Ground-based monitoring of aerosol optical properties and surface radiation budget

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Contents

Introduction

- Aerosol is an important factor in human health and climate change.
- Human health <===> Air quality (air pollution)

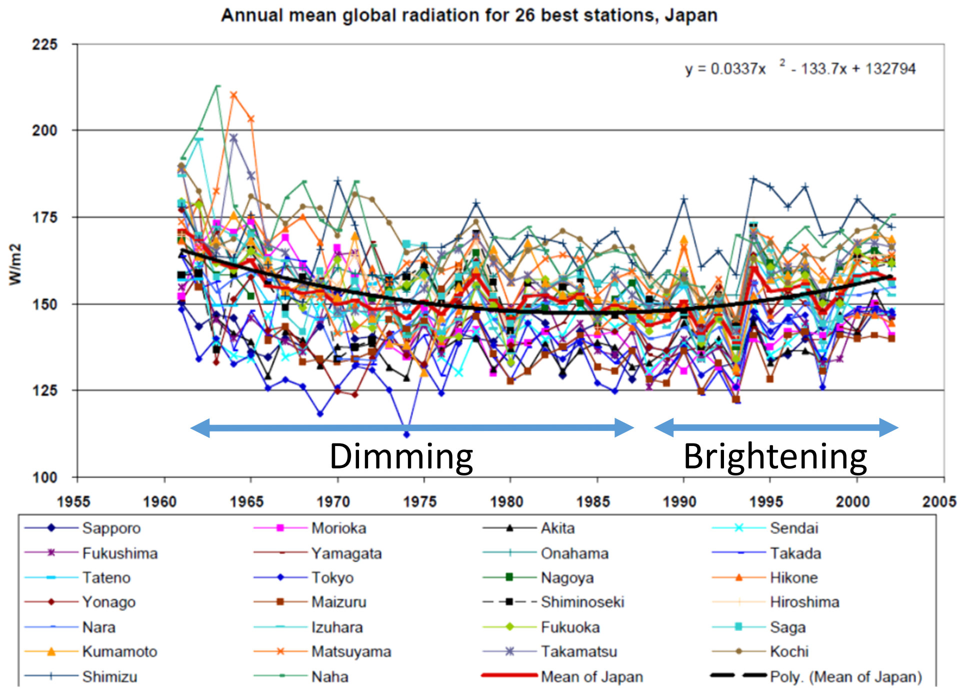
  aerosols : main components of air pollution
- Climate change <===> radiation budget

  aerosols change Earth Radiation Budget (ERB)

  Direct effect: directly by absorbing and scattering solar radiation

  In-direct effect: through their role as cloud condensation nuclei (CCN), thereby increasing cloud reflectivity and lifetimes.
- Today's talk is the ground-based monitoring of aerosol optical properties related to surface solar radiation.

Change of Surface solar irradiance
(Global Dimming and Brightening)



(Wild 2005)

- The long term continuous observations of surface solar radiation at around the world reveals a decreasing trend from the early 1950s until the late 1980s and an increasing trend in the 1990s. The former is called global dimming and the latter is called global brightening.

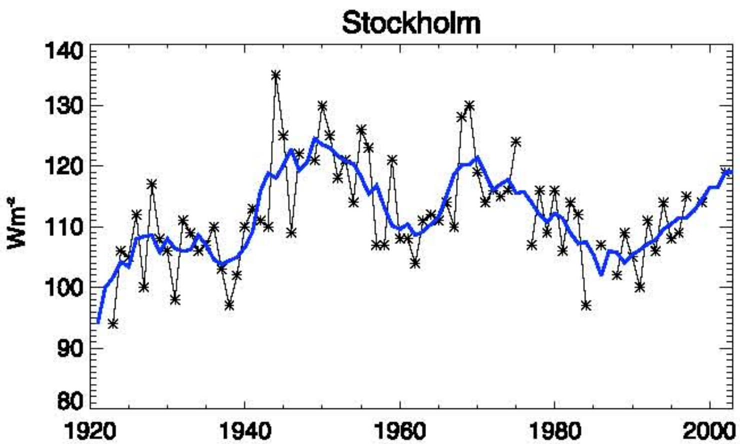


Figure 2. Annual mean surface solar radiation as observed at Stockholm, the longest observational record available form GEBA (since 1923). Five year moving average shown in blue. Units are W m^{-2}.

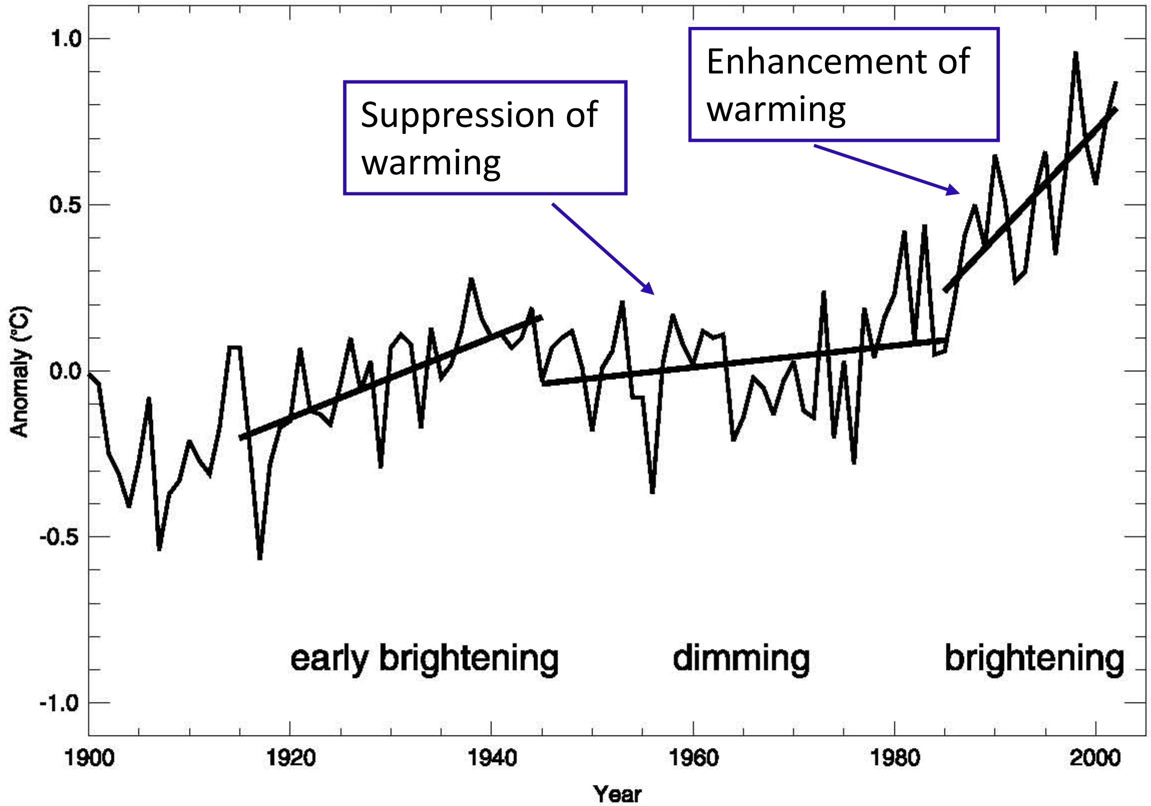
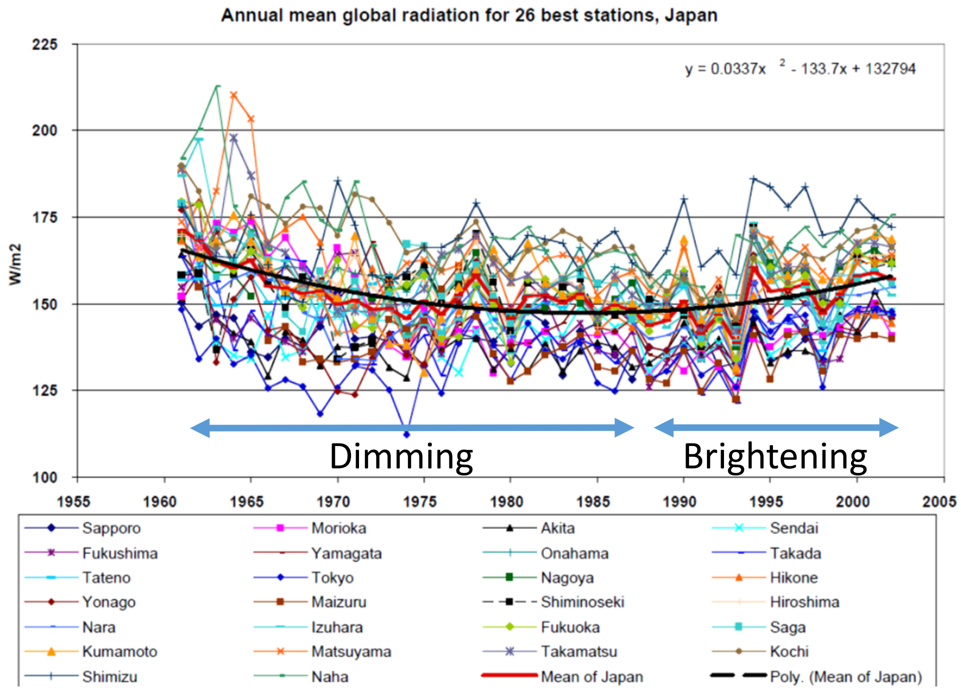


Figure 9. Observed 2-m temperature anomalies over global land surfaces during the 20th century. There is indication for a suppression of greenhouse-induced warming through "global dimming" between the 1950s and 1980s, and an enhancement through "brightening" between the 1920s and 1940s as well as from the 1980s onward. Anomalies with respect to the 20th century average. Units are °C. Adapted from *Wild et al.* [2007].

Change of Surface solar irradiance
(Global Dimming and Brightening)



(Wild 2005)

- Why such a change occurred?
- What caused such a change?
- At least, we want to know the relation between the surface solar radiation and aerosol optical properties.

- We analyzed global irradiance and direct irradiance data, and investigated the relation between surface radiation and aerosol optical properties.

- What we can get global and direct irradiance data ?
- After 1970's , the measurement accuracy is improved.

  ➔ We can make quantitative analysis based on theory of radiative transfer
- Direct component has information on aerosol quantity (amount).

  ➔ optical thickness
- Scattered (global-direct) component has information on aerosol quality.

  ➔ SSA(ratio of scattering coeff. to total extinction coeff.),

  scattering pattern (phase function, asymmetry factor）

Radiative transfer eq.

$$\frac{dI(\mathbf{r})}{dx} = -k_{ext} I(\mathbf{r}) + J$$

Assuming plane parallel atmosphere
(horizontally homogenous, vertically inhomogeneous)

$$\mu \frac{dI(z)}{dz} = -k_{ext} I(z) + J$$

$$\mu \frac{dI(z)}{dz} = -(k_{sca} + k_{abs}) I(z) + \frac{k_{sca}}{4\pi} \int P(\Omega, \Omega') I(\Omega') d\Omega' + k_{abs} B(T)$$

$$\mu \frac{dI(\mu,\phi)}{d\tau} = I(\mu,\phi) - \frac{\varpi_0}{4\pi} \iint P(\mu,\phi;\mu',\phi') I(\mu',\phi') d\mu' d\phi' - (1-\varpi_0) B(T(z))$$

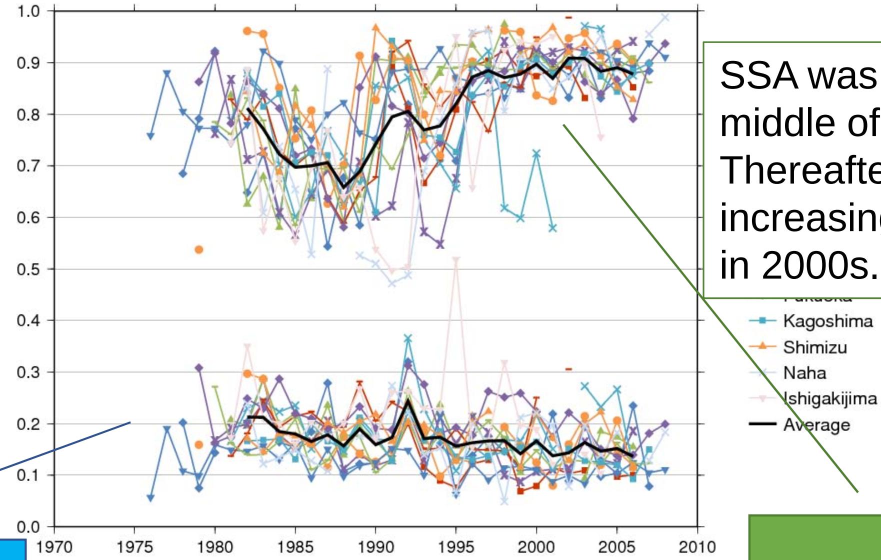
$\tau = \int_z^{ztop} k_{ext} dz$: <u>optical thickness</u>

$\omega_0 = k_{sca}/(k_{sca}+k_{abs})$: <u>single scattering albedo (SSA)</u>

$P(\Omega,\Omega')$: phase function

Optical properties
(Optical thickness, Single scattering albedo)

We analyzed direct and diffuse radiation on clear day from 1970s to 2000s in Japan.



SSA was minimum in middle of 1980s. Thereafter, SSA was increasing and became flat in 2000s.

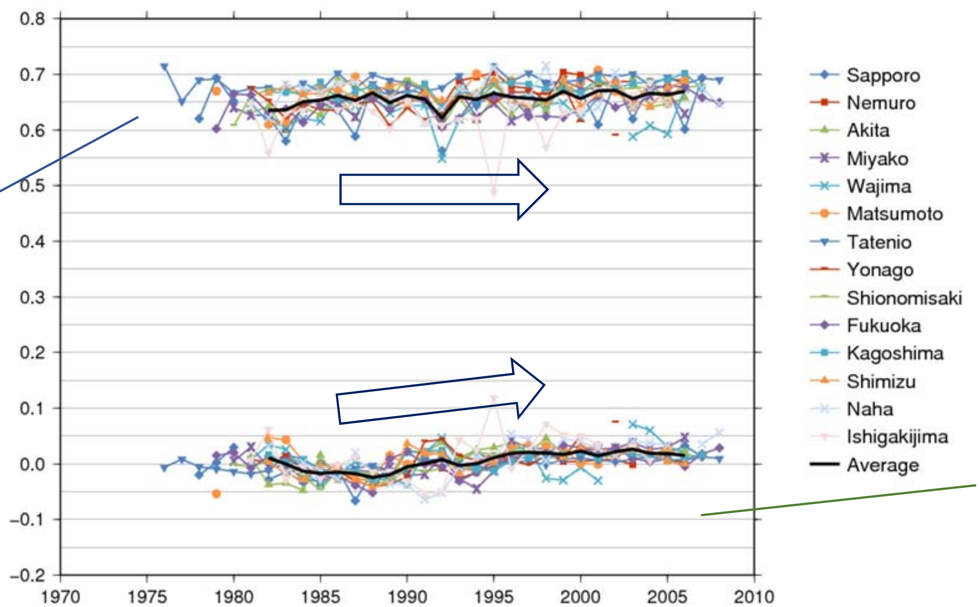
AOT is gradually decreasing.

AOT
1985-1989: 0.17±0.013
2000-2004: 0.15±0.013
Difference: -0.02*

SSA
1985-1989: 0.69±0.019
2000-2004: 0.89±0.017
Difference: +0.20**

Effect of AOT and SSA on surface solar irradiance

(AOT: aerosol optical thickness, SSA: single scattering albedo)



AOT change
（SSA fix）
1985-1989: 0.65±0.007
2000-2004: 0.66±0.007
Difference: +0.01

SSA change – SSA fix

1985-1989: -0.02±0.004
2000-2004: 0.02±0.003
Difference: +0.04**

<u>The brightening of surface solar irradiance in Japan is due to changes in aerosol optical properties, especially SSA.</u>

(Kudo, R., A. Uchiyama, O. Ijima, N. Ohkawara, and S. Ohta (2012), Aerosol impact on the brightening in Japan, *J. Geophys. Res.*, **117**, D07208, doi:10.1029/2011JD017158.)

This result shows that we have to monitor not only AOT but also SSA.

- Using the broad band global (scattered) and direct irradiances more than 30 years, we could investigate the relation between surface solar radiation and aerosol optical properties.
- When we analyze these data, we make some assumptions and therefore the conclusion is limited.

  ➔ In order to reduce the assumptions, spectral radiance and irradiance data are necessary.

- We use skyradiometer (Prede POM-01,-02), and measure solar direct irradiances and sky radiances at selected wavelengths, where gas absorption can be neglected or small.

  ➔ optical thickness and SSA at selected wavelengths

Sky-Radiometer

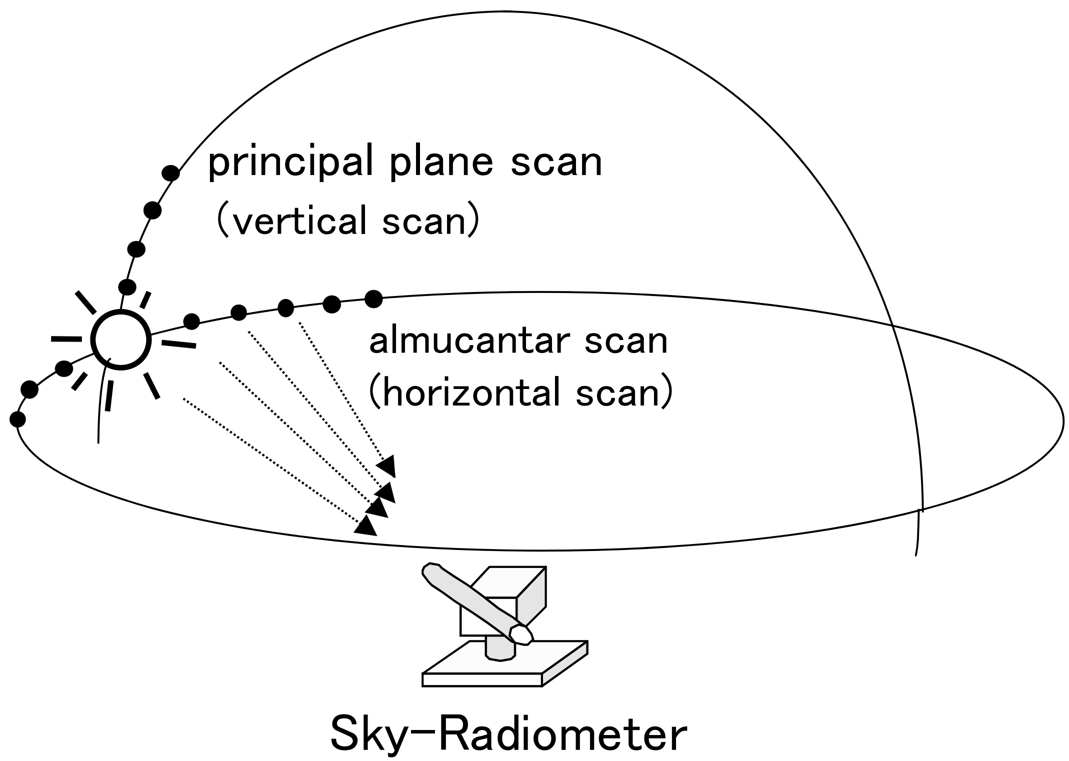
Wavelength

POM-01	POM-02
315nm	340nm
	380
400	400
500	500
675	675
870	870
940(H2O)	940(H2O)
1020	1020
	(1225)
	1627
	2200

: optical thickness of aerosol
: cloud micro-physics

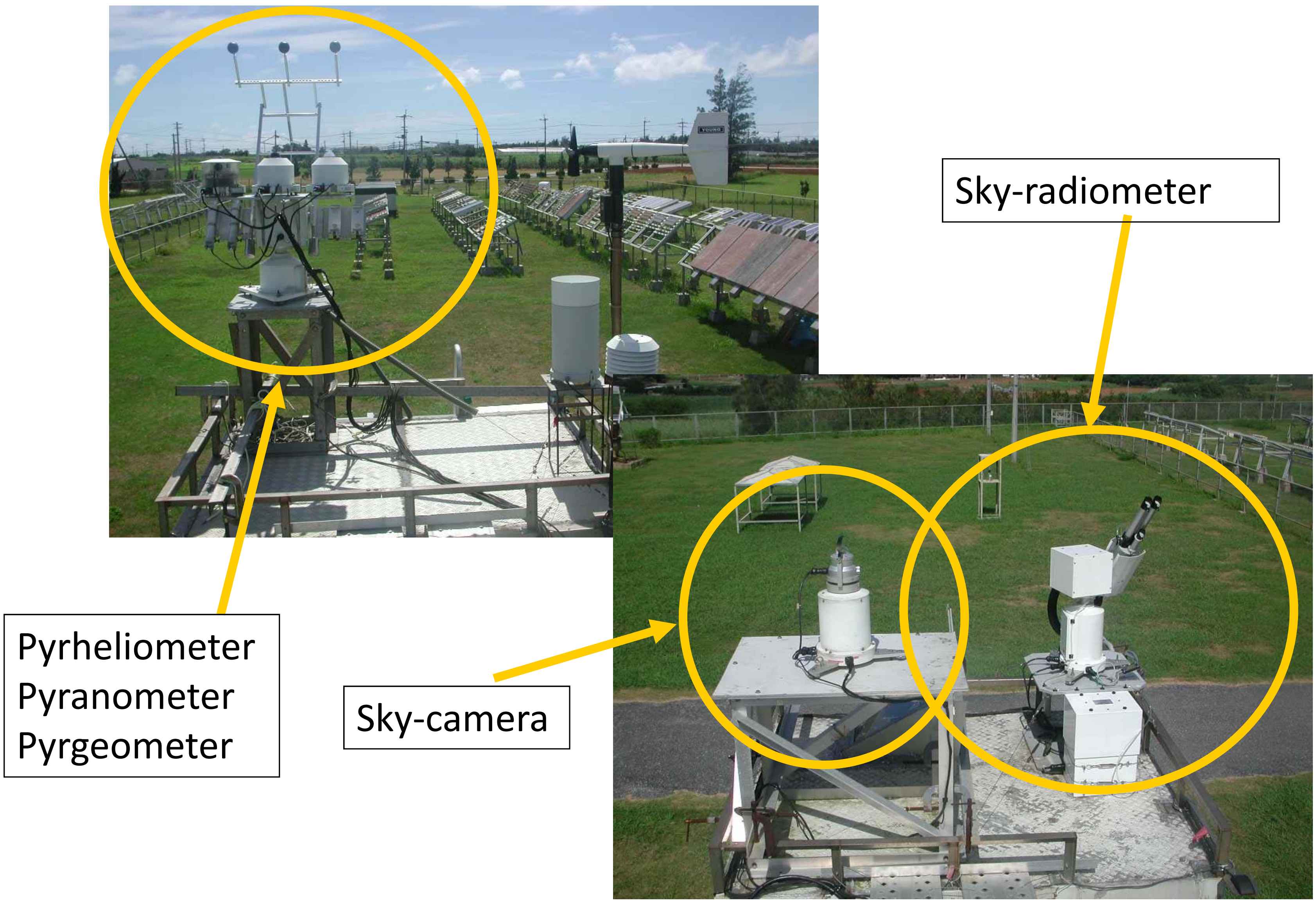
- Optical thickness（attenuation of direct solar irradiance）
- diffuse sky radiances

Scan Geometry of sky-radiometer



almucantar (horizontal) scan : $0 \sim 2\theta_0$

principal plane (vertical) scan : $0 \sim \theta_0 + 90°$



Sky-radiometer
Pyrheliometer
Pyranometer
Pyrgeometer
Sky-camera

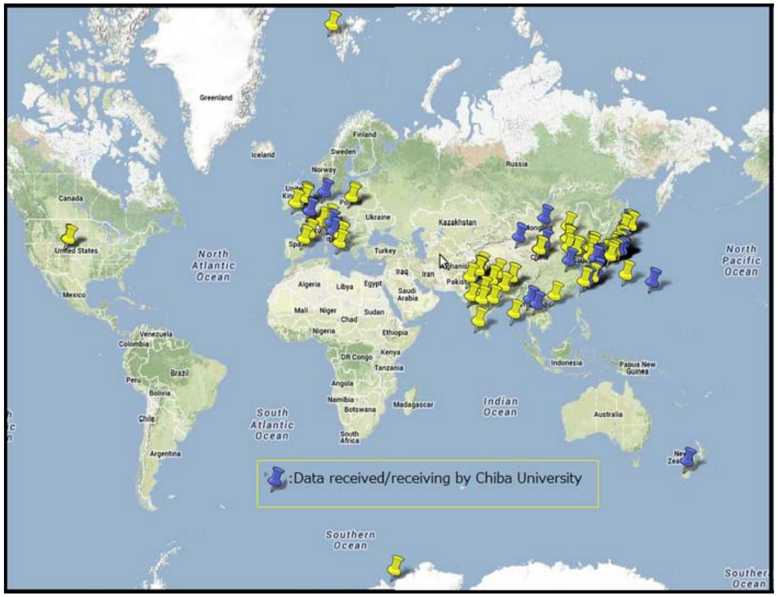
SKYNET (http://atmos2.cr.chiba-u.jp/skynet/)

- **SKYNET** is an observation network to understand aerosol-cloud-radiation interaction in the atmosphere. The main instruments consist of a sky-radiometer and radiation instruments such as a pyranometer and pyrgeometer…..
- The SKYNET is a voluntary-based activity, which is supported by many researchers and collaborators in the community.
- The primary objectives of SKYNET are

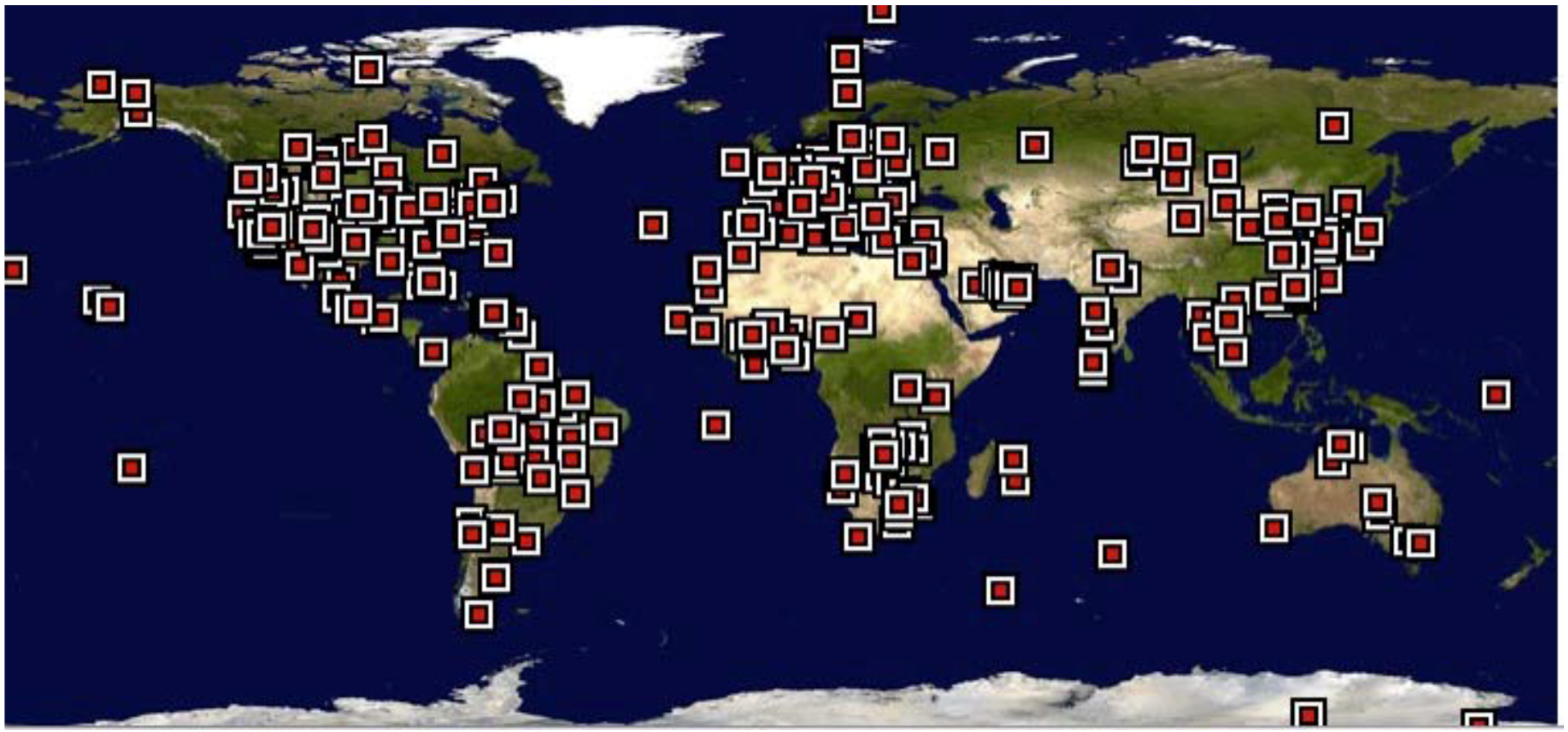
  1) to quantitatively evaluate long-term variations of aerosols, clouds, and atmospheric radiation,

  2) to understand their effects on climate through aerosol-cloud-radiation interaction,

  3) the validation for satellite observations, climate model simulations



AERONET observation sites



- MRI/JMA (Meteorological Research Institute/Japan Meteorological Agency participates in SKYNET.

  MRI observation site : Tsukuba, Miyakojima, Minamitorishima, Fukuoka, Beijing,Qingdao

  MRI contributions to SKYNET: development of retrieval algorithm & calibration method

  Kobayashi, E., A. Uchiyama, A. Yamazaki and K. Matsuse, J. Meteor. Soc. Japan, 84, 1047-1062, 2006.

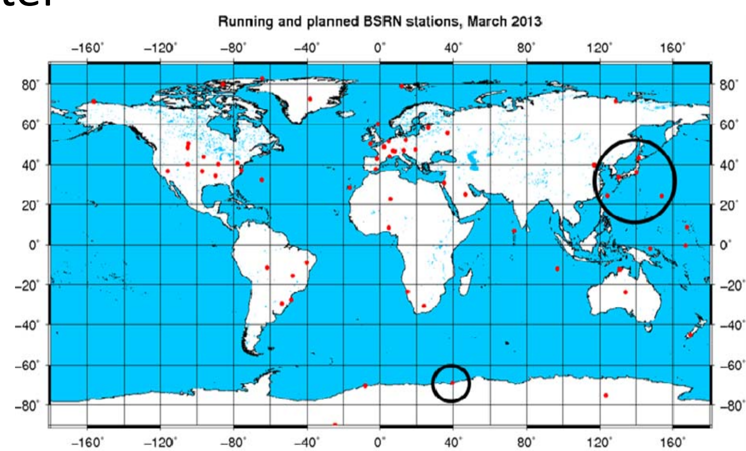
  Kobayashi E, A. Uchiyama, A. Yamazaki, R. Kudo, J. Meteor. Soc. Japan, 88, 847-856, Doi:10.2151/jmsj.2010-505, 2010.

  Uchiyama, A., A. Yamazaki, R. Kudo, *J. Meteorol. Soc. Japan*, **92A**, 195-203, DOI:10.2151/jmsj.2014-A13, 2014.

- JMA operates 4 BSRN (Baseline Surface Radiation Network) sites.

  instruments: Pyrheliometer, Pyranometer, Pyrgeometer

  JMA has a plan to install a skyradiometer in the near future.



Phimai (Thailand)

Location: 15.184N, 102.564E, 212 m a.s.l.
Site owners for SKYNET-related facilities:
Hitoshi Irie, Pradeep Khatri, and Tamio Takamura (CEReS/Chiba-U.)

The observatory is located in Bureau of Royal Rainmaking and Agricultural Aviation (BRRAA), Rang Ka Yai, Phimai, Nakhon, Ratchasima 30110, Thailand. Observations have been performed under close collaboration with Chulalongkorn university.

Phimai observatory and some instruments.

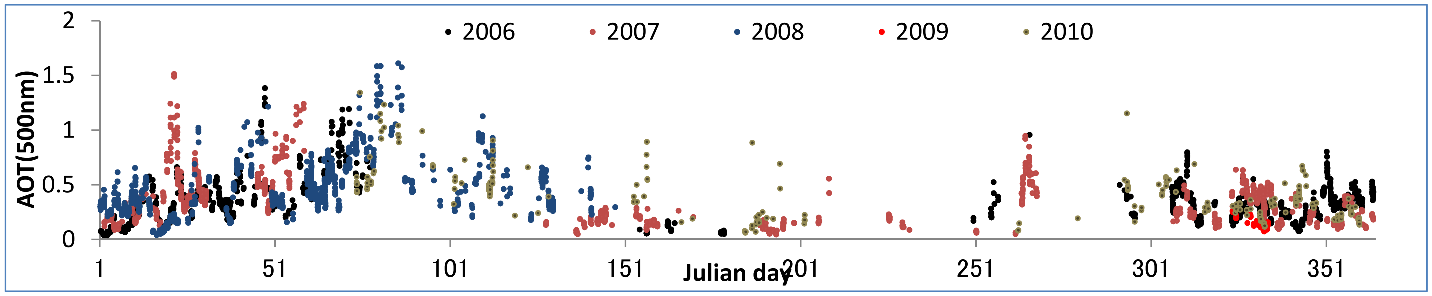
Example of Skyradiometer results

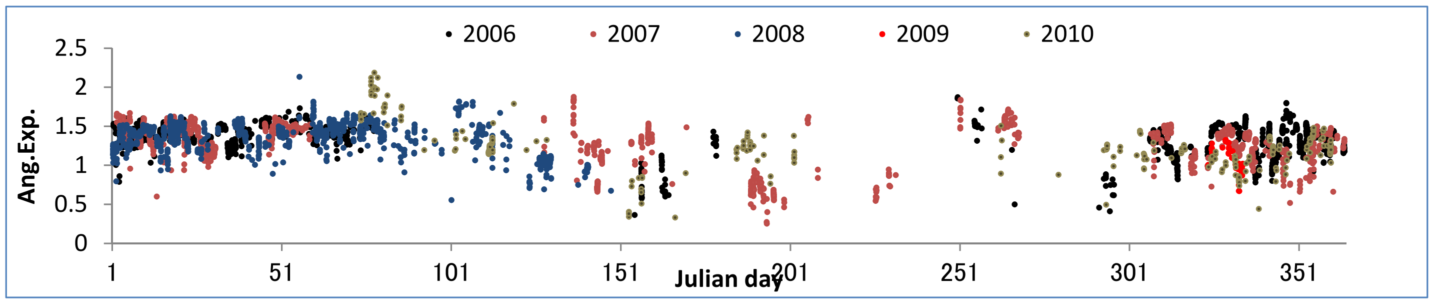
Phimai (Thailand)

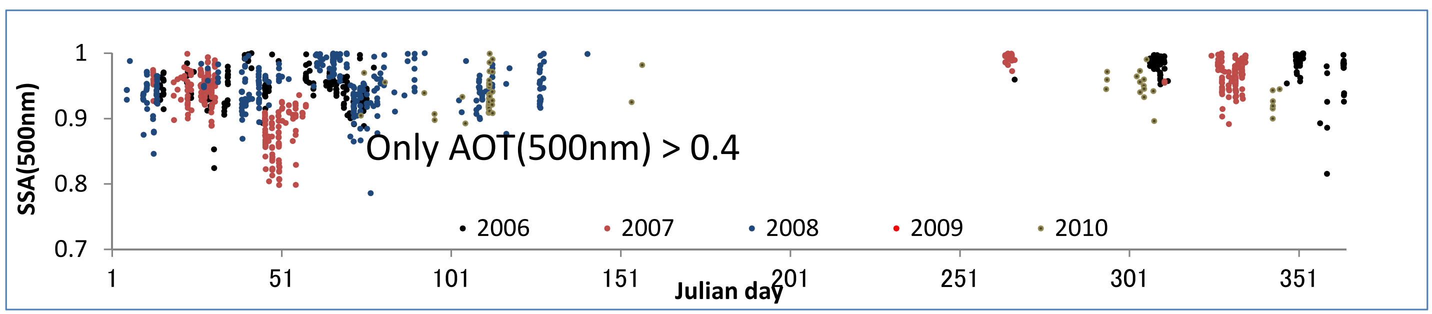
- Dry & wet season
- AOT is relatively thick.
- Ångström exponent is 1.0 to 1.6.
- SSA is slightly high.

$$AOT \propto \lambda^{-\alpha}$$

α: Ångström Exponent







（Pradeep Khatri & Tamio Takamura, Chiba Univ.)

In-situ measurement of optical properties on the ground

- Monitoring of aerosol optical properties by radiometer is limited on a fine weather day.
- The measurement can be made only in the daytime.
- The measurement cannot be made on the condition of very heavy haze.

  ===> The radiometer needs the sun.
- The in-situ (direct) measurement can be made on all weather condition, and in both night and daytime.
- But, the measurement is limited on the ground.
- The in-situ (direct) measurement of aerosol optical properties

  Scattering coefficient : Integrating Nephelometer (TSI model 3563, Aurora 3000)

  Absorption coefficient : PSAP, MAAP, Aethalometer (filter transmittance)

  PASS-3 (photo-acoustic method)

  Extinction coefficient : CAPS (CRD)

  Scattering pattern (phase function) :Polar Neph. (no commercially available one)

Instrument

Aethalometer AE31
(Magee Scientific)

PSAP, PSAP 3λ
(Radiance Research)

Integrating Nephelometer
TSI model 3563

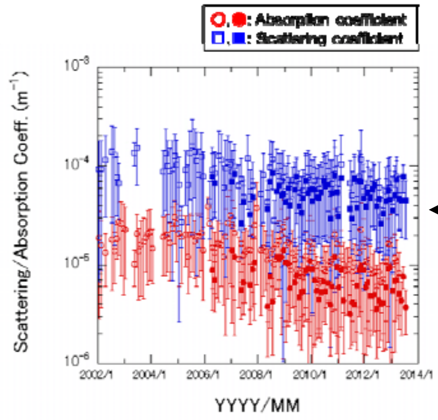
MAAP
(Thermo Scientific)

PASS-3
(DMT)

CAPS
(Aerodyne)

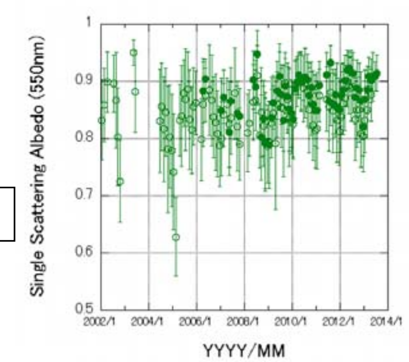
Integrating Nephelometer
Aurora 3000 (Ecotech)

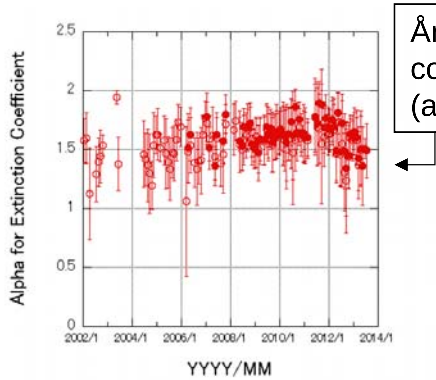
PSAP: Particulate Soot Absorption Photometer
MAAP: Multiangle Absorption Photometer
PASS:Photo Acoustic Soot Spectrometer
CAPS:Cavity Attenuated Phase Shift Spectroscopy



Scattering and absorption coeff. are decreasing.

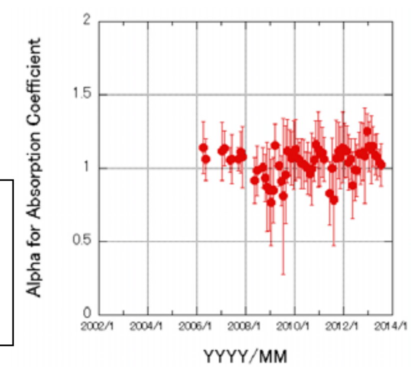
SSAs are slightly increasing.





Ångström exponent for extinction coeff. (alph_ext) is increasing. (alph_ext is index of size distribution)

Ångström exponent for absorption coeff. (alph_abs) is increasing. (alph_abs depends on composition of absorbing aerosol)



・Most aerosol characteristics had seasonal variation and decreasing or increasing trends significant at the 95 % confidence level.

・The aerosol characteristics estimated from optical data were consistent with those derived from radiometer data.

(A. Uchiyama, A. Yamazaki, R. Kudo, E. Kobayashi, H. Togawa, and D. Uesawa, 2014: Continuous Ground-Based Observation of Aerosol Optical Properties at Tsukuba, Japan: Trend and Climatology. J. Meteor. Soc. Japan, 92A, 93-108, DOI:10.2151/jmsj.2014-A06)

Summary

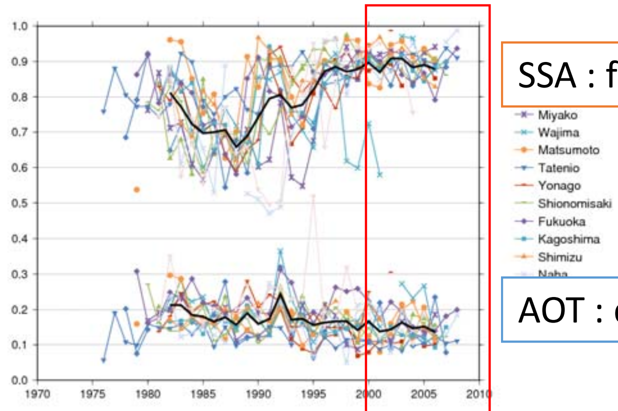
- By monitoring both surface radiation and aerosol characteristics together, we can estimate the effect of aerosol on surface radiation more precisely.
- It is important to monitor both aerosol quantity (optical thickness) and quality (SSA, asymmetry factor).
- The long-term trend of aerosol optical properties are almost same as radiometer results. Therefore, in-situ measurements is useful.
- It takes time to accumulate data and to detect the climate change. Therefore, it is necessary to begin observation for monitoring as soon as possible.

- If you are interested in SKYNET, please participate in SKYNET activity. A member of SKYNET can cooperate with you.

Thank you for your attention.

Trend of SSA and AOT

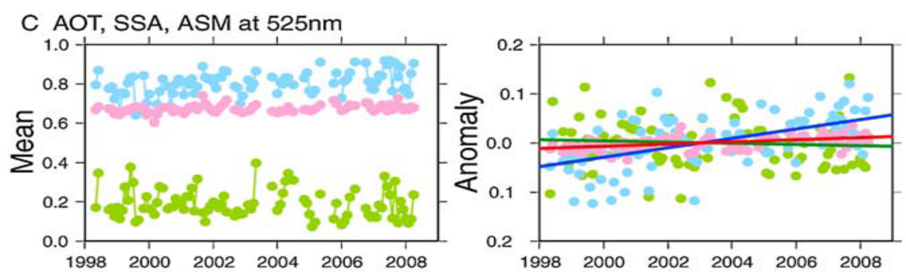
Direct and diffuse solar flux (VIS, NIR)



SSA : flat

AOT : decreasing

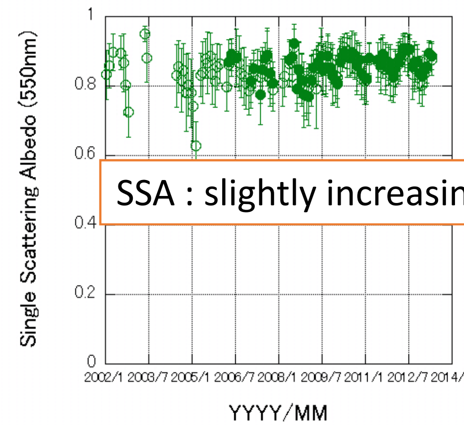
(Kudo et al., 2012)



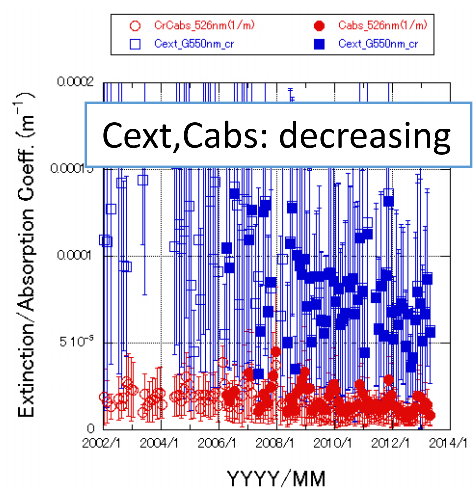
(Kudo et al., 2010)

Blue(SSA) increasing*
Green(Optical thickness) slightly decreasing
Pink(Asymmetry factor) flat

Nephelometer and PSAP(3l)



SSA : slightly increasing

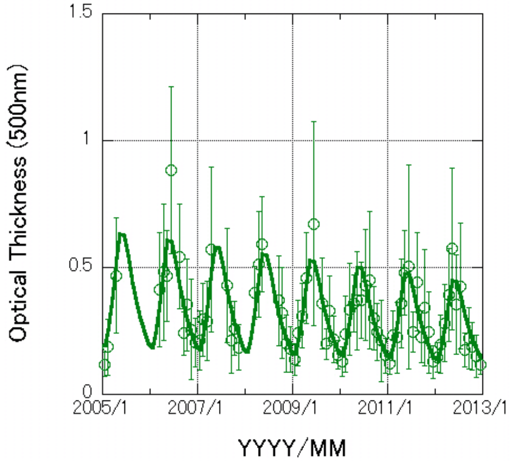


Cext,Cabs: decreasing

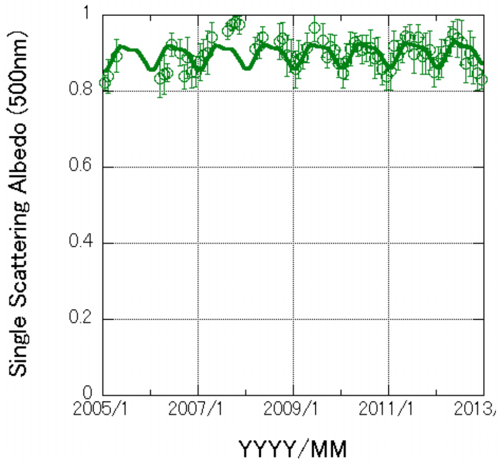
Trend of SSA and AOT

Skyradiometer (Tsukuba, 2005-2012)

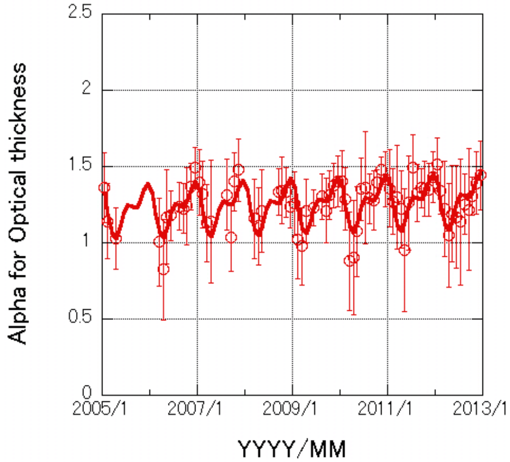
AOT(500nm)



SSA(500nm)



Alpha



Trend (Skyradiometer) (2005-2012)

dAOT(500)/dt = -1.65E-02* dSSA(500)/dt = 1.51-03 dAlpha/dt = 9.46E-03

Trend (Neph.+PSAP) (2006-2012)

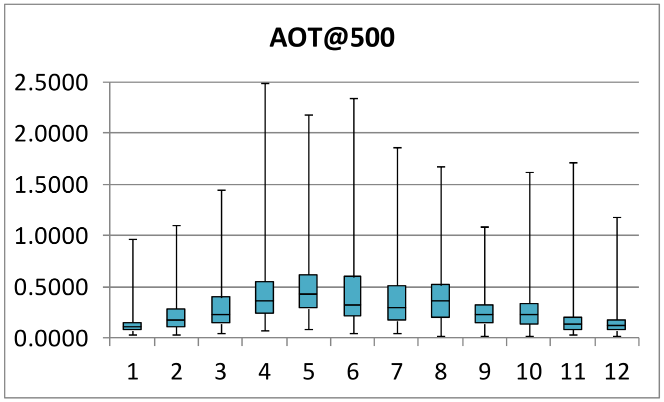
dCext(550)/dt = -5.80E-06* dSSA(550)/dt = 7.05E-03* dAlpha_ext/dt = 4.96E-02

Asterisk (*) means that the trend is significant in the confidence level 95%.

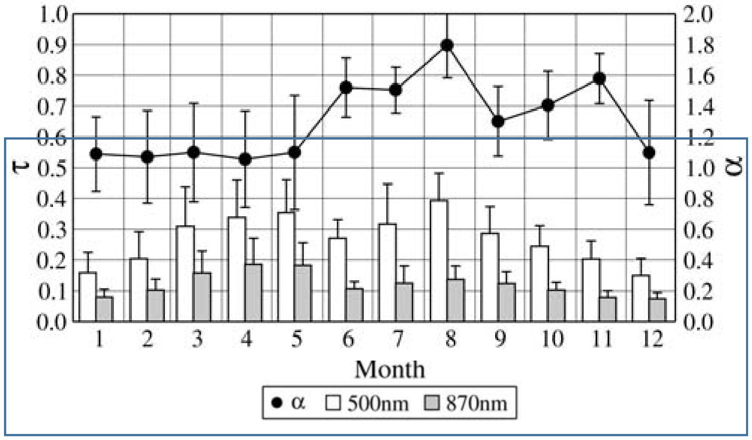
The trends of SSA and AOT from the radiometer data (Skyradiometer, solar Irradiance) are same trends of Cext and SSA by the Nephelometer and PSAP data.

Seasonal variation of AOT

Skyradiometer

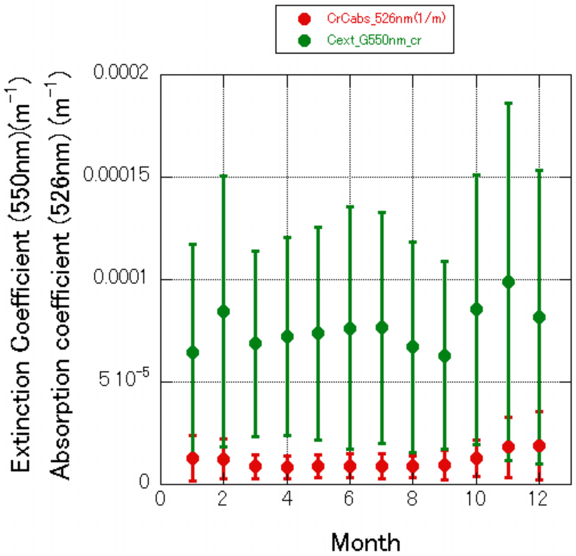


Direct and diffuse solar flux (VIS, NIR)



(Kudo et al., 2010)

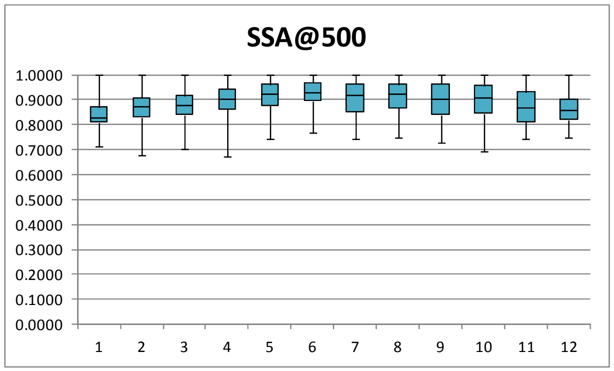
Nephelometer and PSAP(3λ)



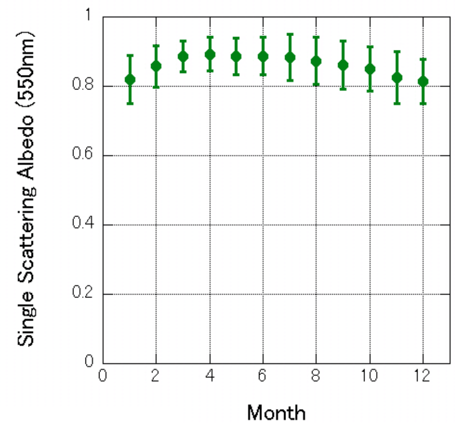
Maximum value is observed in the winter season.

Seasonal variation of Single scattering albedo

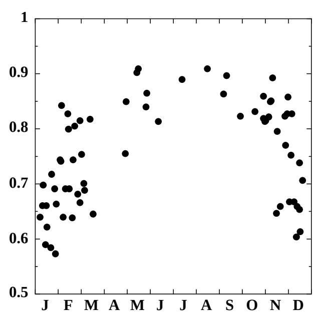
Skyradiometer



Neph.+PSAP(3λ)

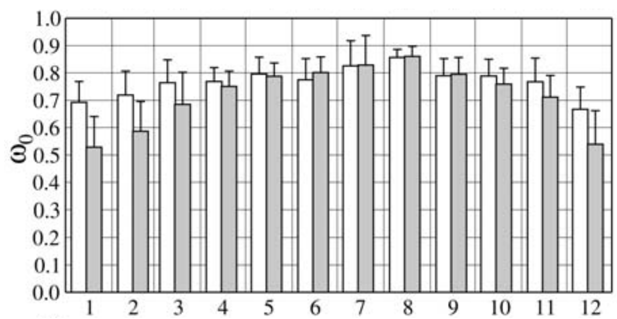


Sunphotometer,
Global and Diffuse (VIS,NIR)



(Nishizawa, et al., 2004)

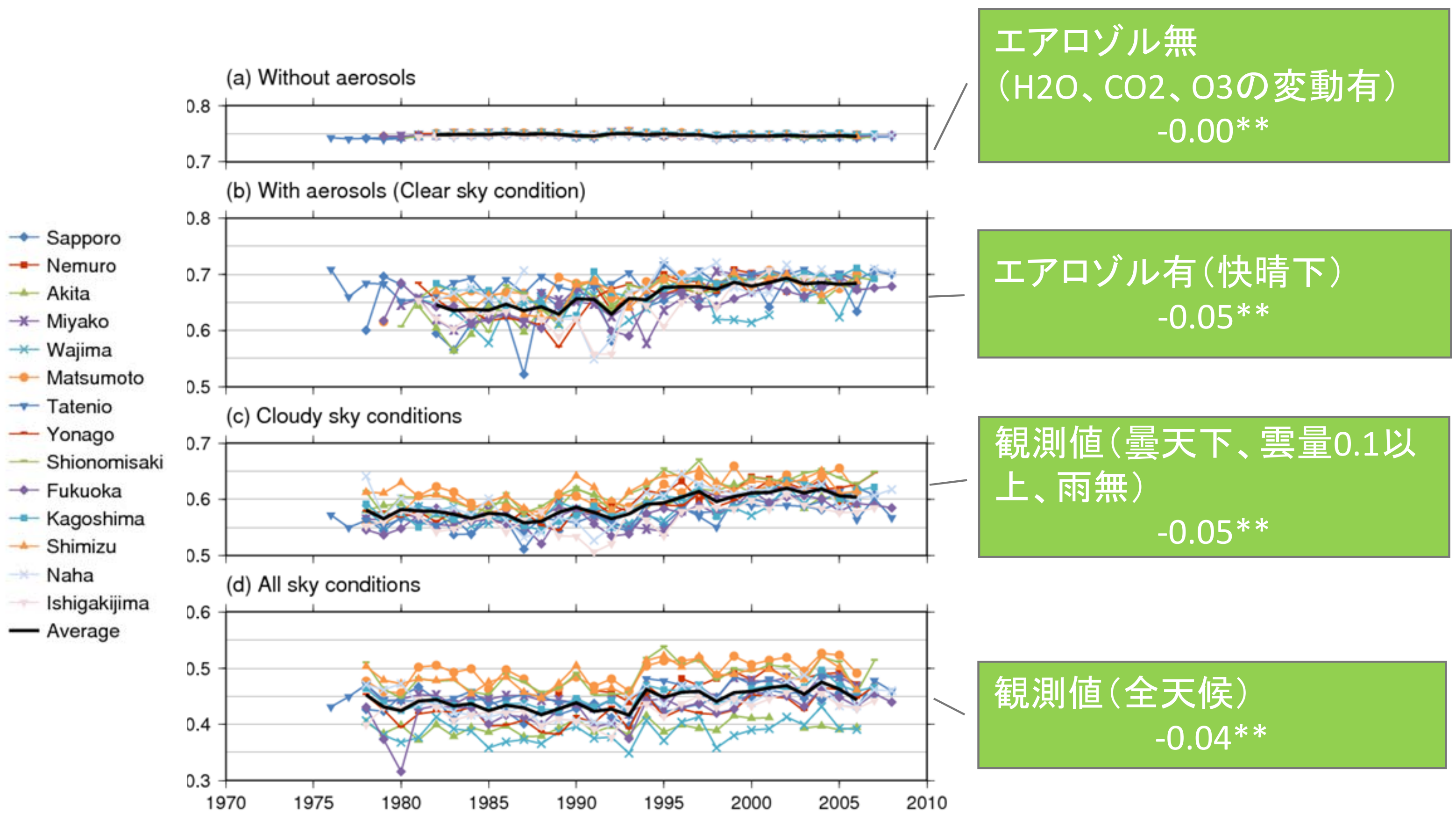
Direct and Diffuse (VIS,NIR)



(Kudo et al., 2010)

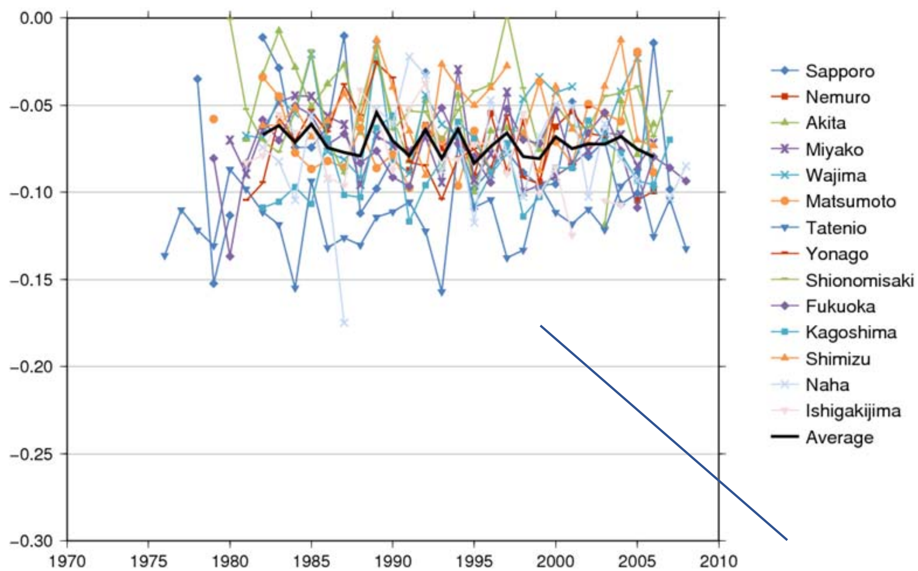
- In the summer season, SSA is high and in the winter season, SSA is low.
- SSA(skyradiometer) > SSA(Neph.+PSAP(3λ)) > SSA (Irradiance data)

Surface solar irradiance



ガスの変動の影響はない。地上日射は、天候に関わらず、増加傾向。

Effect of cloud on surface solar irradiance （＝(cloudy) ー (clear day)）



1985-1989: -0.07±0.011
2000-2004: -0.07±0.003
Difference: -0.00

雲の影響に、顕著な傾向はなかった。
よって、地上日射のBrighteningは、エアロゾルによってもたらされていたと考えられる。

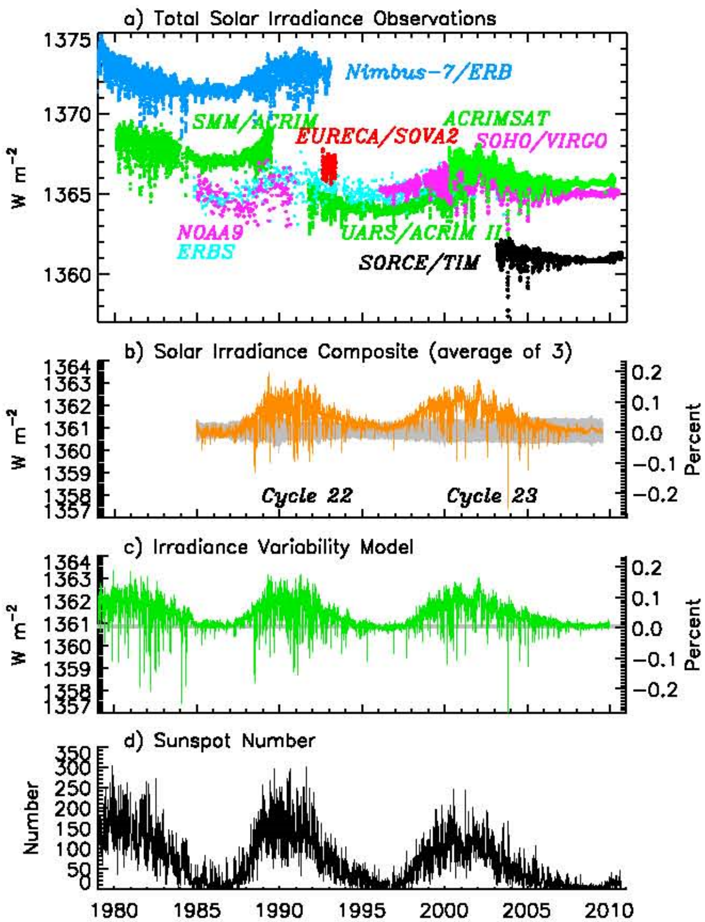


Figure 1. (a) Space-borne total solar irradiance (TSI) measurements are shown on "native" scales with offsets attributable to calibration errors. Instrument overlap allows corrections for offsets and the creation of a composite TSI record. (b) The average of three different reported composites [ACRIM, PMOD, and RMIB] adjusted to match the SORCE/TIM absolute scale. The grey shading indicates the standard deviation of the three composites. (c) Irradiance variations estimated from an empirical model that combines the two primary influences of facular brightening and sunspot darkening with their relative proportions determined via regression from direct observations made by SORCE/TIM. (d) The daily sunspot numbers indicate fluctuating levels of solar activity for the duration of the database.