



Aerosol Optical Depth Retrieval from Satellite Data over Land

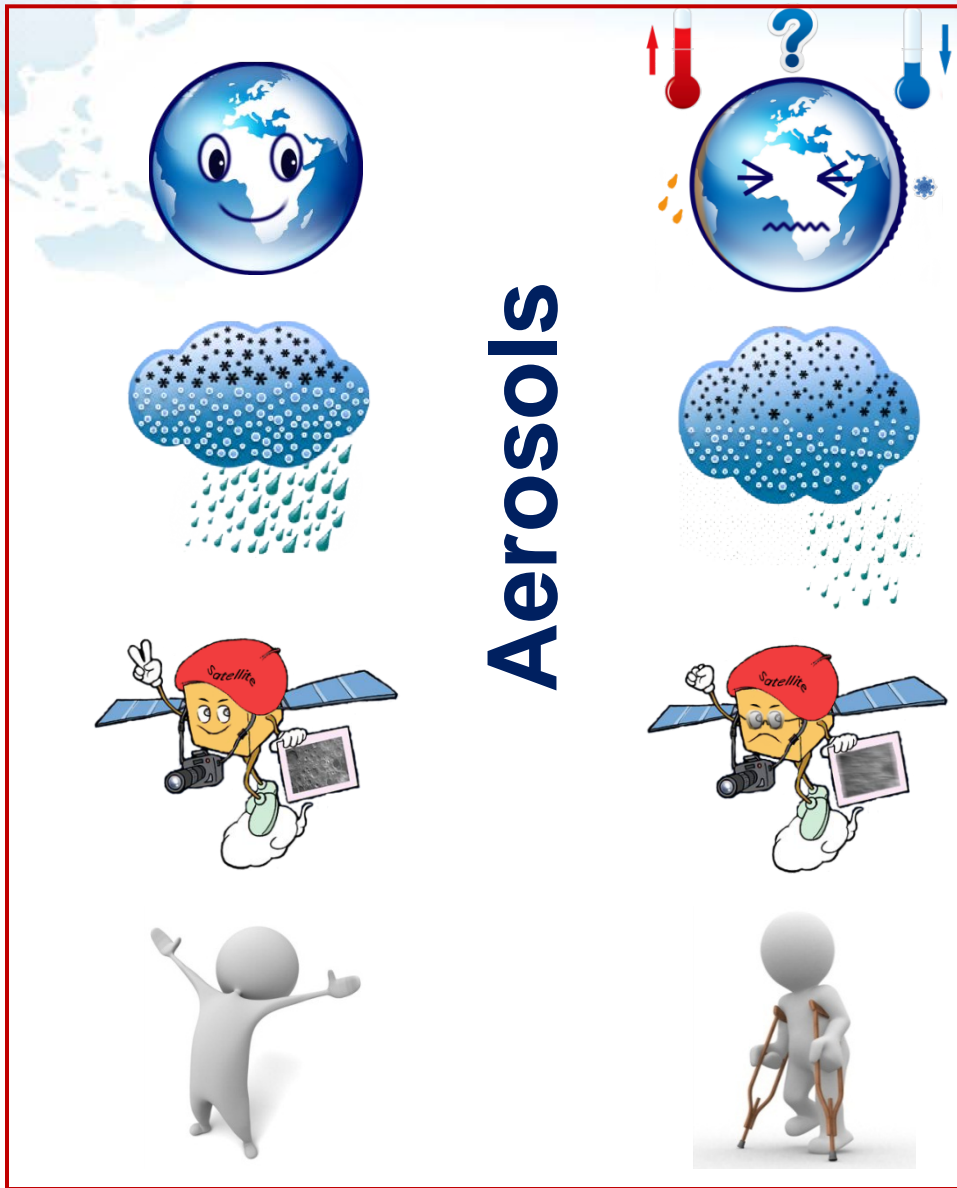
Professor Dr. Yong Xue

TeleGeoProcessing (TGP) Research Group

Research 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

Aerosol Effects



Global Climate Change and Radiative Forcing

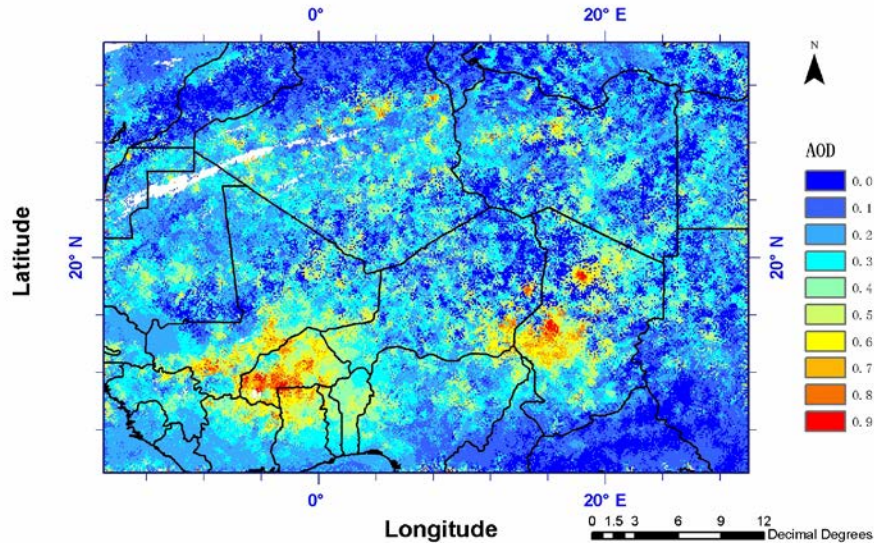
Aerosol direct and in-direct Effects

Quantitative Remote Sensing – Atmospheric Correction

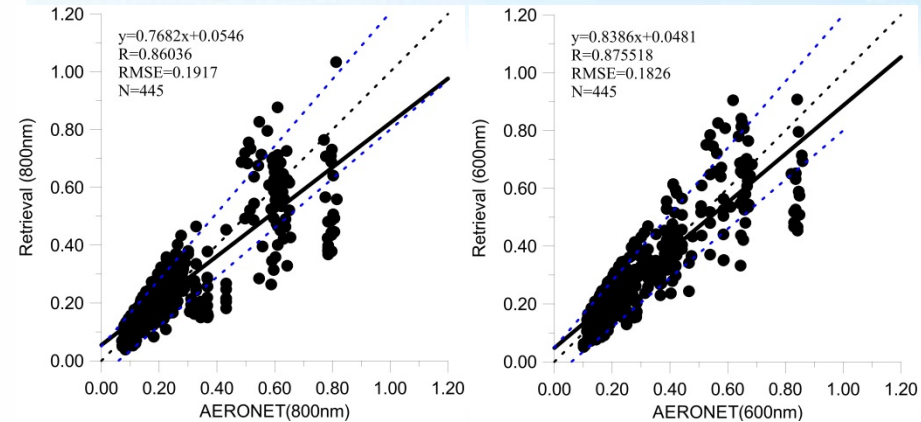
Public and Environmental Health

Hourly AOD from MSG/SEVIRI Data

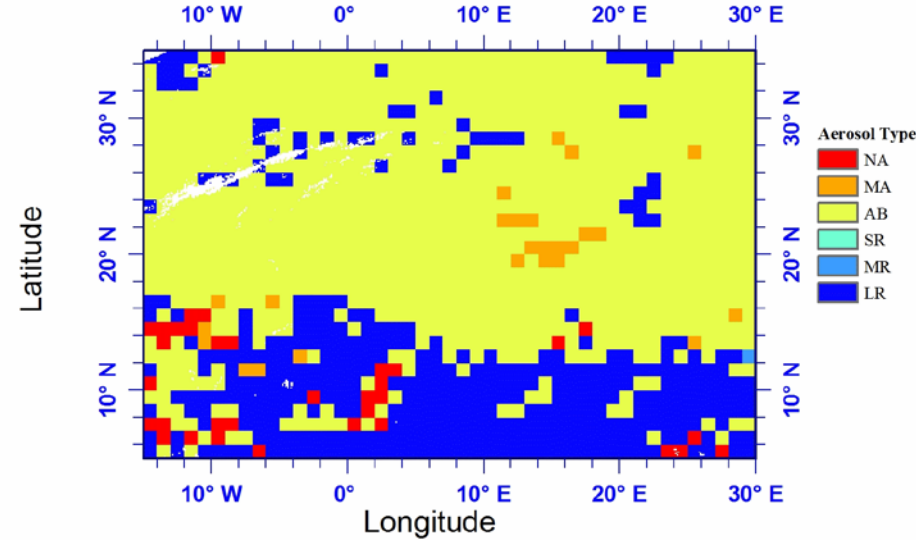
AOD_10KM_TS(0.8μm) SEVIRI_MSG_2010_04_14_08:45



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



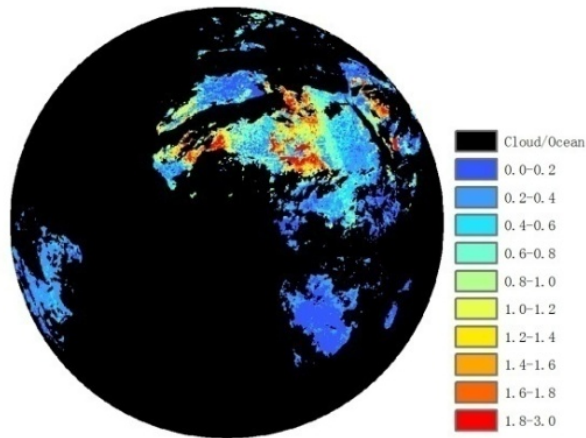
Aerosol Type SEVIRI_MSG_2010_04_14_08:45



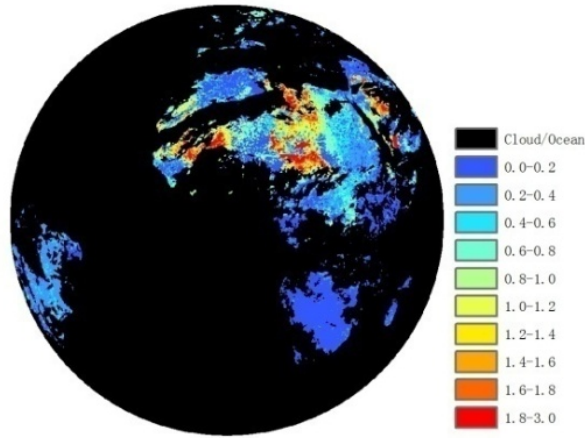
Mei, L., Xue, Y., et al.: Retrieval of aerosol optical depth over land based on a time series technique using MSG/SEVIRI data, *Atmos. Chem. Phys.*, 12, pp9167-9185, 2012.

Hourly AOD and Reflectance from MSG Satellite SEVIRI Data

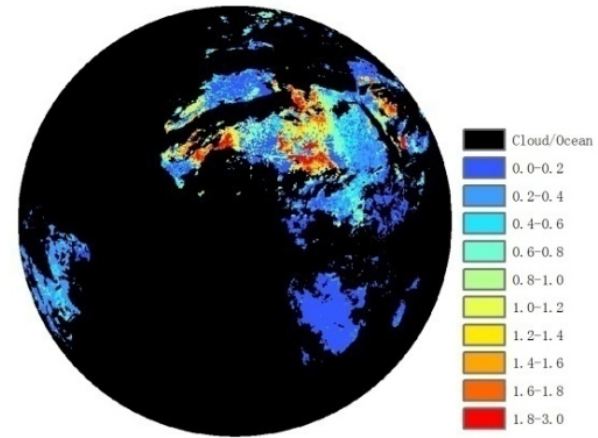
MSG/SEVIRI_AOD_12KM(0.6 μ m)
2010_04_14_10:30



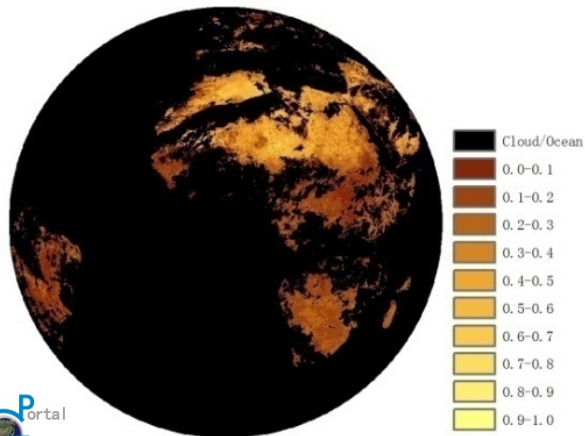
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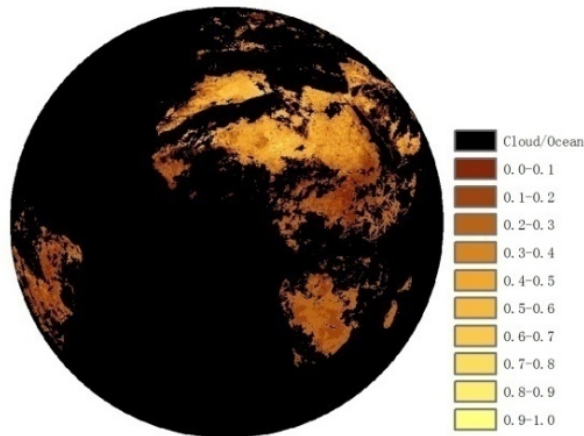
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2010_04_14_11:00



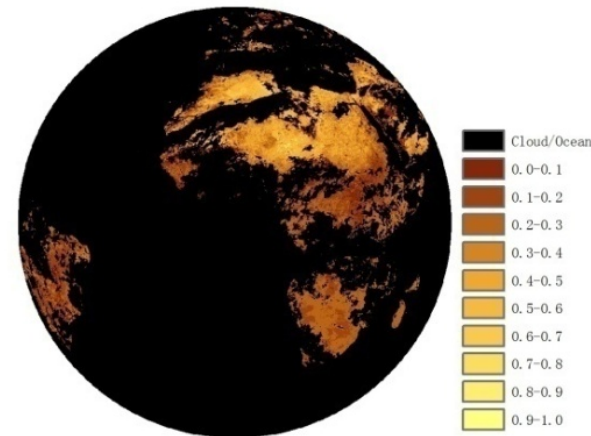
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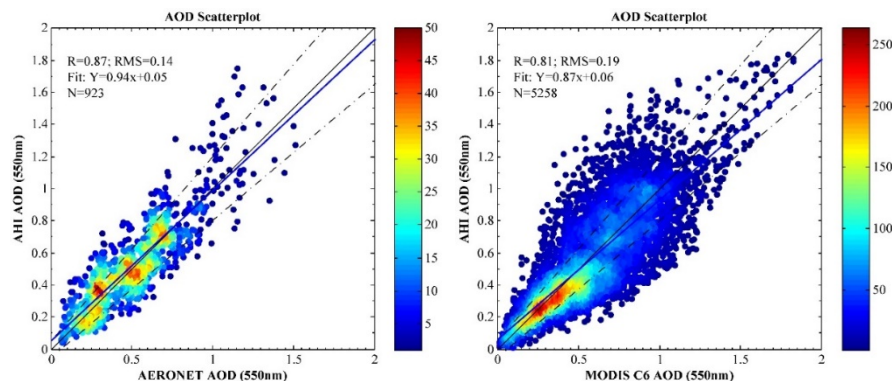


MSG/SEVIRI_REF_12KM(0.6 μ m)
2010_04_14_11:00

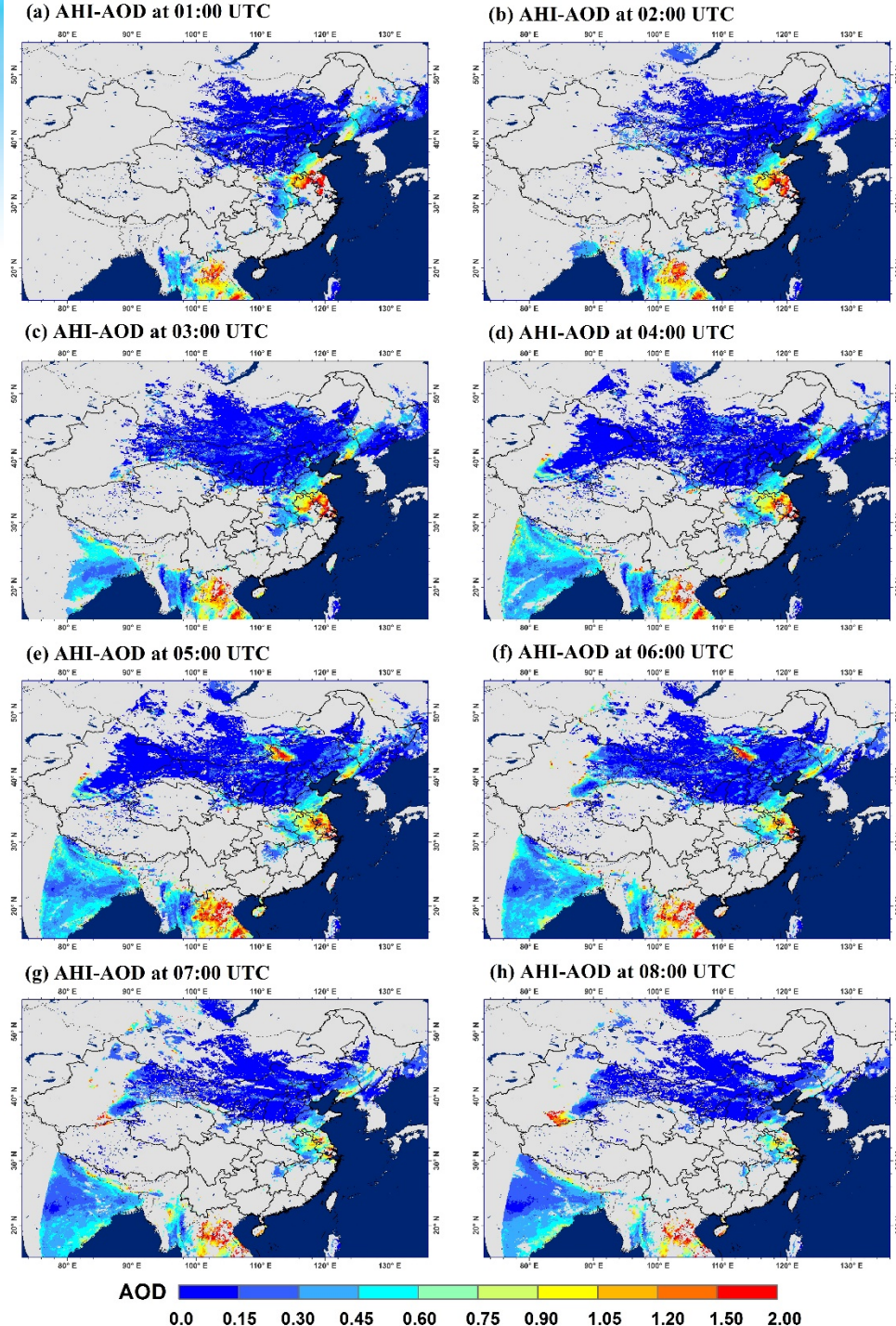


Hourly AOD from the Advanced Himawari Imager (AHI) aboard Himawari-8 geostationary satellite

Channel name	Central wavelength (μm)	Channel name	Central wavelength (μm)
1	0.47	9	6.94
2	0.51	10	7.35
3	0.64	11	8.60
4	0.86	12	9.64
5	1.61	13	10.41
6	2.25	14	11.24
7	3.89	15	12.38
8	6.24	16	13.28



Lu She, Linlu Mei, **Yong Xue**, Yahui Che, Jie Guang, 2017, SAHARA: a Simplified AtmosphERIC correction AlgoRithm for Chinese gAofen data: 1. Aerosol algorithm. *Remote Sensing*, **9**(3), 253; (doi:10.3390/rs9030253)



AVHRR Data

- More than 35 years
- Big scanning Angle, wide scanning band
- Short revisit cycle (four times per day)
- The continuity of time and space coverage

Sensor type	Satellite name	Service time	Ascending / Descending time
AVHRR	TIROS-N	1978.10 - 1980.01	15:00/03:00
AVHRR/1	NOAA-6*	1979.06 - 1986.11	19:30/07:30
	NOAA-8	1983.06 - 1984.06/ 1985.07 - 1985.11	19:30/07:30
	NOAA-10	1986.11 - 1991.09	19:30/07:30
AVHRR/2	NOAA-7	1981.04 - 1986.06	14:30/02:30
	NOAA-9	1985.02 - 1988.11	14:20/02:20
	NOAA-11	1988.11 - 1995.04	13:30/01:30
	NOAA-12	1991.09 - 1998.12	19:30/07:30
	NOAA-14	1995.04 - 2007.05	13:30/01:30
AVHRR/3	NOAA-15	1998.12 -	19:30/07:30
	NOAA-16	2001.03 -	14:00/02:00
	NOAA-17	2002.10 -	22:00/10:00
	NOAA-18	2005.08 -	14:00/02:00
	Metop-A	2006.11 -	21:30/09:30
	NOAA-19	2009.06 -	14:00/02:00
	Metop-B	2012.09 -	21:30/09:30

*Red represents the morning satellite

	AVHRR	AVHRR/1	AVHRR/2	AVHRR/3
Channels	1, 2, 3, 4	1, 2, 3, 4	1, 2, 3, 4, 5	1, 2, 3a, 3b, 4, 5
Solar channels	1, 2	1, 2	1, 2	1, 2, 3a*
Thermal channels	3, 4	3, 4	3, 4, 5	3a*, 3b, 4, 5
Channel 1 wavelengths(μm)	0.55-0.90	0.58-0.68	0.58-0.68	0.58-0.68
Channel 2 wavelengths(μm)	0.725-1.10	0.725-1.10	0.725-1.10	0.725-1.00
Gain	Single	Single	Single	Dual
Footprint at nadir(km)	1.1	1.1	1.1	1.1
Platforms	TIROS-N	NOAA-6, 8,10	NOAA-7,9, 11,12,14	NOAA-15,16,17, 18,19, Metop-A,B

Post Calibration of Channels 1 and 2 of Long-term AVHRR Data Record Based on SeaWiFS Data and Pseudo-invariant Targets

▼ Calculate calibration slopes

▼ Calculate S for two bands at each observation; Dual-gain after NOAA-15 (Heidinger, 2002)

$$R = \frac{\rho_{AVHRR}^{TOA} \times \cos \theta_s}{d^2}$$

$$DC \leq SC : 100 \times R = S_{low}(DC - ZC)$$

$$DC > SC : 100 \times R = S_{high}(DC - SC) + S_{low}(SC - ZC)$$

▼ Time series fitting

$$S = \sum_{i=0}^2 C_i \times D^i$$

- **C_i:** fitted coefficients
- **D:** days since the January 1 of the beginning year with data availability

Satellite	Channel	C ₀	C ₁	C ₂	Satellite	Channel	C ₀	C ₁	C ₂
TIROS-N	band 1	0.098	3.931E-05	-1.077E-08	NOAA-16	band 1_low	0.098	3.931E-05	-1.077E-08
	band 2	0.144	-8.296E-05	9.682E-08		band 2_low	0.144	-8.296E-05	9.682E-08
NOAA-6	band 1	0.105	4.397E-05	-3.454E-08		band 1_high	0.105	4.397E-05	-3.454E-08
	band 2	0.098	9.885E-05	-7.337E-08		band 2_high	0.098	9.885E-05	-7.337E-08
NOAA-7	band 1	0.113	9.649E-06	1.376E-09	NOAA-17	band 1_low	0.113	9.649E-06	1.376E-09
	band 2	0.110	3.234E-05	-1.192E-08		band 2_low	0.110	3.234E-05	-1.192E-08
NOAA-8	band 1	0.119	1.904E-05	-3.955E-10		band 1_high	0.119	1.904E-05	-3.955E-10
	band 2	0.114	8.508E-05	-5.086E-08		band 2_high	0.114	8.508E-05	-5.086E-08
NOAA-9	band 1	0.106	1.776E-05	1.411E-09	NOAA-18	band 1_low	0.106	1.776E-05	1.411E-09
	band 2	0.113	1.512E-05	-4.218E-09		band 2_low	0.113	1.512E-05	-4.218E-09
NOAA-10	band 1	0.107	2.450E-05	-8.826E-09		band 1_high	0.107	2.450E-05	-8.826E-09
	band 2	0.129	1.262E-05	-4.548E-09		band 2_high	0.129	1.262E-05	-4.548E-09
NOAA-11	band 1	0.106	2.284E-06	6.052E-10	Metop-A	band 1_low	0.106	2.284E-06	6.052E-10
	band 2	0.108	5.332E-06	-1.202E-09		band 2_low	0.108	5.332E-06	-1.202E-09
NOAA-12	band 1	0.113	1.938E-05	-4.382E-09		band 1_high	0.113	1.938E-05	-4.382E-09
	band 2	0.134	1.608E-05	-3.073E-09		band 2_high	0.134	1.608E-05	-3.073E-09
NOAA-14	band 1	0.115	1.707E-05	-3.657E-09	NOAA-19	band 1_low	0.115	1.707E-05	-3.657E-09
	band 2	0.140	7.249E-06	3.918E-10		band 2_low	0.140	7.249E-06	3.918E-10
NOAA-15	band 1	0.122	-1.147E-06	1.427E-10		band 1_high	0.122	-1.147E-06	1.427E-10
	band 2	0.131	4.276E-06	-6.600E-10		band 2_high	0.131	4.276E-06	-6.600E-10
Metop-B	band 1	0.054	1.871E-06	-9.302E-11					
	band 2	0.055	2.370E-06	-2.251E-10					

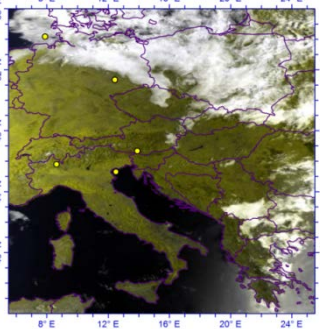
Quadratic fit results of AVHRR calibration slope time series. Note that NOAA-15 and Metop-B are presented with equivalent single gain slopes.

Chi Li, Yong Xue, Quanhua Liu, Jie Guang, Xingwei He, Jiahua Zhang, Tingkai Wang, Xinjie Liu, 2014, Post Calibration of Channels 1 and 2 of Long-term AVHRR Data Record Based on SeaWiFS Data and Pseudo-invariant Targets. *Remote Sensing of Environment*, Vol. 150, Pages 104–119. (DOI information: 10.1016/j.rse.2014.04.020)

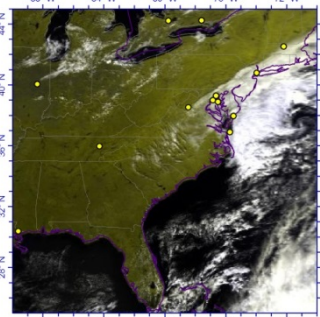
Long-term (30 yrs) AOD data from AVHRR Data

Yingjie Li, Yong Xue, Gerrit de Leeuw, Chi Li, Leiku Yang, Tingting Hou, 2013, Retrieval of Aerosol Optical Depth and Surface Reflectance over Land from NOAA AVHRR Data. *Remote Sensing of Environment*, Vol. 133, Pages 1–20.

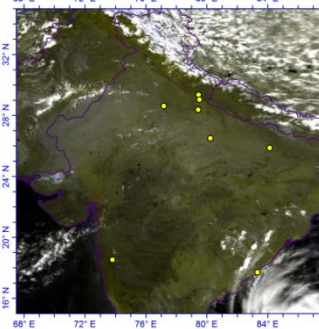
NOAA-15 AVHRR RGB Image over EUR on 08/14/2001



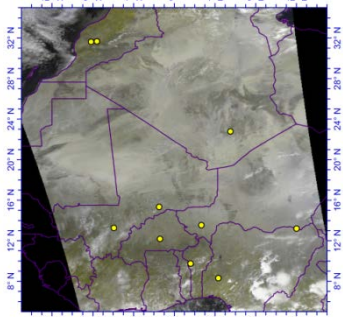
NOAA-16 AVHRR RGB Image over AME on 10/01/2001



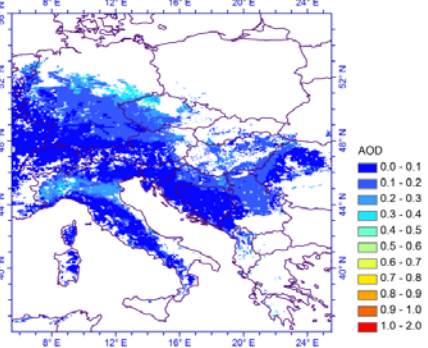
NOAA-18 AVHRR RGB Image over IND on 04/29/2008



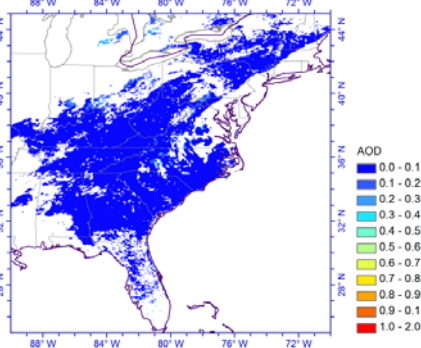
NOAA-18 AVHRR RGB Image over SAH on 04/29/2006



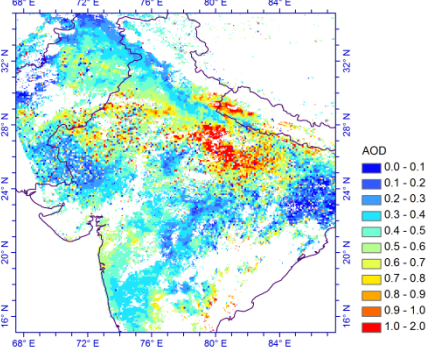
NOAA-15 AVHRR AOD at 0.63 μ m over EUR on 08/14/2001



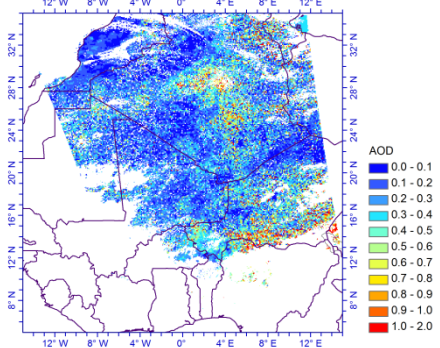
NOAA-16 AVHRR AOD at 0.63 μ m over AME on 10/01/2001



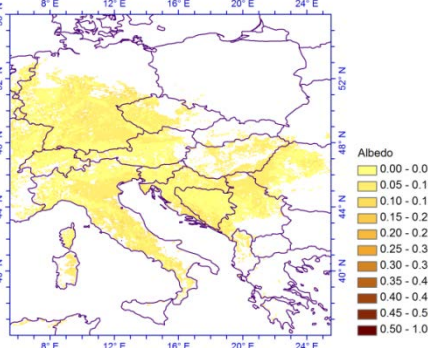
NOAA-18 AVHRR AOD at 0.63 μ m over IND on 04/29/2008



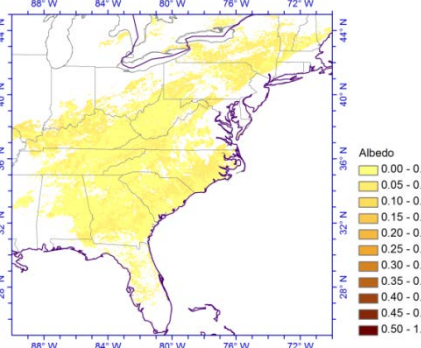
NOAA-18 AVHRR AOD at 0.63 μ m over SAH on 04/29/2006



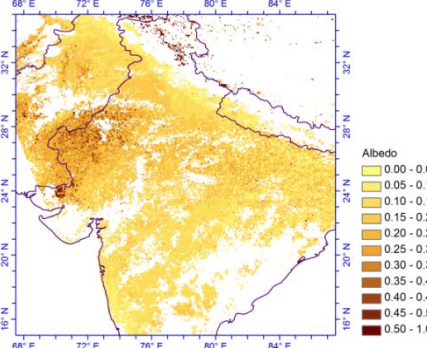
NOAA-16 AVHRR Albedo at 0.63 μ m over EUR 08/14/2001 - 08/15/2001



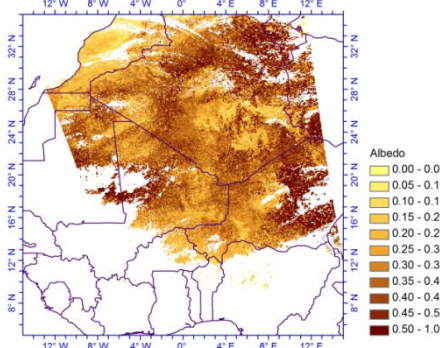
NOAA-16 AVHRR Albedo at 0.63 μ m over AME 10/01/2001 - 10/04/2001



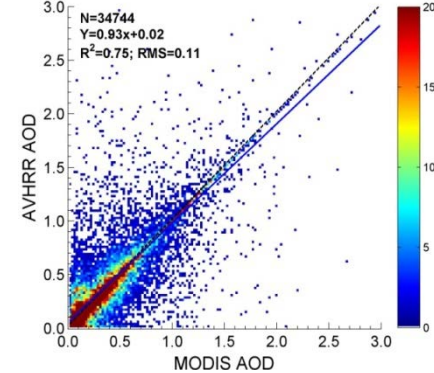
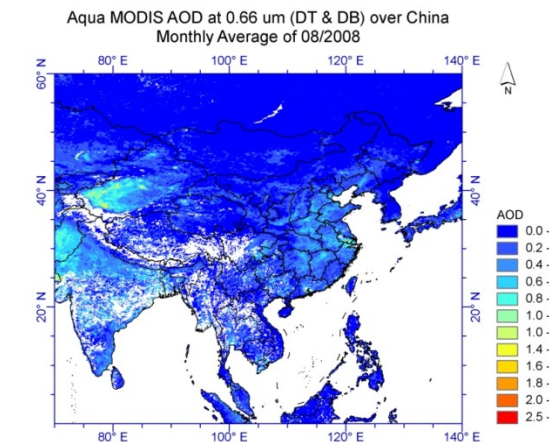
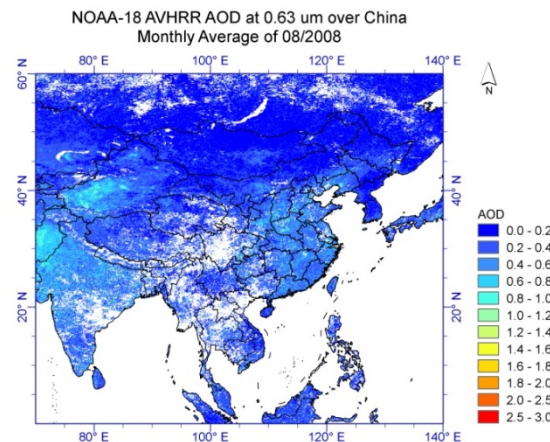
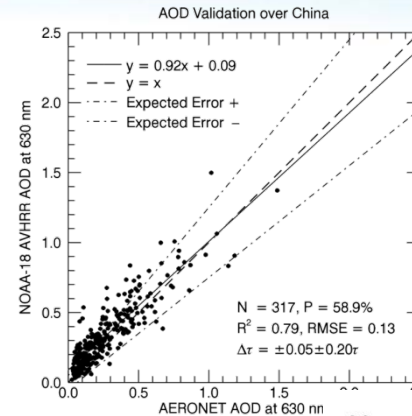
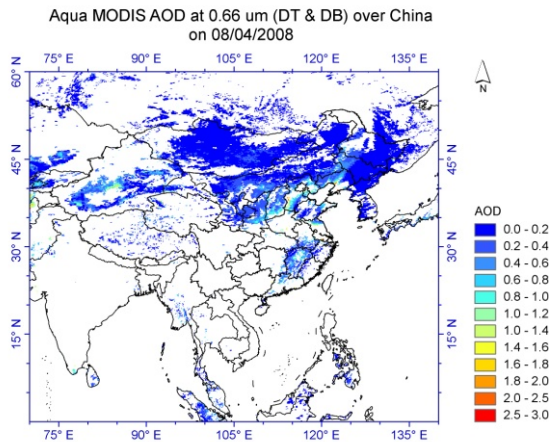
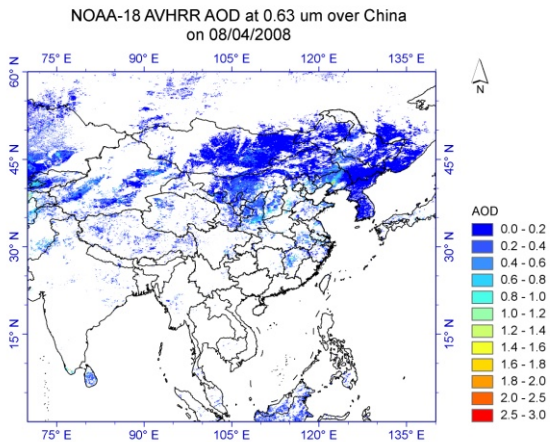
NOAA-18 AVHRR Albedo at 0.63 μ m over IND 04/29/2008 - 05/02/2008



NOAA-18 AVHRR Albedo at 0.63 μ m over SAH 04/29/2006 - 04/30/2006



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



AVHRR is the only satellite platform that could provide global daily AOD observation data over 30 years.

Yingjie Li, Yong Xue, Gerrit de Leeuw, Chi Li, Leiku Yang, Tingting Hou, 2013, Retrieval of Aerosol Optical Depth and Surface Reflectance over Land from NOAA AVHRR Data. *Remote Sensing of Environment*, Vol. 133, Pages 1–20.

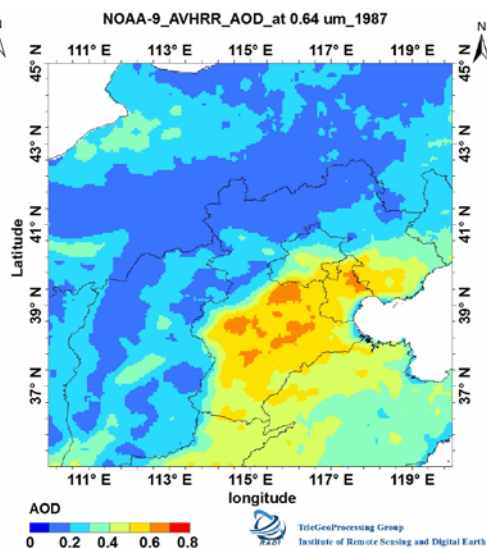
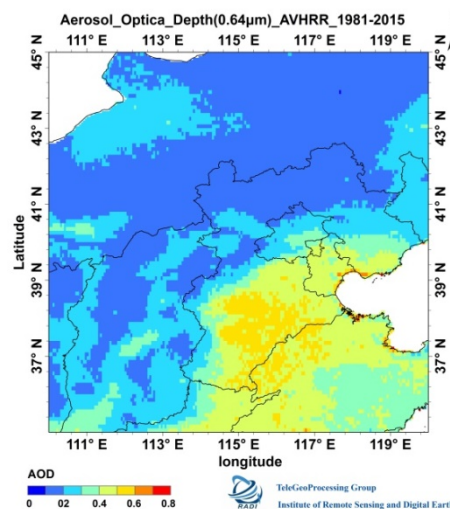
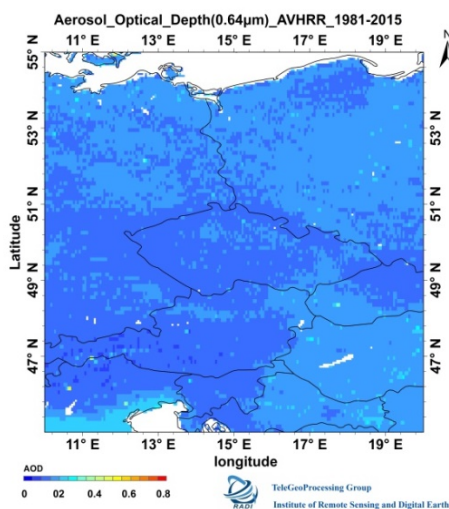
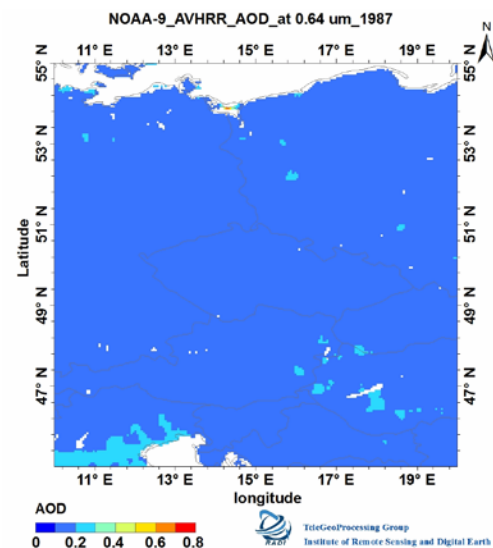
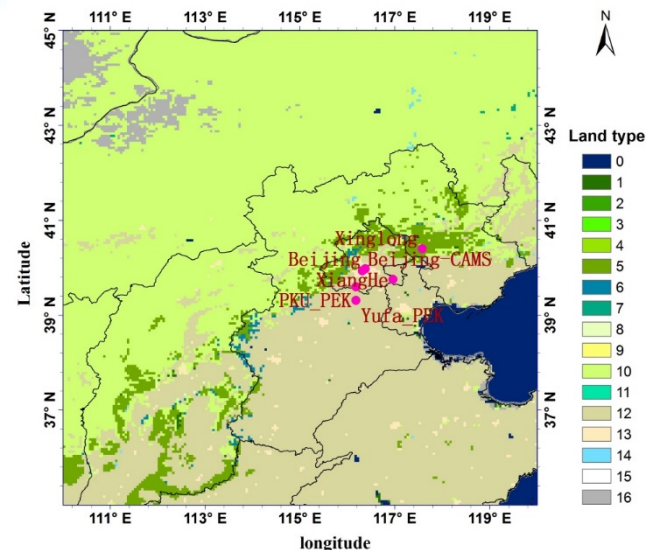
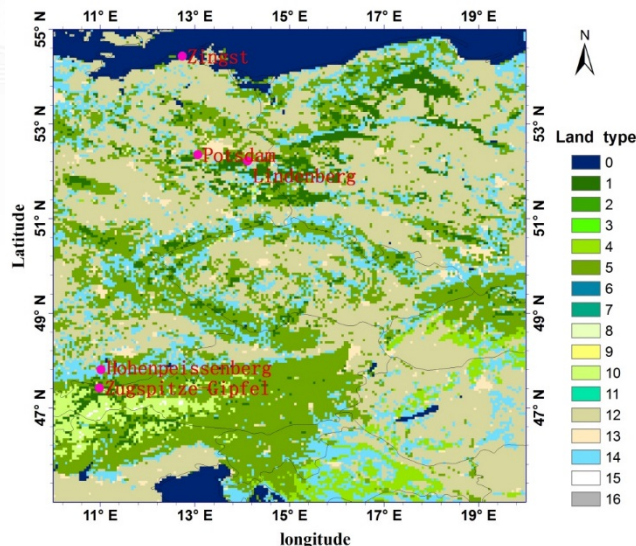
Central
Europe

Case study

North
China

– Data Selection

Re-calibrated Level 1B datasets from AVHRR on-board the TIROS-N and the Metop-B satellites to retrieve the AOD over North China and Central Europe.

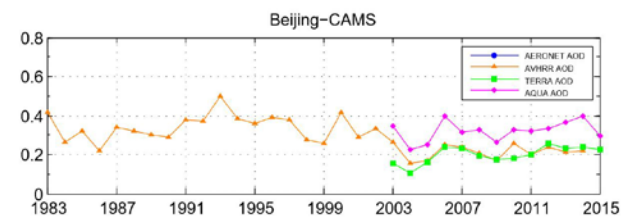
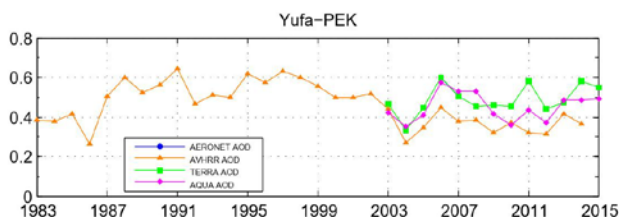
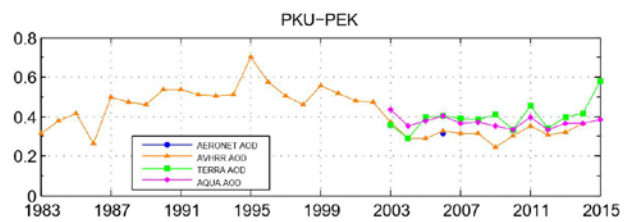
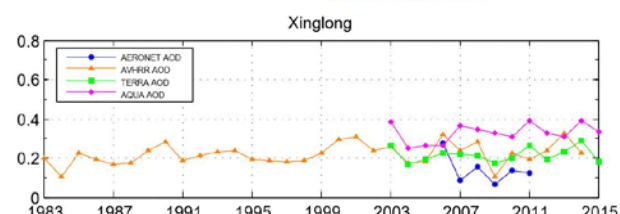
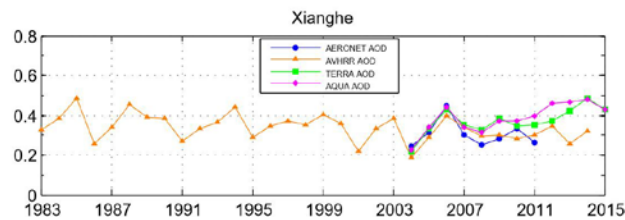
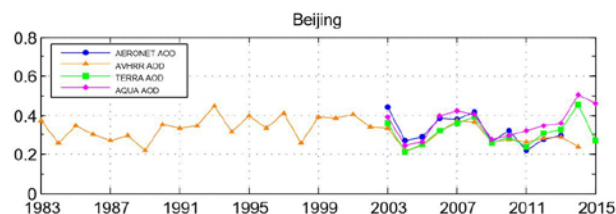
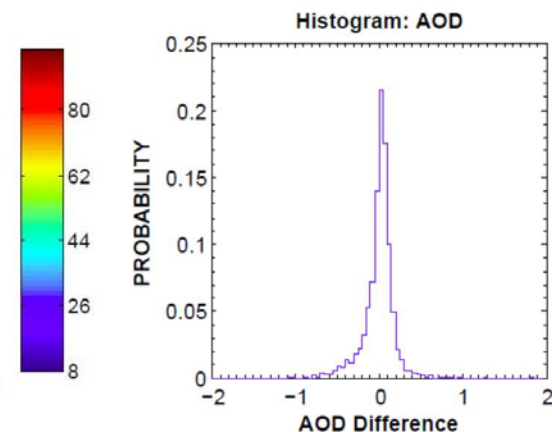
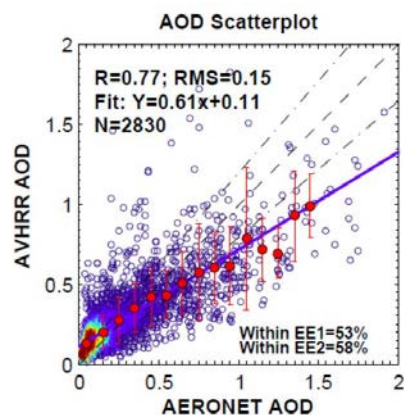


Comparison of Annual AOD

To validate the ALAD-retrieved AOD, a comparison with co-located AERONET measurements has been made. Six AERONET stations North China study region were used for the validation from 2003 to 2015.

Six AERONET sites information

site_name	lat_AERO	lon_AERO	elev_AERO
Beijing-CAMS	39.933	116.317	106
Beijing	39.977	116.381	92
PKU_PEK	39.593	116.184	66
XiangHe	39.754	116.962	36
Xinglong	40.396	117.578	970
Yufa_PEK	39.309	116.184	20

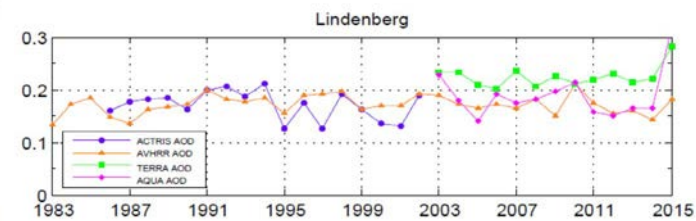
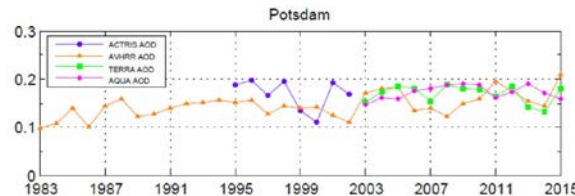
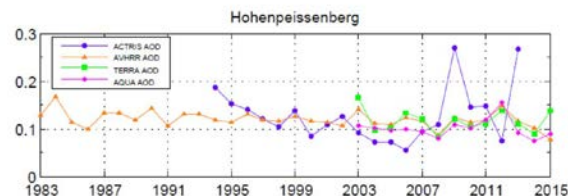
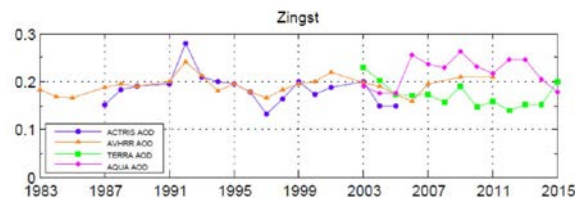
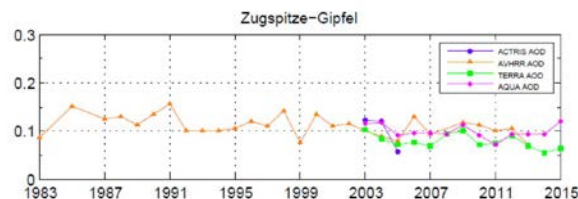
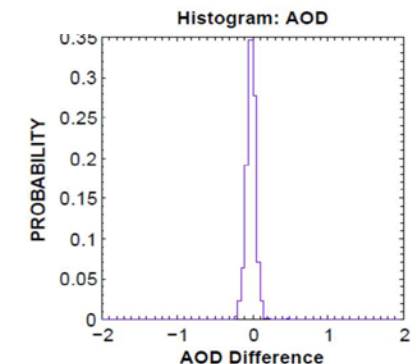
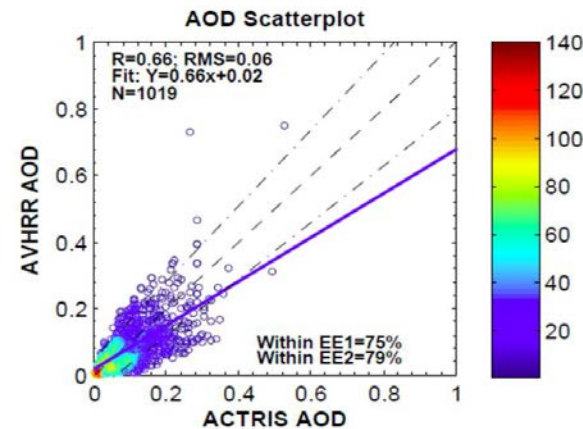


Validation for Central Europe

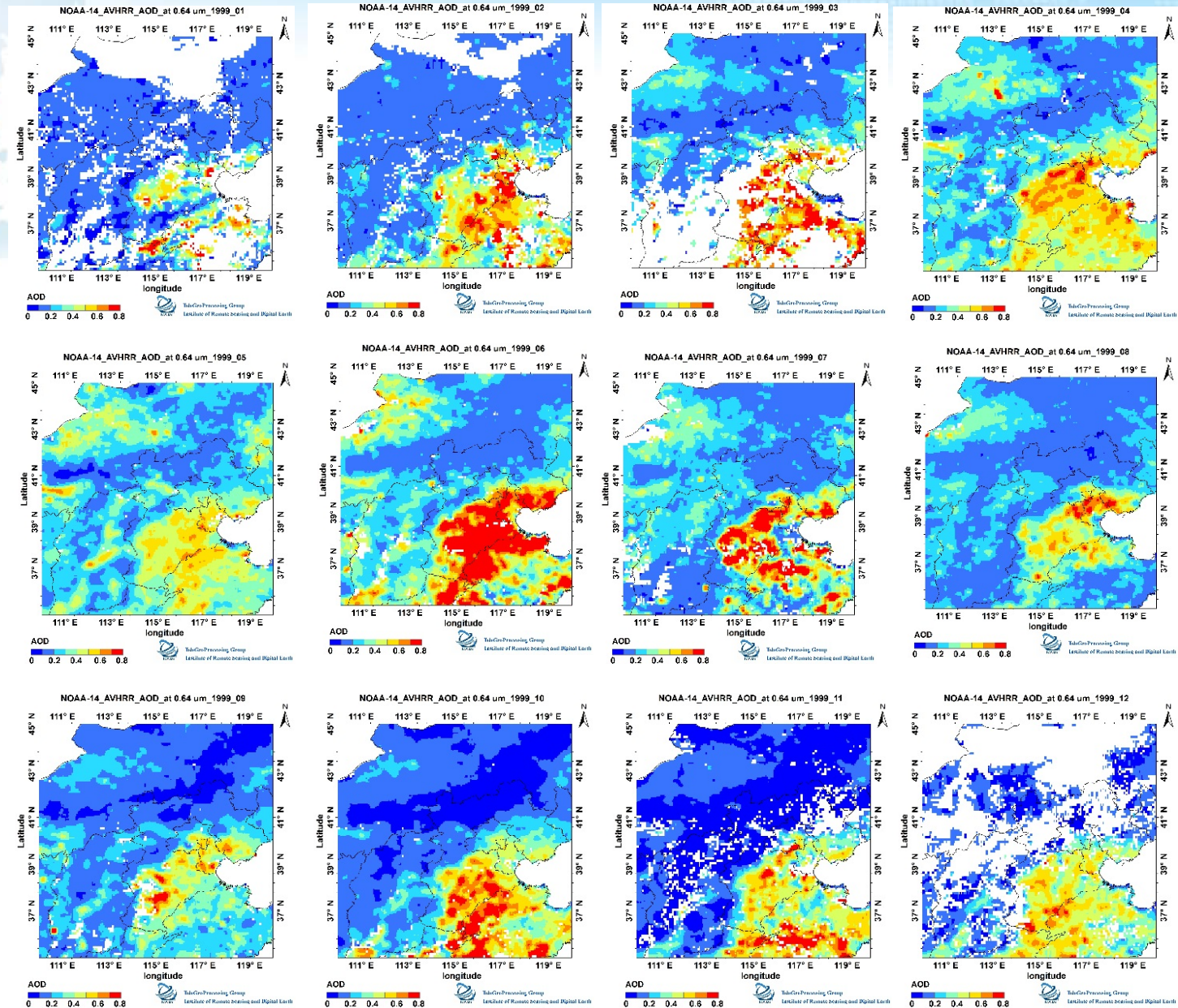
- For the Central Europe area we compare the retrieved AOD with PFR derived AOD in the ACTRIS network at five ACTRIS sites in Central Europe for which data were available for the period from 1980 to 2015.

Five ACTRI sites information in Central Europe

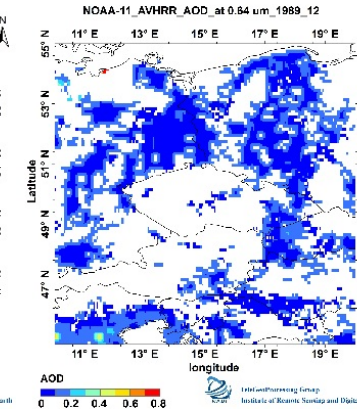
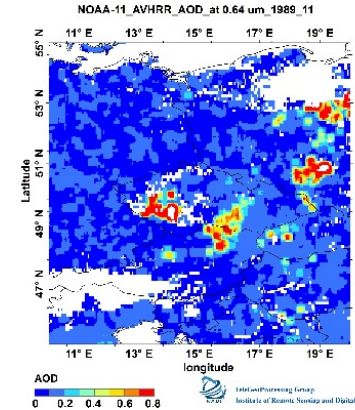
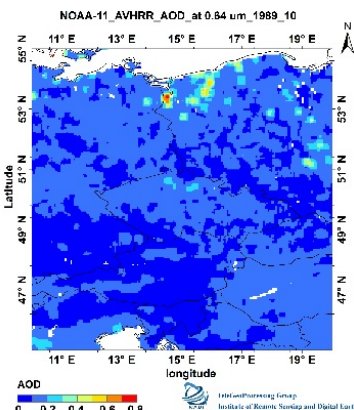
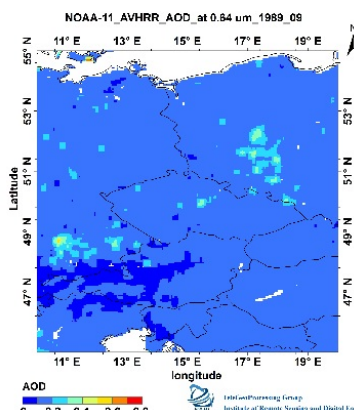
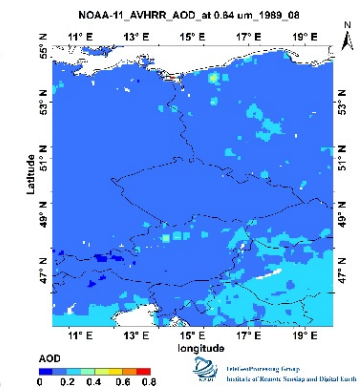
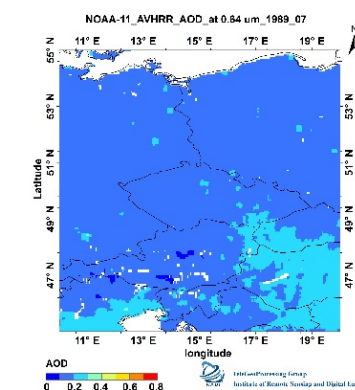
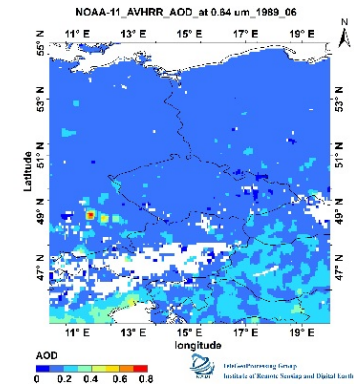
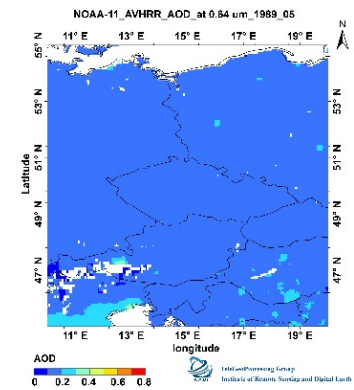
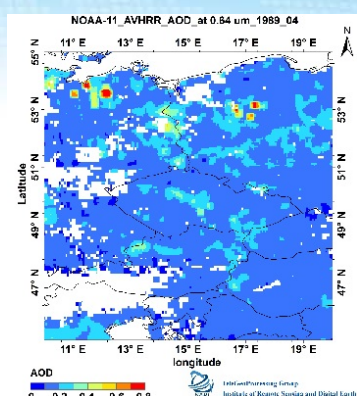
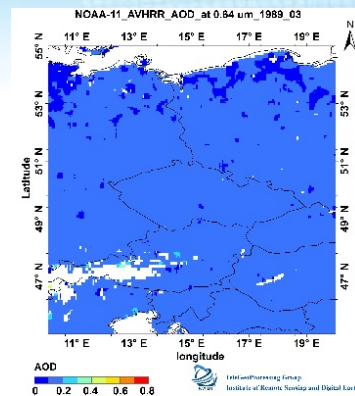
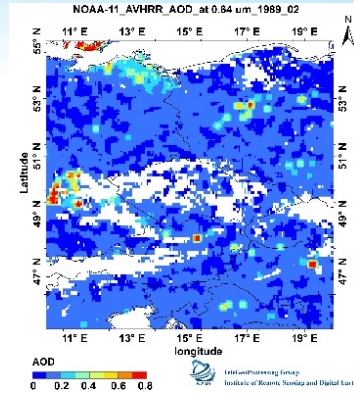
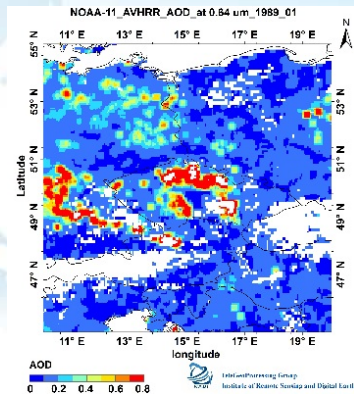
site_name	Lat ACTRIS	Lon ACTRIS	Elev ACTRIS	time range
Zingst	54.43	12.73	1.0	1987.04-2005.01
ohenpeissenberg	47.80	11.02	985.0	1993.11-2013.01
Zugspitze-Gipfel	47.42	10.98	2950.0	2003.01-2005.01
Lindenberg	52.22	14.12	112.0	1986.03-2005.01
Potsdam	52.35	13.07	89.0	1994.11-2002.01



Monthly AOD



Monthly AOD

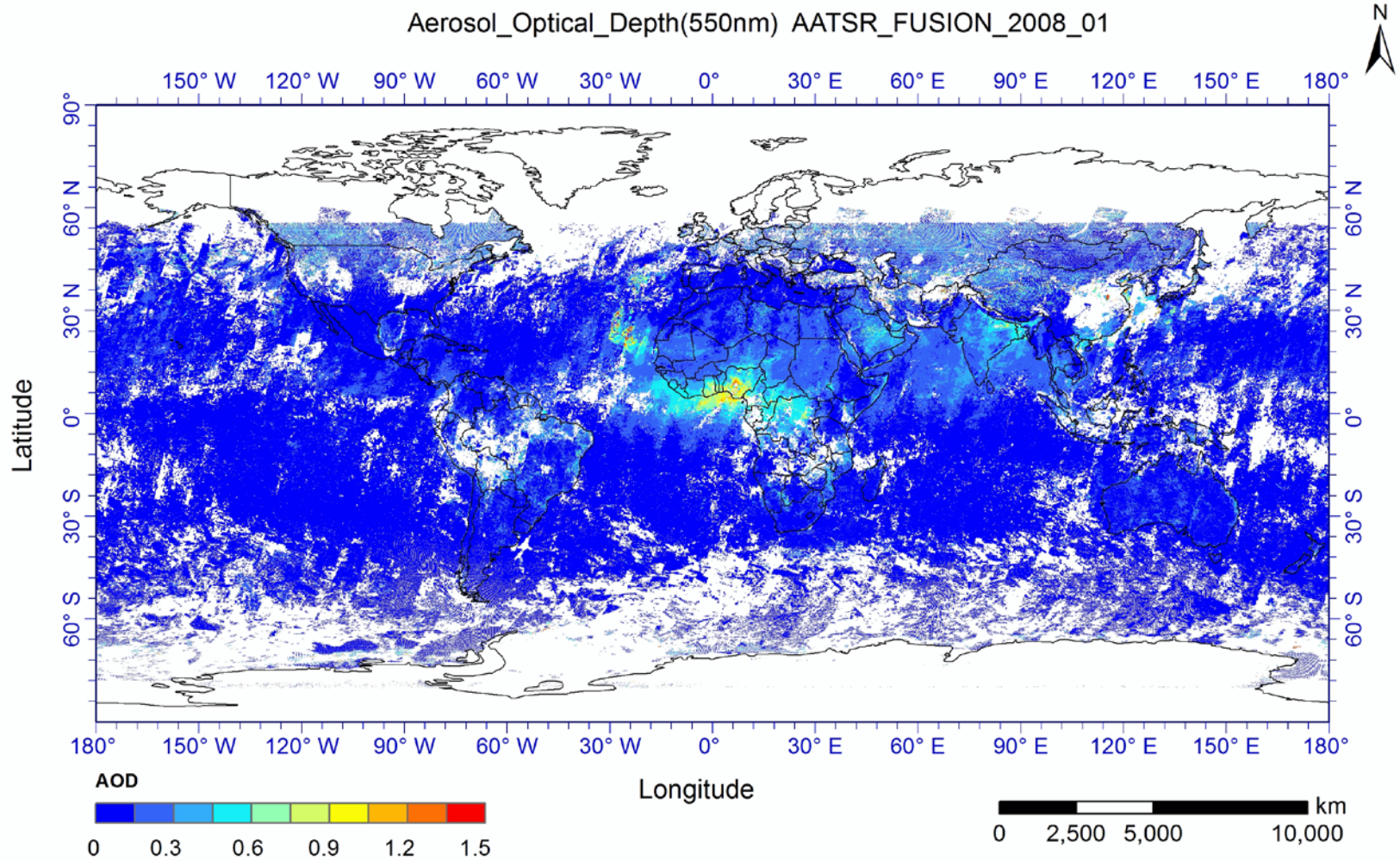


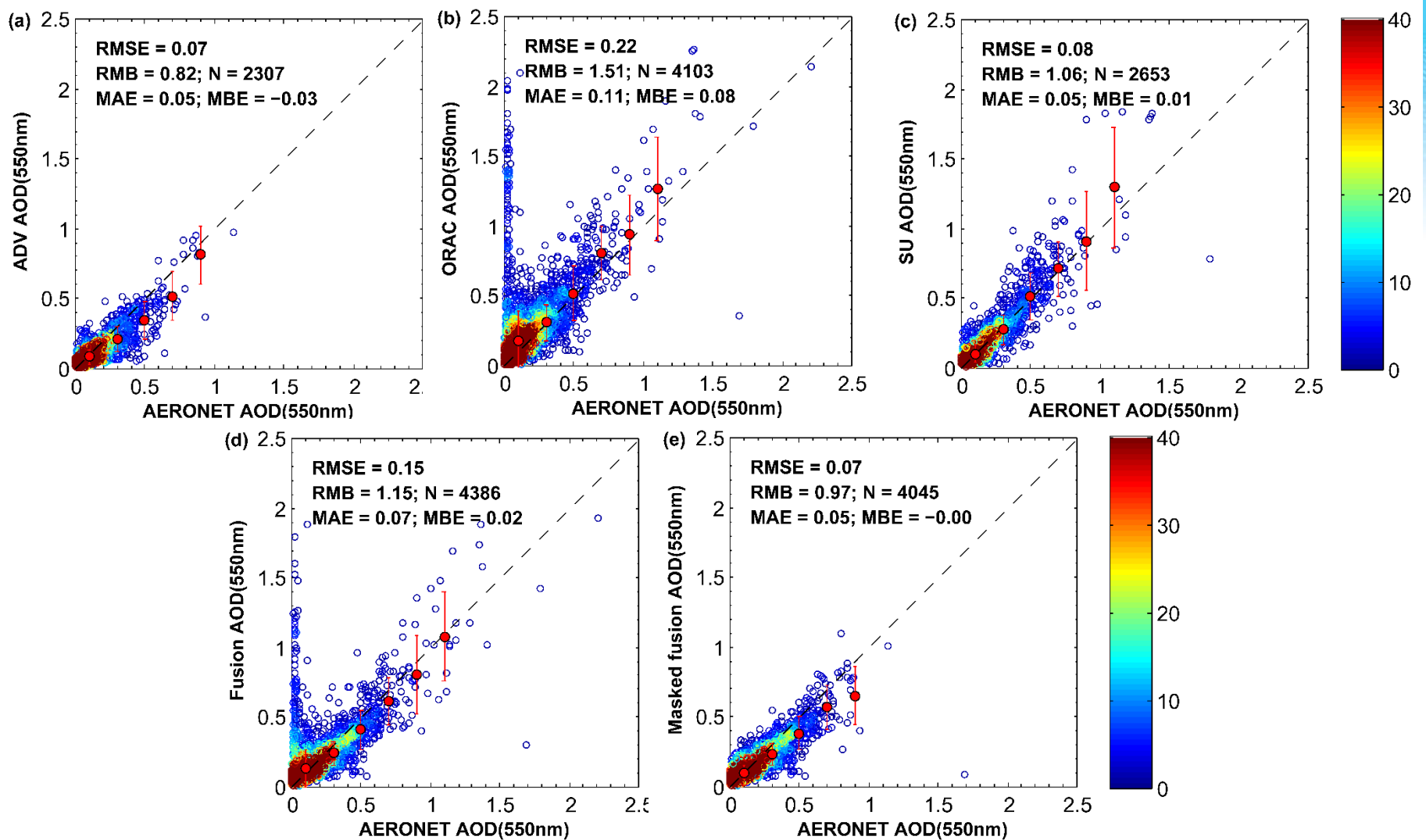
Introduction to Fusion Process

This study includes four parts: removing systematic error, determining uncertainty of AOD, fusion based on maximum likelihood method and data mask.

- Three AOD data sets are analyzed to determine whether there is obvious systematic error, and then according to the relationship among system error, reflectance and AOD to establish look-up table and remove systematic error.
- According to the relationship between uncertainty, reflectance and AOD, a look-up table is established and the uncertainty dataset of AOD is calculated .
- The maximum likelihood method was used to fuse the AOD product according to the corresponding uncertainty data set.
- Abnormal data is excluded from the fused data set according to the size of the standard deviation of the effective value in the 50km * 50km window.

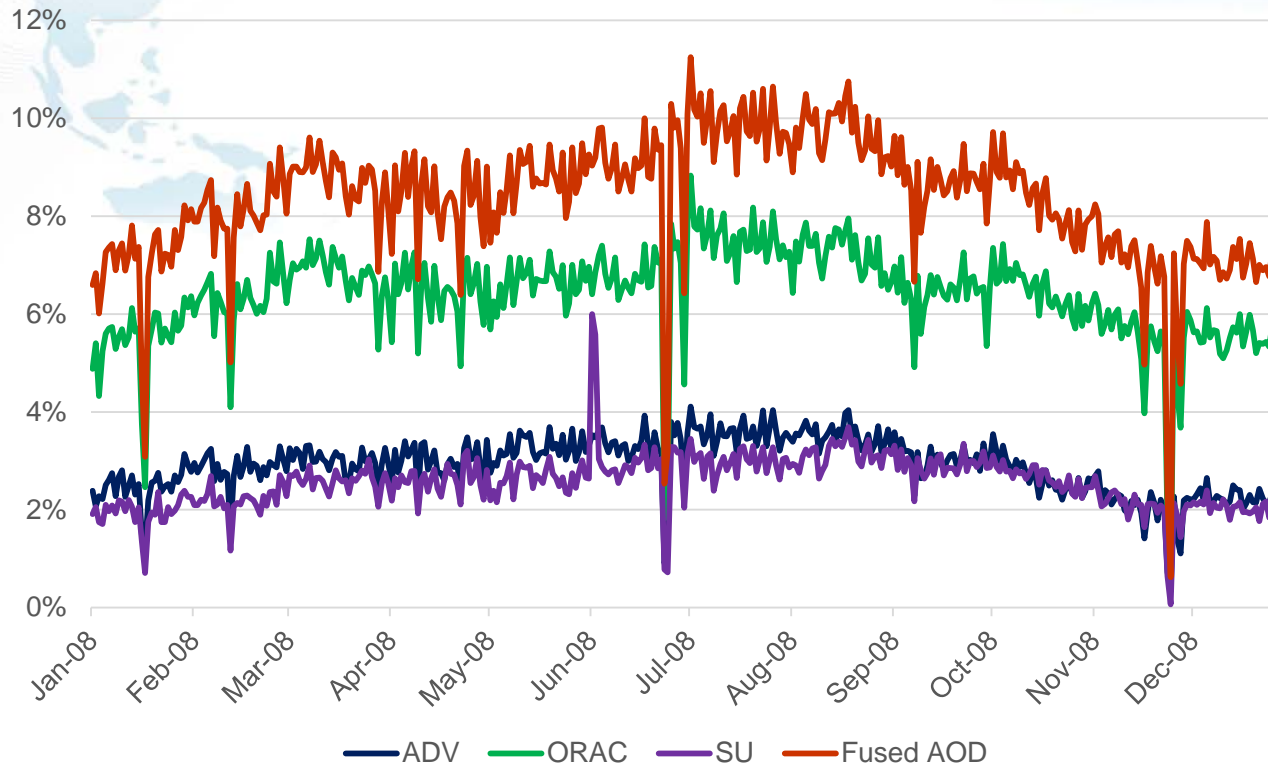
The spatial distribution of the monthly mean fused AOD in 2008





Scatter plots of three original data sets, the fusion data set and the fusion data set masked with a threshold of 0.12 against AERONET data in 2008: (a) ADV AOD; (b) ORAC AOD; (c) SU AOD; (d) Fusion AOD; (e) Fusion AOD masked with a threshold of 0.12. The black dotted line represents the 1–1 line. The magenta points are means for specific ranges of AERONET AOD, and the magenta lines are the mean $\pm 2\sigma$ of retrievals in a certain range. The color of a point is determined by the density of the position at which the point is located.

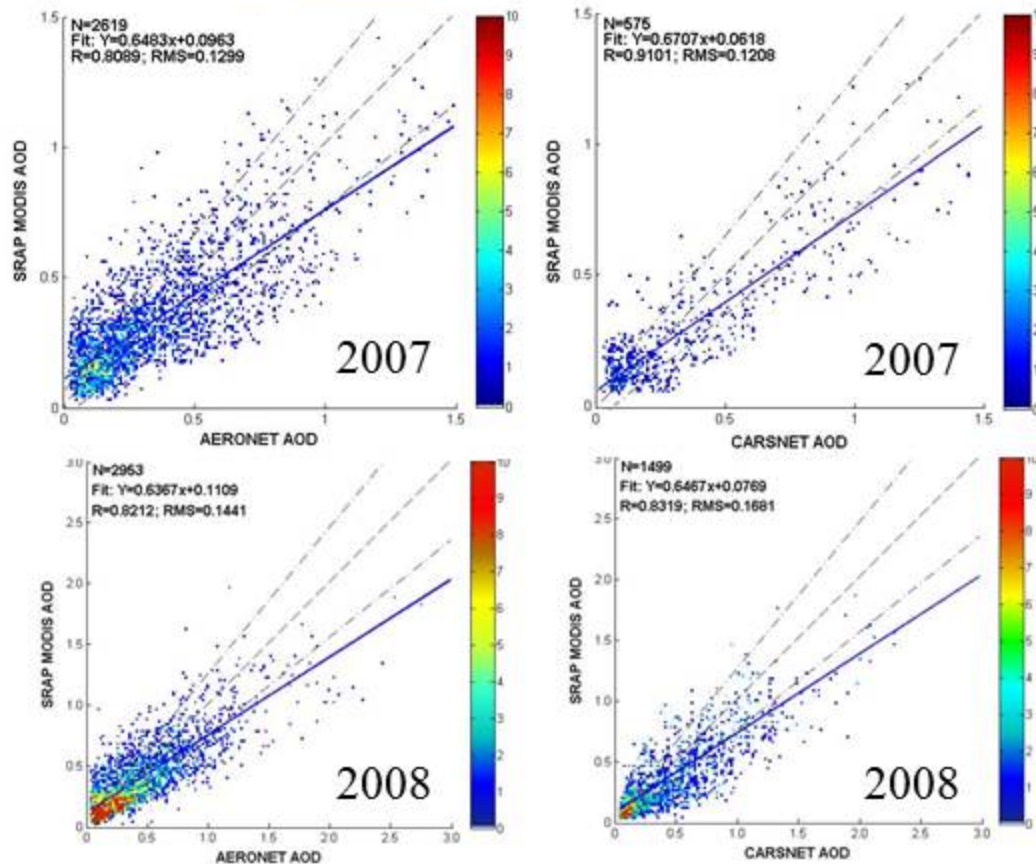
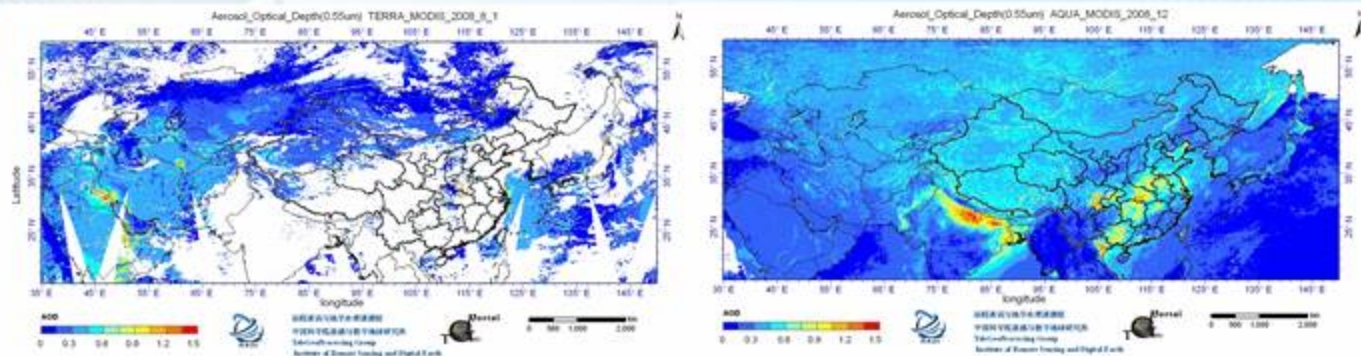
Spatial Coverage Analysis



Temporal variations of completeness of the ADV AOD, ORAC AOD, SU AOD and the fused AOD in 2008.

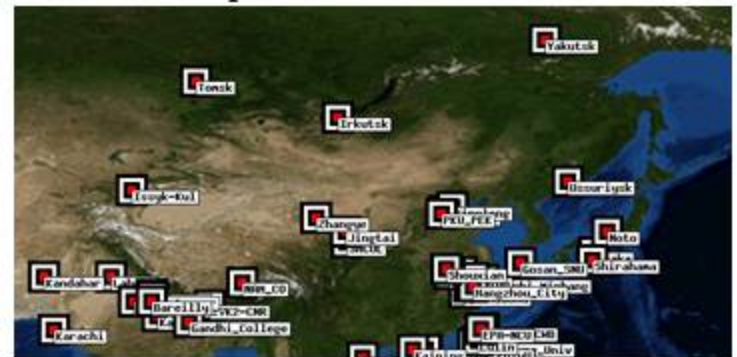
The spatial coverage of ADV, ORAC, SU and fused AOD are 2.92%, 6.41%, 2.57% and 8.35%.

Validation of China Collection 2.0



Mainland China and East Asia

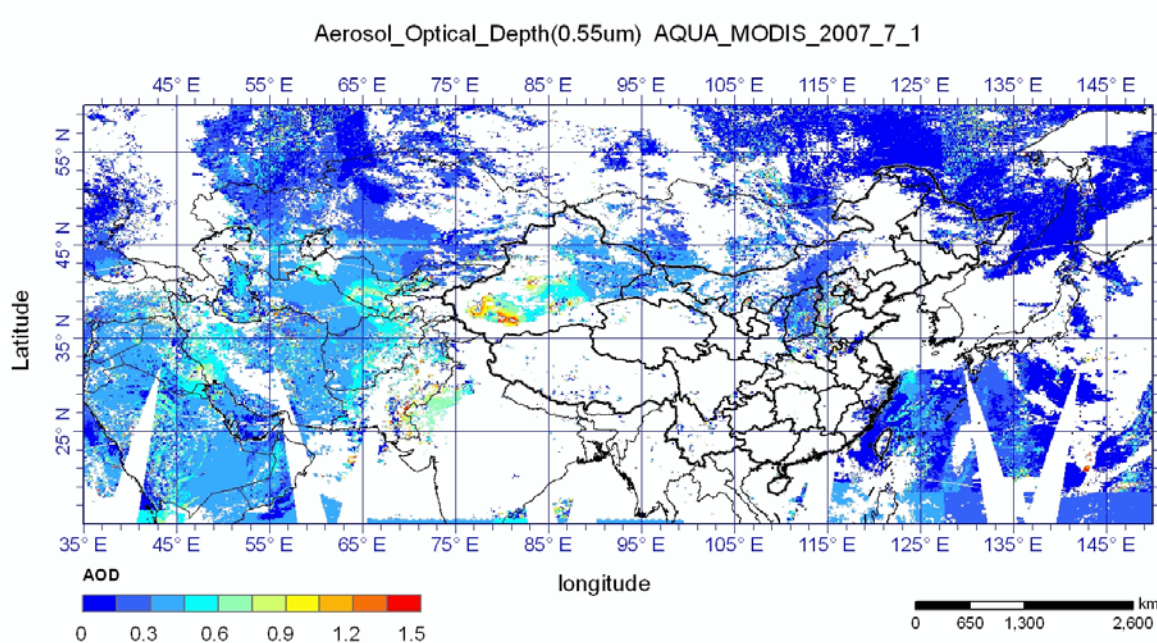
China Collection 2.0 AODs at 550 nm collocated with AERONET and CARSNET AODs at the same wavelength for both the Terra and Aqua datasets.



Yong Xue, Xingwei He, Hui Xu, Jie Guang, Jianping Guo, and Linlu Mei, 2014, CHINA COLLECTION 2.0: The Aerosol Optical Depth Dataset from the Synergetic Retrieval of Aerosol Properties Algorithm. *Atmospheric Environment*, 95, 45–58. (DOI: 10.1016/j.atmosenv.2014.06.019)

AOD data collection over Mainland China

China Collection 2.0 & 2.1 Website: www.tgp.ac.cn



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

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Yong Xue, Xingwei He, Hui Xu, Jie Guang, Jianping Guo, and Linlu Mei, 2014, CHINA COLLECTION 2.0: The Aerosol Optical Depth Dataset from the Synergetic Retrieval of Aerosol Properties Algorithm. *Atmospheric Environment*, 95, Pages 45 –58. (DOI: 10.1016/j.atmosenv.2014.06.019)

