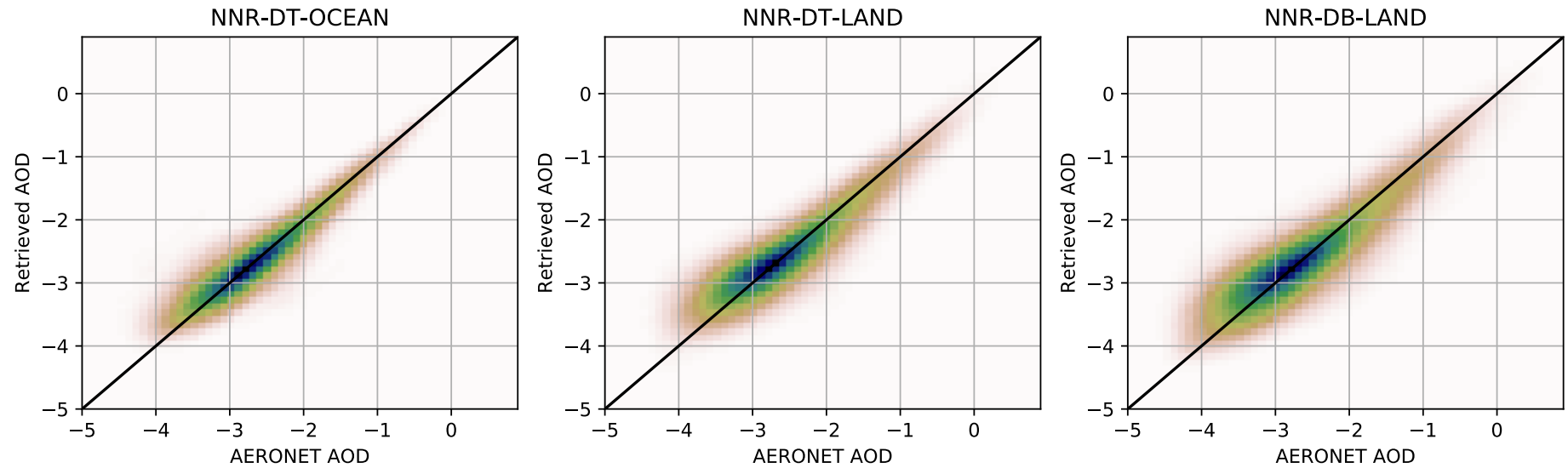


870 nm AOD

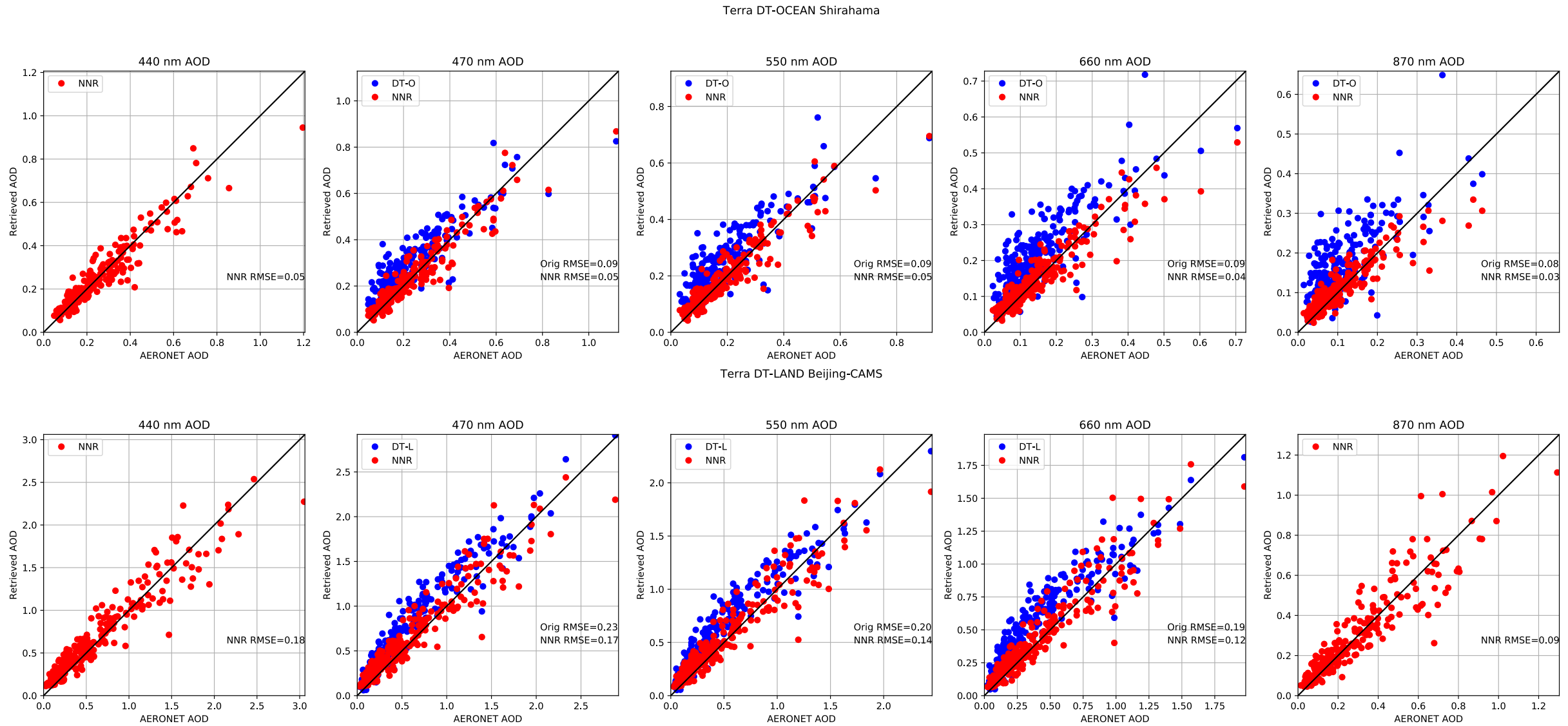
DT & DB →



NNR →

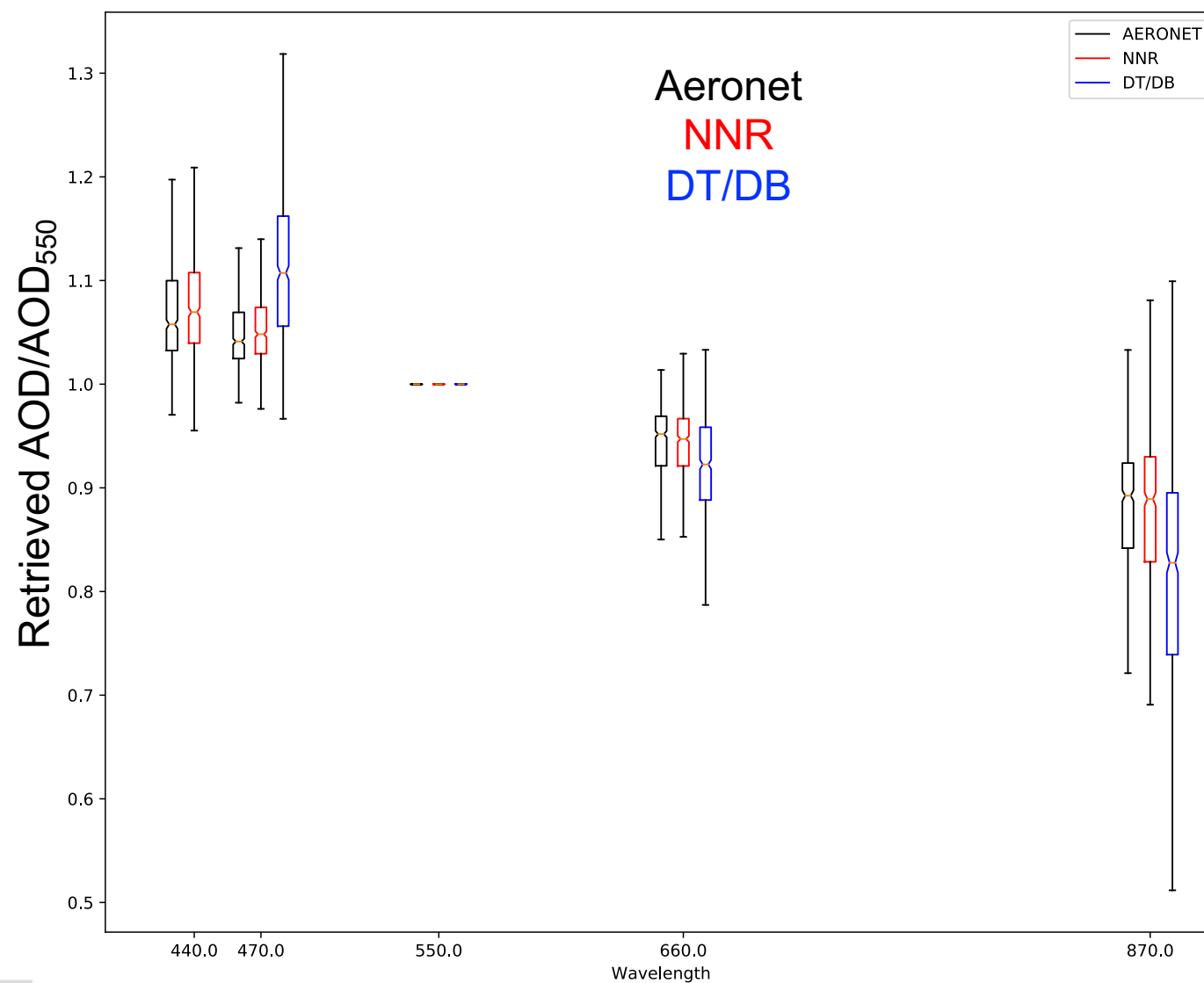


Testing at Specific Sites



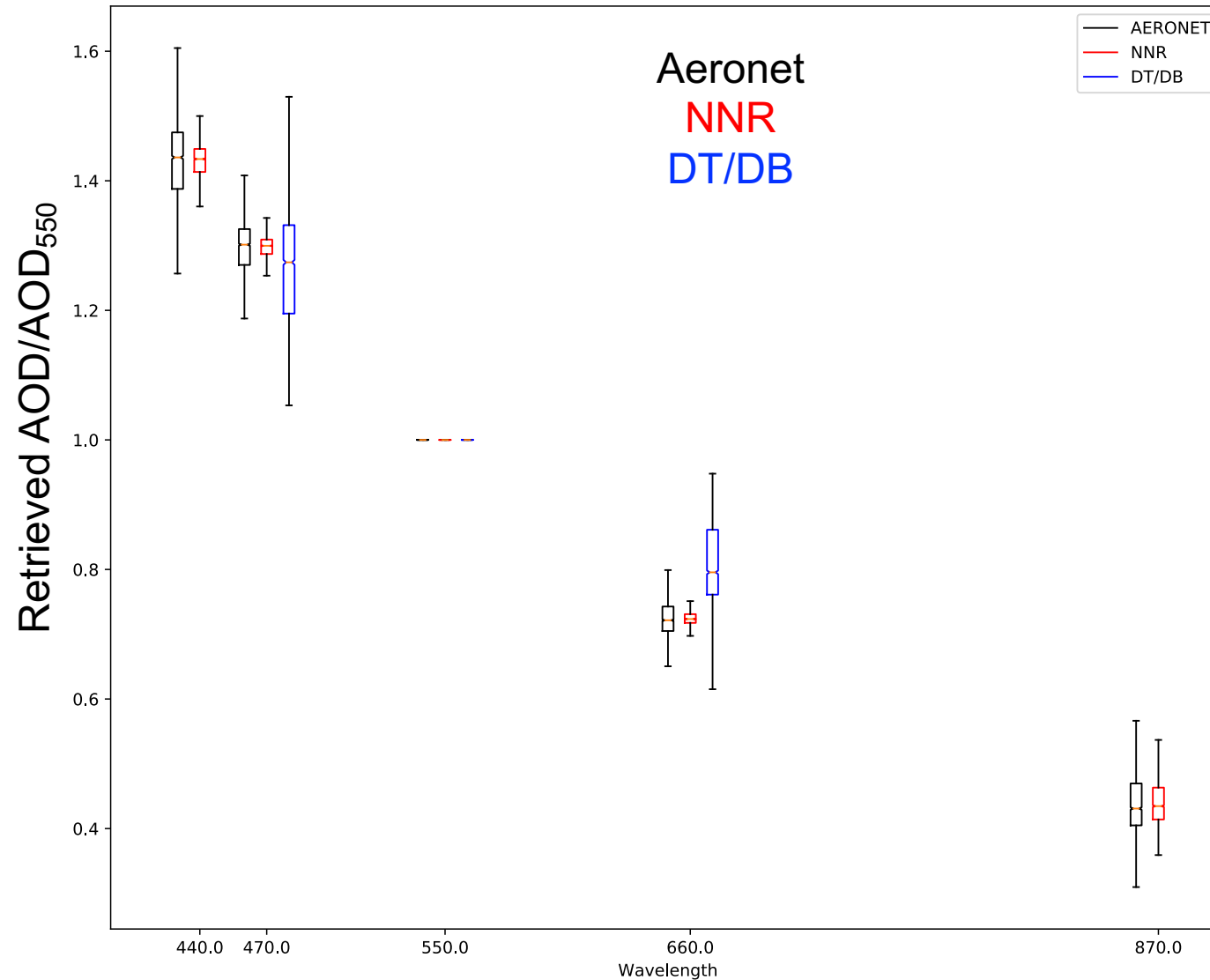
AOD Spectral Dependence

Dust Dominated



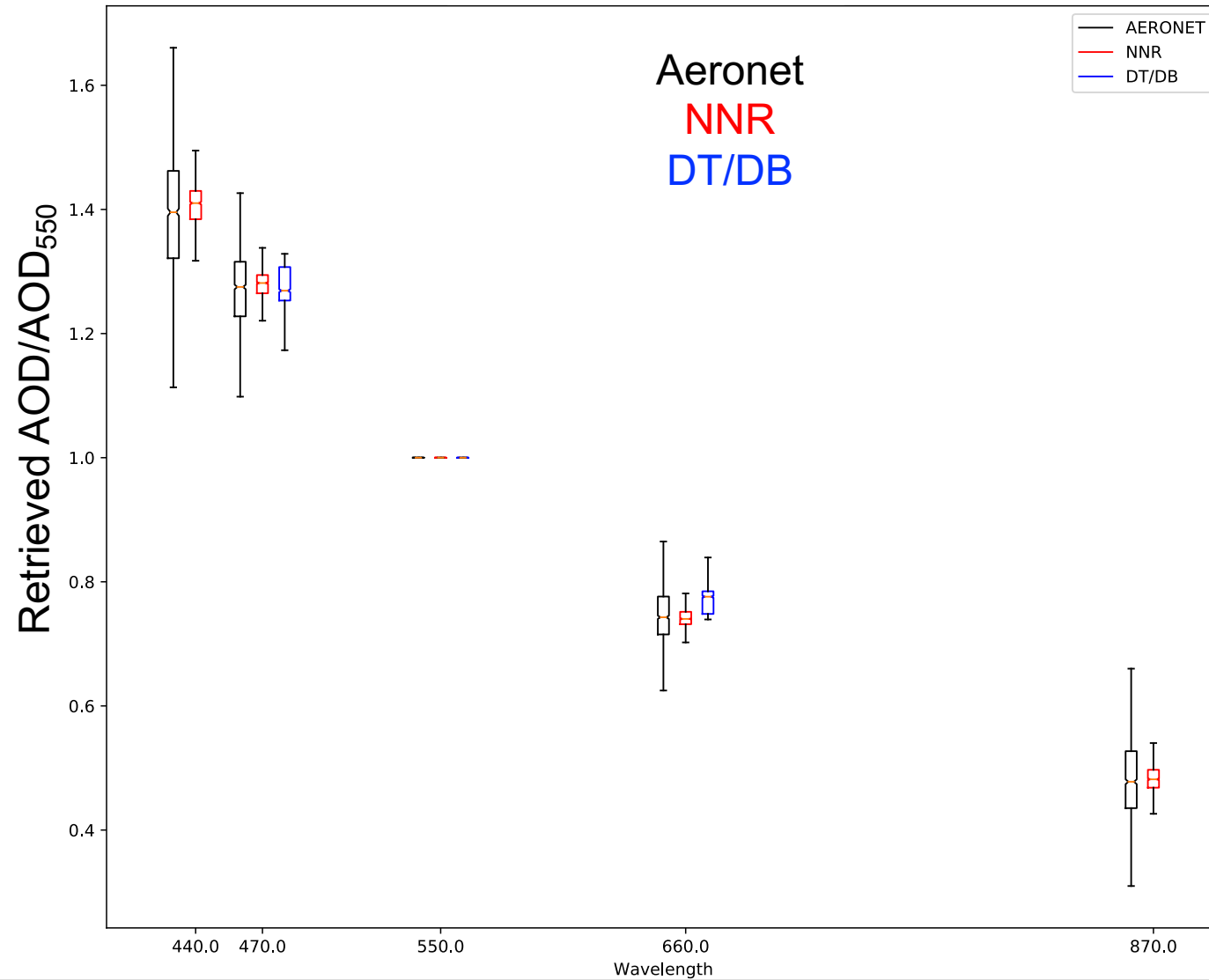
AOD Spectral Dependence

Smoke Dominated



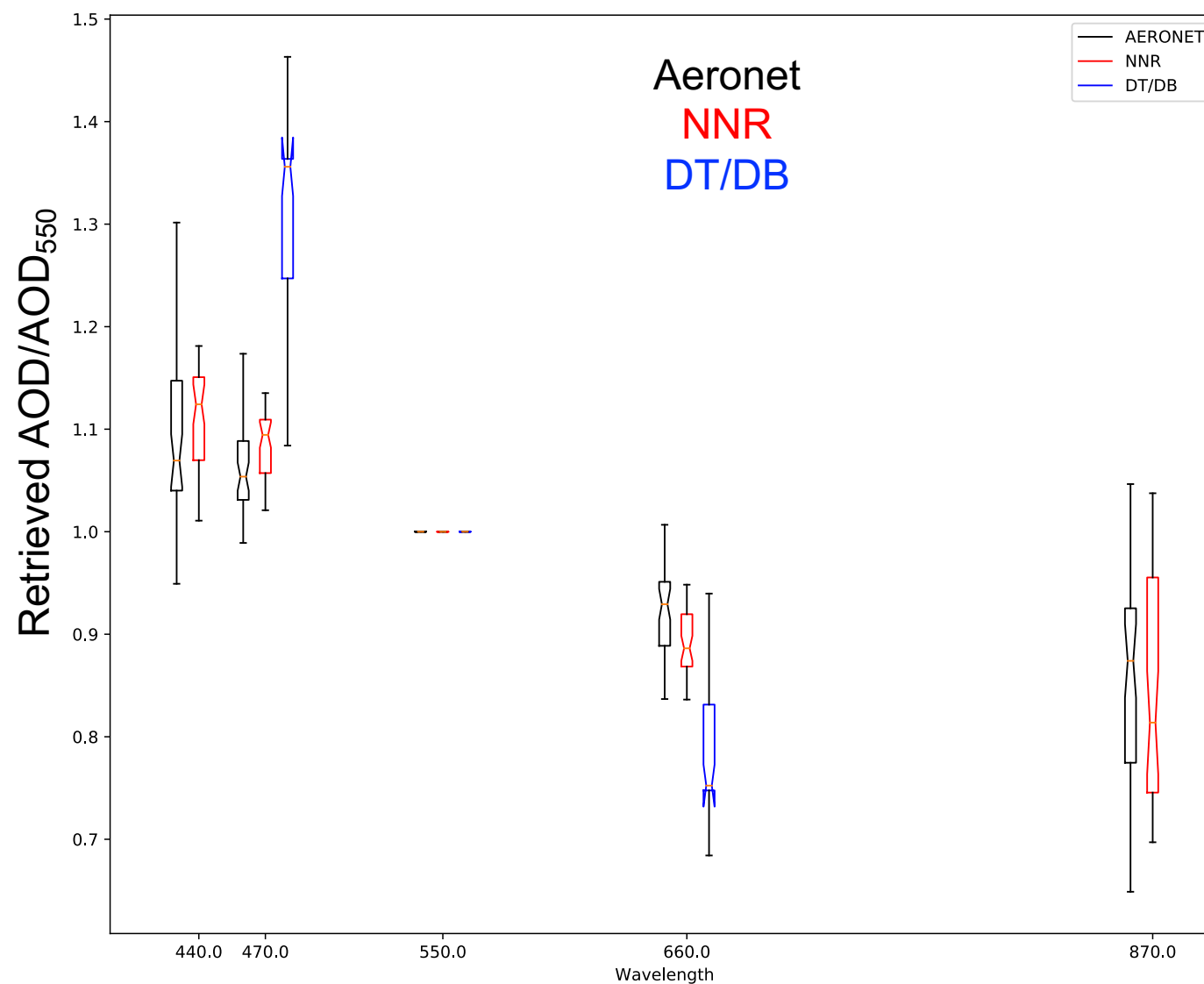
AOD Spectral Dependence

Sulfate Dominated



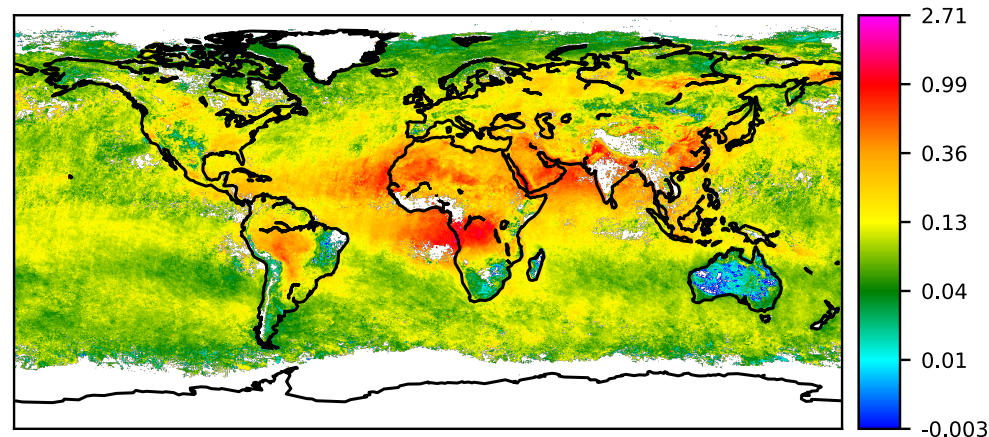
AOD Spectral Dependence

Sea Salt Dominated

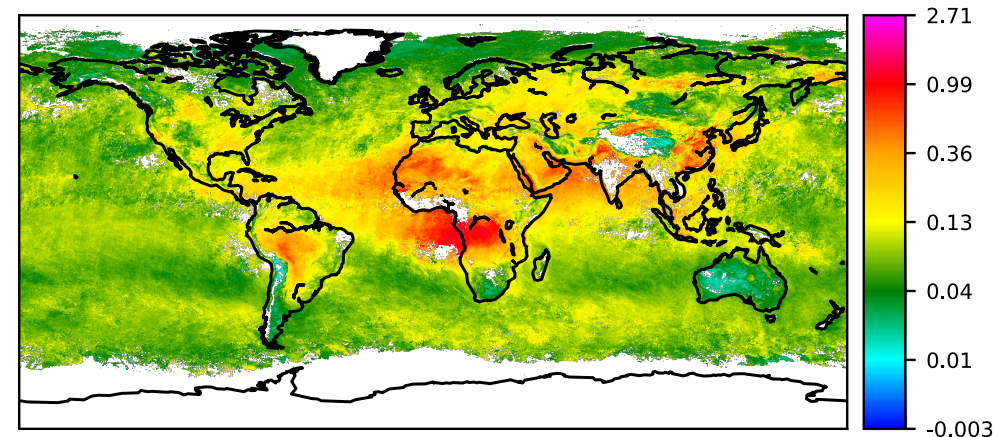


Monthly Means of AOD550

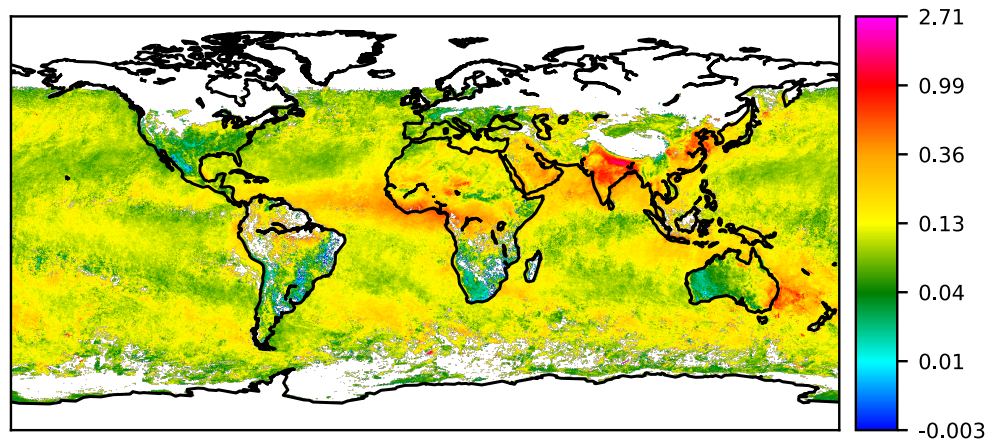
MOD04 ALL AOD 20160801



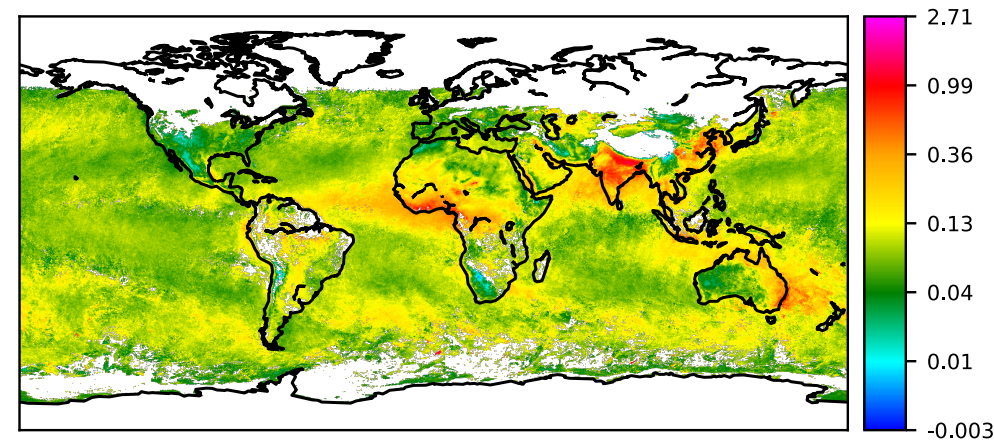
NNR ALL AOD 20160801



MOD04 ALL AOD 20191201

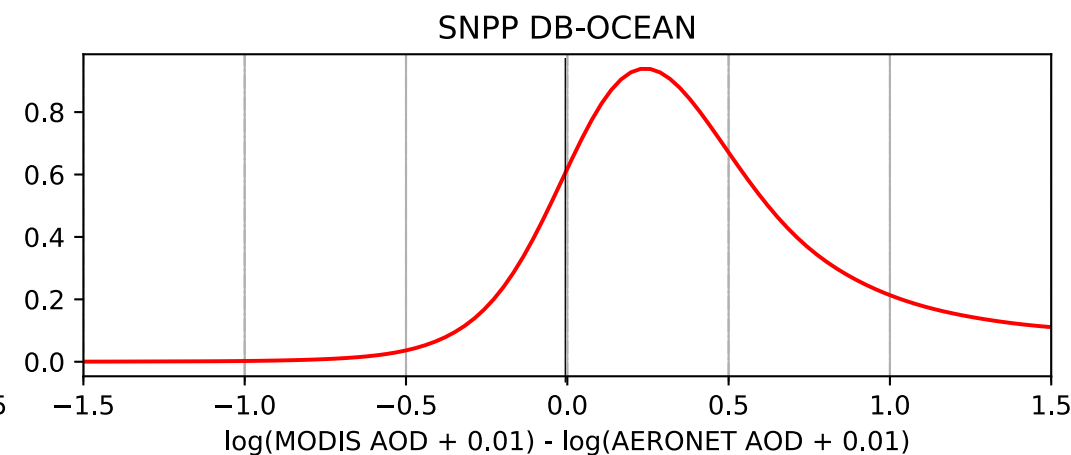
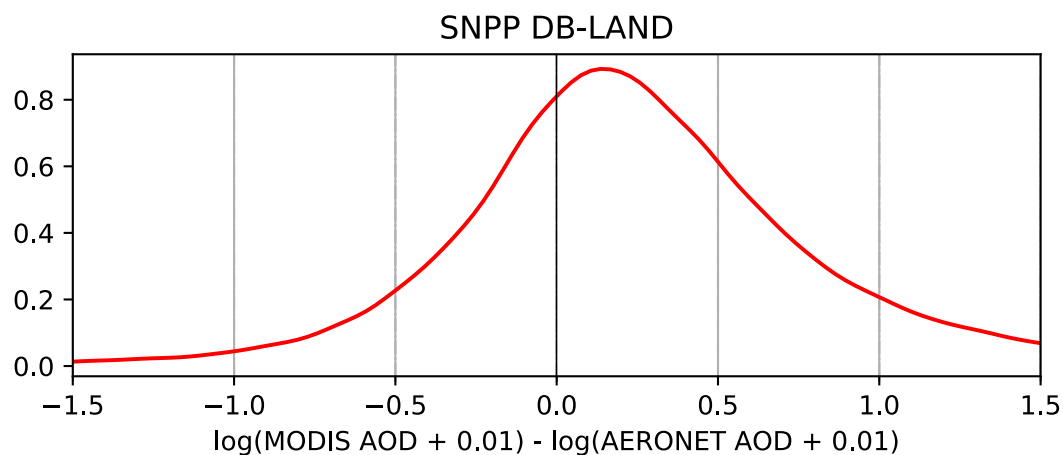
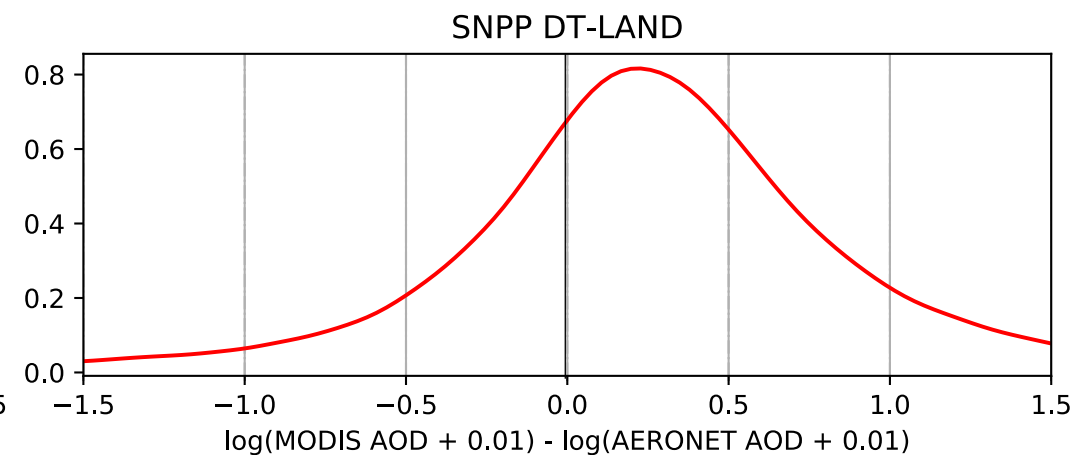
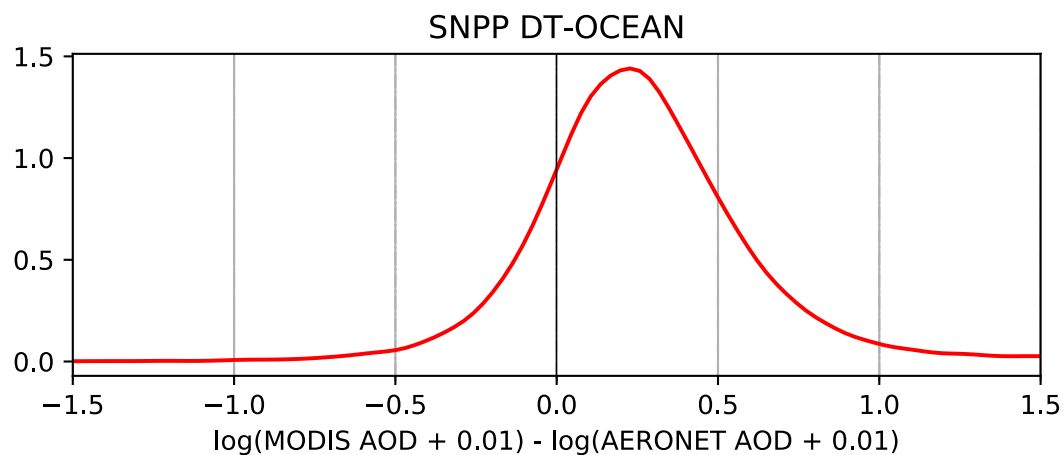


NNR ALL AOD 20191201



Transition to DB & DT Applied to VIIRS

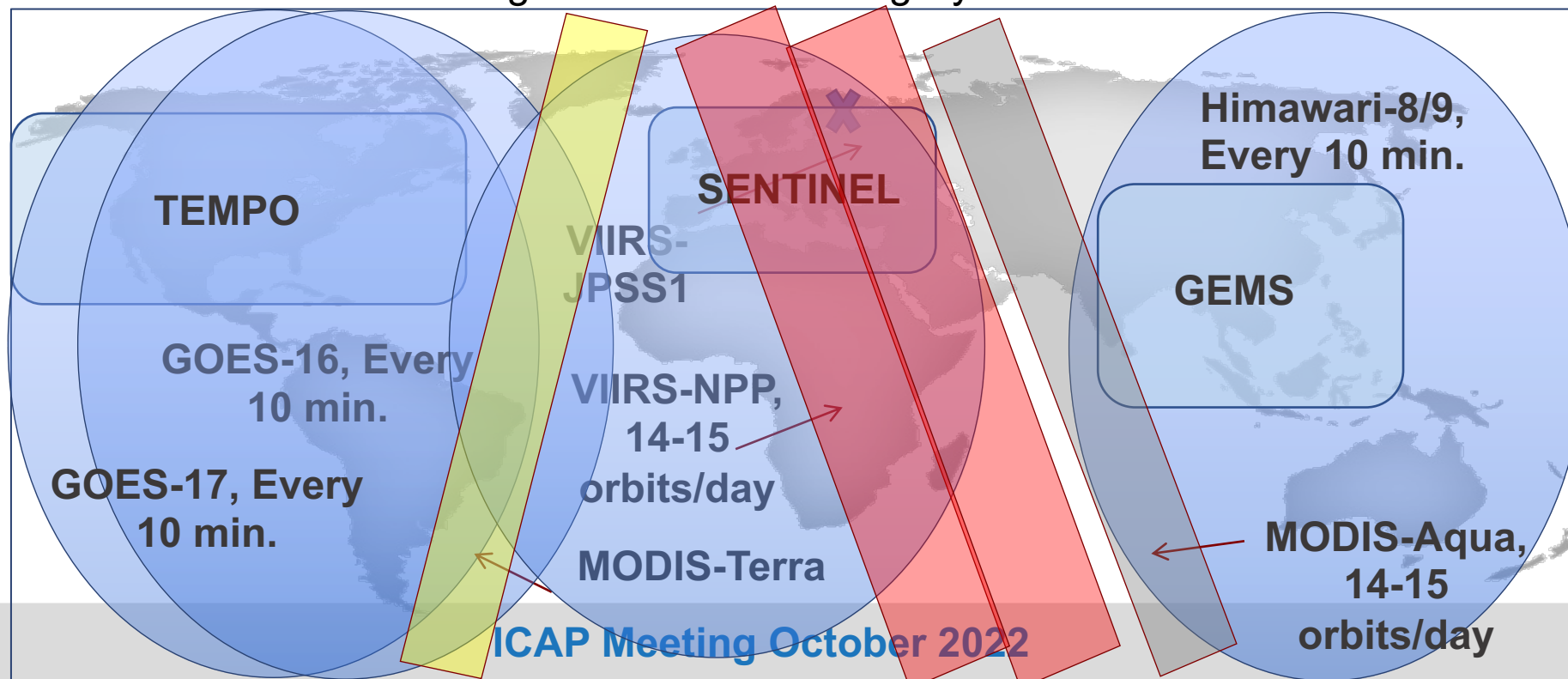
550 nm AOD



Summary and Outlook

- The NNR provides a way to homogenize the AOD observing system for data assimilation
- A NNR for VIIRS, GOES-16 and AHI-8 will be developed using the same methodology as the MODIS-NNR
- JEDI-based aerosol analysis system supports new multi-wavelength NNR AOD
 - may expand wavelength range to 340–1020

Target Aerosol Observing System in GEOS



Summary and Outlook

- Innovate the training methodology to give probabilistic predictions
 - e.g. ensemble learning, gaussian process learning, deep evidential regression
 - Benefits: provides quantitative uncertainties of the predictions that can be used in the aerosol assimilation

