Development of Skyrad pack MRI v2

Rei Kudo, A. Yamazaki, R. Nagasawa, N. Ohkawara, H. Ishida (MRI, Japan)

H. Diémoz (ARPA Valle d' Aosta, Italy)

V. Estellés (Valencia University, Spain)

M. Campanelli (ISAC-CNR, Italy)

M. Momoi (Chiba University, Japan)

F. Marenco (Met Office, UK)

C. L. Ryder (University of Reading, UK)

O. Ijima, K. Nakashima (JMA, Japan)

A. Uchiyama, Y. Jin, T. Nishizawa (NIES, Japan)

Kudo, R., Diémoz, H., Estellés, V., Campanelli, M., Momoi, M., Marenco, F., Ryder, C. L., Ijima, O., Uchiyama, A., Nakashima, K., Yamazaki, A., Nagasawa, R., Ohkawara, N., and Ishida, H.: Optimal use of the Prede POM sky radiometer for aerosol, water vapor, and ozone retrievals, Atmos. Meas. Tech., 14, 3395–3426, https://doi.org/10.5194/amt-14-3395-2021, 2021.

Introduction

- Aerosol, water vapor, and ozone have significant impacts on the radiative balance in the solar wavelength region under the clear sky condition.
- Sky radiometer measurements cover almost all the solar wavelength region.
- Aerosol physical and optical properties, PWV, and TO3 are available from sky radiometer.

- 315, 1627, and 2200nm are not used in the aerosol retrieval.
- The principal plane scan is not used for the retrieval. But it has the wider range of scattering angles than the almucantar scan when the solar zenith angle is small.
- Known problems of SSA and SD retrievals in the Skyrad pack v4.2.

This study: Development of Skyrad pack MRI v2

Tri-modal SD

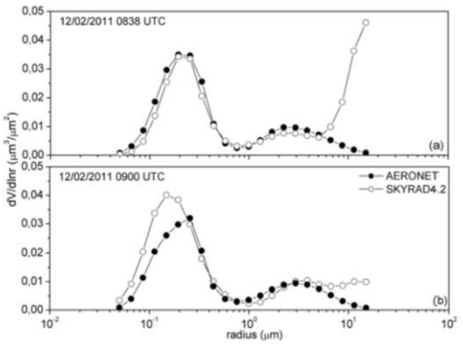
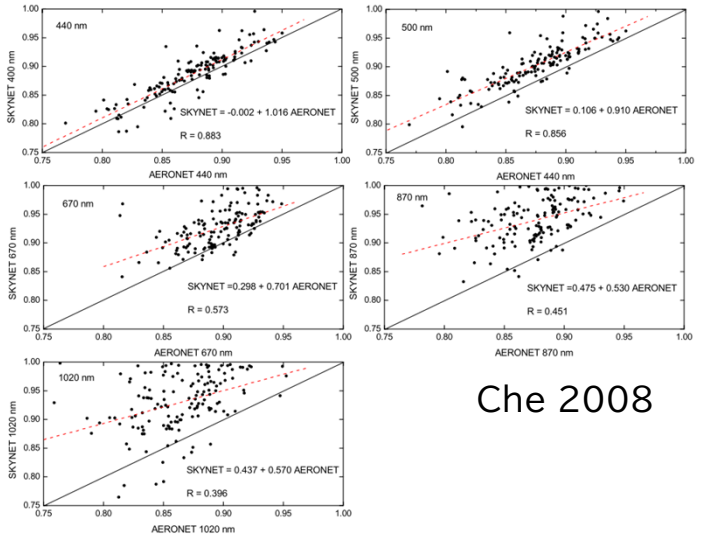


Fig. 4. Two representative cases of type II SKYRAD solutions with a second coarse mode that leaves the distributions tails open.

Estellés 2012

Positive bias of SSA



Che 2008

Fig. 4. Scattergrams of single scattering albedo between PREDE skyradiometer and CIMEL sunphotometer data at wavelengths of 400, 500, 670, 870 and 1020 nm over Beijing. Only data with AOD>0.4 are shown. The red dotted line means the fitted linear regression curve.

Specifications of Skyrad pack series

	Skyrad v4.2 Nakajima 1996	Skyrad v5 Hashimoto 2012	MRI v1 Kobayashi 2006, 2010	MRI v2 Kudo 2021
Measurements				
Wavelength	340, 380, 400, 500, 675, 870, 1020 nm			315, 340, 380, 400, 500, 675, 870, 940, 1020, 1627, 2200 nm
Almucantar	○			○
Principal plane	×			○
Parameters to be optimized				
Size distribution	20 lognormal functions			20 lognormal functions
Radius range	0.01~20μm			0.03~30μm
Real part of Refractive index	○			○
Imaginary part of Refractive index	○			○
Non-spherical particle model	×		Spheroid (Duvobik 2006)	Spheroid (Dubovik 2006), Voronoi (Ishimoto 2010), Hexahedral (Saito 2021)
Retrieval of non-spherical particle	×			○ (Volume ratio of non-spherical particles in the coarse mode)
PWV	×			○ (940nm)
TO3	×			○ (315nm)
Optimization method				
Cost function	-	MAP		MML
Minimization method	-	Newton method		Gauss-Newton method + Line search
Measurement error (Contribution to cost function)				
AOD (Transmittance in MRI v2)	Fixed	Depend on AOD	Fixed	Fixed
Diffuse radiance / direct irradiance	Fixed	Depend on AOD	Fixed	Depend on AOD
Smoothness constraint				
Real part of refractive index	○	×	○	○
Imaginary part of refractive index	○	×	○	○
Size distribution	○	×	○	○
A priori distribution				
Real part of refractive index	×	○	○ (updated in iteration)	×
Imaginary part of refractive index	×	○	○ (updated in iteration)	×
Size distribution	×	○	○ (updated in iteration)	×
Forward model				
Radiative Transfer Model	RSTAR			RSTAR or PSTAR parallelized by OpenMP
Gaseous absorption	O3			O3, H2O, CO2, N2O, CO, CH4, O2
Surface albedo	Lambert reflection			Lambert reflection (Black- and White-albedo)
Aerosol vertical profile	1 layer			Constant, Exponential, Normal distribution

Comparison with previous methods

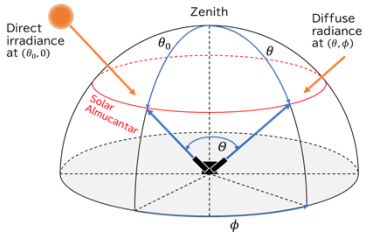
- Site: Tsukuba, rural city about 50 km northeast from Tokyo
- Period: February to October in 2018
- Retrieval algorithms

  MRI v2

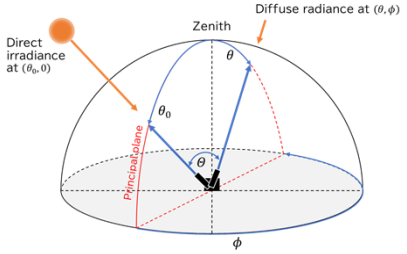
ALM-SW	Almucantar,	340~1020nm,	Aerosol
ALM-LW	Almucantar,	315~2200nm,	Aerosol･PWV･TO3
PPL-SW	Principal plane,	340~1020nm,	Aerosol
PPL-LW	Principal plane,	315~2200nm,	Aerosol･PWV･TO3

  Skyrad v4.2 Same as ALM-SW

  Skyrad v5 Same as ALM-SW



Almucantar

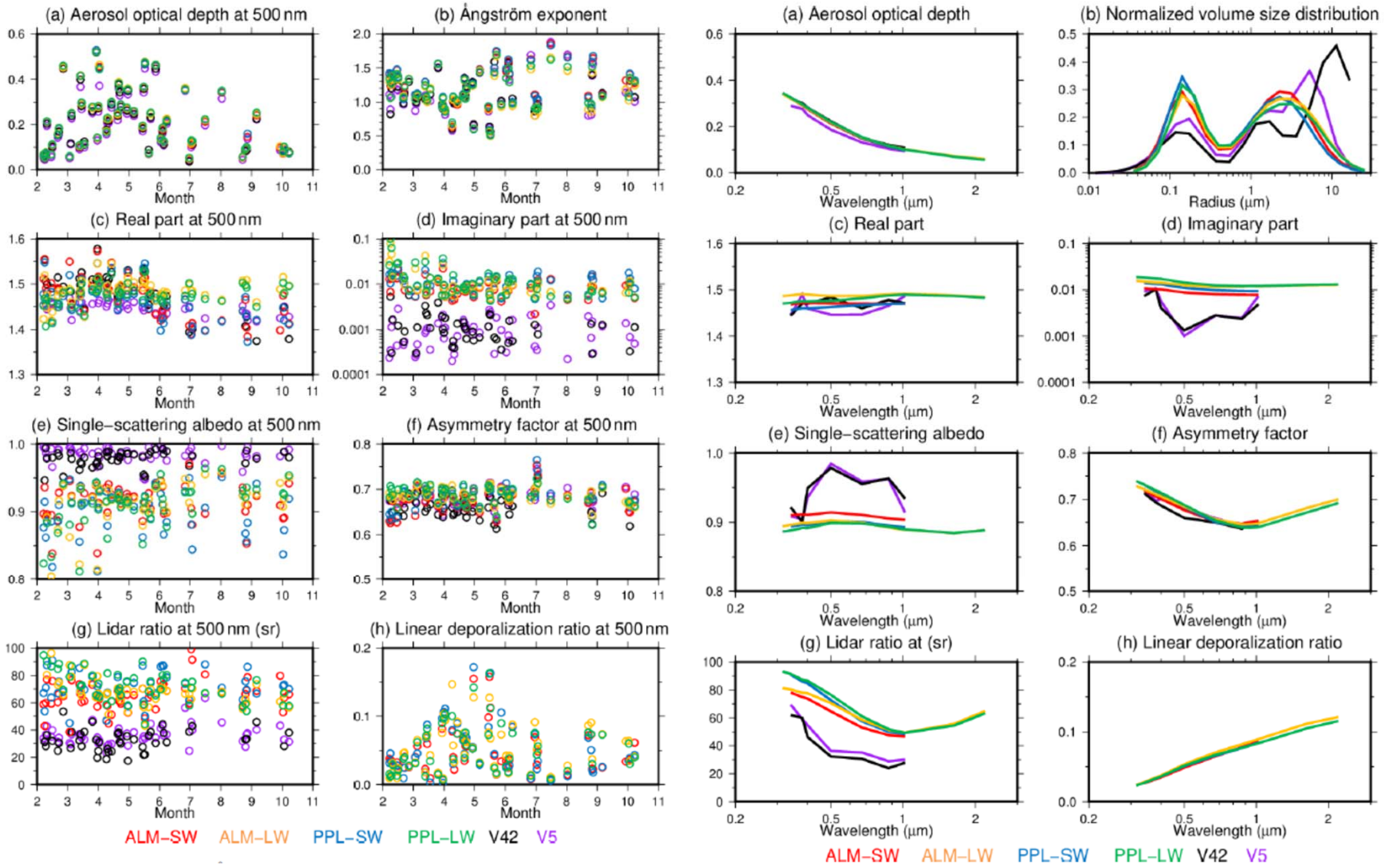


Principal plane

- Aerosol (AOD, ANG, RR, RI, SSA, ASM, LIR, DEP) are compared among methods.
- PWV is compared with sonde sounding data
- TO3 is compared with Brewer spectrometer measurements
- Radiative closure study

  Global, direct, and diffuse components of surface solar radiation (SSR) calculated from the retrievals are compared with BSRN measurements.

Result of Aerosol



- Large difference in the spectral dependency of SSA, RI, LIR.
- SD of Skyrad v4.2 & 5 has third mode around radius of 10 μm.
- Others agree well with each other.

MRI v2

ALM-SW	Almucantar,	340~1020nm, Aerosol
ALM-LW	Almucantar,	315~2200nm, Aerosol･PWV･TO3
PPL-SW	Principal plane,	340~1020nm, Aerosol
PPL-LW	Principal plane,	315~2200nm, Aerosol･PWV･TO3
Skyrad v4.2	Same as ALM-SW	
Skyrad v5	Same as ALM-SW	

Results of PWV and TO3

PWV

Difference
+0.1±2.7mm
+0.1±3.9mm

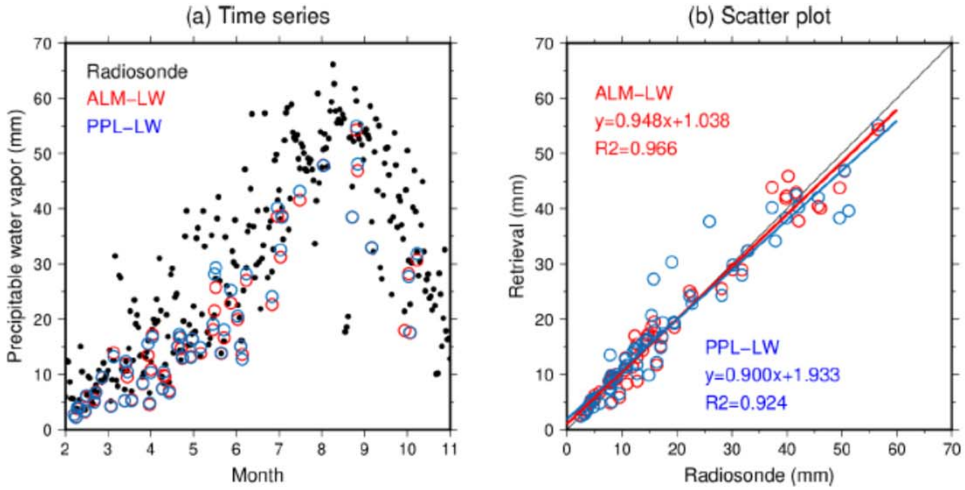


Figure 12. Seasonal changes (**a**) and scatter plots (**b**) for the precipitable water vapor of the ALM-LW (red), PPL-LW (blue), and radiosonde observations (black); $y = ax + b$ and R2 are the linear fitting and coefficient of determination.

TO3

Difference
+24±25 m atm-cm
+23±24 m atm-cm

Positive bias. Error source is unknown now.

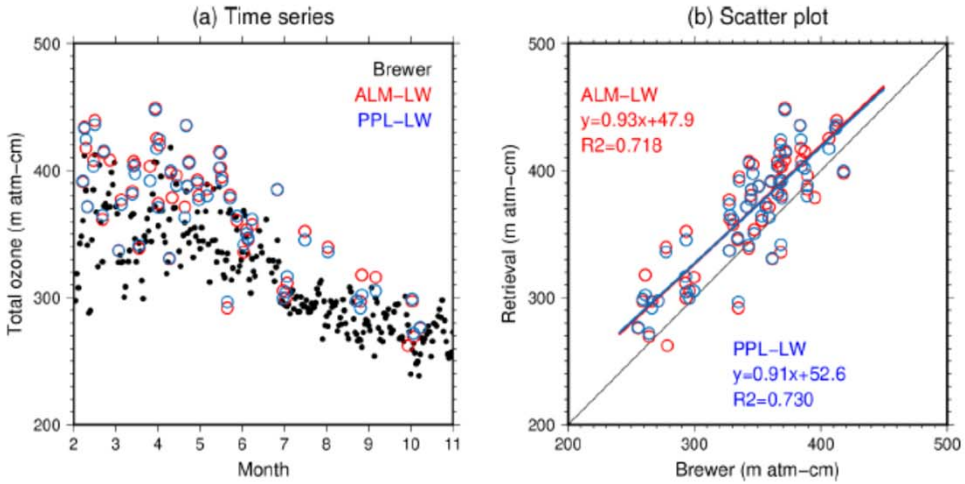
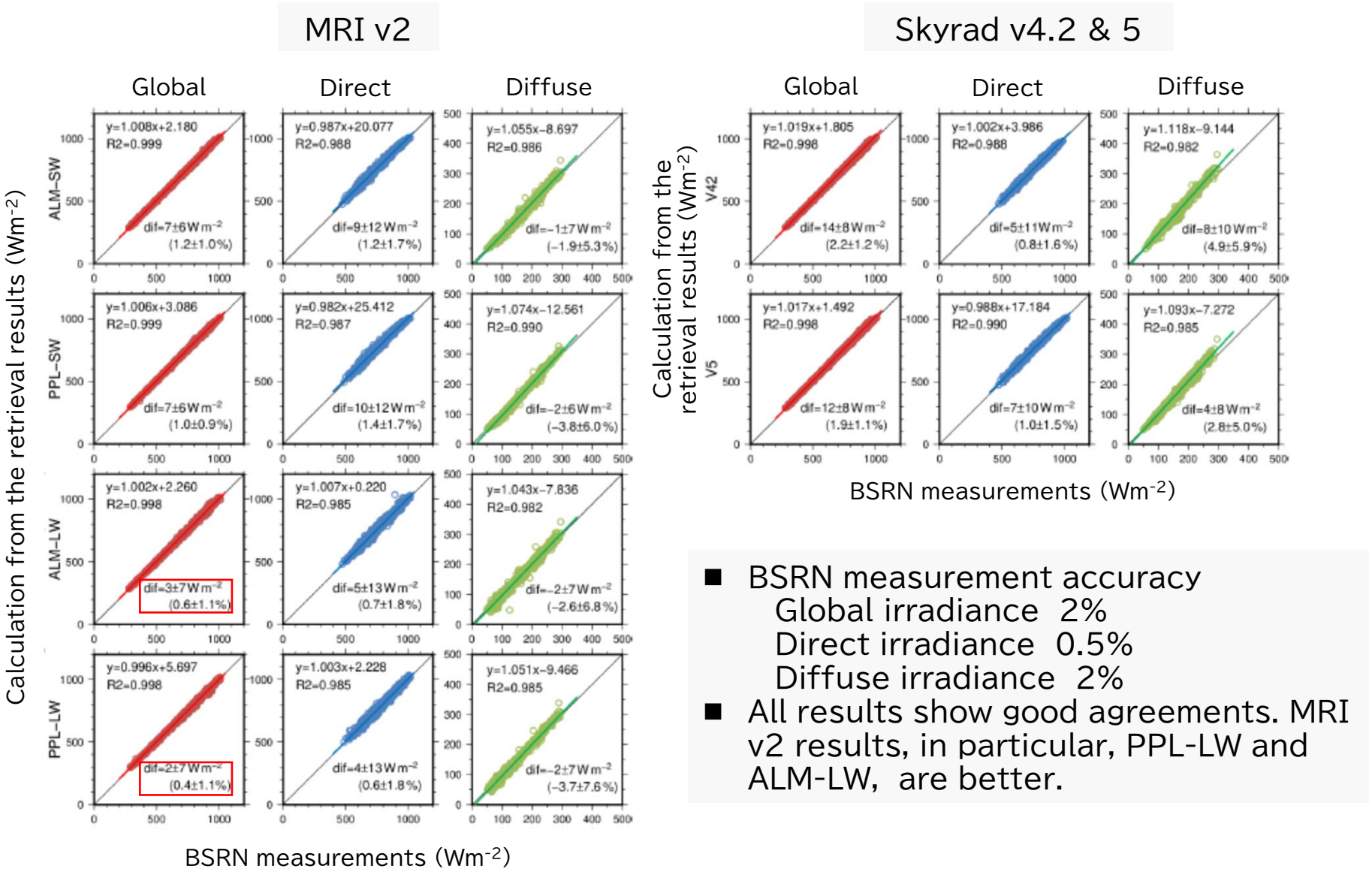


Figure 13. Seasonal changes (**a**) and scatter plots (**b**) for the total ozone of the ALM-LW (red), PPL-LW (blue), and Brewer spectrophotometer observations (black); $y = ax + b$ and R2 are the linear fitting and coefficient of determination.

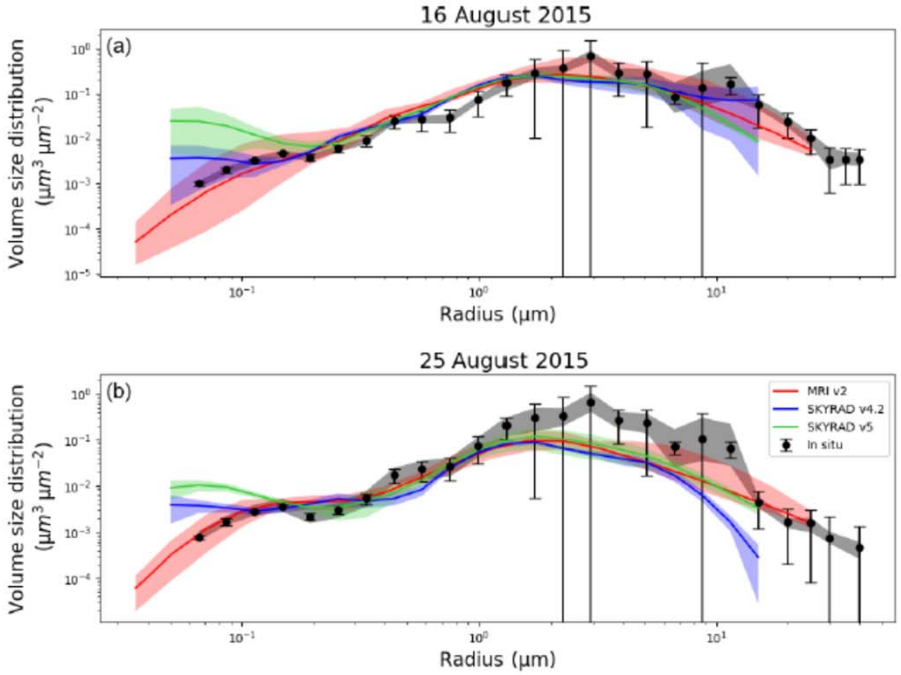
Result of SSR



- BSRN measurement accuracy
  - Global irradiance 2%
  - Direct irradiance 0.5%
  - Diffuse irradiance 2%
- All results show good agreements. MRI v2 results, in particular, PPL-LW and ALM-LW, are better.

Comparison with aircraft in-situ measurements

Diémoz (SKYNET Workshop, India)



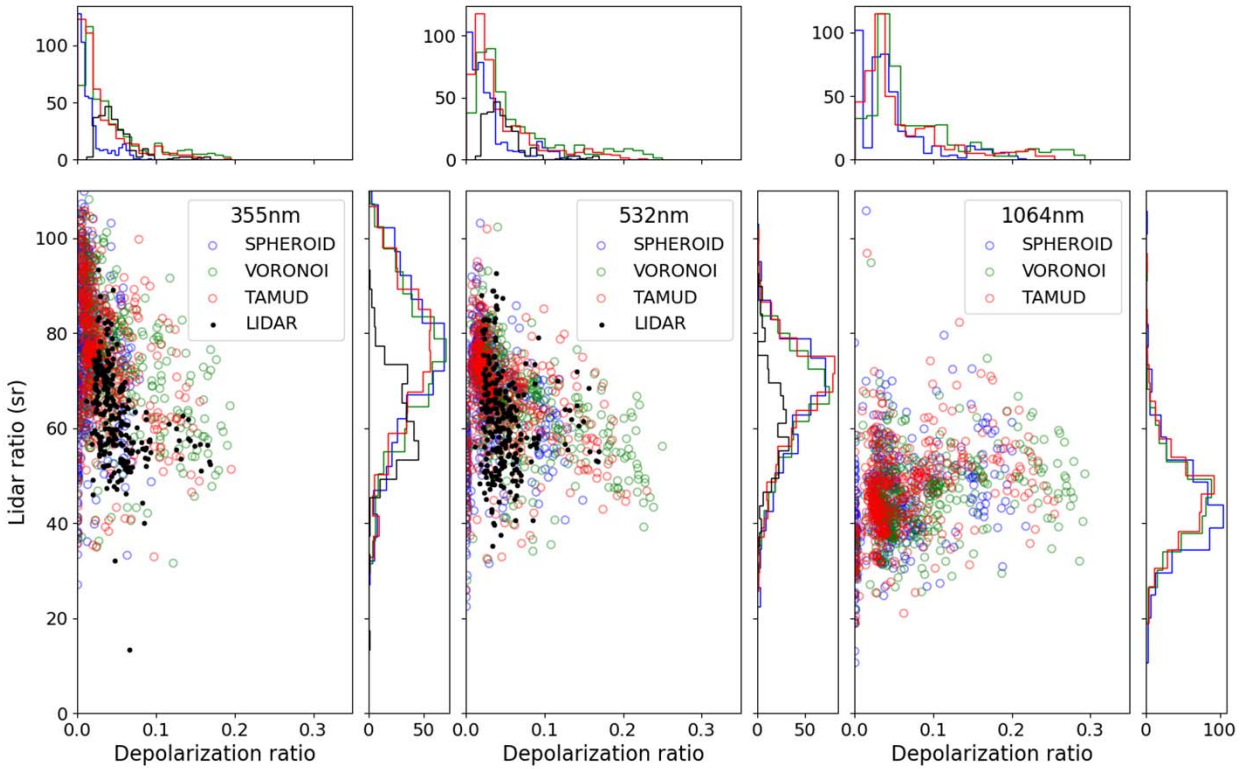
The Sunphotometer Airborne Validation Experiment in Dust (SAVEX-D)

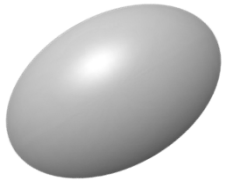
- Saharan dust was observed by the sky radiometer and aircraft in-situ measurements.
- MRI v2 results of SSA, SD, RR, RI, LIR agreed well with those of integrated airborne measurements.

Optical property	MRI v2 (500 nm)		AER-D	SAMUM 2
	16 August 2015	25 August 2015	(550 nm)	(532 nm)
Aerosol optical depth	0.64 ± 0.10	0.25 ± 0.04		
Real part of the refractive index	1.49 ± 0.03	1.47 ± 0.03	1.48[a]	
Imaginary part of the refractive index	0.0012 ± 0.0014	0.0015 ± 0.001	0.0012–0.0030[a]	
Single-scattering albedo	0.97 ± 0.03	0.96 ± 0.02	0.91–0.98[a] (mean 0.95)	
Asymmetry factor	0.75 ± 0.02	0.74 ± 0.02	0.74[a]	
Lidar ratio (sr)	45 ± 9 (46 ± 10 at 443 nm)	52 ± 10 (55 ± 10 at 443 nm)	54 ± 8[b] (355 nm)	63 ± 6[c]
Linear depolarization ratio	0.25 ± 0.08	0.25 ± 0.01		0.29–0.31[c]

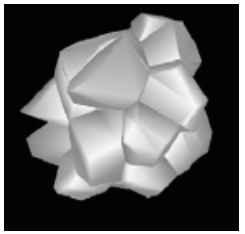
[a] Aircraft in situ measurements over the Cape Verde islands during AER-D in 2015 (Ryder et al., 2018). [b] Elastic backscatter lidar measurements over the Cape Verde islands during AER-D in 2015 (Marenco et al., 2018). [c] Raman lidar measurements over the Cape Verde islands during SAMUM 2 in 2008 (Groß et al., 2011).

Ongoing research: Comparison with HSRL

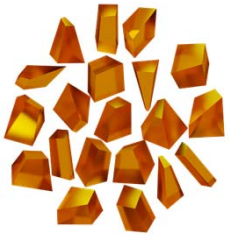




Spheroidal particle
(Dubovik 2006)



Voronoi particle
(Ishimoto 2010)



Hexahedral particle
(TAMUdust2020,
Saito 2021)

- MRI v2 derived LIR and DEP were compared with High Spectral Resolution Lidar (HSRL) of NIES.
- Data: Tsukuba, June to September in 2020
- Retrieved LIR is 10-20 larger than HSRL.
- DEP of TAMUD looks better than others.

Summary

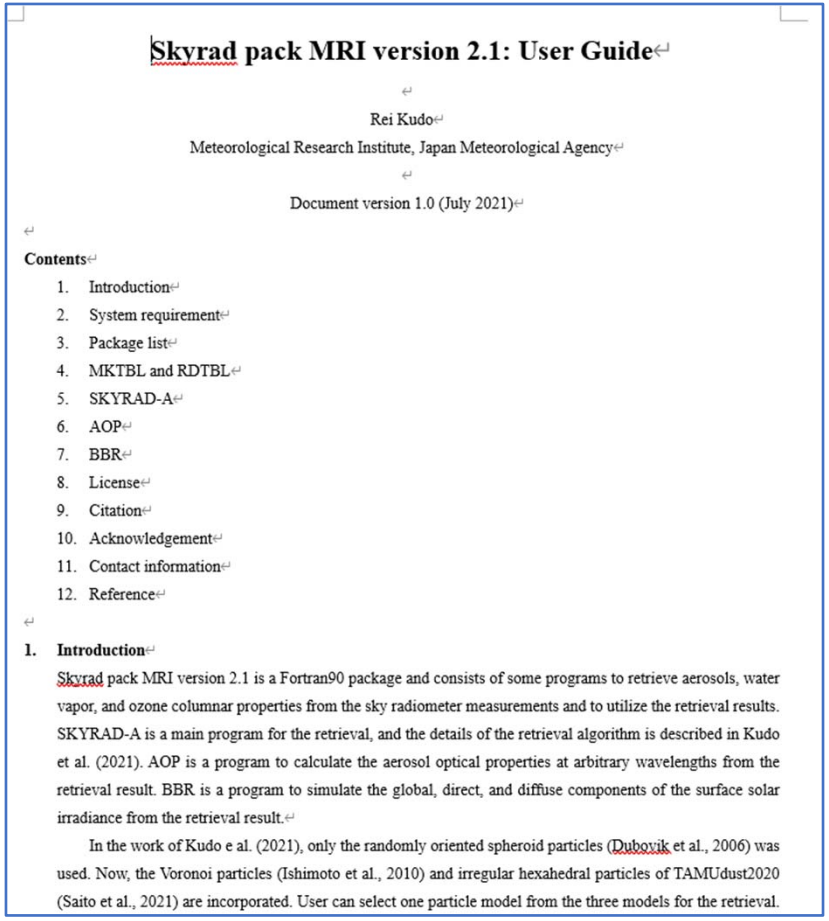
- Skyrad pack MRI v2 was developed.
- MR v2 overcomes the problems of SD and SSA of the previous methods.
- Radiative closure of the surface solar irradiance was confirmed.
- For Saharan dust, the good agreements with aircraft in-situ measurements were obtained.

Software of MRI Version 2

- MRI v2 works on Linux and Windows platforms with free Fortran compilers (Intel oneAPI and GNU Fortran).

- If you would like to use MRI v2, please contact me.

reikudo@mri-jma.go.jp



Skyrad pack MRI version 2.1: User Guide

Rei Kudo
Meteorological Research Institute, Japan Meteorological Agency

Document version 1.0 (July 2021)

Contents

1. Introduction

Skyrad pack MRI version 2.1 is a Fortran90 package and consists of some programs to retrieve aerosols, water vapor, and ozone columnar properties from the sky radiometer measurements and to utilize the retrieval results. SKYRAD-A is a main program for the retrieval, and the details of the retrieval algorithm is described in Kudo et al. (2021). AOP is a program to calculate the aerosol optical properties at arbitrary wavelengths from the retrieval result. BBR is a program to simulate the global, direct, and diffuse components of the surface solar irradiance from the retrieval result.

In the work of Kudo e al. (2021), only the randomly oriented spheroid particles (Dubovik et al., 2006) was used. Now, the Voronoi particles (Ishimoto et al., 2010) and irregular hexahedral particles of TAMUdust2020 (Saito et al., 2021) are incorporated. User can select one particle model from the three models for the retrieval.


Thank you!
2021/10/28 16:30:18
Tsukuba