Validation of GOSAT-2/CAI-2 Aerosol products (Optical properties) in Southeast Asia

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A. Uchiyama and T. Matsunaga
(National Institute for Environmental Studies)

Contents

1. Introduction

- The main objective of the GOSAT-2 project is to estimate greenhouse effect gases from space.
- In addition, air pollutants is also estimated in this project.
- The GOSAT-2 is equipped with two instruments.
- One is Thermal And Near infrared Sensor for carbon Observation – Fourier Transform Spectrometer-2 (TANSO-FTS-2 or FTS-2), and
- the other is Thermal And Near infrared Sensor for carbon Observation – Cloud and Aerosol Imager-2 (TANSO-CAI-2 or CAI-2).
- The spectroscopic data measured by FTS-2 is used to estimate the column amount of greenhouse effect gases.
- The CAI-2 measurements are used

  to discriminate between cloud and cloud-free areas for greenhouse gas estimation, and

  to provide aerosol information.
- Please see the GOSAT-2 web page for details of CAI-2. (https://www.gosat-2.nies.go.jp/)

- National Institute for Environmental Studies (NIES) introduced existing programs with the cooperation of developers. (Hashimoto et al (2017) for land area and Shi et al (2019, 2021) for sea area)
- When estimating a physical quantity from satellite data, the data is processed under various assumptions to create a product.
- Therefore, it is necessary to validate the estimated data.
- Satellite observations are made globally. Therefore, the validation of the estimated data must be performed under various atmospheric and surface conditions.
- The optical properties are estimated by comparing the observed radiance with the radiance calculated by solving the radiative transfer equation.
- Therefore, first of all, the optical properties are validated.
- Last year, we already made a validation using global data.
- Today, we show the results of the comparison in Southeast Asia and correction method.

2. GOSAT-2/CAI-2 L2 Aerosol Products(AERP)

- Aerosol property products (AERP) estimated from CAI-2 contain Aerosol Optical Depth at wavelength λ (AOD(λ)), Single Scattering Albedo at wavelength λ (SSA(λ)), Ångströme exponent, PM2.5, and BC amount .
- The spatial resolution of the products is normally with 5 km by 5 km (10 pixels by 10 pixels) resolution and 2 km by 2 km (4 pixels by 4 pixels) resolution for some specified areas in Asia.
- That is, the data sampled once every 5 km by 5 km (2 km by 2 km) is used for product estimation.
- Product version : 0103,　input data version ： 0005

  This data was released to the adopters of the GOSAT-2 Research Announcement.
- Period of data ：2019/03/01 ～2020/02/28 (1 year)
- Elements to be validated.

  AOD(λ), SSA(λ),

  Ångström exponent (AE) , which is a parameter indicating the wavelength dependence of AOD.

  AOD of absorption (AOD_abs), which can be calculated from the AOD and SSA.

  AE of absorption (AE_abs), which indicates the wavelength dependence of the AOD_abs,
-

3. Ground-based observation data

- The validation is performed by comparing satellite estimates with ground-based observations.
- The ground-based observation should be made under various atmospheric and surface conditions.
- The data should be available to everyone and should be regularly available without delay from the measurement.
- The quality of the data should be homogeneous and its accuracy should be known.
- AERONET (Holben et al. 1998) is one of the observation networks that meet these conditions.
- Though there are not many observation sites, SKYNET (Takamura et al. 2004, Nakajima et al., 2020) and European Skynet Radiometers network (Campanelli et al, 2012) is one of the available observation networks.
- AERONET (https://aeronet.gsfc.nasa.gov/)

  Level 1.5 : pre-calibration result applied, Level 2.0 : pre- and post-calibration results applied.

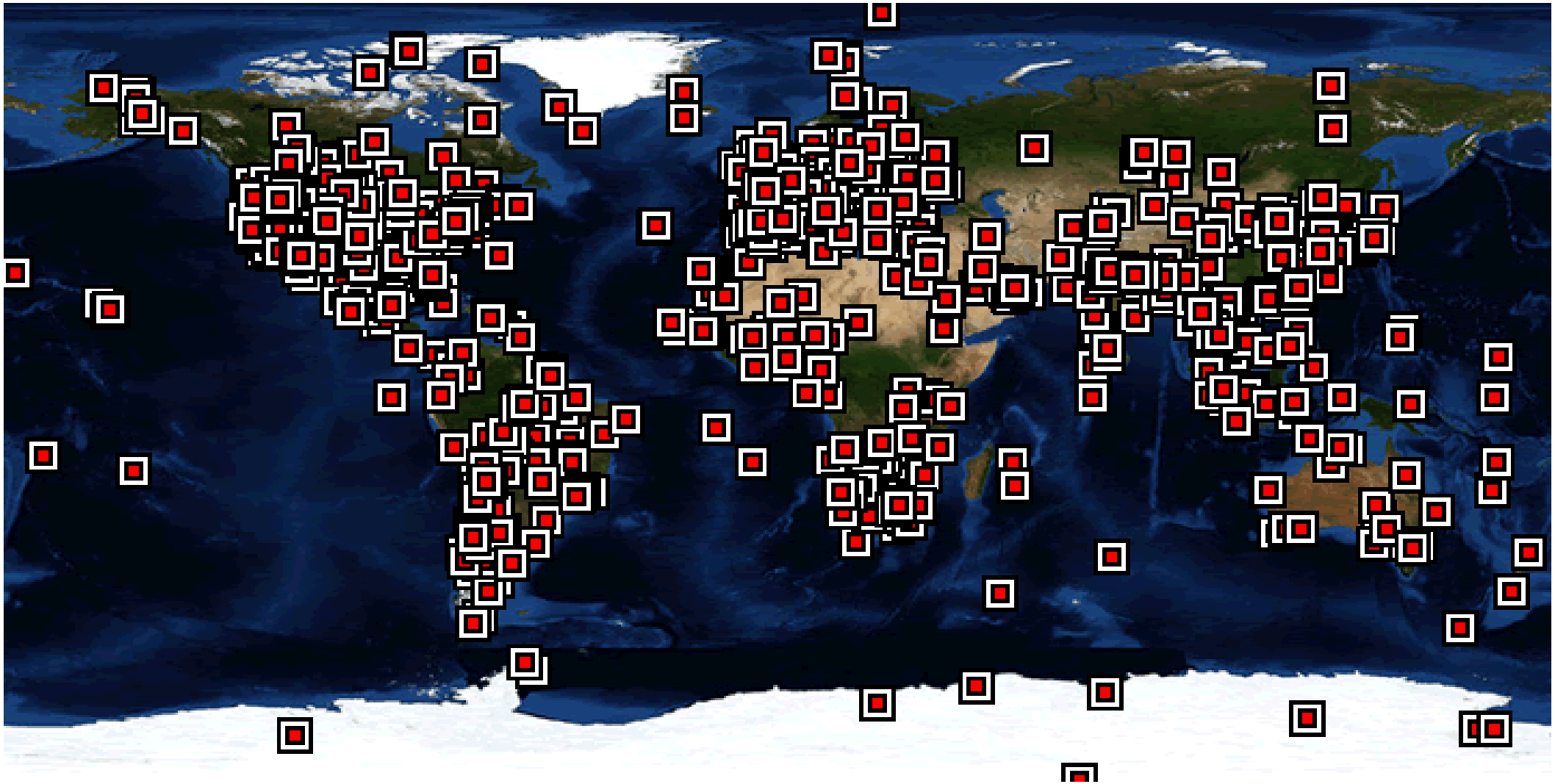
  All sites in the 2019/2020 AERONET Site Lists (V3)

  level 1.5 : 526/486 sites, level 2.0 : 466/313 sites

  AERONET MARITIME AEROSOL NETWORK (MAN) (Level 2.0) only Aerosol Optical Depth
- SKYNET (Chiba University CEReS)

  Most of the observation sites are in East Asia (especially Japan). (about 20 sites)

AERONET sites



4. Matching conditions

- Comparisons are made using match-up data between satellite estimates and ground-based observations.
- Since the data used for comparison has a problem of representativeness, spatially and temporally smoothed data by averaging is used.

- The conditions for matching are as follows,

(1) The distance to the satellite measurement point closest to the ground-based observation site is within 5 km.

(2) Satellite data : average value of satellite estimates within a radius of 10 km from the ground-based observation site.

(3) Ground-based obs. data : average value within ±30 minutes of the time when the satellite observed the ground-based observation site.

5. Summary of Results in Global data

- Last year, we already compared satellite estimates with ground-based observations using global data.
- First, some results of the global comparison are briefly summarized.
- After that, the results in Southeast Asia are shown.
- In the comparison, the bias, standard deviation (SD), correlation coefficient (CorrCef), and coefficients of the linear regression equation (C1, C2) are calculated.
- We check if both data are equivalent with a 95% confidence limit. (Check if the slope is 1 and the intercept is zero.)

Summary and conclusion (Global data)

- As for AOD, the correlation coefficient was relatively high; more than about 0.6.

  In some cases, it was very high value more than above 0.8 over sea area.

- The Bias of AOD was less than about 0.1 in the overall data, and was slightly higher, about 0.20 to 0.25 over sea area.
- The SD of AOD was about 0.1 to 0.2.
- The current algorithm cannot estimate an AOD < about 0.2.
- The Bias of AOD had a geographical distribution.

  In the optically thick regions (West Africa, India, Southeast Asia), the AOD tends to be underestimated.

  in the optically thin regions (North America, Europe), the AOD tends to be overestimated.

- The correlation of the Ångströme exponent (AE) ranged from positive to negative depending on the observation site. Overall, there was no or little correlation.
- AE estimated from the satellite did not have a value greater than about 1.4.
- The accuracy of physical quantities related to absorption is insufficient.

- Some of the error characteristics reflect the characteristics of the aerosol model assumed by the algorithm.

(continued)

- Some of the error characteristics reflect the characteristics of the aerosol model assumed by the algorithm.

- As a result of this conclusion, What will happen?

  = = >

- Systematic errors occur depending on the aerosol characteristics.
- Since the aerosol characteristics have a geographical distribution, the errors also have a geographic distribution.

  = = >

- Optimistically, we can say that

  if the error is systematic, it may be possible to correct it.

  it may be possible to reduce errors by making corrections on a region-by-region basis.

6. Results in Southeast Asia

- We show only results for the AOD (550nm).

23.5N

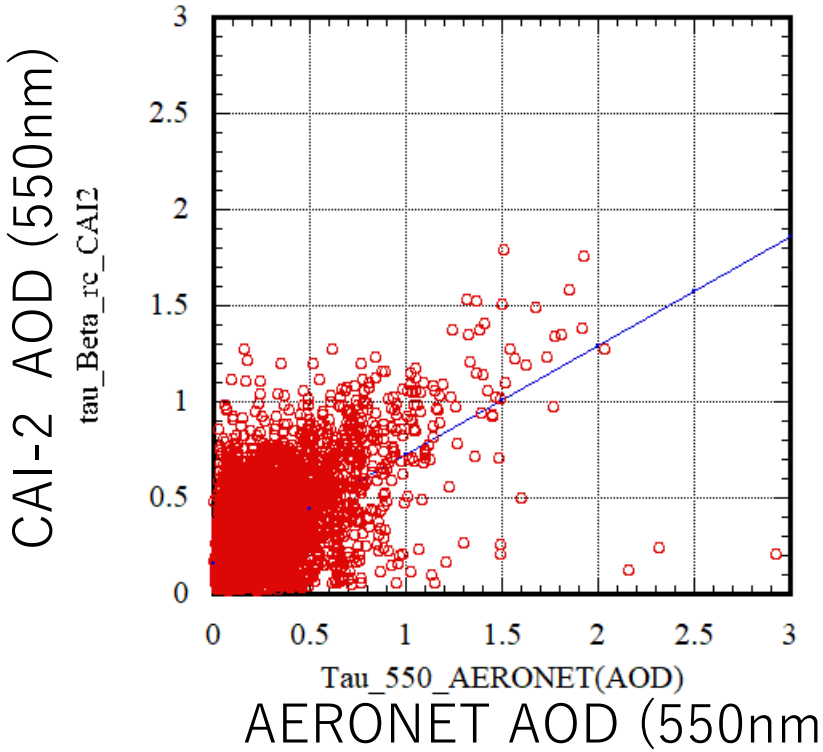
10S

95E

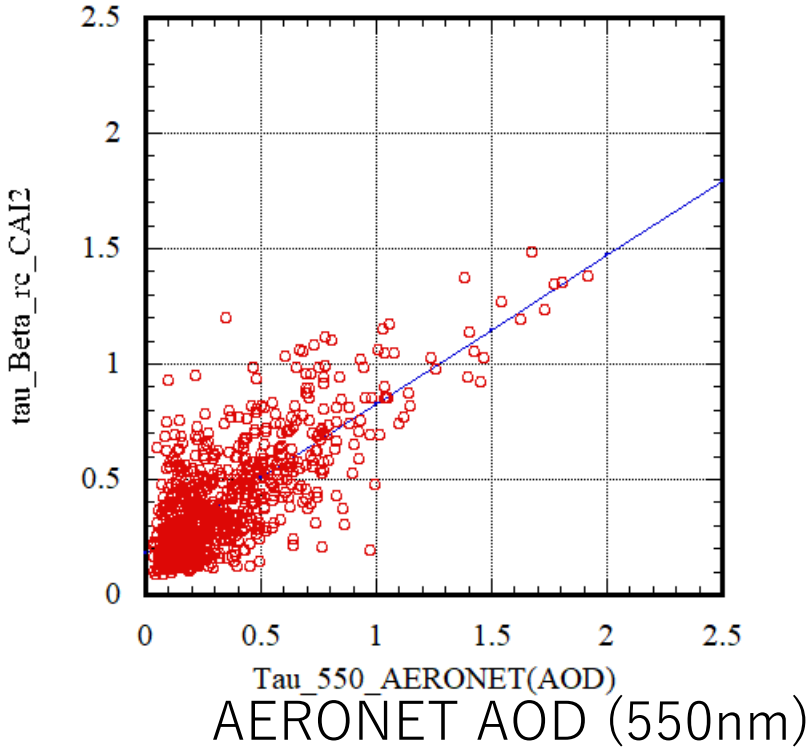
150E

Scatter plots of AOD(550nm)

Global



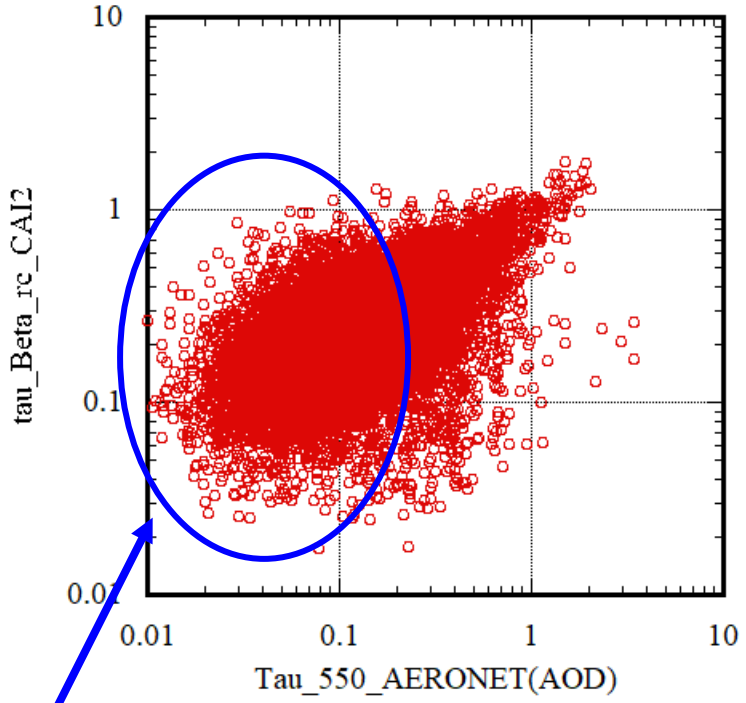
Southeast Asia



	No_of_data	Bias	SD	RMS	CorrCef	C1	C1_cnf95	C2	C2_cnf95	RMS_reg
Global	11966	0.089	0.164	0.187	0.586	0.565	0.014	0.163	0.003	0.143
Southeast	854	0.063	0.189	0.199	0.750	0.645	0.038	0.182	0.017	0.160

- The correlation coefficient is higher in Southeast Asia than in the global.
- The number of optically thin data is small.
- The AOD is relatively thick.

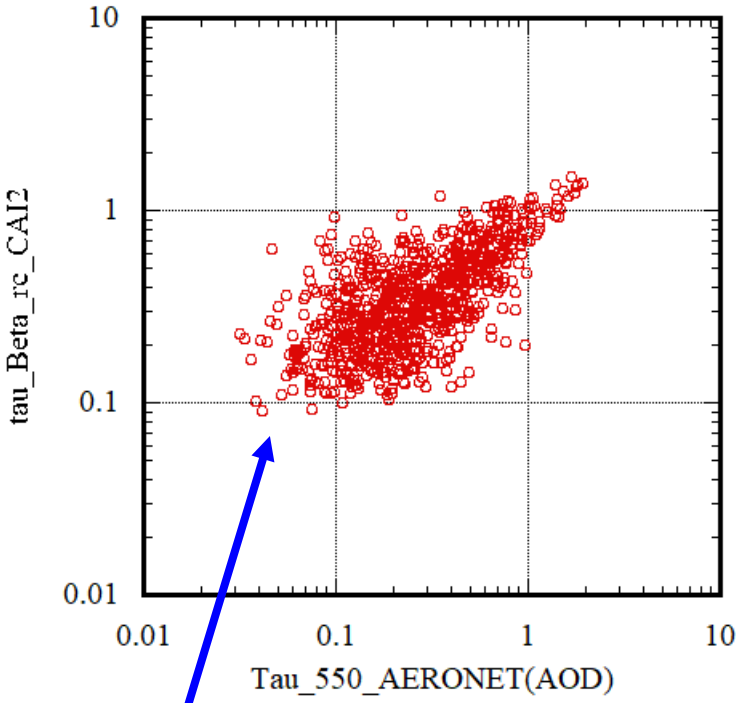
Global



Logarithmic scale axis

There is a lot of optically thin data.

Southeast Asia



Logarithmic scale axis

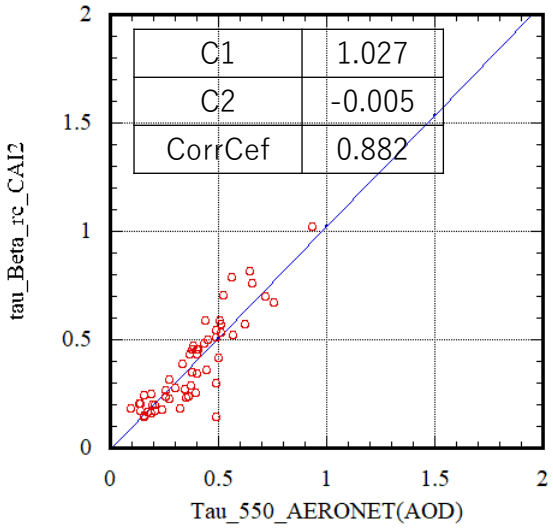
There are few data with AOD less than 0.1.
The AOD is relatively thick.

AOD(550nm)

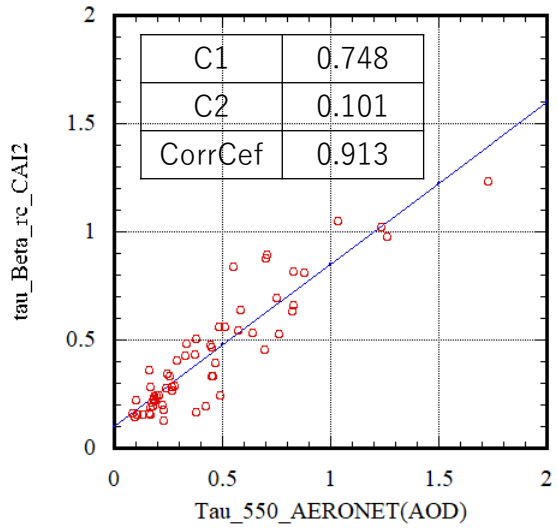
- Scatter plots for each observation site in Southeast Asia.
- The observation sites shown here have more than 10 match-up data.
- Scatter plots of observation sites in Taiwan and the South China Sea are not shown.

Thailand

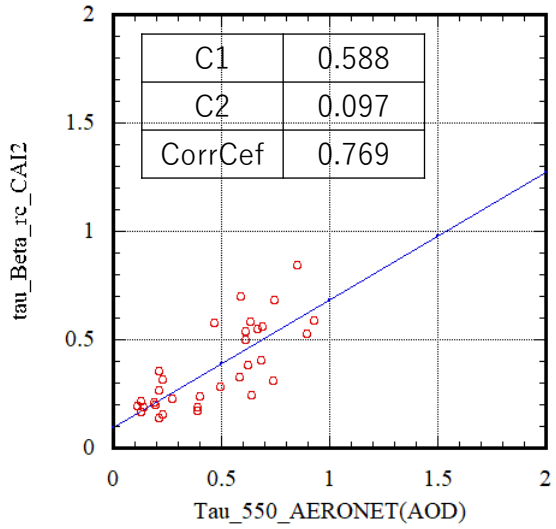
Silpakorn_Univ



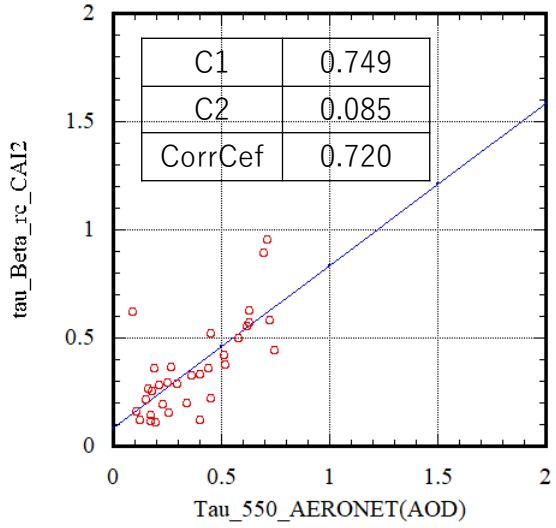
Chiang_Mai_Met_Sta



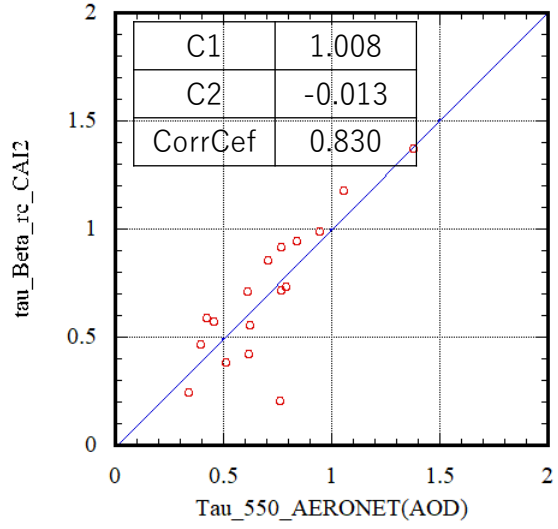
Nong_khai



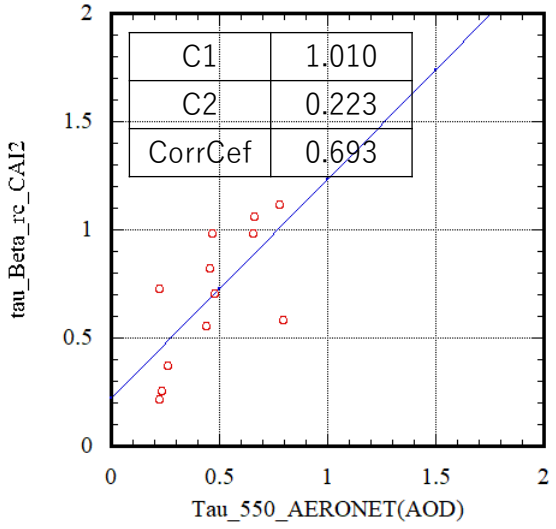
Sra_Kaeo



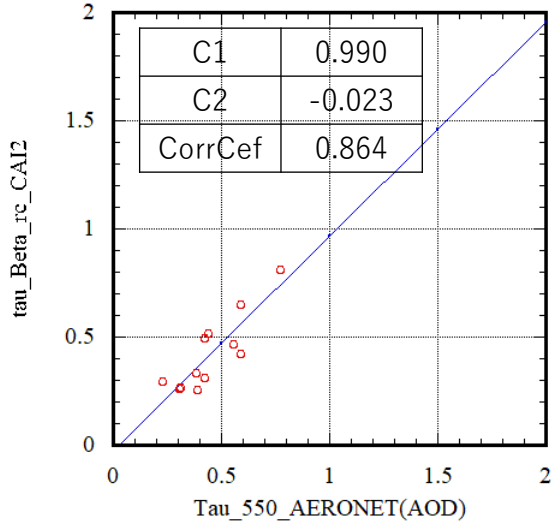
Fang



Doi_Ang_Khang

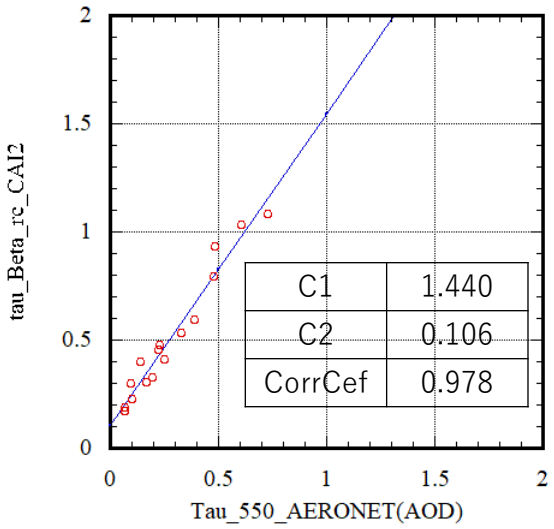


Bangkok

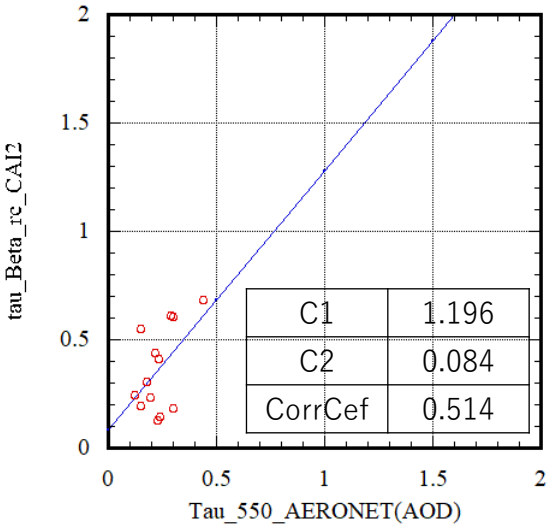


Vietnam

NhaTrang

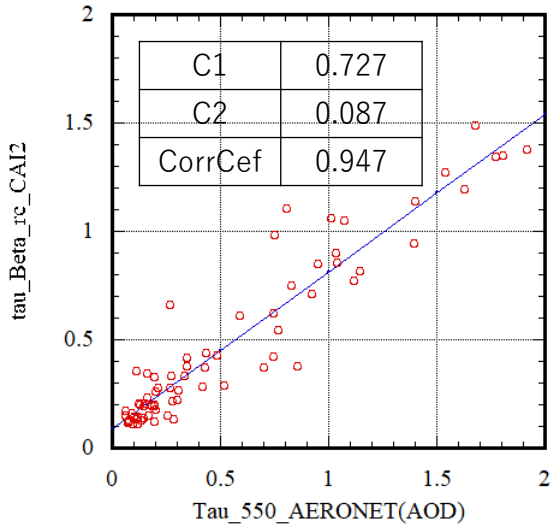


Bac_Lie



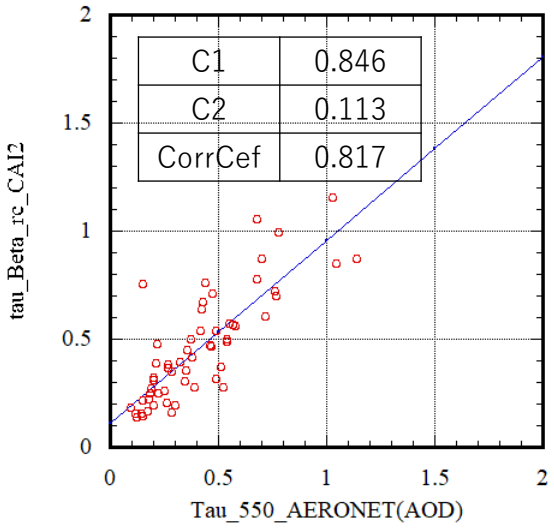
Laos

Luang_Namtha



Myanmar

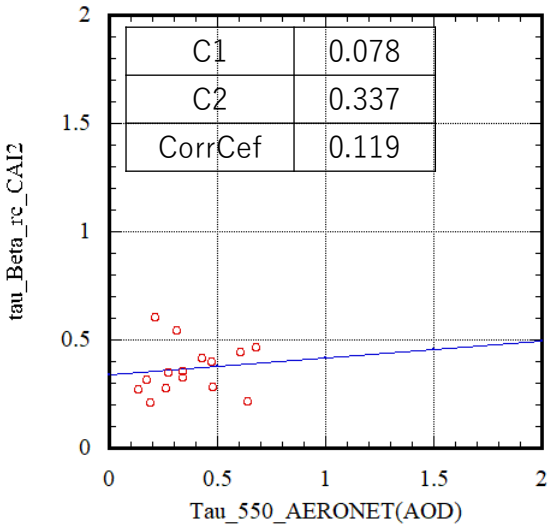
Mandalay_MTU



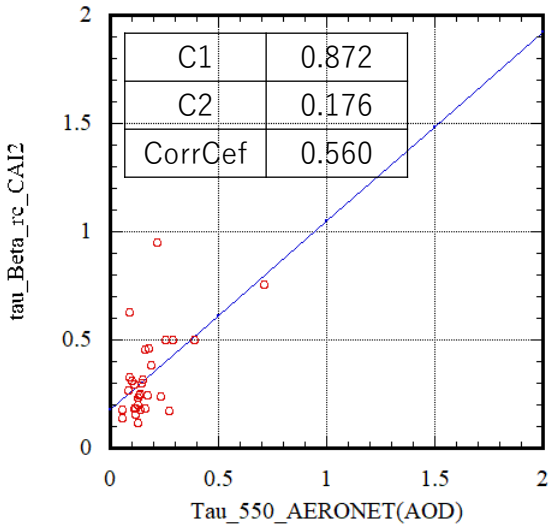
- These observation sites have a high correlation between satellites and ground-based observations.
- These observation sites are located on the Indochina Peninsula.

Indonesia

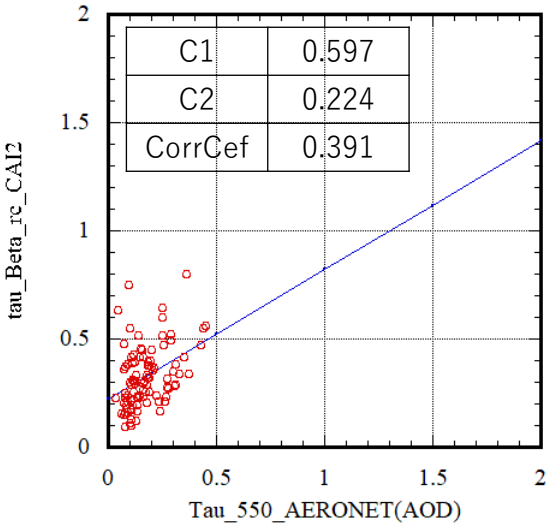
Bandung



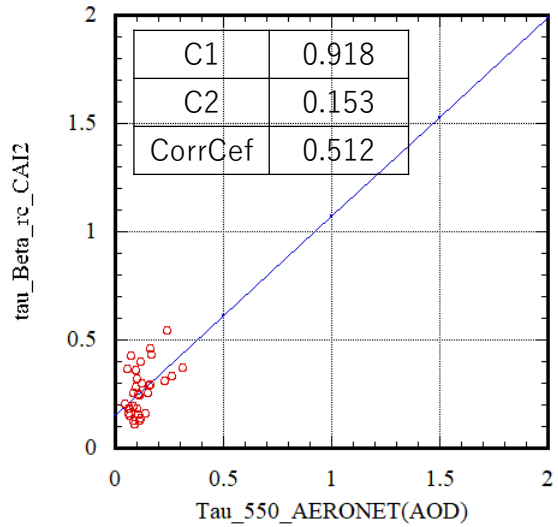
Pontianak



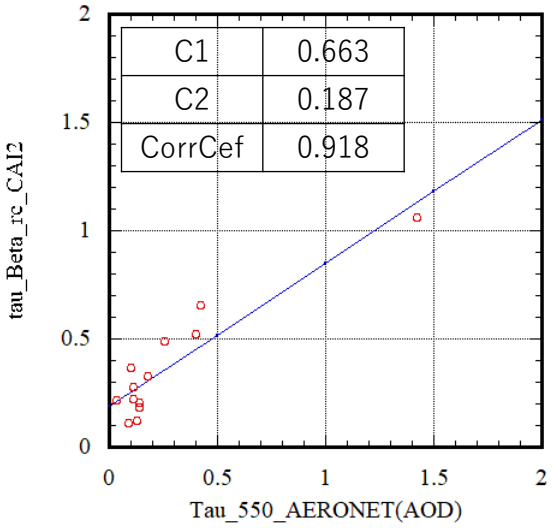
Makassar



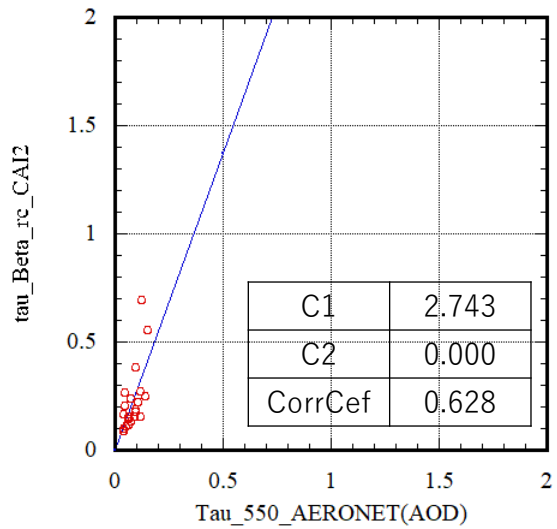
Sorong



Palangkaraya

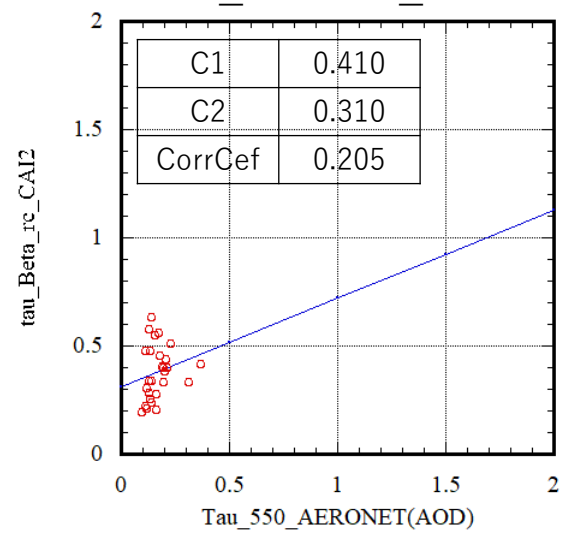


BMKG_GAW_PALU

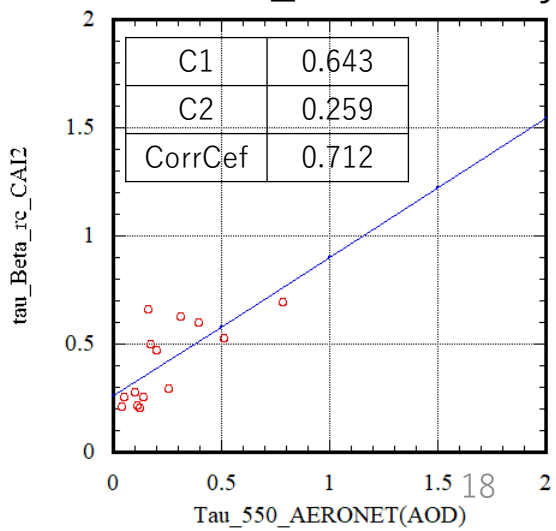


Philippines

ND_Marbel_Univ

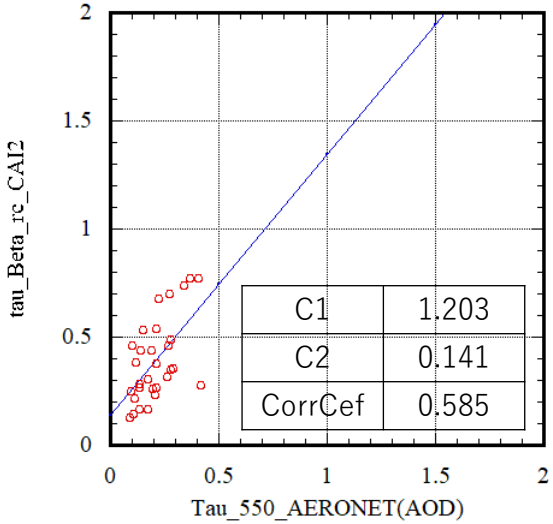


Manila_Observatory

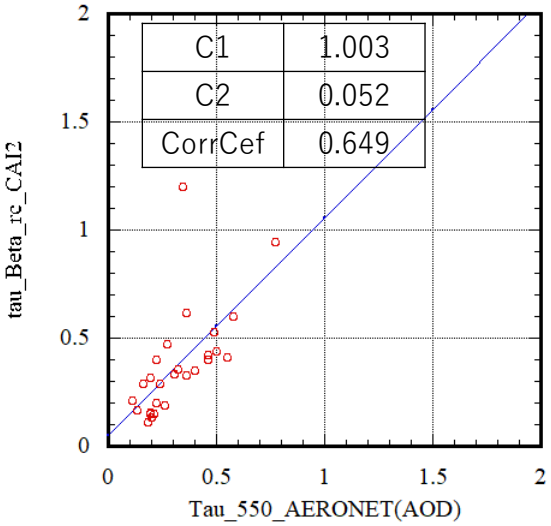


Malaysia

Songkhla_Met_Sta

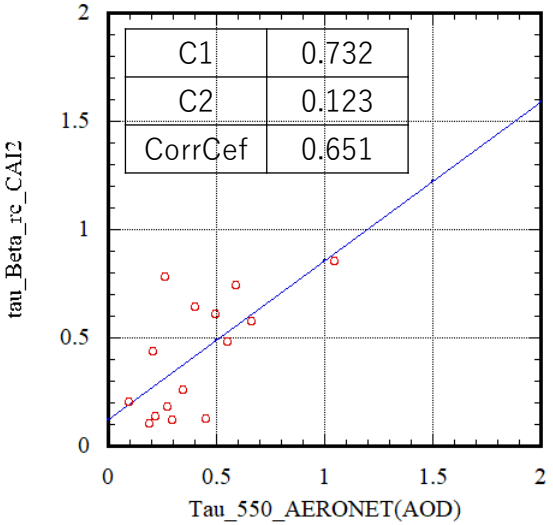


USM_Penang



Singapore

Singapore



- Correlation coefficients are somewhat high.
- These observation sites are located on the Malay Peninsula.

7. Correction of AOD

- “If the error is systematic, it may be possible to correct it.”

- We considered two methods to use the regression equation.
- Method 1

  Using regression equation for differences and explanatory variables

  (difference)=A*(explanatory variable)+B

  If there is a variable that is highly correlated with the error, it is corrected using the regression equation.

- Method 2

  Using regression equation for satellite estimates and ground-based observations

  method 2.1 (satellite estimate)=A1* (ground observation)+B1

  (ground observation)=((satellite estimate)-B1)/A1

  method 2.2 (ground observation)= A2*(satellite estimate)+B2

  Estimate (predict) ground observations from satellite estimates using regression equations.

-

Method 1

- If there is a variable that is highly correlated with the error, we use that explanatory variable to correct for the error.
- Correlation coefficients between differences and explanatory variables

  (differences)=(satellite estimates) – (ground-based observations)
- Explanatory variables

  latitude, longitude, height, satellite zenith angle,

  solar zenith angle, relative azimuth angle, scattering angle,

  airmass factor, sun and earth distance, NDVI,

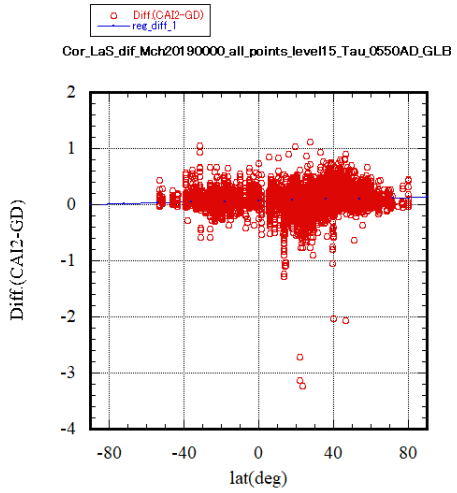
  albedo (556nm), standard deviation of albedo (556nm)
- These variables are those stored in the aerosol product file and those that can be calculated from them.
- These variables are not necessarily independent of each other.
-

Correlation coefficients (Global)

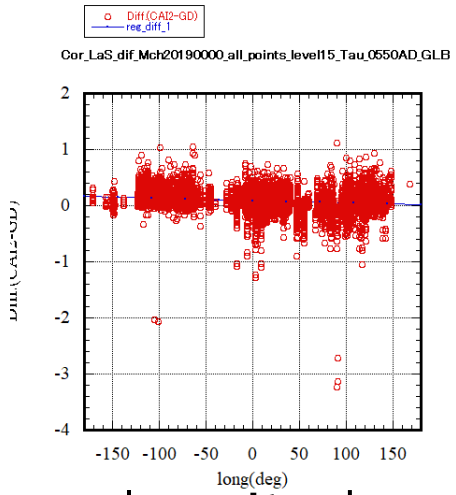
		Before correction							After correction						
Parameters	No_of_data	Bias	SD	RMSE	CorrCef	C1	C2	RMSE_reg	Bias	SD	RMSE	CorrCef	C1	C2	RMSE_reg
latitude	11966	0.089	0.164	0.187	0.110	0.073	0.069	0.163	0.000	0.163	0.163	0.000	0.000	0.000	0.163
longitude	11966	0.089	0.164	0.187	-0.191	-0.039	0.089	0.161	0.000	0.161	0.161	0.000	0.000	0.000	0.161
height	11966	0.089	0.164	0.187	0.063	0.019	0.082	0.164	0.000	0.164	0.164	0.000	0.000	0.000	0.164
satellite_zenith_angle	11966	0.089	0.164	0.187	-0.048	-0.115	0.125	0.164	0.000	0.164	0.164	0.000	0.000	0.000	0.164
solar_zenith_angle	11966	0.089	0.164	0.187	-0.098	-0.112	0.131	0.163	0.000	0.163	0.163	0.000	0.000	0.000	0.163
relative_azimuth_angle	11966	0.089	0.164	0.187	-0.041	-0.015	0.099	0.164	0.000	0.164	0.164	0.000	0.000	0.000	0.164
scattering_angle	11966	0.089	0.164	0.187	0.051	0.042	0.036	0.164	0.000	0.164	0.164	0.000	0.000	0.000	0.164
airmass_factor	11966	0.089	0.164	0.187	-0.113	-0.050	0.218	0.163	0.000	0.163	0.163	0.000	0.000	0.000	0.163
1-(sun & earth distance)	11966	0.089	0.164	0.187	-0.163	-2.326	0.083	0.162	0.000	0.162	0.162	0.000	0.000	0.000	0.162
NDVI	11966	0.089	0.164	0.187	0.118	0.076	0.061	0.163	0.000	0.163	0.163	0.000	0.000	0.000	0.163
albedo(556nm)	11959	0.089	0.164	0.187	-0.284	-0.964	0.193	0.157	0.000	0.157	0.157	0.000	0.000	0.000	0.157
SD_albedo(556nm)	11445	0.087	0.163	0.184	-0.071	-0.464	0.102	0.162	0.000	0.162	0.162	0.000	0.000	0.000	0.162

There are no variables that strongly correlate with the error.
After correction, the bias can be reduced to 0, but the standard deviation (SD) is hardly improved.

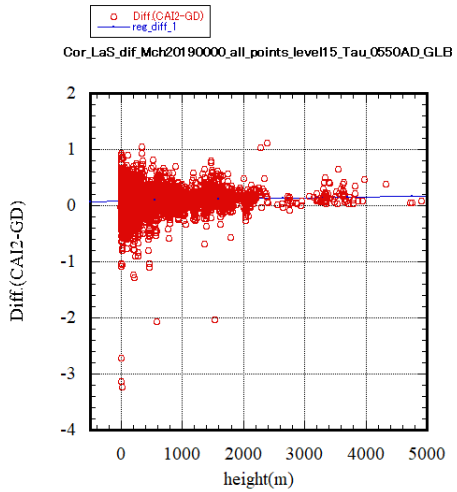
Scatter plots of differences and variables (Global)



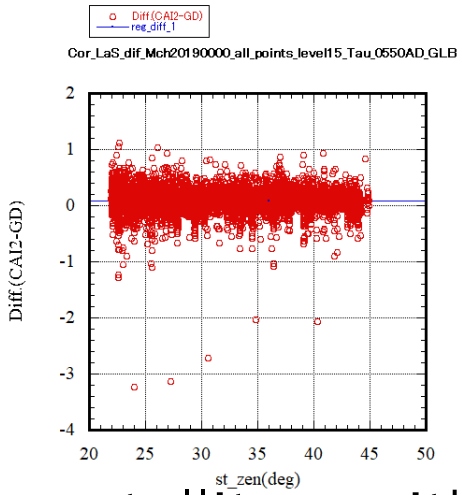
latitude



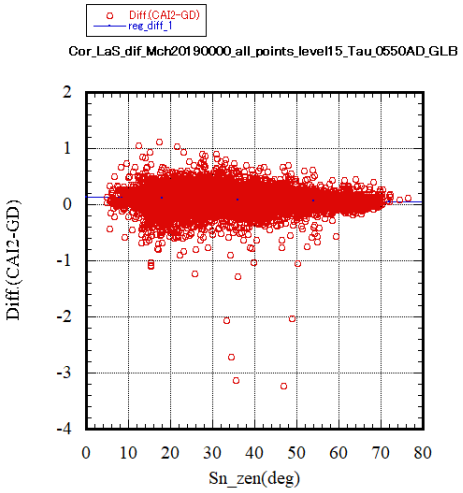
longitude



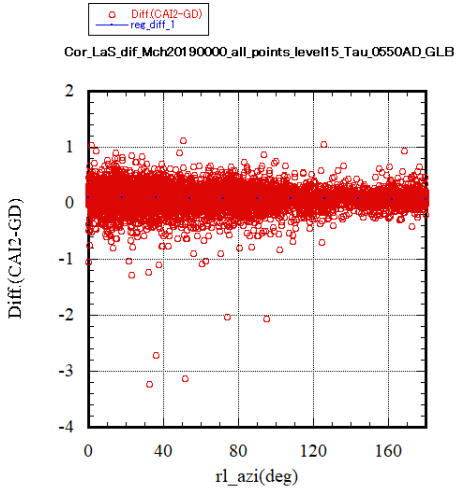
height



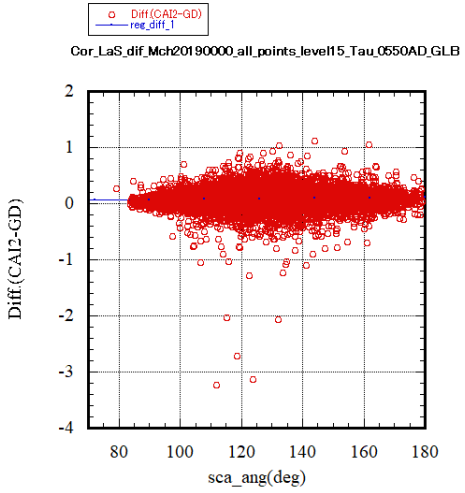
satellite zenith



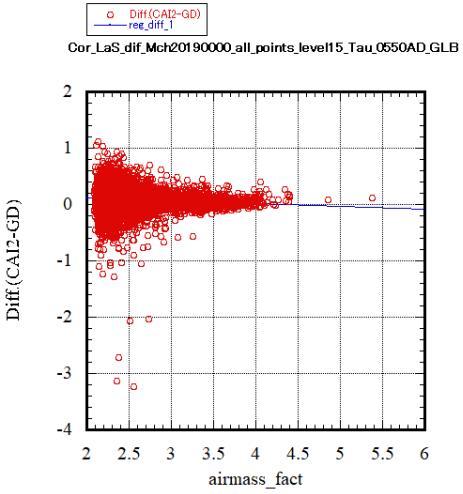
solar zenith



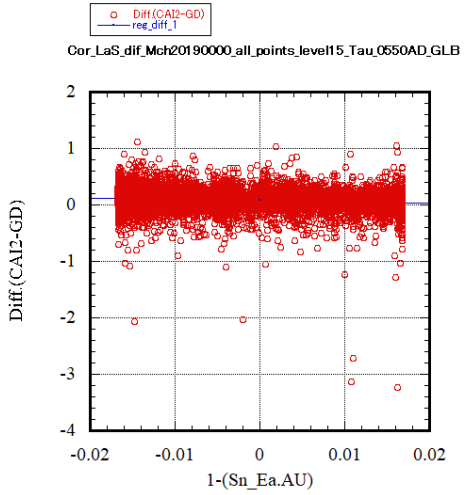
relative azimuth



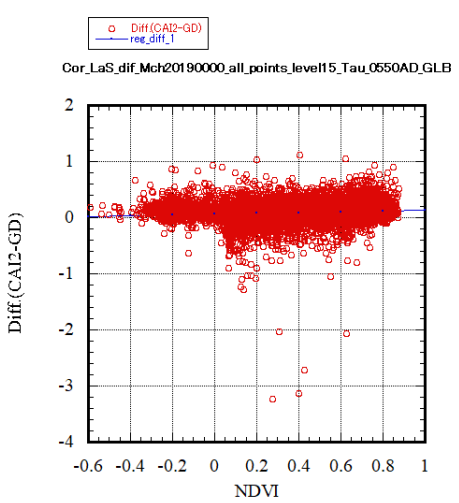
scattering angle



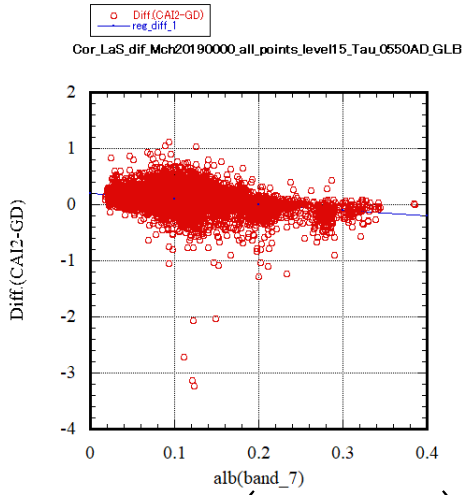
airmass factor



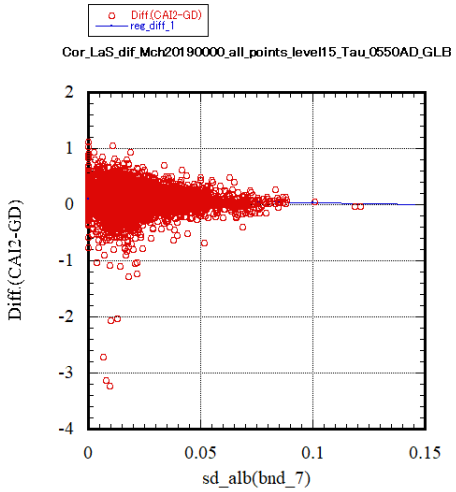
1-sun_earth_distance



NDVI



albedo(band7)



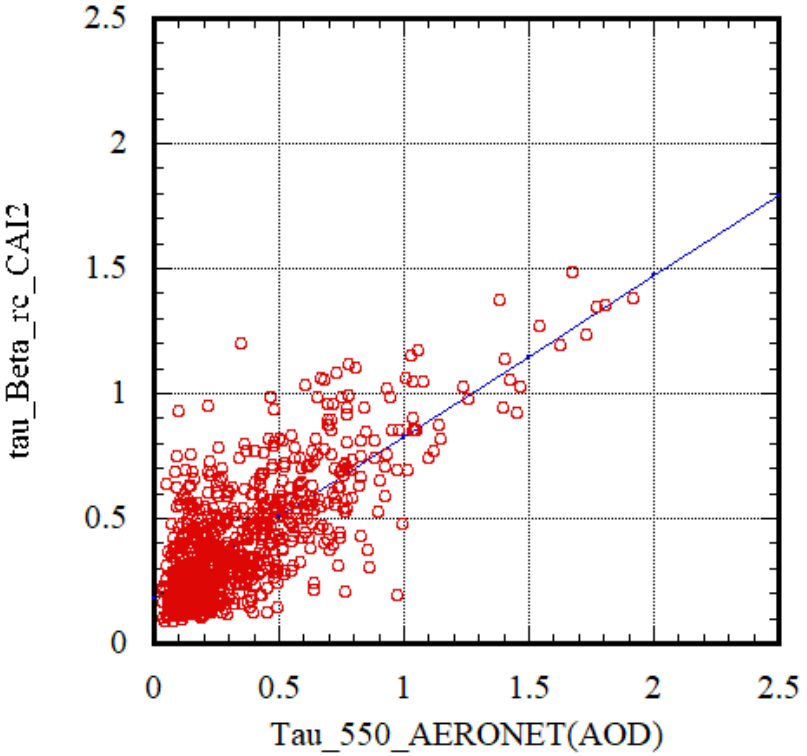
SD of albedo(band7)

There are no variables that show a clear correlation.

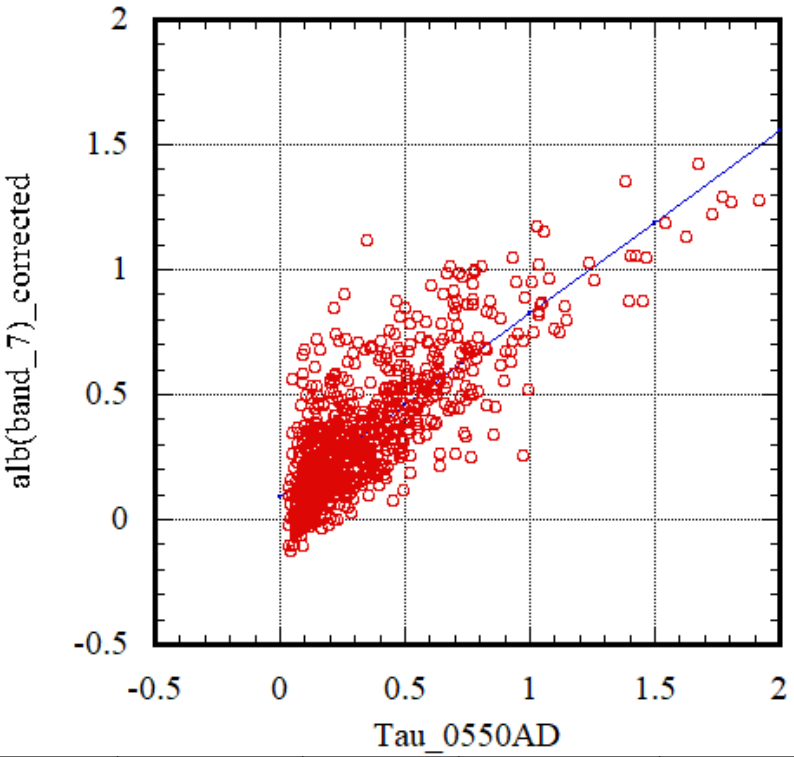
Southeast Asia
Almost the same as for global data.

Example of Method 1

Before Correction



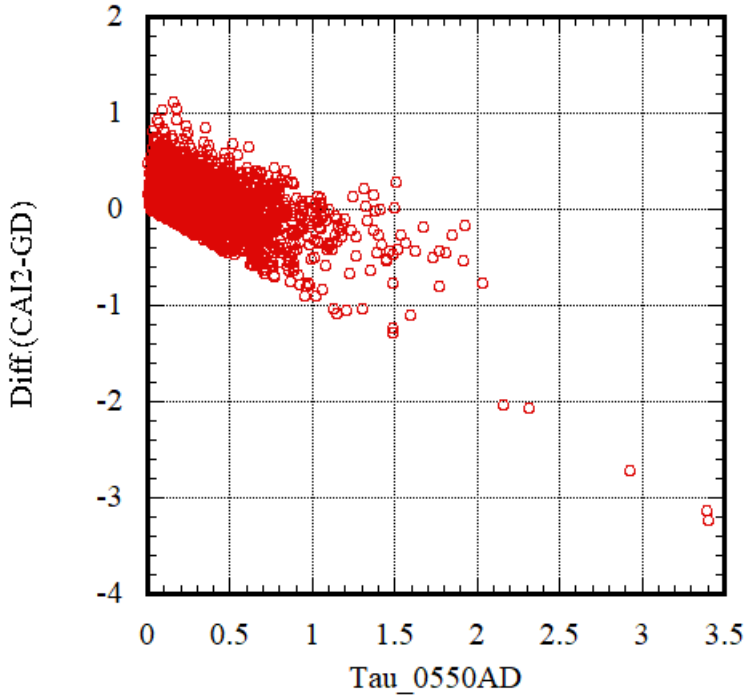
After Correction



	Parameters	No_of_data	Bias	SD	RMSE	CorrCef	C1	C1_cnf95	C2	C2_cnf95	RMS_reg
Non_corrected	AOD (550nm)	854	0.063	0.189	0.199	0.750	0.645	0.038	0.182	0.017	0.160
Corrected (alb_band_7)	AOD (550nm)	854	0.000	0.175	0.175	0.795	0.734	0.038	0.090	0.017	0.158

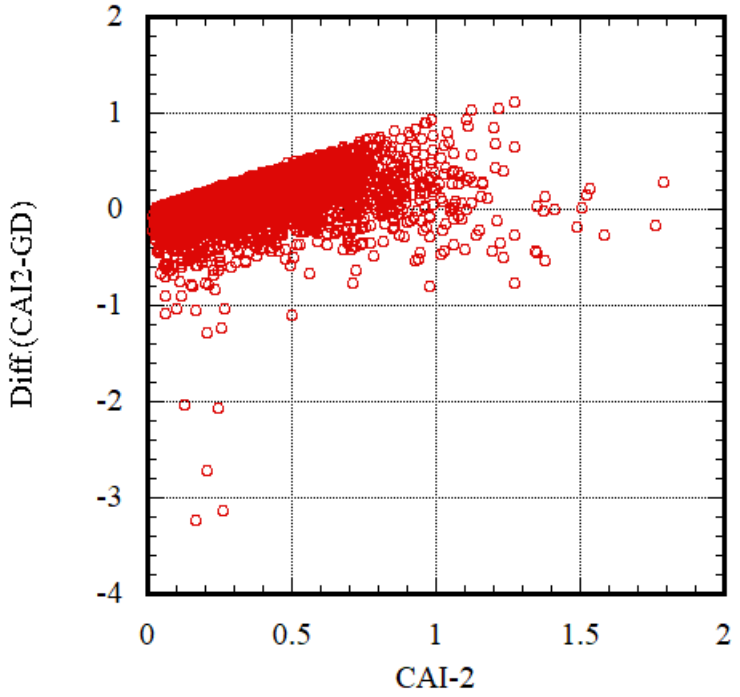
- The regression equation of differences and albedo (band7) are used for corection.
- Bias is zero, SD is a little smaller, correlation is a little higher, and C1 is a little closer to 1.
- No significant improvement is seen in this method.

Scatter plots of differences and AOD (Global)



AERONET AOD(550nm)

C1_df	-0.435
C2_df	0.163
CorrCef	-0.487



CAI-2 AOD(550nm)

- As a matter of fact, the correlation between the difference and AOD is high.
- One possible approach is to use the relationship between differences and AOD for correction, or to directly connect satellite estimated AOD to ground-based observation AOD. ＝＝＞ Method 2.

Method 2

- We create a regression equation between the satellite estimate and the ground-based observation, and use that equation to estimate the target object from the satellite estimate (to convert satellite estimates to target object).
- There are two methods to create a regression equation.

  method 2.1 : Y=A1*X + B1 (=> X=(Y-B1)/A1)

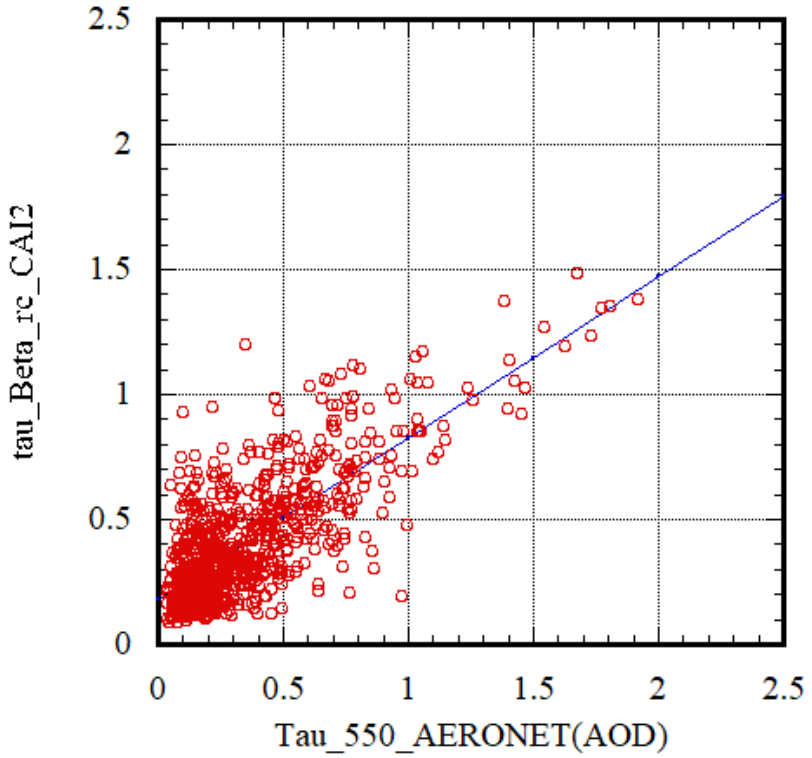
  method 2.2 : X=A2*Y + B2

  Y=(satellite estimate), X=(ground-based observation)

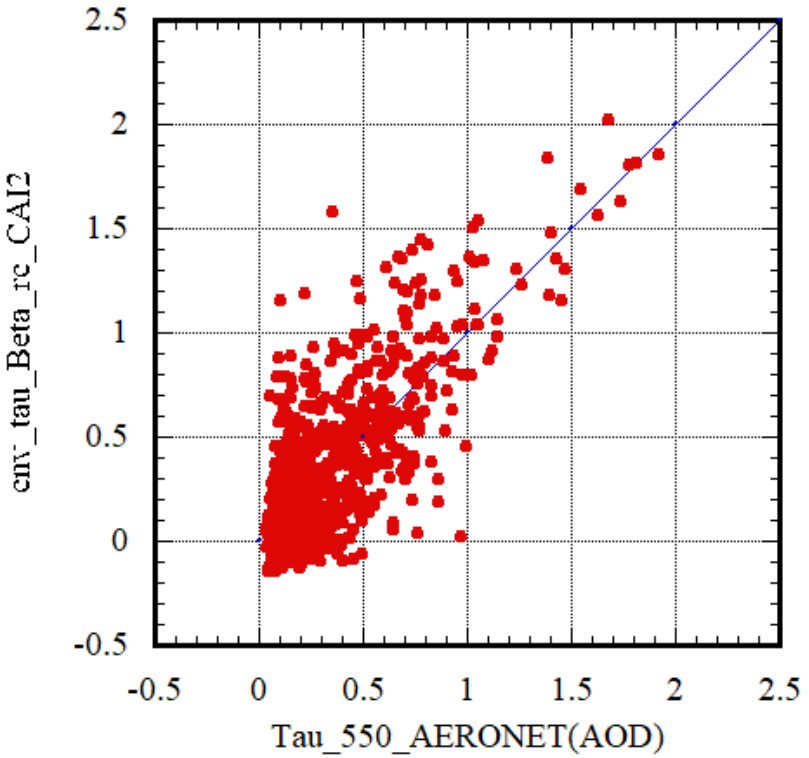
  (A1, B1), (A2, B2) are regression coefficients.

Example of Method 2.1 AOD(550nm)

Before Correction



After Correction

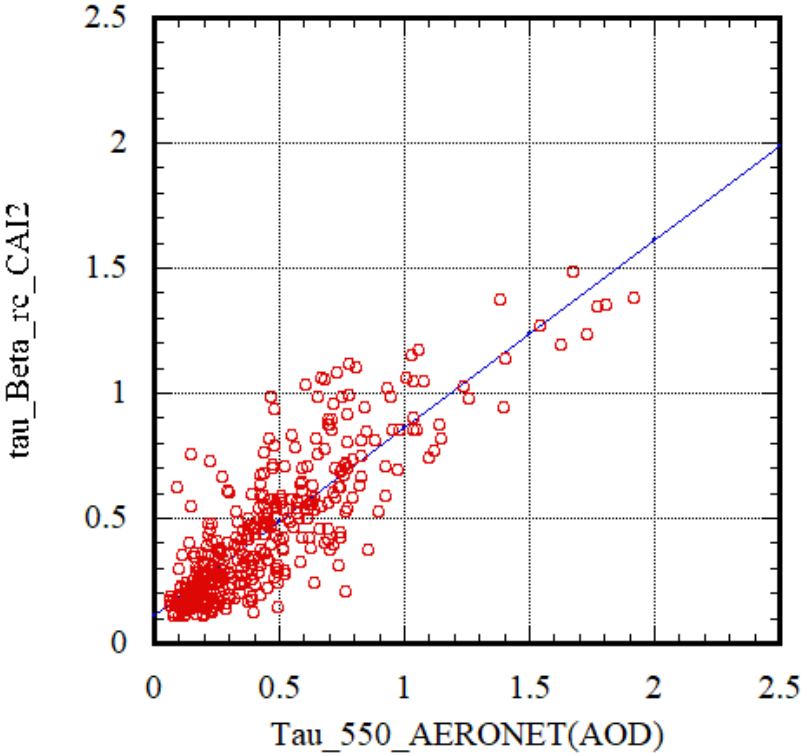


	Parameters	No_of_data	Bias	SD	RMSE	CorrCef	C1	C1_cnf95	C2	C2_cnf95	RMS_reg
Non-corrected	AOD (550nm)	854	0.063	0.189	0.199	0.750	0.645	0.038	0.182	0.017	0.160
Corrected	AOD (550nm)	854	0.000	0.249	0.249	0.750	1.000	0.059	0.000	0.026	0.249

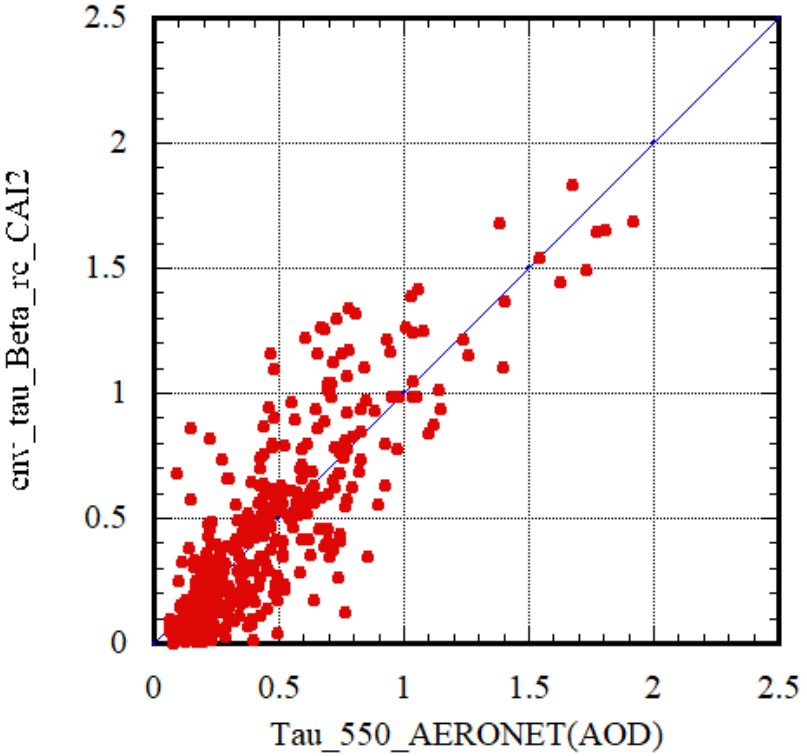
After correction, Bias=0.0, C1=1.0 and C2=0.0. But, SD became larger.
When C1 before correction is less than 1.0, SD after correction becomes larger.

Example of Method 2.1 AOD(550nm) (Indochina Peninsula)

Before Correction



After Correction

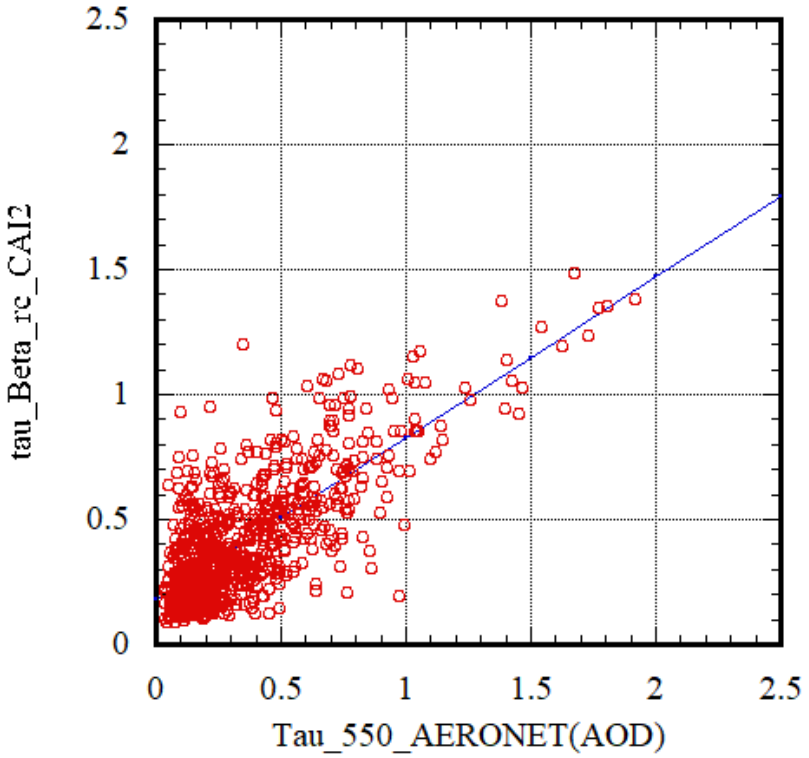


	Parameters	No_of_data	Bias	SD	RMSE	CorrCef	C1	C1_cnf95	C2	C2_cnf95	RMS_reg
Non_corrected	AOD (550nm)	385	0.002	0.173	0.173	0.844	0.750	0.048	0.114	0.026	0.153
Corrected	AOD (550nm)	385	0.000	0.204	0.204	0.844	1.000	0.064	0.000	0.035	0.204

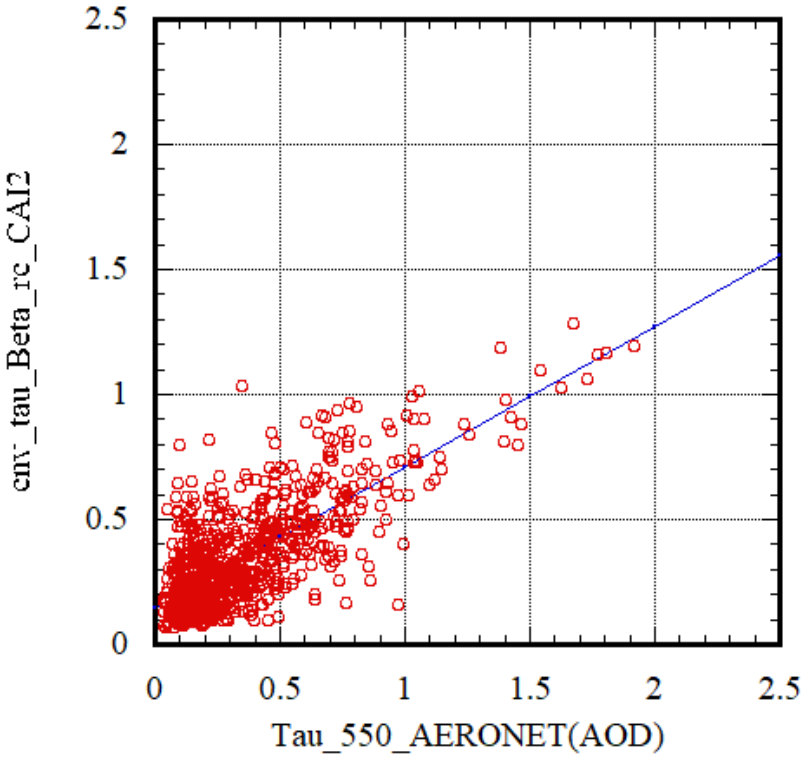
When we use data only for the Indochina Peninsula,
SD is a little larger, but the correction works reasonably well.

Example of Method 2.2 AOD(550nm)

Before Correction



After Correction



	Parameters	No_of_data	Bias	SD	RMSE	CorrCef	C1	C1_cnf95	C2	C2_cnf95	RMS_reg
Non-corrected	AOD (550nm)	854	0.063	0.189	0.199	0.750	0.645	0.038	0.182	0.017	0.160
Corrected	AOD (550nm)	854	0.000	0.187	0.187	0.750	0.562	0.033	0.148	0.015	0.140

No significant improvement is seen in this method.

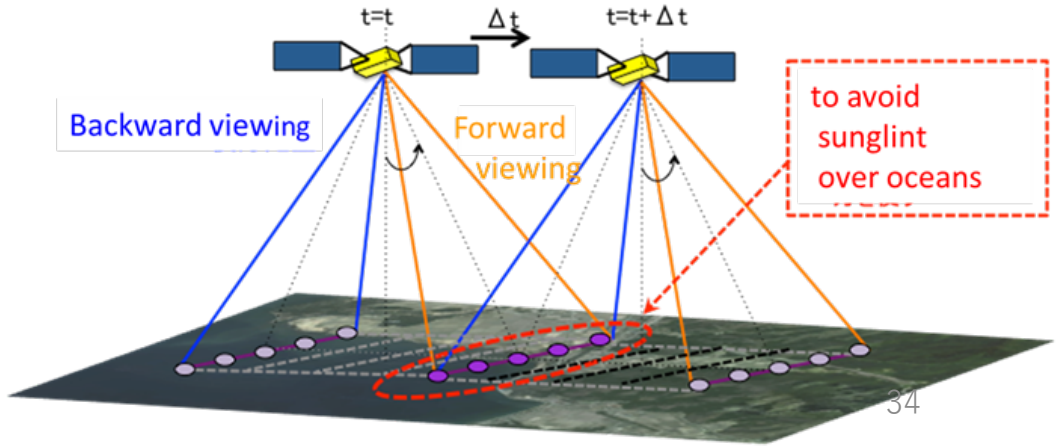
8. Summary

- As for AOD, the correlation is relatively high. However, there is a regional distribution of aerosol characteristics, and reflecting this, there is also a regional distribution of error characteristics.
- Southeast Asia has a higher correlation than the global.
- Very high correlations have been obtained for some observation sites; for example, in the Indochina Peninsula.
- We tried to correct the error using a regression equation.
- No explanatory variables were found that well explained the error.
- We attempted to correct using regression equation that directly connects satellite estimates and ground-based observations.
- This method improved accuracy but not precision; Bias becomes 0, but SD remains almost unchanged or increased.
- If we narrow the target area, for example, Indochina Peninsula, the correction worked reasonably well.
- In Southeast Asia, AOD may be usable with a correction.

Thank you for your attention!

- The CAI-2 is a push-broom image sensor with 7 wavelengths/10 bands in the near-ultraviolet to short-wavelength infrared.
- One of the unique features of CAI-2 is that it has an observation band in the near-ultraviolet region.
- Near-UV bands are very effective in estimating aerosol characteristics over land.
- The CAI-2 has also a function to measure the forward and backward views at 5 bands each with a tilt of ±20 degrees to avoid the sun-glint contamination.
- The swath width is 920 km and

  the spatial resolution is 460 m or 920 m.



Basic specifications of CAI-2

	Forward					Backward				
Band	1	2	3	4	5	6	7	8	9	10
Center of wavelength [μm]	0.339 ± 0.005	0.441 ± 0.005	0.672 ± 0.005	0.865 ± 0.005	1.630 ± 0.075	0.377 ± 0.005	0.546 ± 0.005	0.672 ± 0.005	0.865 ± 0.005	1.630 ± 0.075
Wavelength width [μm]	0.013	0.012	0.013	0.011	0.073	0.015	0.015	0.013	0.011	0.073
Resolution [m]	460				920	460				920
Effective pixels	Dummy pixels: 8 pixels Effective pixels: 2048 pixels				67-1024pixels (256 pixels/ch)	Dummy pixels: 8 pixels Effective pixels: 2048 pixels				67-1024pixels (256 pixels/ch)
Tilt angle [Degree]	+20					-20				
Swath [km]	920 km									

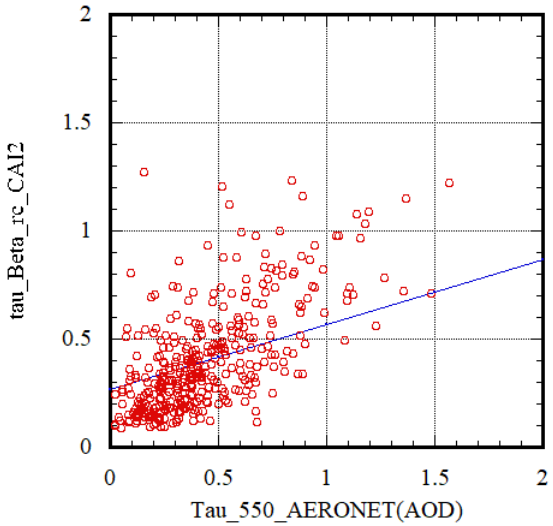
#. Scatter plots of AOD(550nm) for other regions

- Whether the same method could be used for other regions.
- Scatter plot of AOD (550 nm) for other regions.

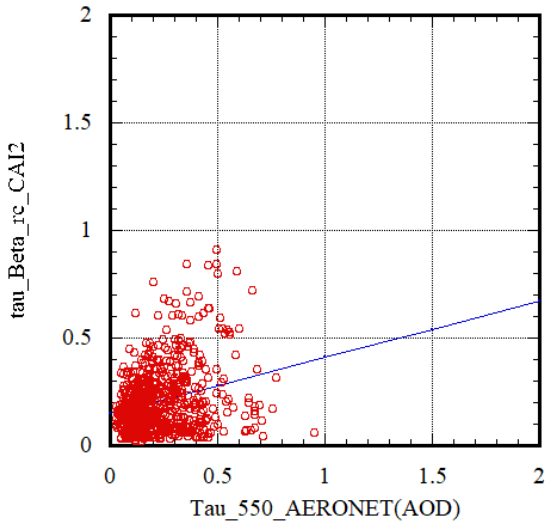
- India : region with serious air pollution
- Middle East : region affected by deserts
- West Africa : region affected by the Sahara Desert
- Europe : optically thin region
- North America : optically thin region similar to Europe
- East Asia : similar to Southeast Asia

Scatter plots of AOD(550nm)

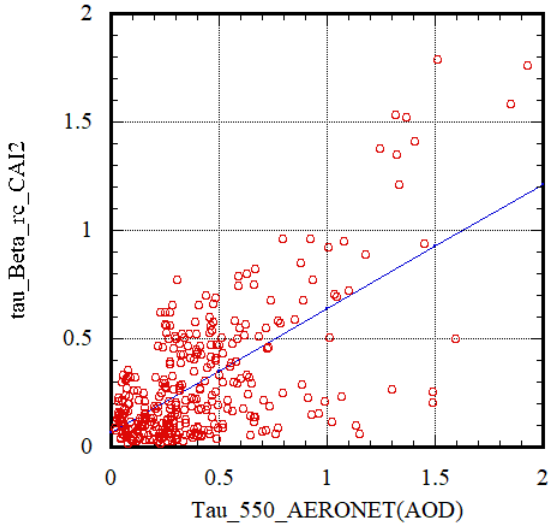
India



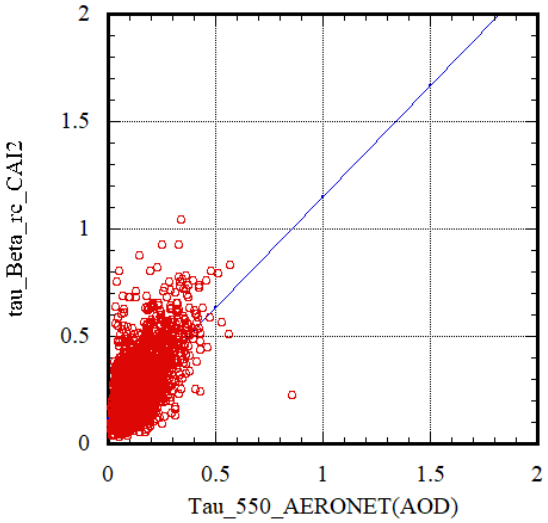
Middle east



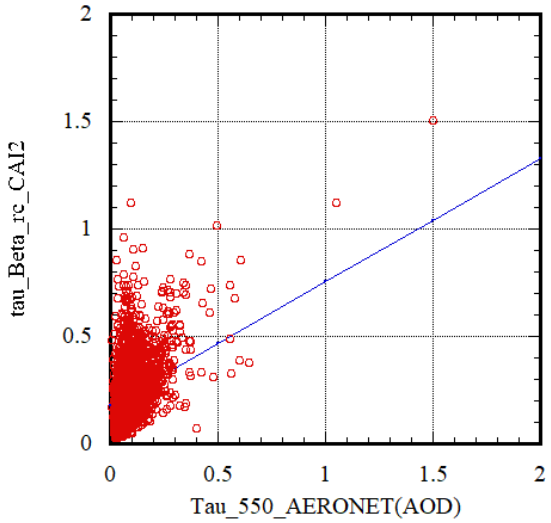
West Africa



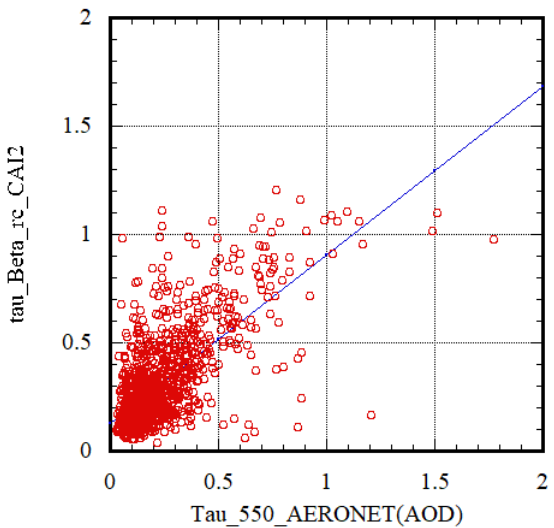
Europe



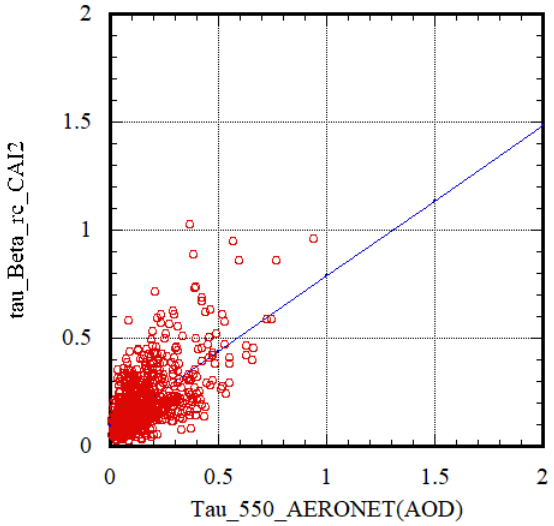
North America



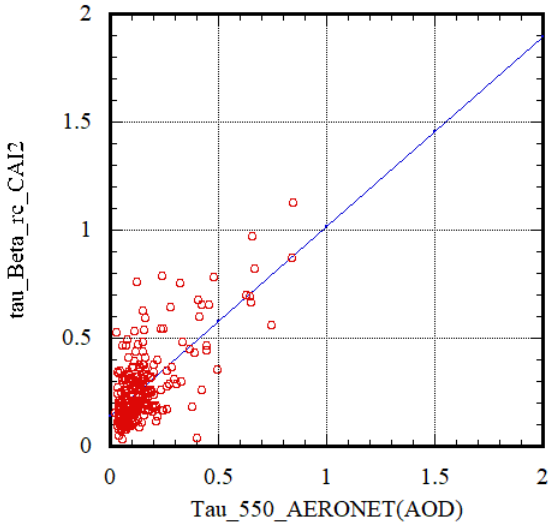
East Asia



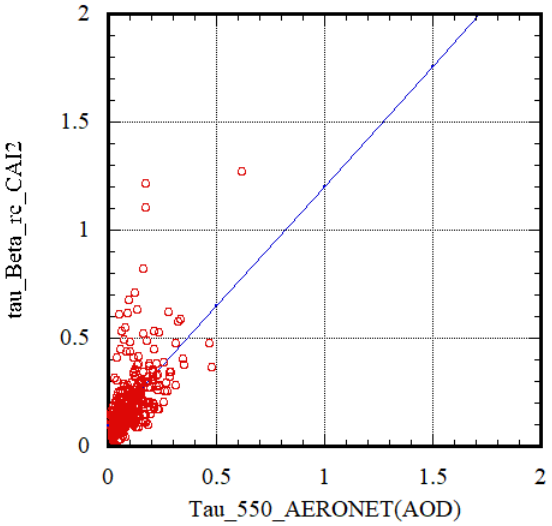
South Africa



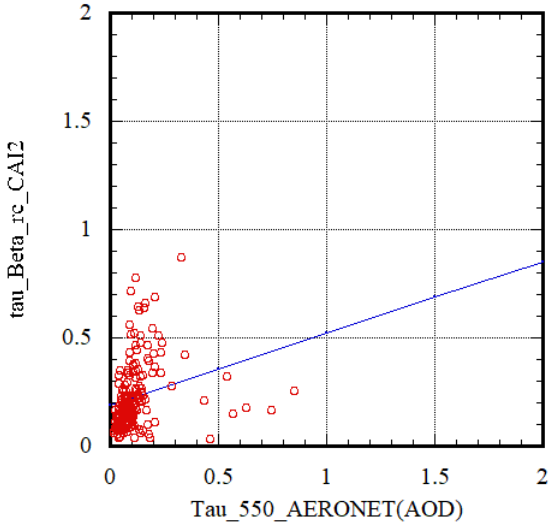
North South America



South South America



Australia



- Each region is different from the others.
  ==> Differences correspond to different aerosol types.
- In some regions, the scatter plots are divided into several groups.
  ==> Even in one region, there are different types of aerosols.
  For example, there may be seasonal variations in aerosol type.
- If the area is not too large, it may be possible to correct for errors using regression equations.
-