Institute of Remote Sensing and Digital Earth
Chinese Academy of Sciences

Aerosol Optical Depth Retrieval from Satellite Data in China

Professor Dr. Yong Xue

Research Report Outline

- Multi-scale quantitative retrieval of Aerosol optical depth (AOD) over land
  - Spatial resolution: 10km, 1km, 100m
    - for researches of global AOD variation, especially the spatial and temporal AOD evolution and air pollution researches in urban regions over China
  - Temporal resolution：polar-orbit satellites V.S. geostationary satellites
    - for studies on extreme weather cases e.g. dust storms

Time Series Retrieval

Time Series (TS) technique makes use of the two visible bands at 0.6 μm and 0.8 μm (with support of 1.6 μm) in three orderly scan.

Land-Atmosphere (Mei et al., 2011)

$$\rho = \frac{[a+c(\Gamma-\rho_{TOA})]e^{k\tau}+[b+c(\rho_{TOA}\Gamma-1)]\Gamma e^{-k\tau}+(\Gamma^2-1)G^{+}e^{-\frac{\tau}{\mu_0}}}{[a+c(\Gamma-\rho_{TOA})]\Gamma e^{k\tau}+[b+c(\rho_{TOA}\Gamma-1)]e^{-k\tau}+(\Gamma^2-1)G^{-}e^{-\frac{\tau}{\mu_0}}}$$

A prior knowledge (Multi-Channel)

$\tau(\lambda)=\beta\lambda^{-\alpha}$ (Angstrom et al., 1961)

Land model (Multi-Temporal)

$\frac{\rho_1(\lambda)}{\rho_2(\lambda)} \approx k(\lambda)$ (Flowerdew et al., 1995)

Inputs: 3 scans/2 bands

10 Equations =10 Un-knows

Other constrains:

Aerosol Type (Govarert et al., 2010)

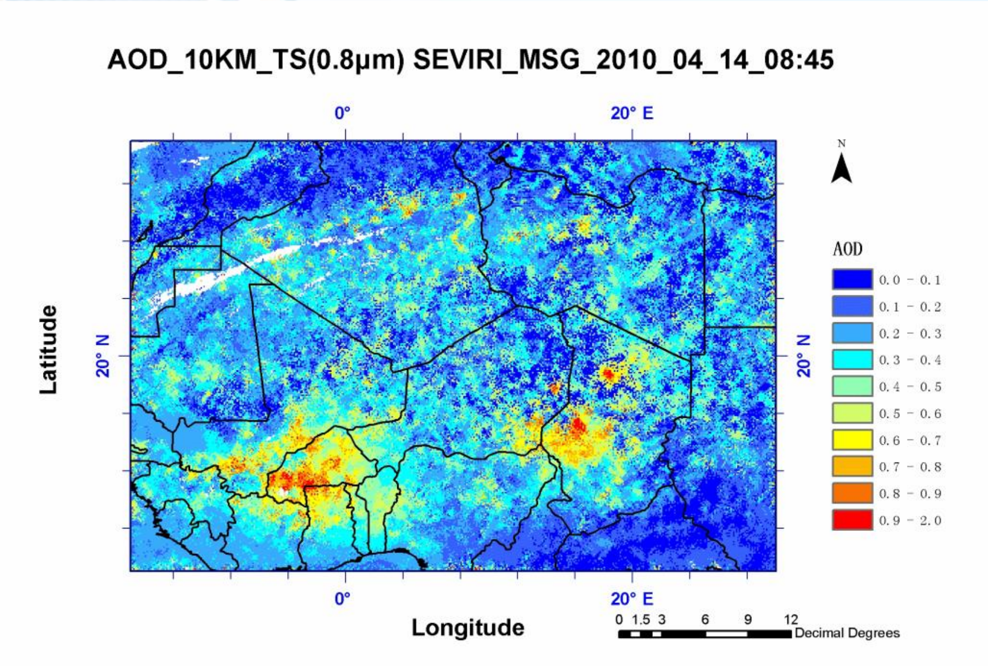
Single Scattering Albedo

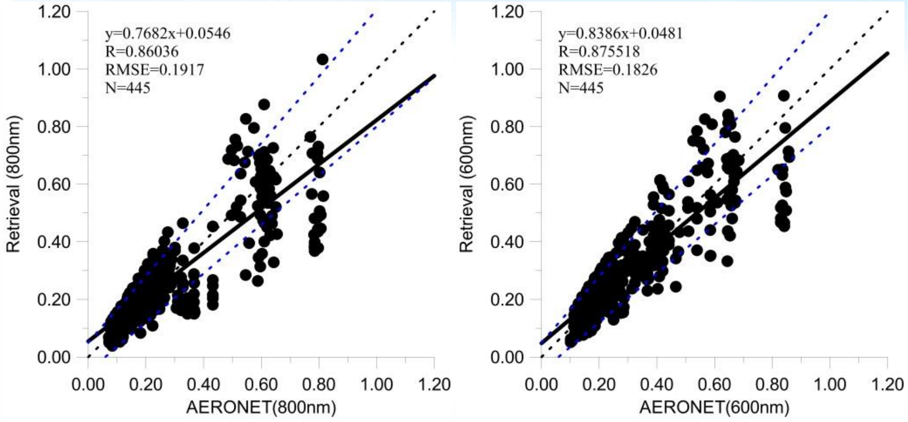
Asymmetry factor

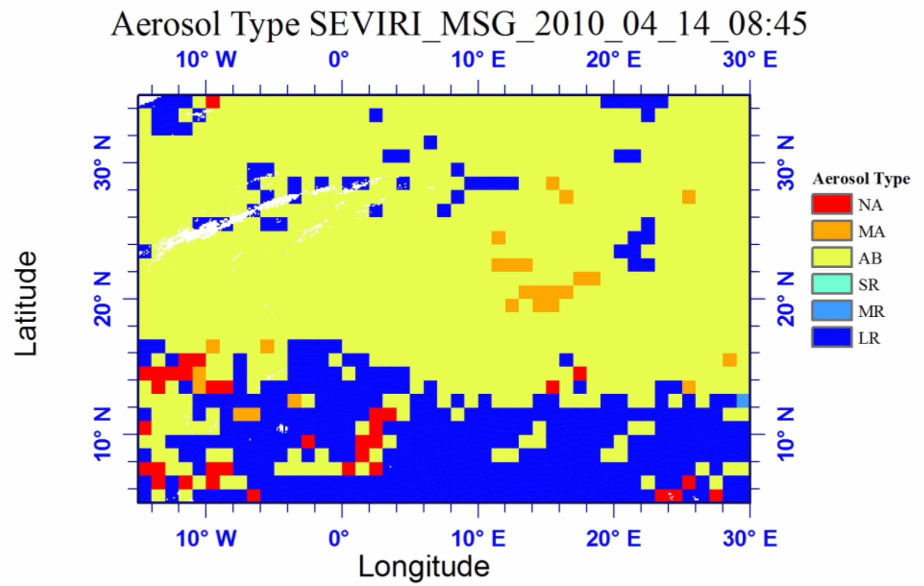
Reflectance (Kim et al., 2008)

$$\varepsilon = \min\{\sum_{t}\sum_{j=1}^{n}(A^{k}_{\lambda_{t,j}} - A^{k}_{\lambda_{t+1,j}}3)^2\}$$

Hourly AOD from MSG/SEVIRI Data



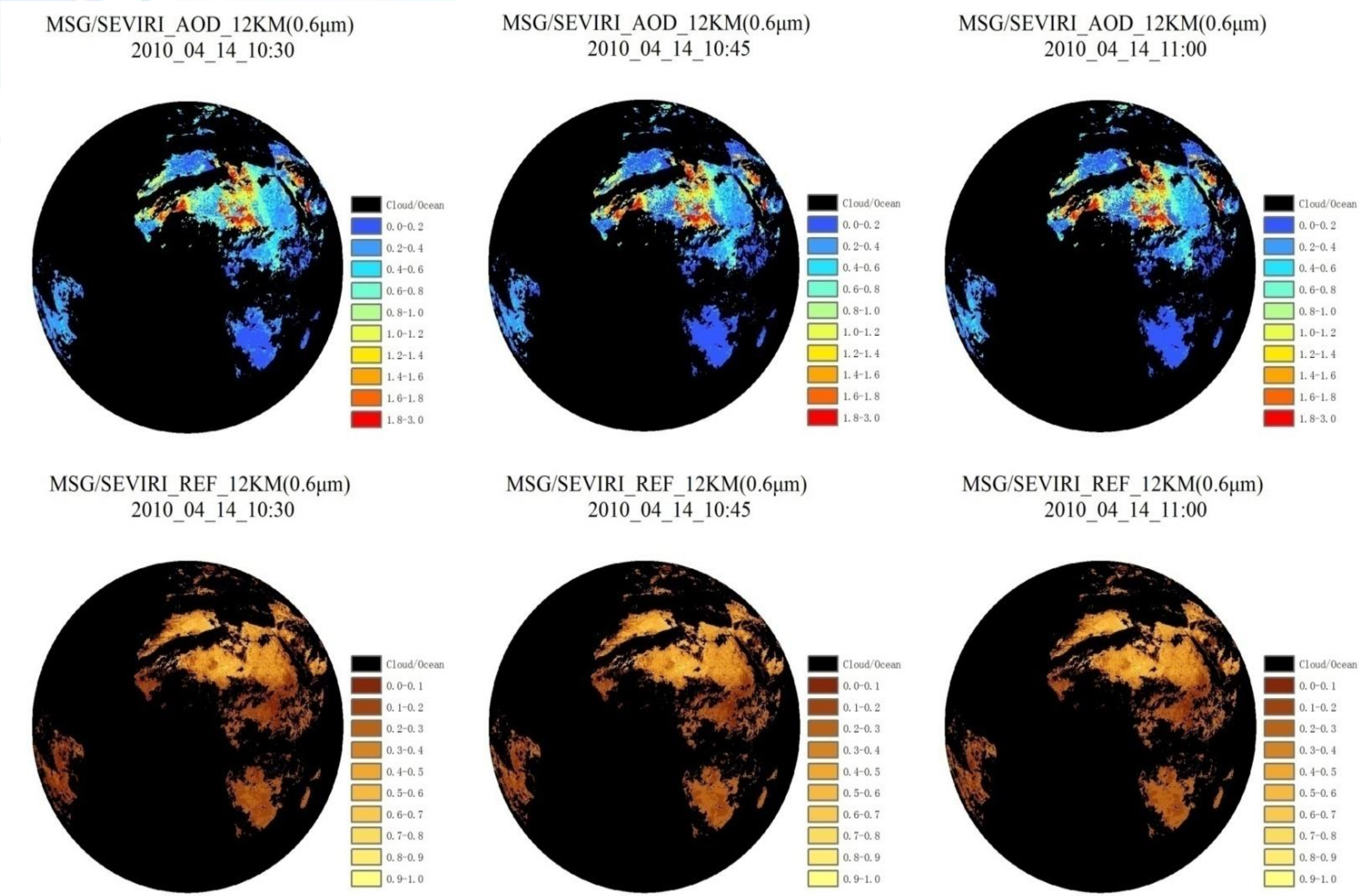




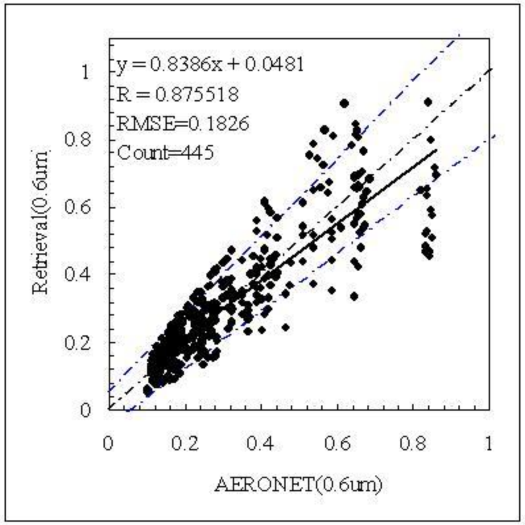
NA: Spherical Non Absorbing
MA: Spherical Moderately Absorbing
AB: Spherical Absorbing
SR: Non Spherical Small
MR: Non Spherical Medium
LR: Non Spherical Large

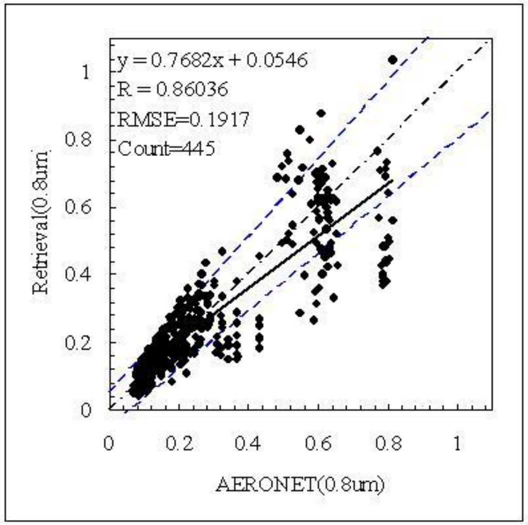
Mei, L., Xue, Y., et al..: Retrieval of aerosol optical depth over land based o a time series technique using MSG/SEVIRI data, *Atmos. Chem. Phys.*, 12, pp9167-9185, 2012.

Hourly AOD from Geostationary Satellite Data

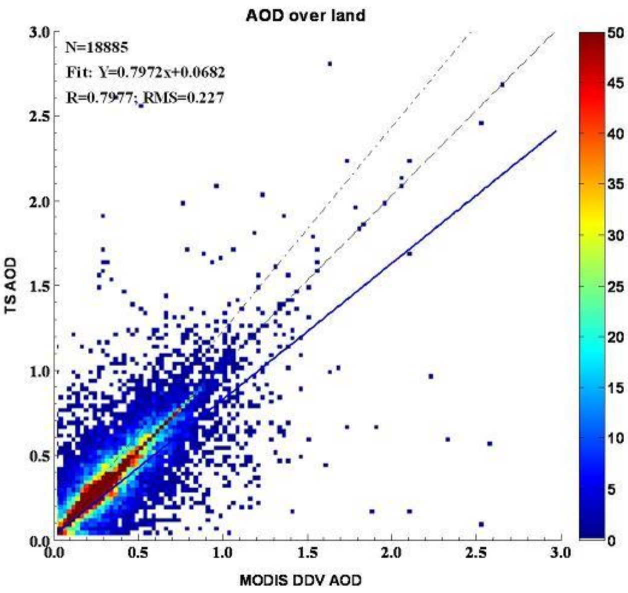


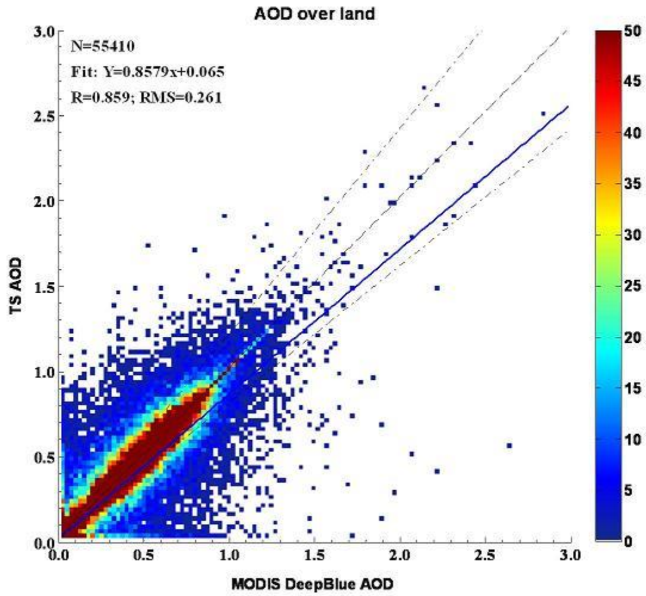
Validations





MSG vs AERONET





MSG vs MODIS

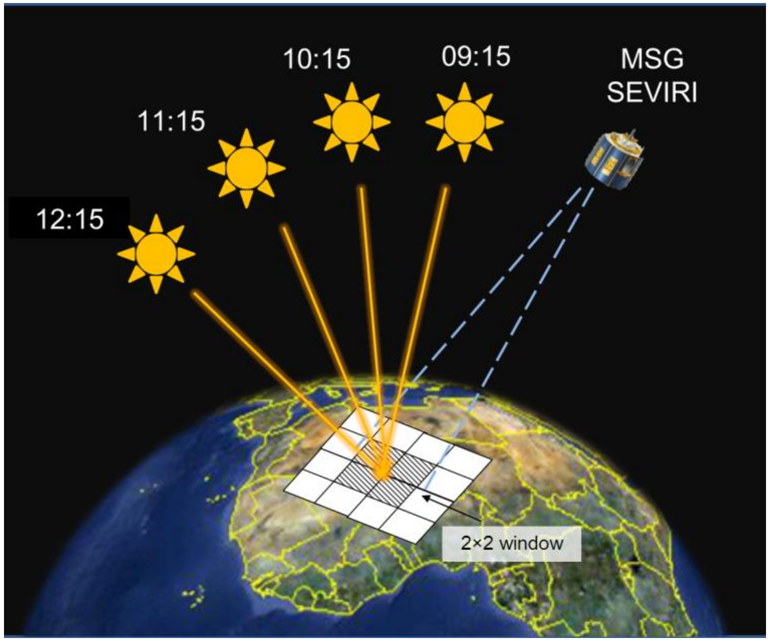
Land Aerosol property and Bidirectional reflectance Inversion by Time Series technique (LABITS)

Basic Assumptions :

1. Surface reflectance (R) changes quickly with location but remain the same in short time interval. Thus, during observations in a row, for single visible band we can assume that R is invariant in each pixel.

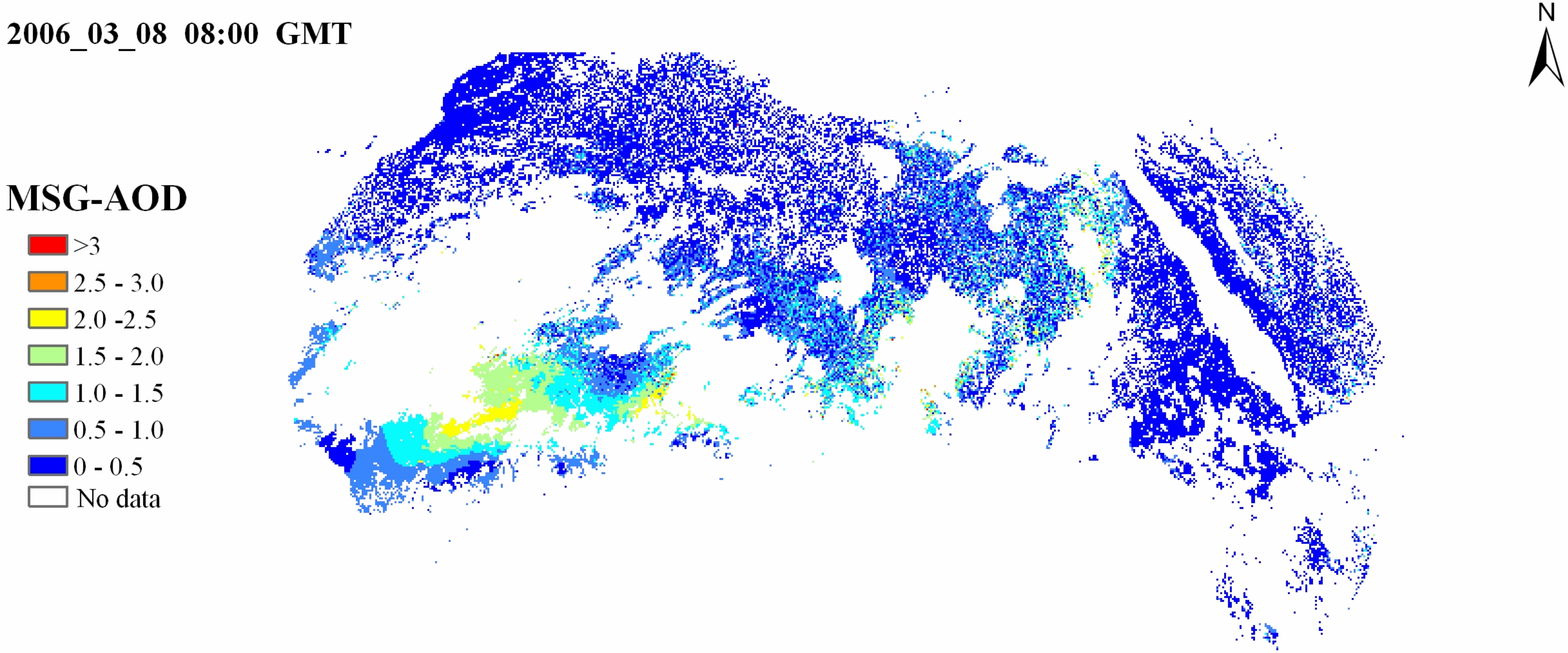
2. Aerosol optical depth (AOD) has a high temporal variation but is consistent spatially in a small area.

Area with the size of N, multi-observations number as K, for single visible band, there are KN^2 measurements and $K + 3N^2$ unknowns. If $KN^2 \geq K+3N^2$, we can retrieval AOD and BRDF parameters simultaneously. Here, we set $K = 4$ and $N = 2$.



Yingjie Li, Yong Xue, Gerrit de Leeuw, et al. (2013), Retrieval of aerosol optical depth and surface reflectance over land from NOAA AVHRR data, *Remote Sensing of Environment*, 133, 1-20.

Hourly Time-Series AOD Results from MSG/SEVIRI Data



AOD Results from MSG/SEVIRI Data

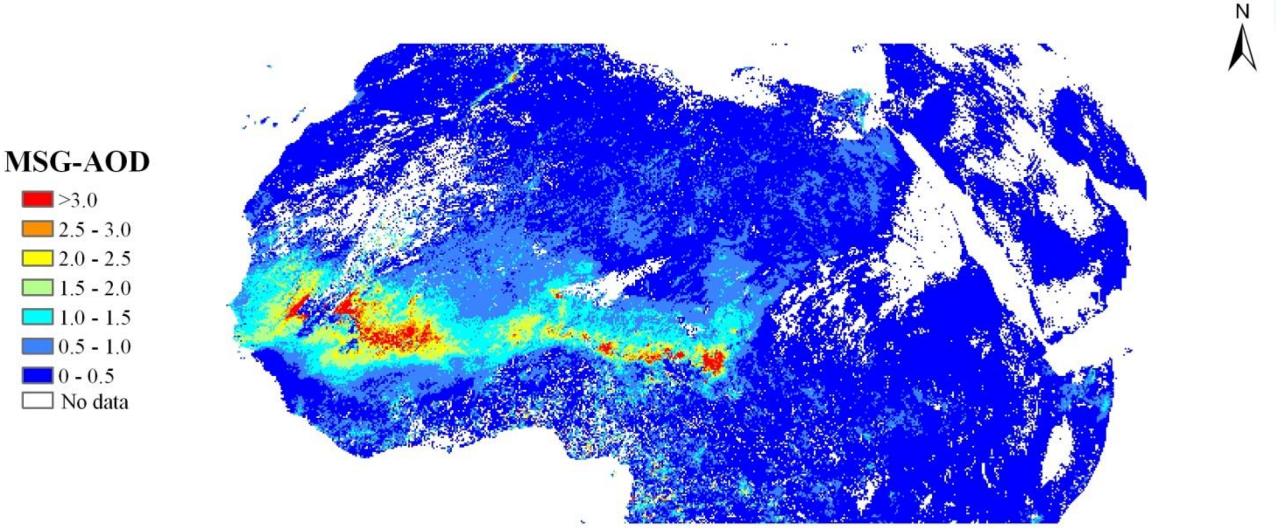


Figure 1. Spatial distribution of MSG AOD by the operational MSG aerosol inversion algorithm on 8 March 2006 over North Africa

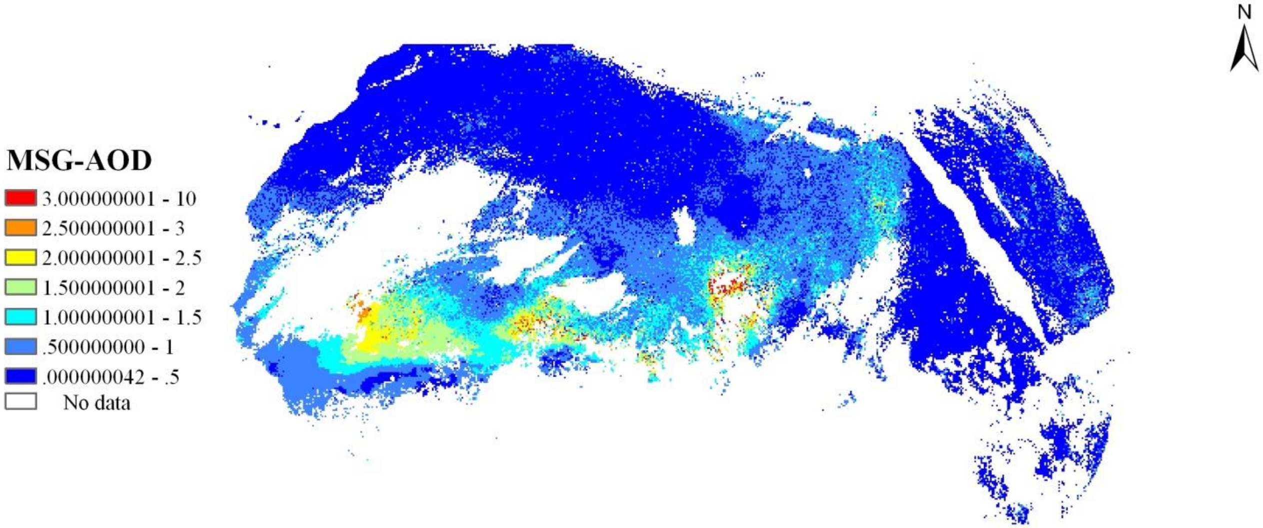
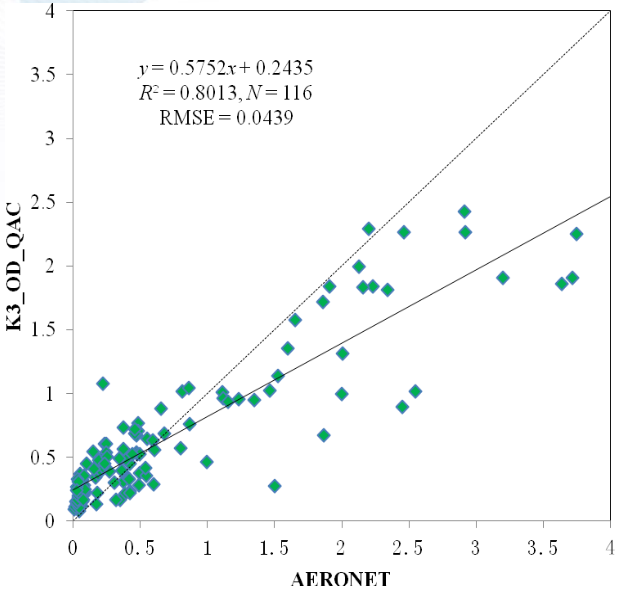
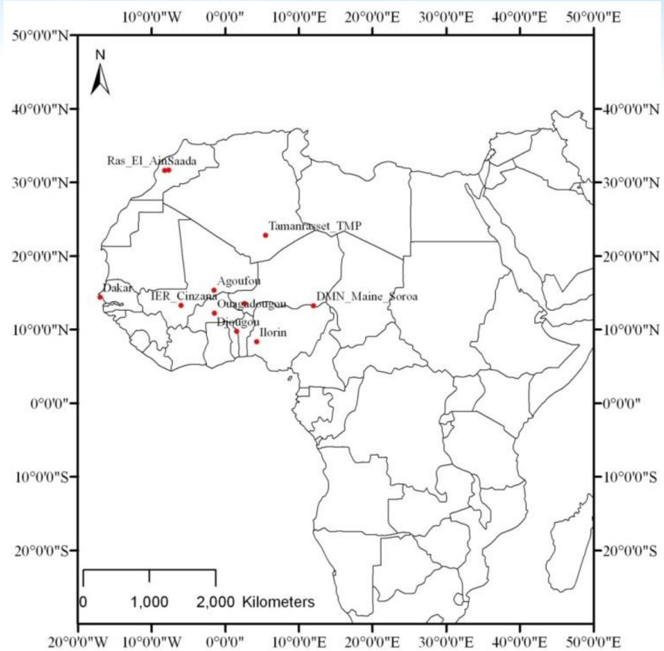


Figure 2. Spatial distribution of daily means MSG AOD by LABITS algorithm on 8 March 2006 over North Africa

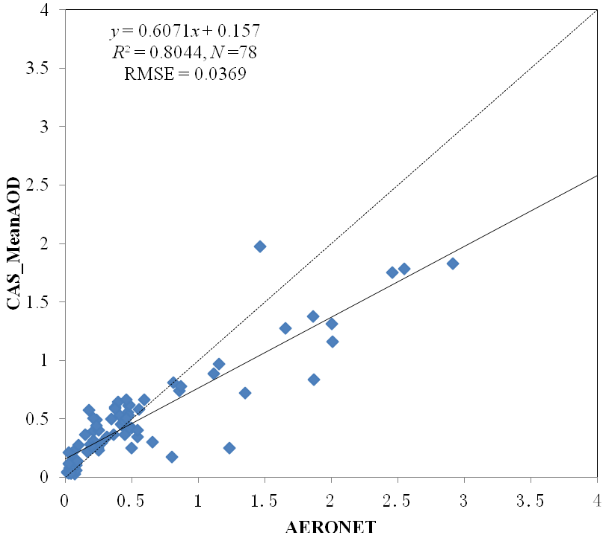
Preliminary validation



Scatterplots between daily average AERONET and MSG AOD estimates by the operational MSG aerosol inversion algorithm during 1 March 2006 to 15 March 2006



Location of the AERONET stations investigated in the present study



Scatterplots between daily average AERONET and Mean MSG AOD estimates by LABITS algorithm during 1 March 2006 to 15 March 2006

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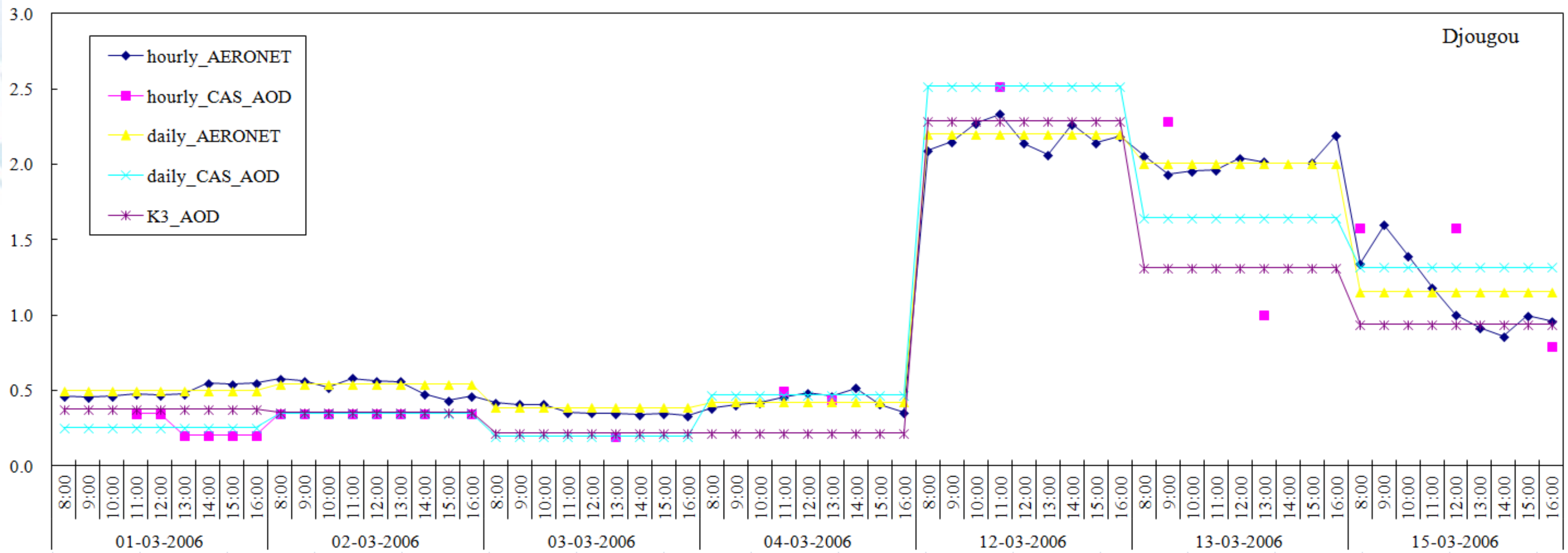
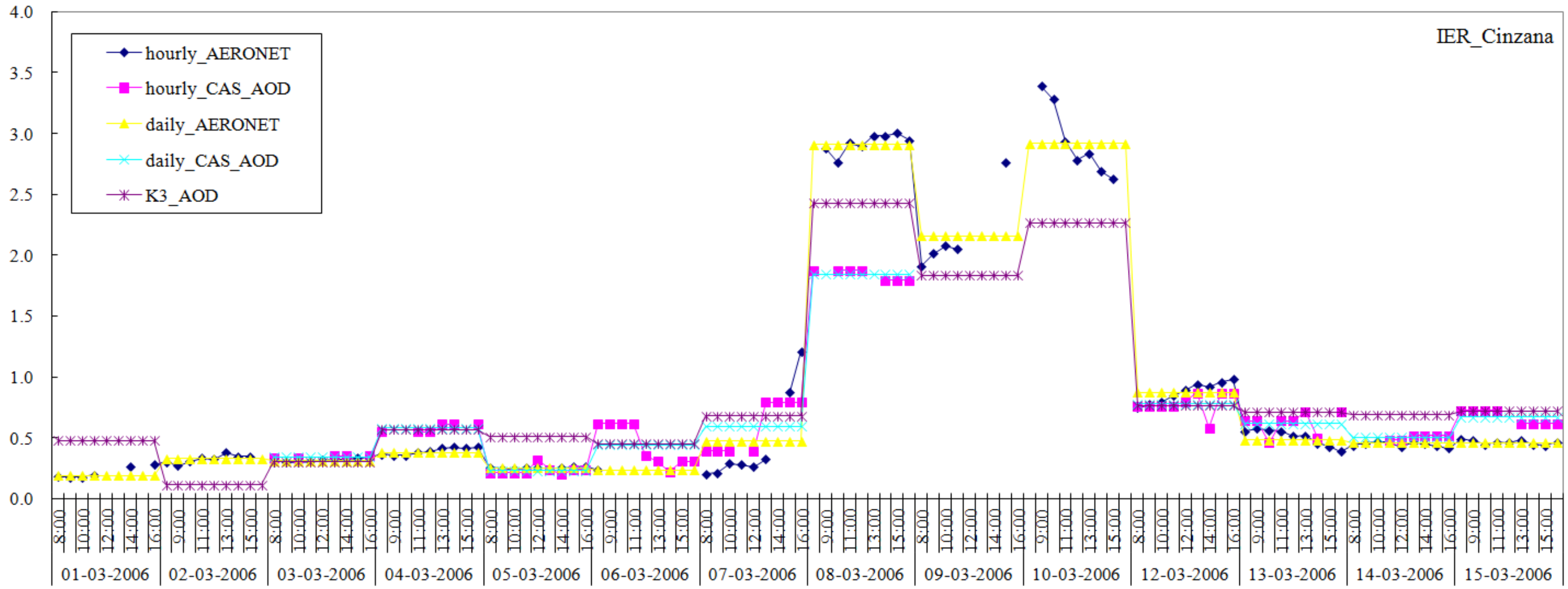
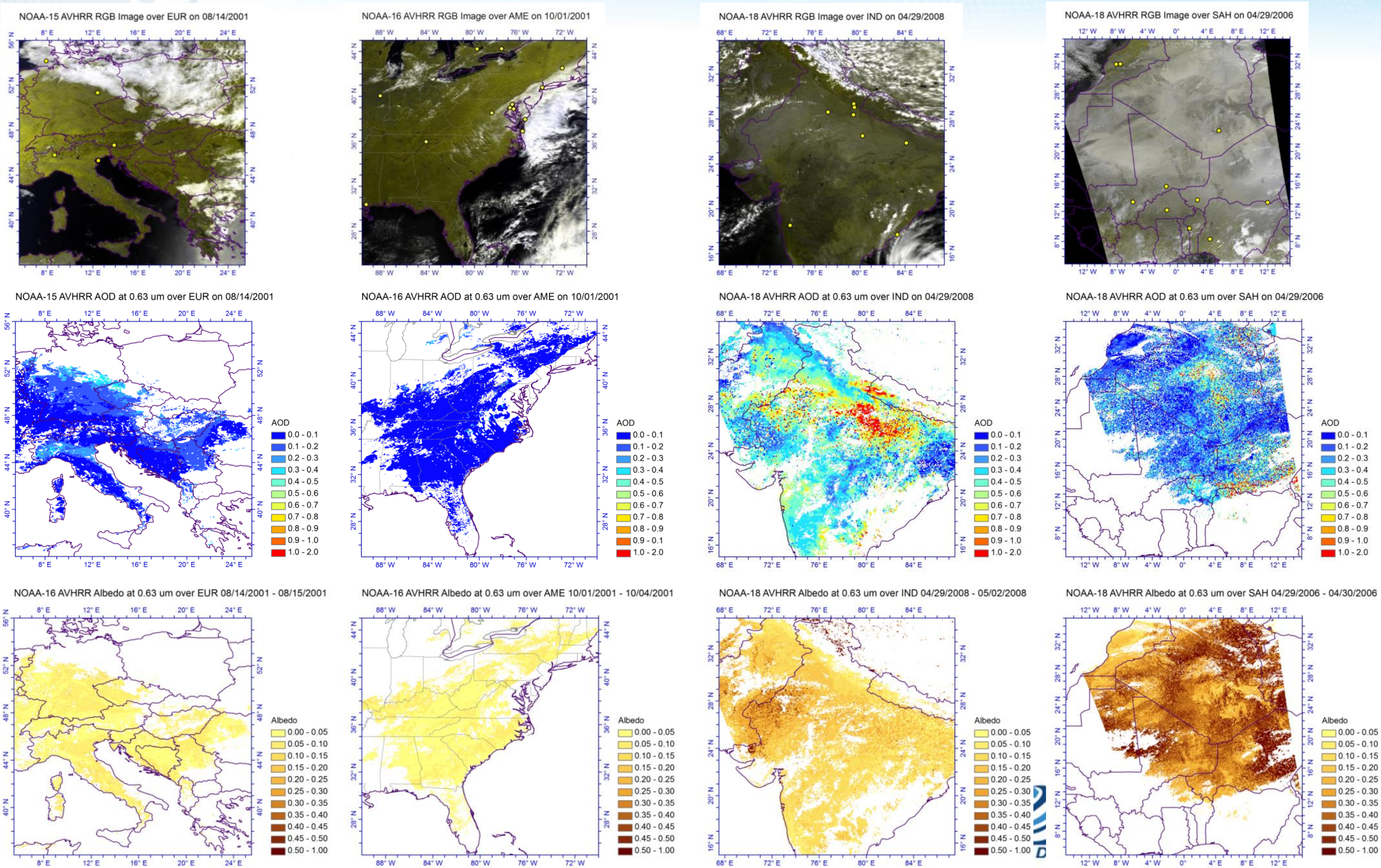
Preliminary validation





Long-term (30 yrs) AOD data from AVHRR Data



Improved Aerosol Optical Depth and Ångstrom Exponent Retrieval over Land from MODIS Based on the Non-Lambertian Forward Model

Non-Lambertian Forward Model

$$\rho^* = \rho_a + \frac{\vec{T}(\mu_s)\vec{R}\vec{T}(\mu_v) - e^{-\tau/\mu_s}\left|\vec{R}\right| e^{-\tau/\mu_v} \cdot S}{1 - \rho_{BHR} S}$$

Lambertian Forward Model (NASA MODIS DT)

$$\rho^*(\mu_s, \mu_v, \phi) = \rho_a + \frac{T(\mu_s)\rho_t T(\mu_v)}{1 - \rho_t S}$$

$$\vec{R} = \begin{bmatrix} \rho & \rho_{DHR} \\ \rho_{HDR} & \rho_{BHR} \end{bmatrix}$$

denotes the reflectance matrix, while ρ_{DHR} is the directional-hemispherical reflectance (DHR), ρ_{HDR} is the hemispherical-directional reflectance (HDR), ρ_{BHR} is the bi-hemispherical reflectance (BHR) equal to the surface albedo.

$$|\vec{R}| = \rho \cdot \rho_{BHR} - \rho_{HDR} \cdot \rho_{DHR}$$

The determinant of the reflectance matrix $\vec{R}$

VISvs2.12

$$\begin{bmatrix} \rho & \rho_{DHR} \\ \rho_{HDR} & \rho_{BHR} \end{bmatrix}$$

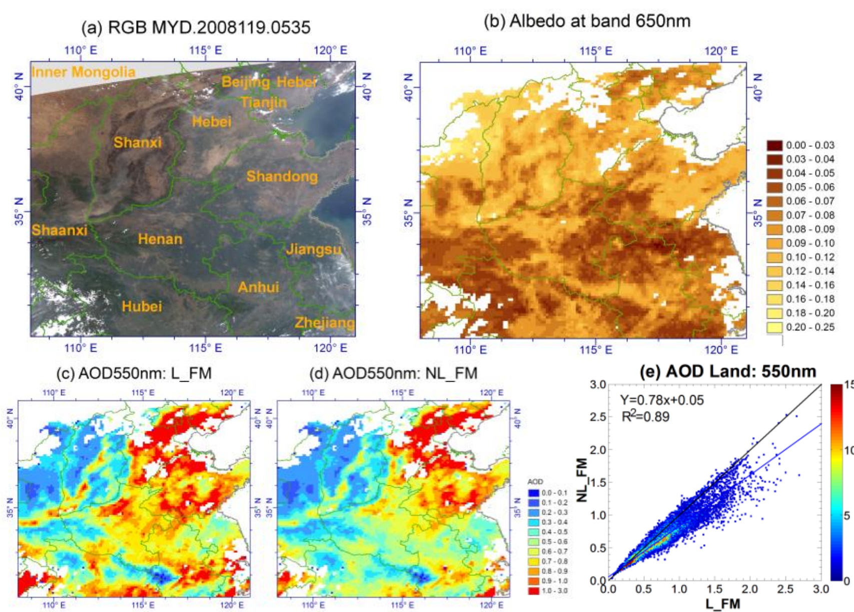
MCD43

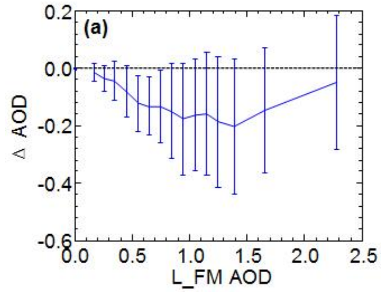
MCD43: BRDF/Albedo product

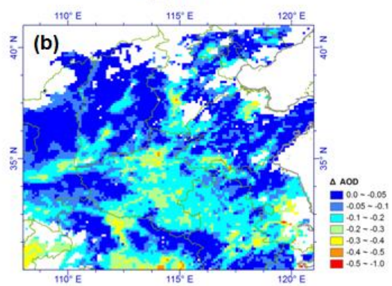
$$\vec{T}(\mu_s) = [e^{-\tau/\mu_s} \quad t_d(\mu_s)]$$
$$\vec{T}(\mu_v) = [e^{-\tau/\mu_v} \quad t_d(\mu_v)]$$

Transmission matrices.

Improved Aerosol Optical Depth and Ångstrom Exponent Retrieval over Land from MODIS Based on the Non-Lambertian Forward Model







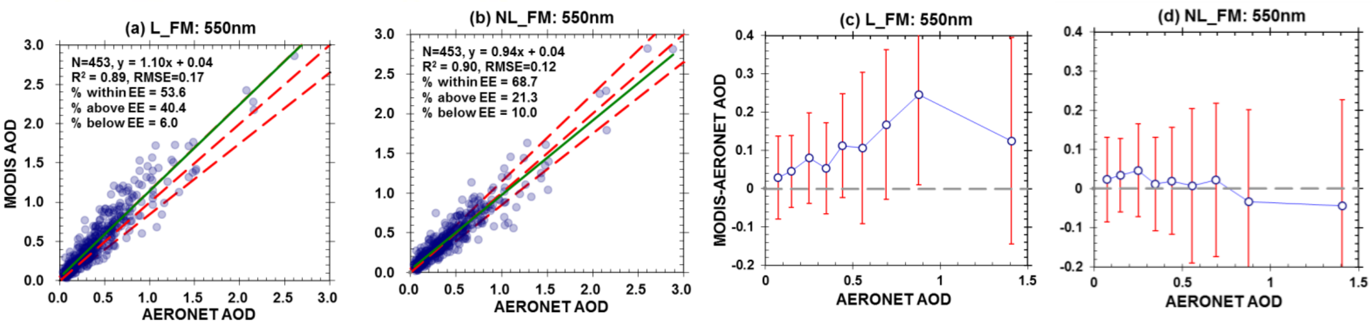
ΔAOD=NL_FM–L_FM

Granule retrieved over Eastern China from the MODIS-Aqua obtained on April 28, 2008 at 05:35 UTC.

AOD:
68.7% vs. 53.6%
EE=±0.05±0.1τ

Systematic overestimation:
40.4% vs. 21.3%

over the study area of Eastern China



Leiku Yang, Yong Xue, Jie Guang, Hassan Kazemian, Chi Li, and Tingkai Wang, 2013, IEEE Geoscience and Remote Sensing Letter, (Revised).

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Aerosol Properties Retrieval over Snow (APRS)

The main concept of the most frequently used approximate radiative transfer equations consists of substituting the exact integrodifferential equation for radiant intensity by common differential equations for the upward and incident radiation fluxes (Kondratyev et al., 1969).

$$\sum_{i=1}^{j}\left(\frac{R^{\mathrm{RTE}}_{Terra,\lambda_i}}{R^{\mathrm{RTE}}_{Aqua,\lambda_i}}-\frac{R^{\mathrm{BRDF}}_{Terra,\lambda_i}}{R^{\mathrm{BRDF}}_{Aqua,\lambda_i}}\right)^2<\chi$$

Two-Stream approximation

$$\frac{dF^{(1)}}{d\tau}=-m^{(1)}(\tau)\left[k+\sigma\Gamma^{(1)}(\tau)\right]F^{(1)}(\tau)+m^{(2)}(\tau)\sigma\Gamma^{(2)}(\tau)F^{(2)}(\tau)$$

$$-\frac{dF^{(2)}}{d\tau}=m^{(2)}(\tau)k\Gamma^{(2)}(\tau)F^{(2)}(\tau)-m^{(2)}(\tau)\left[k+\sigma\Gamma^{(2)}(\tau)\right]F^{(2)}(\tau)$$

9 Equations = 9 Un-knows

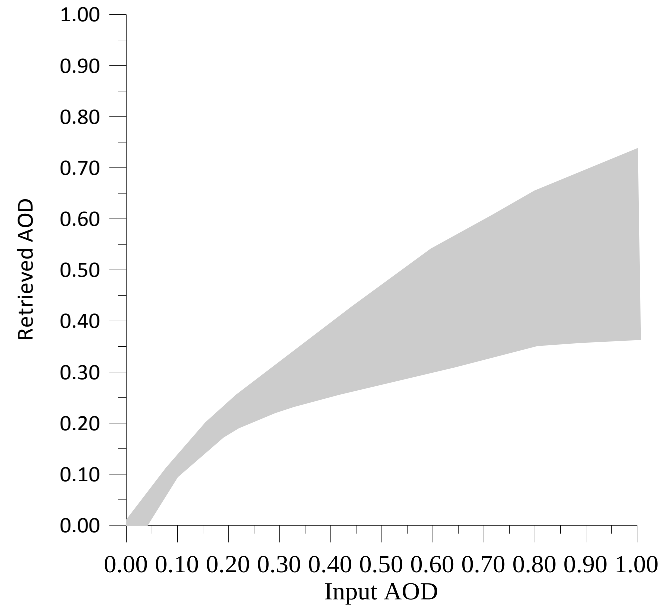
$$R=\frac{(1-R'\mathrm{M}_1)e^{\rho_1\tau_A^{\lambda}}+(R'\mathrm{M}_2-1)e^{\rho_2\tau_A^{\lambda}}}{(R'M_2-1)M_1e^{\rho_2\tau_A^{\lambda}}+(1-R'M_1)M_2e^{\rho_1\tau_A^{\lambda}}}$$

$$M_2=\frac{m^{(1)}(1-\omega)+m^{(1)}\omega\Gamma+\rho_2}{m^{(2)}\omega\Gamma}$$

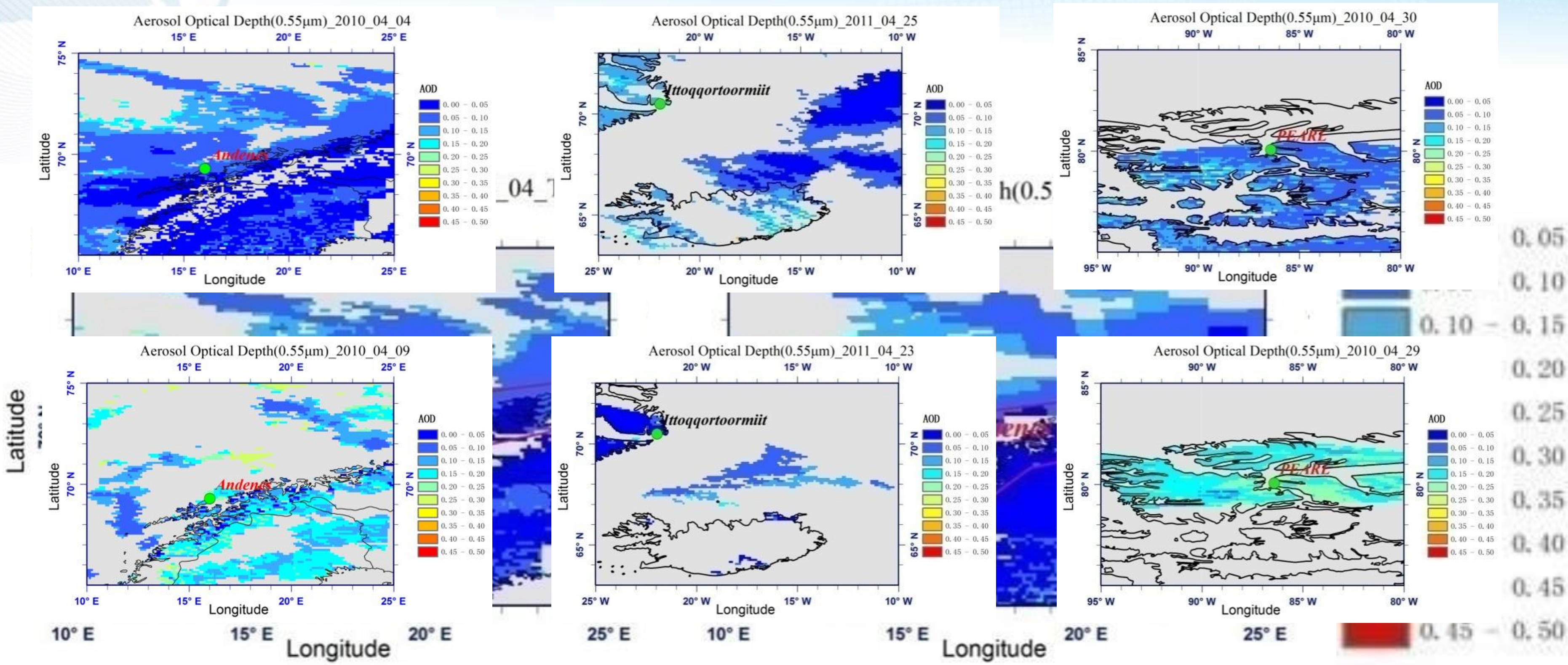
$$M_1=\frac{m^{(1)}(1-\omega)+m^{(1)}\omega\Gamma+\rho_1}{m^{(2)}\omega\Gamma}$$

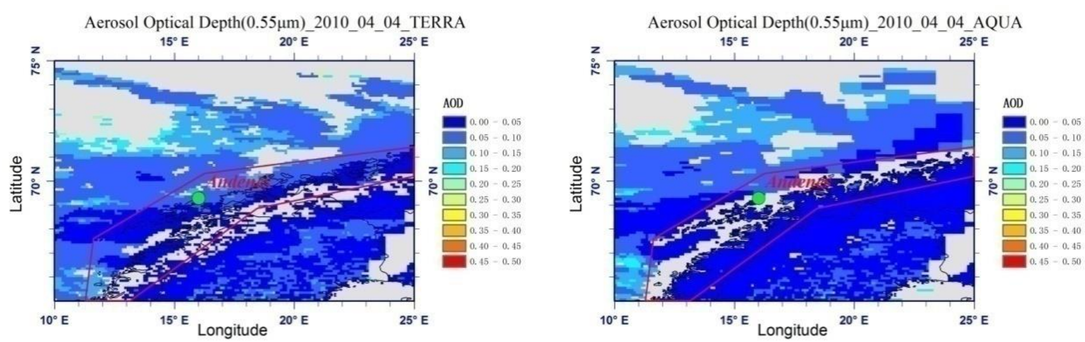
$$\rho_2=\frac{\left(m^{(2)}-m^{(1)}\right)(1-\omega+\omega\Gamma)-\sqrt{\left(m^{(1)}-m^{(2)}\right)^2(1-\omega+\omega\Gamma)^2+4m^{(1)}m^{(2)}(1-\omega)(1-\omega+2\omega\Gamma)}}{2}\quad m^{(1)}=2$$

$$\rho_1=\frac{\left(m^{(2)}-m^{(1)}\right)(1-\omega+\omega\Gamma)+\sqrt{\left(m^{(1)}-m^{(2)}\right)^2(1-\omega+\omega\Gamma)^2+4m^{(1)}m^{(2)}(1-\omega)(1-\omega+2\omega\Gamma)}}{2}\quad m^{(2)}=\sec\theta$$



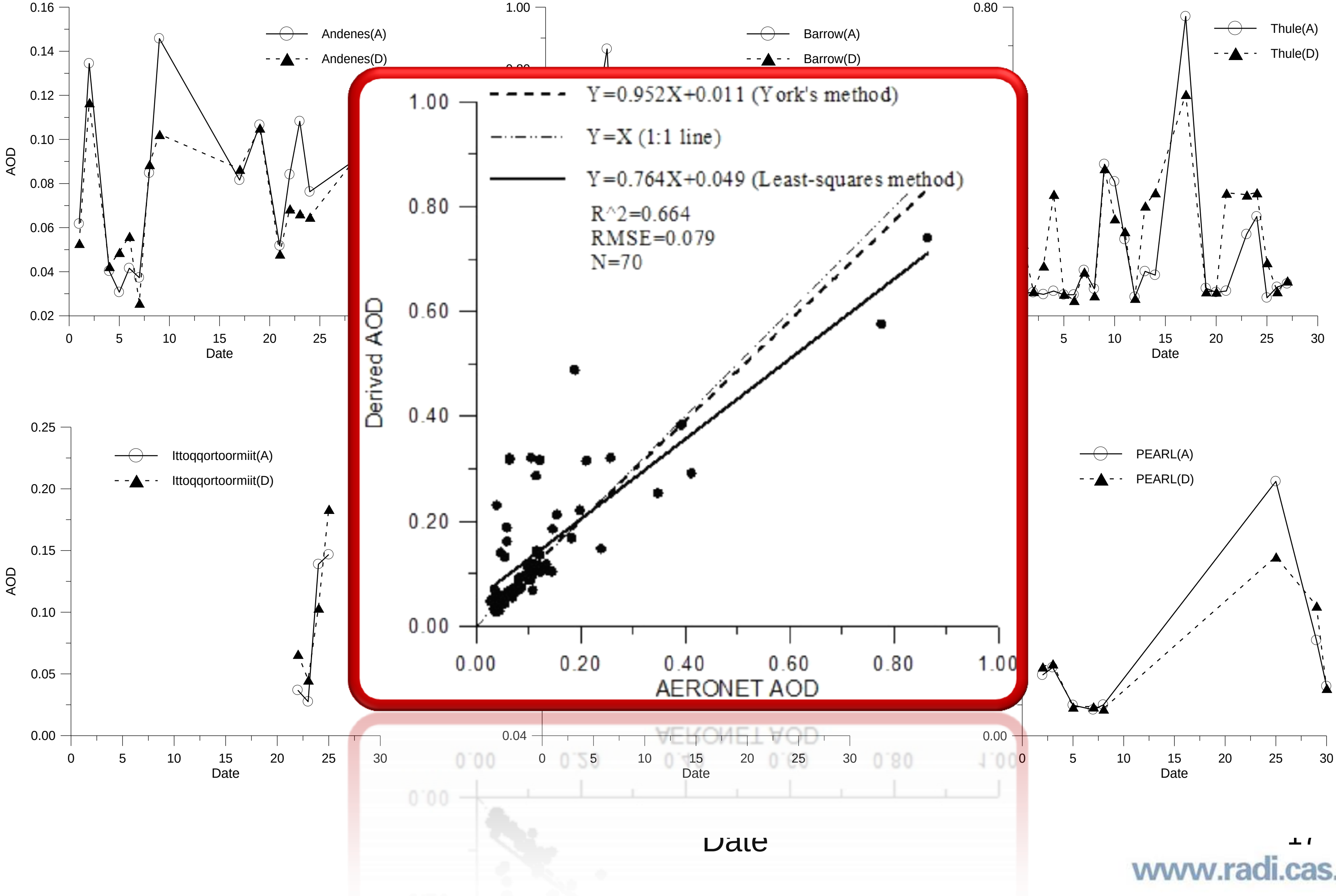
Retrieval Results





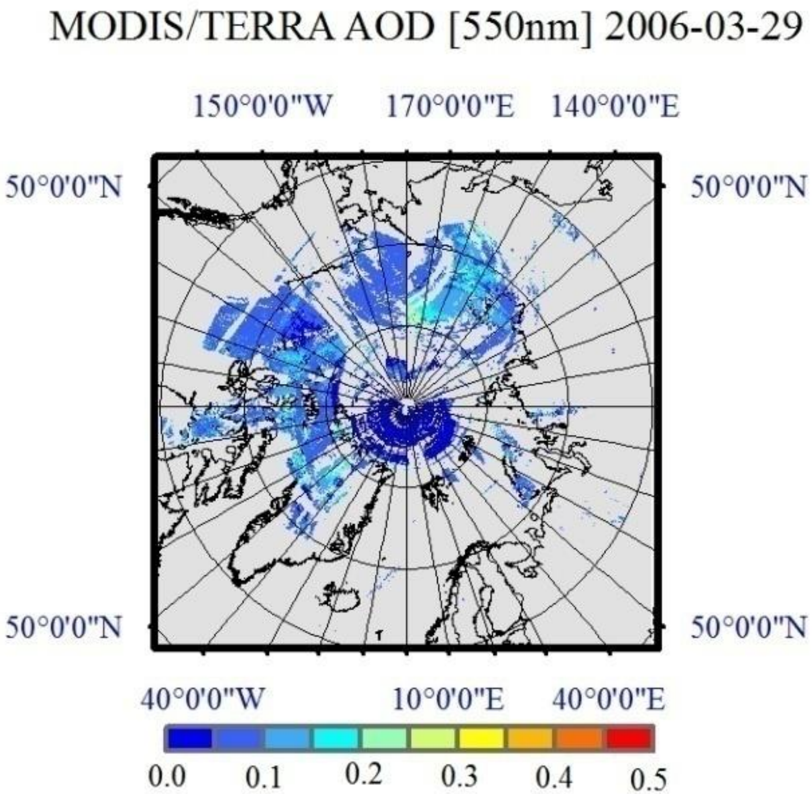
Linlu Mei, Yong Xue, Gerrit de Leeuw, Wolfgang von Hoyningen-Huene, Alexander A. Kokhanovsky, Larysa Istomina, Jie Guang, John P. Burrows, 2013, Aerosol optical depth retrieval in the Arctic region using MODIS data over snow. *Remote Sensing of Environment,* **128,** 234–245.

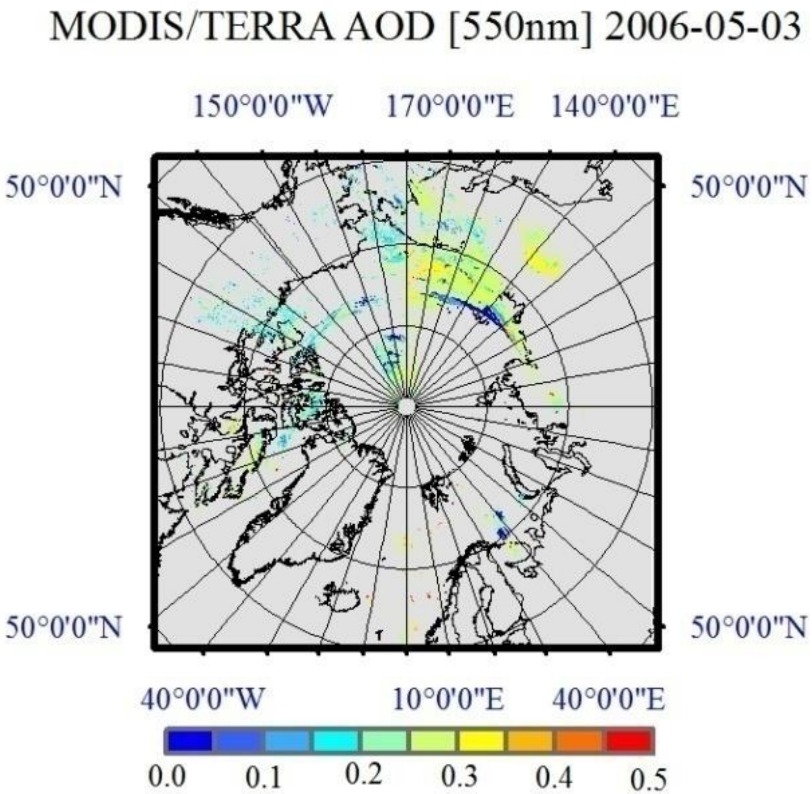
Validations



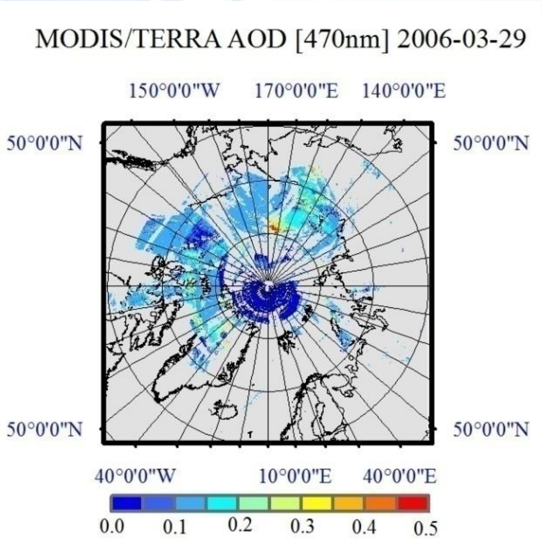
AOD of Arctic Region

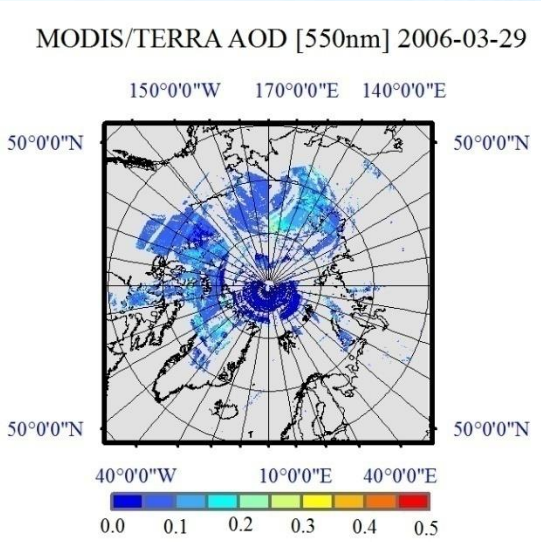
Stohl et al., 2007

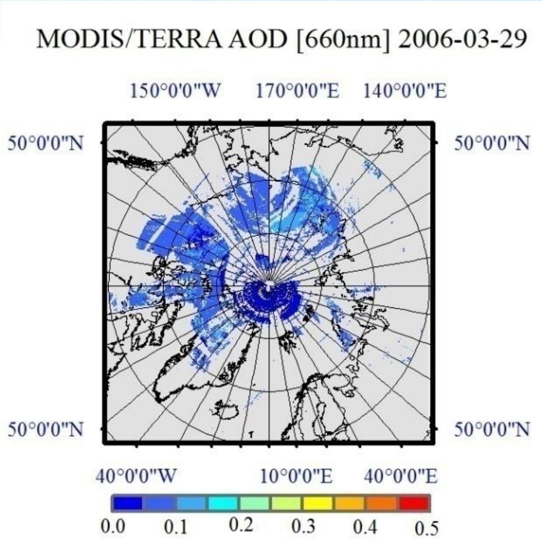


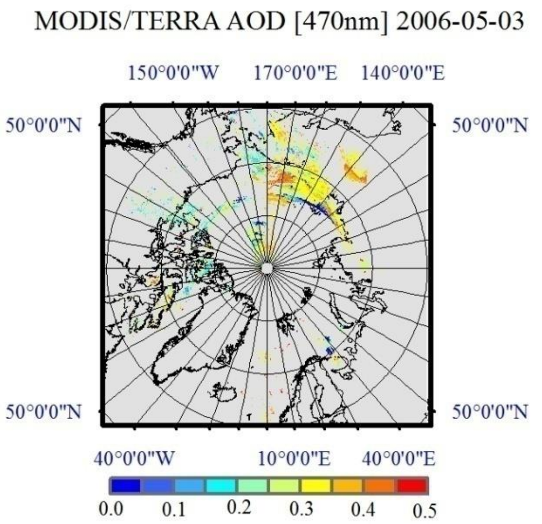


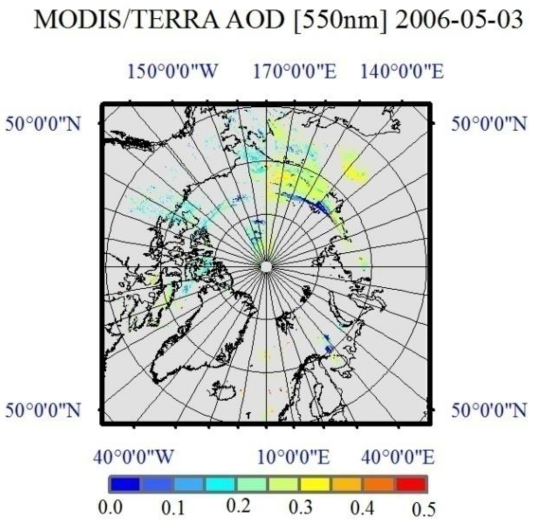
AOD of Arctic Region-Terra

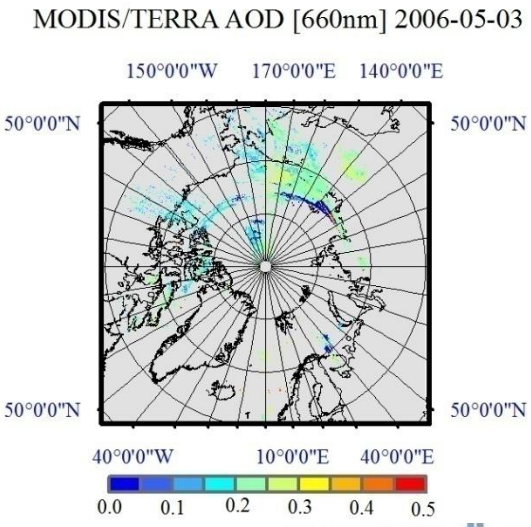




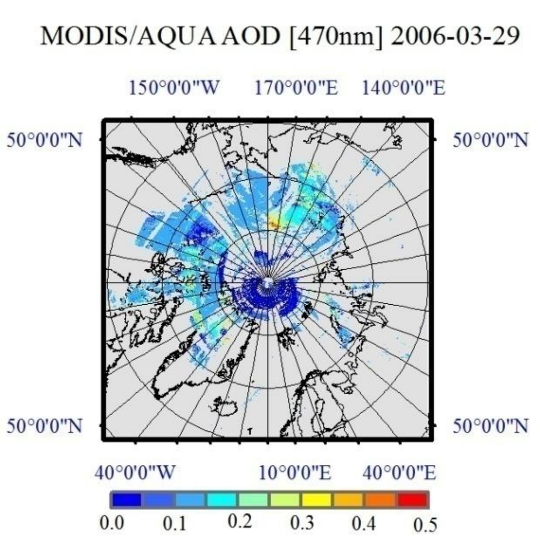


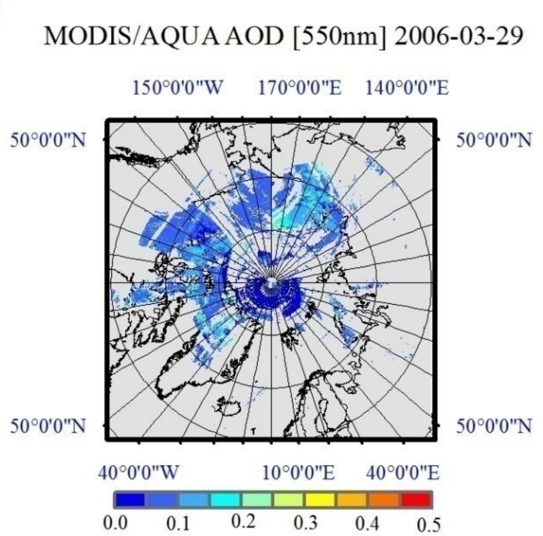


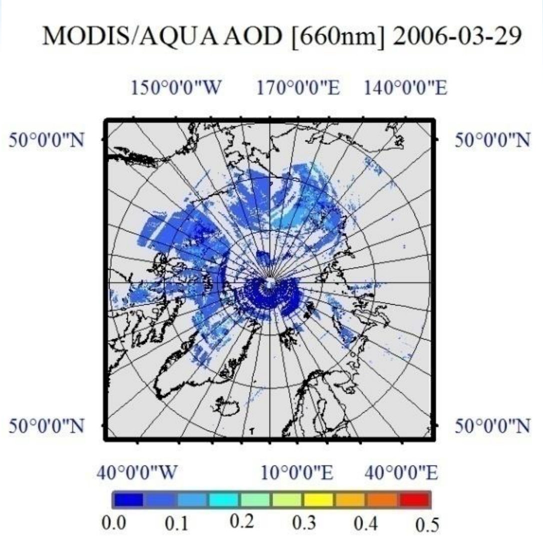


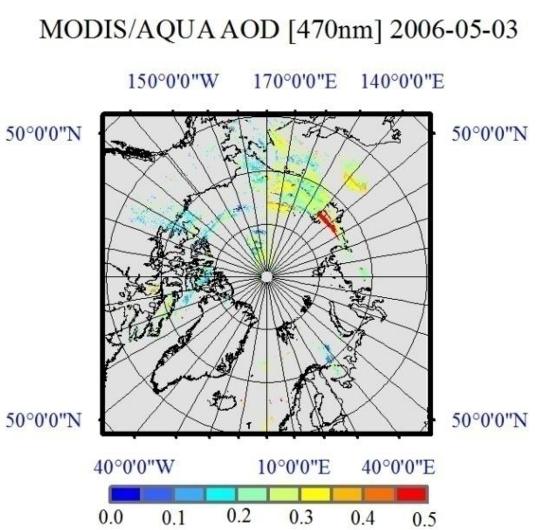


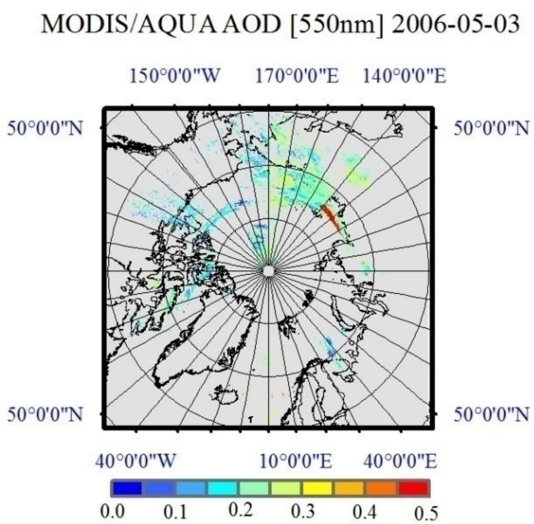
AOD of Arctic Region-Aqua

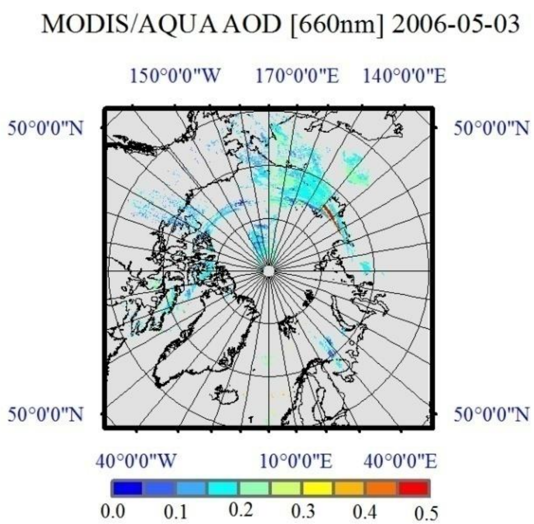






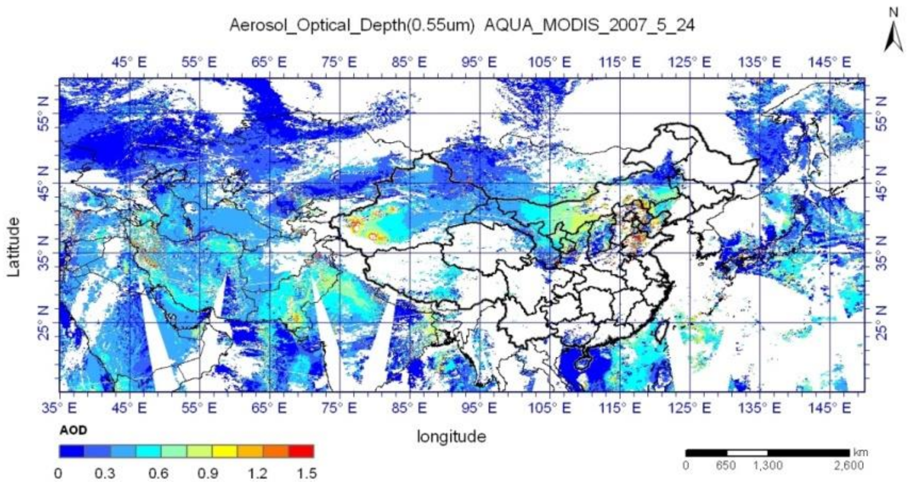


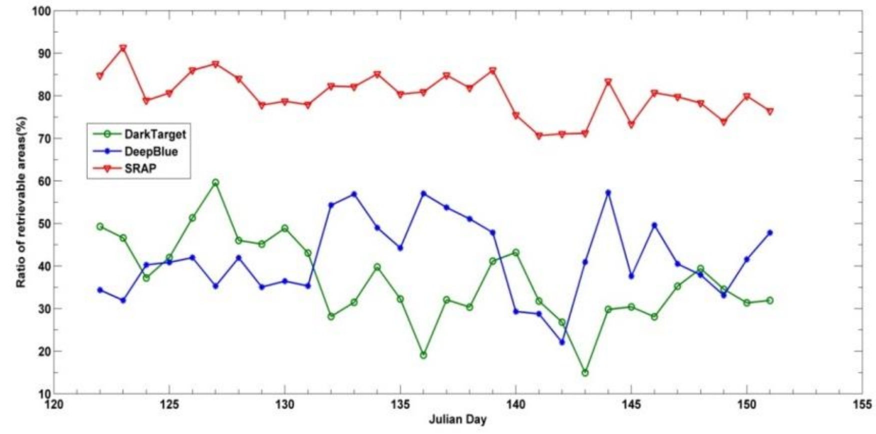


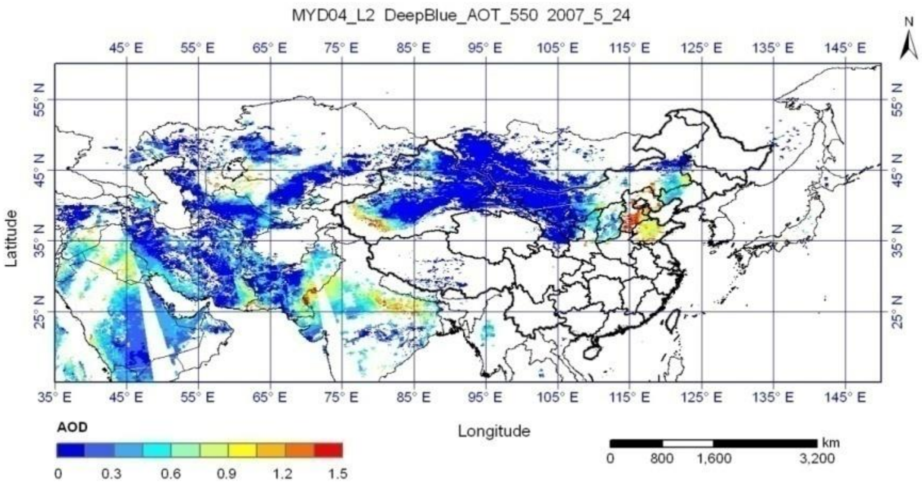


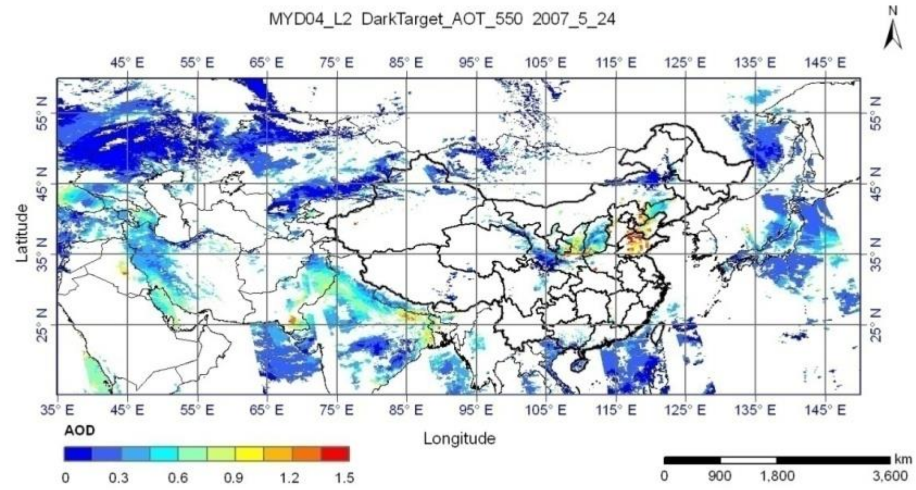
China Collection 2.0

- **Coverage comparison among TGP/SRAP, NASA/DB and NASA/DT**

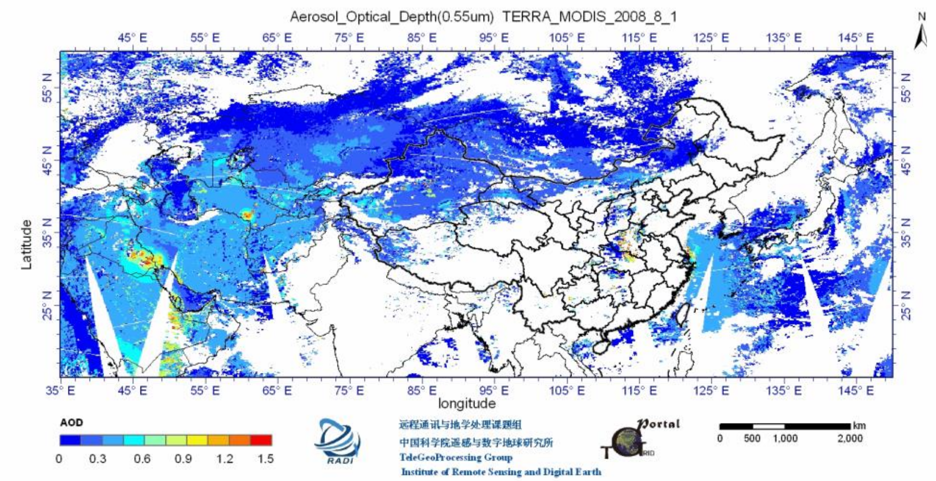


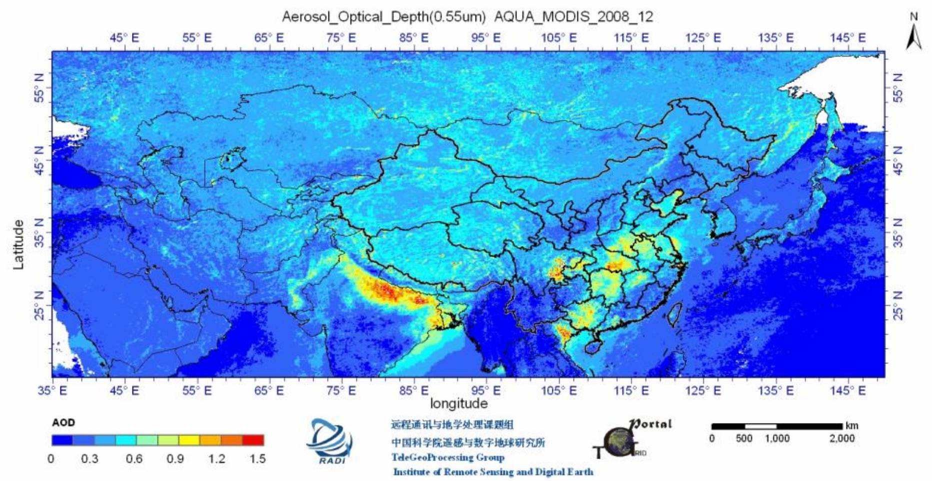




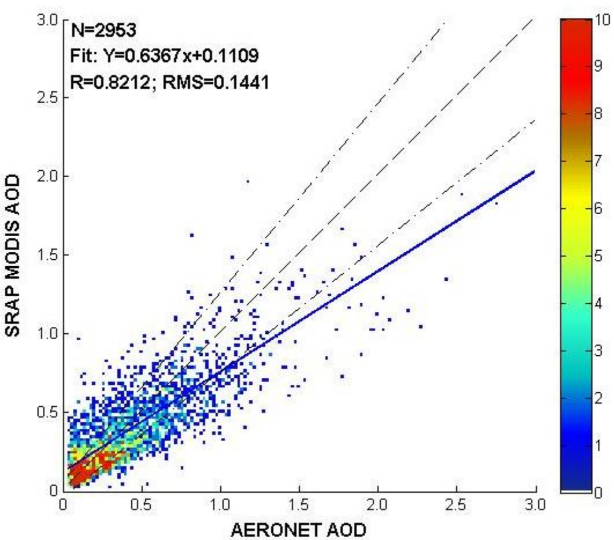


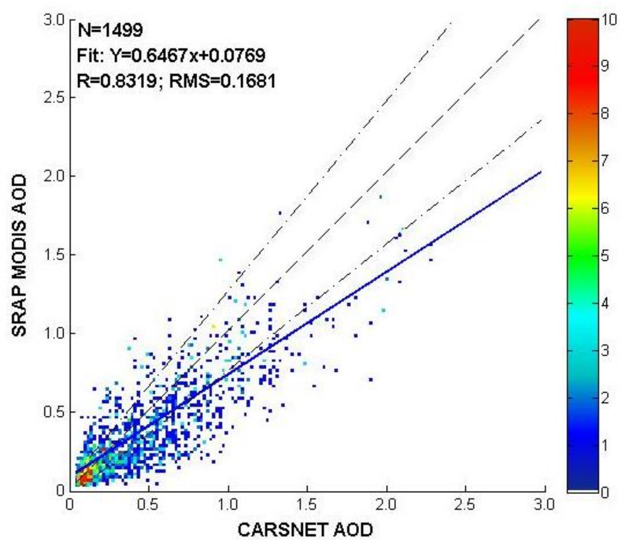
Validation





2008 Mainland China and East Asia





CARSNET

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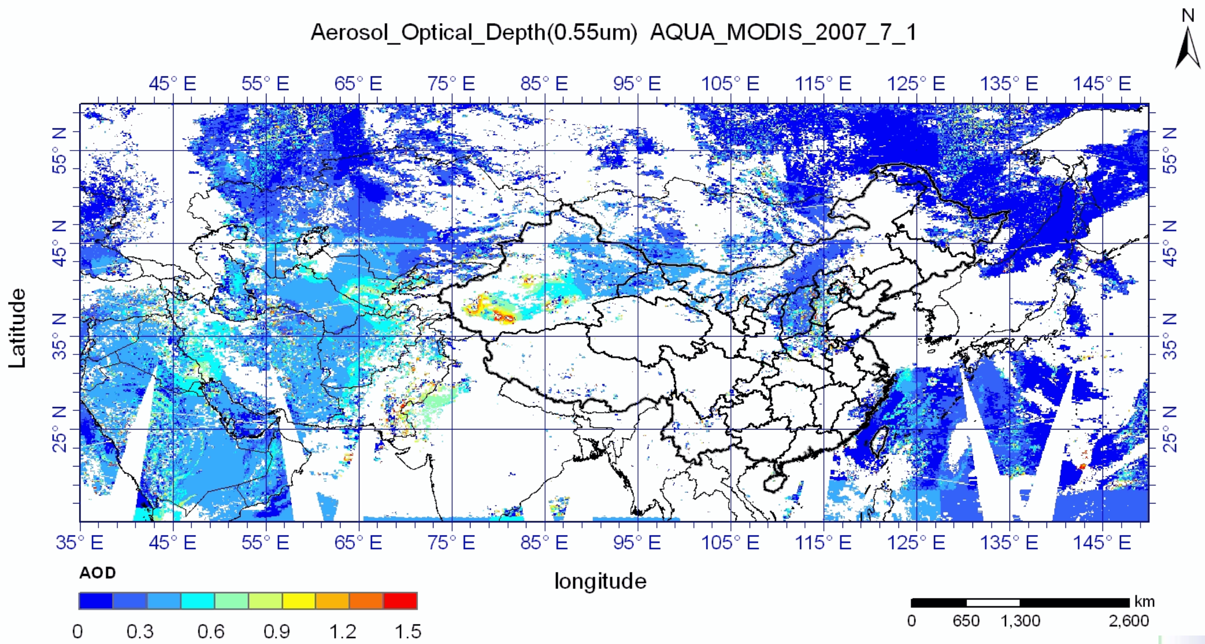
AOD data collection over Mainland China

China Collection 2.0 & 2.1



Spatial Resolution: 10km, 1km
Temporal Scale: from August 2002

(AOD at 1 km resolution)

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