Analysis of shortwave spectrometry of cloudy atmospheres during MAGIC

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Radiation Instruments

Solar Array
Spectrophotometer

SAS-Ze

CIMEL Sunphotometer
operated in cloud mode

CIMEL

Solar Spectral Flux Radiometer
FOV: 2.8^o
Spectral range: 350-1700 nm
Frequency 1 Hz

SSFR

Same family (NASA Ames) as the
Shortwave Spectradiometer (SWS) at SGP

Motivation

- MAGIC's time-resolved hyperspectral measurements reveal details of cloud structure as well as cloud - aerosol interactions.

- Retrievals of cloud and aerosol properties depend on accuracy of radiance measurements.

- Analysis of differences (uncertainties) in radiation measurements and sensitivity of the retrieval methods to these uncertainties is required.

Comparison Methods

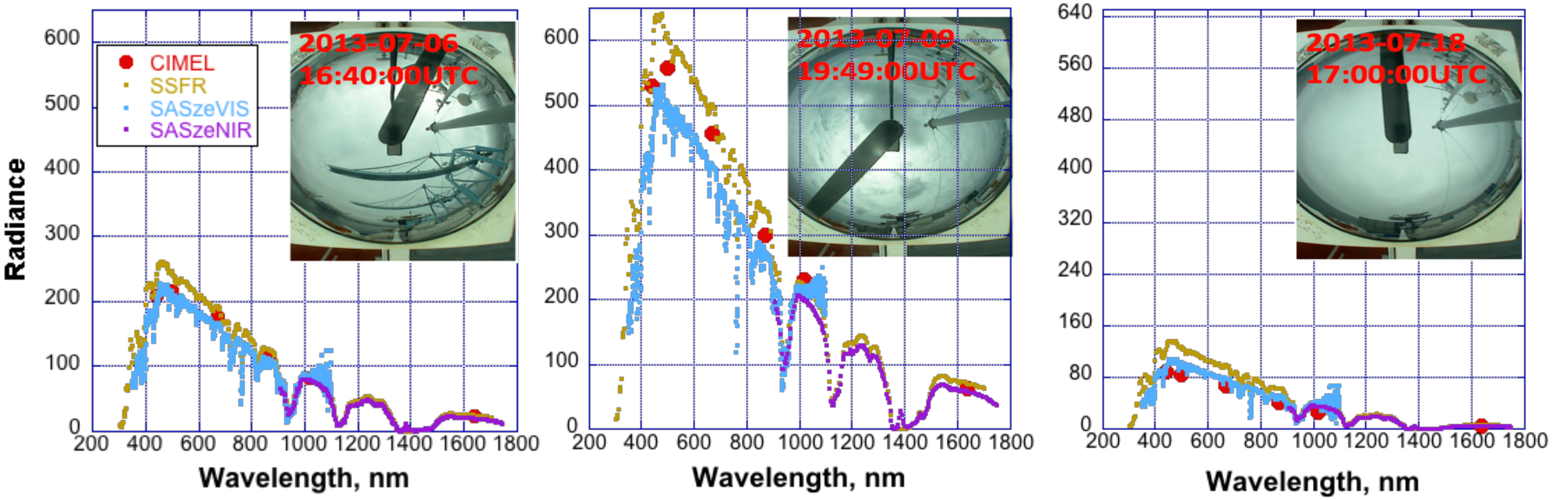
- Zenith radiance measurements from three instruments: SSFR, SAS-Ze and CIMEL are compared and analyzed.

- Several overcast cases are used in the comparison.

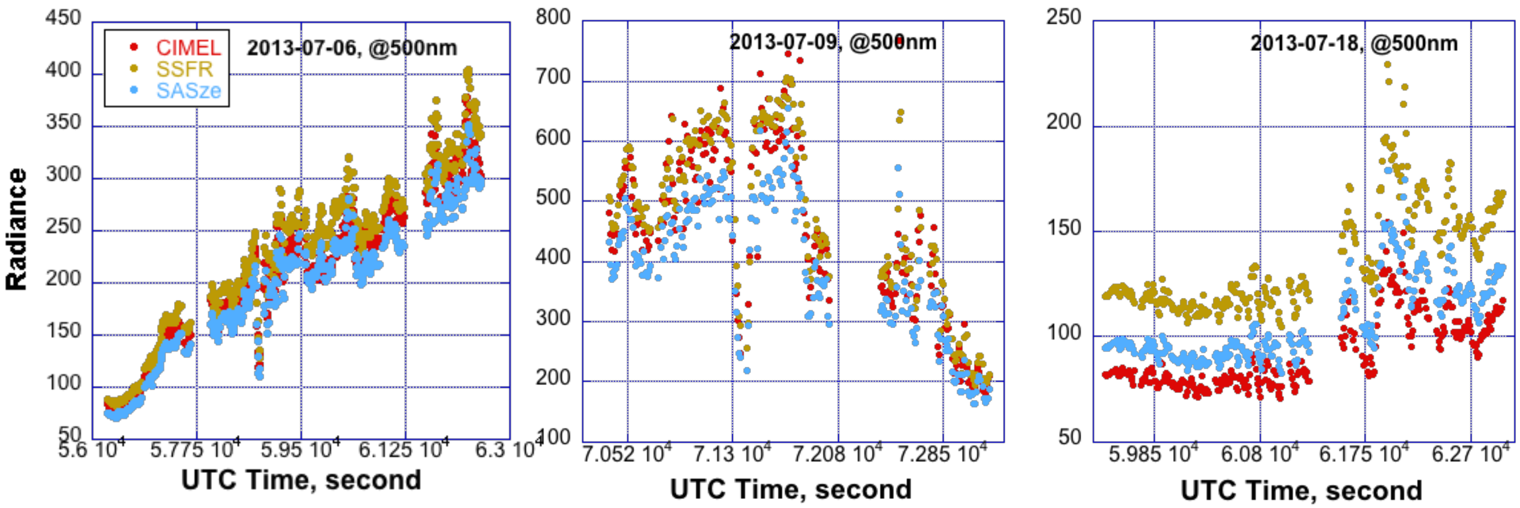
- In comparison with CIMEL, values from SSFR and SAS-Ze are averaged within ± 5s of CIMEL sampling times and ±5nm of CIMEL wavelengths.

Three overcast cases

Spectra at time *T*

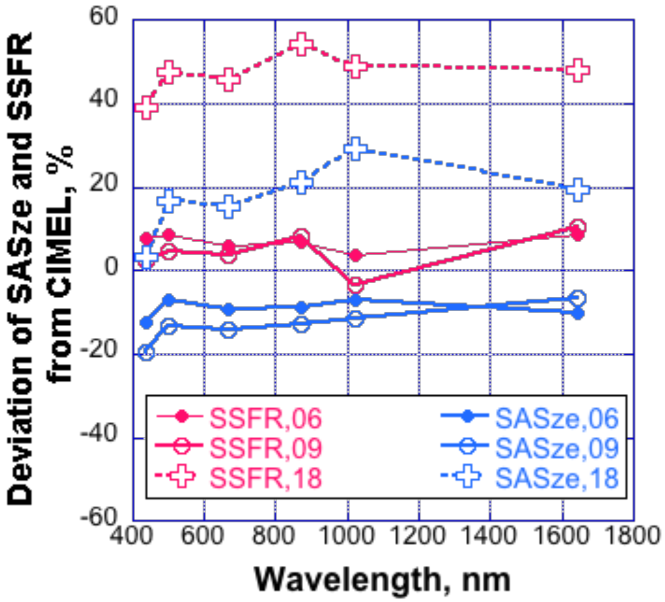


Time-series at 500 nm

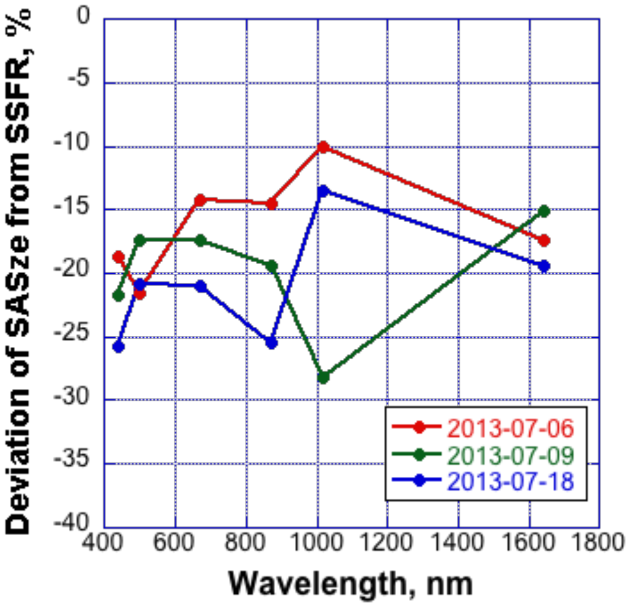


Analysis of deviations between SSFR, SAS and CIMEL

SAS/FSSR-CIMEL (in %)



SAS-FSSR (in %)



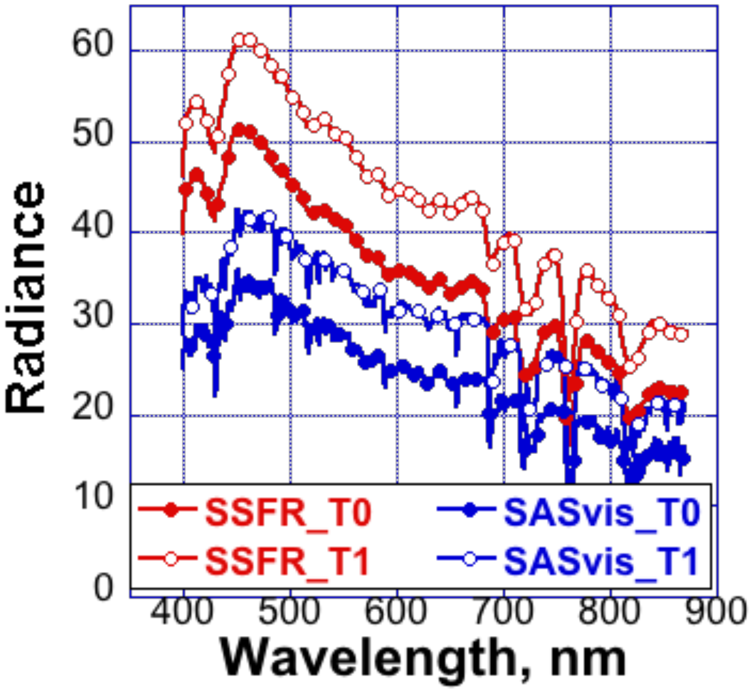
- In the 'good' cases, SSFR is higher than CIMEL by ~10%, while SASze is smaller than CIMEL by 10-20%;

- Deviations of SSFR and SASze from CIMEL have weak spectral dependence;

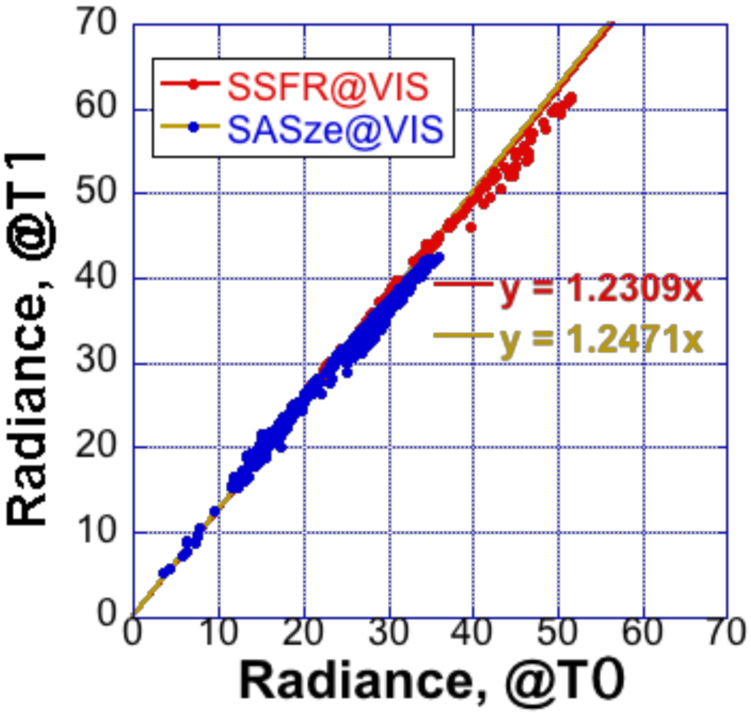
- The differences between SASze and SSFR are between 10% and 30%;

- In the 'bad' cases, deviations of both SSFR and SASze from CIMEL are large, but the differences relative to each other are comparable to the 'good' cases.

Spectral ratios as a linear approximation between two different times



Spectra of SSFR (red) and SAS (blue) measured at time T0 and T1

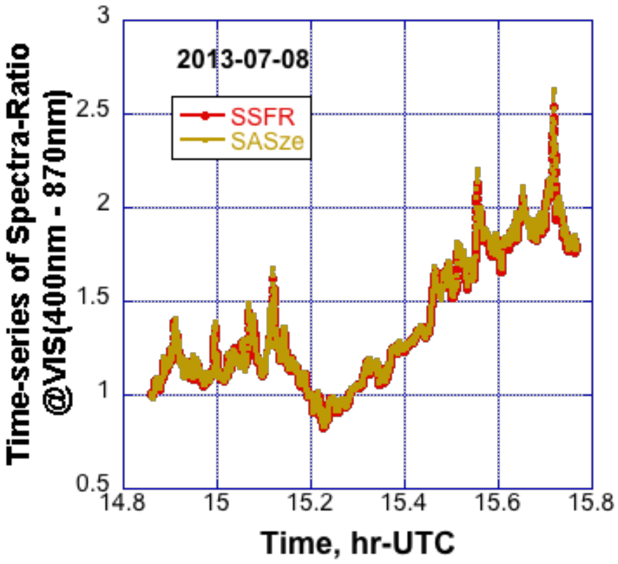


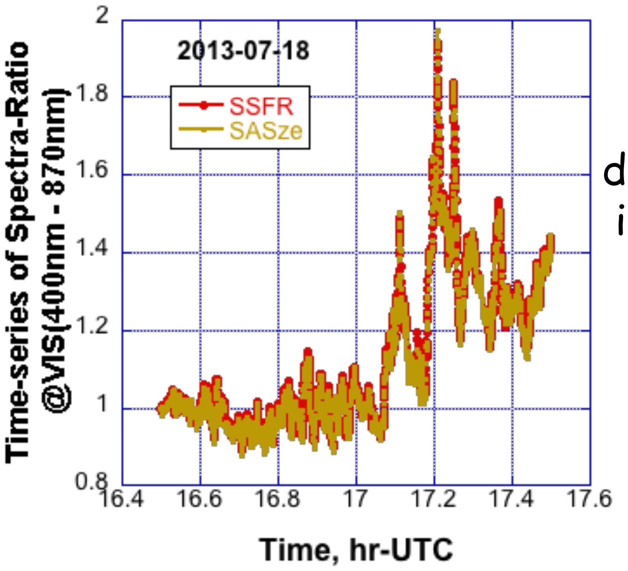
Linear-fit slopes of R(T1) vs. R (T0) for both instruments. The slopes are very close.

Comparison of spectral ratios

$\text{Radiance}(\lambda,t)/\text{Radiance}(\lambda,t_0)$

Small differences in spectral radiances





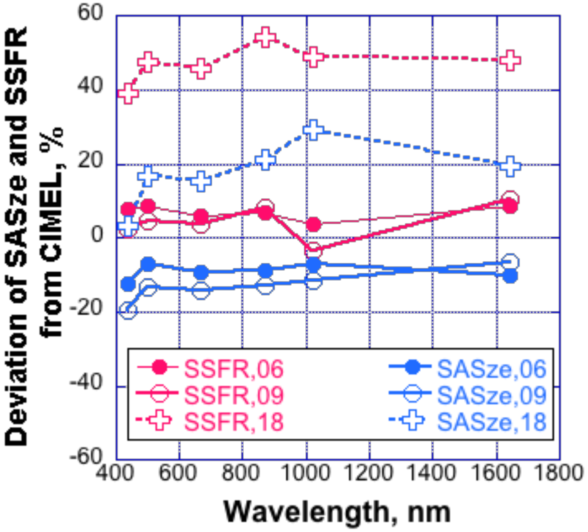
Large differences in spectral radiances

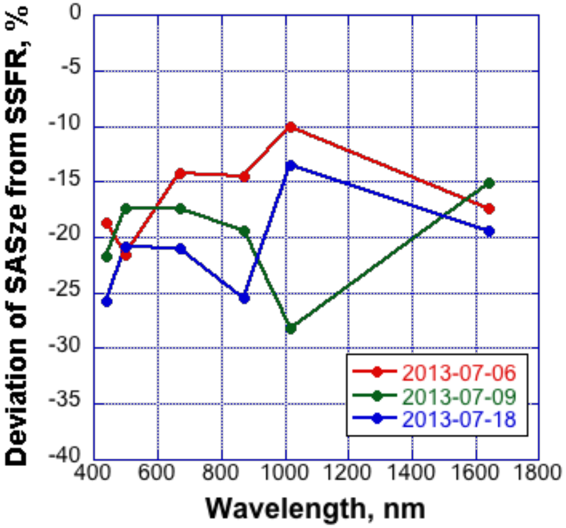
The 'self-normalized' spectra of SSFR and SAS are in *unison* though their radiances can be very different.

Hence retrievals and analysis of cloud/aerosol properties based on 'self-normalized' spectra are more reliable than using radiances directly

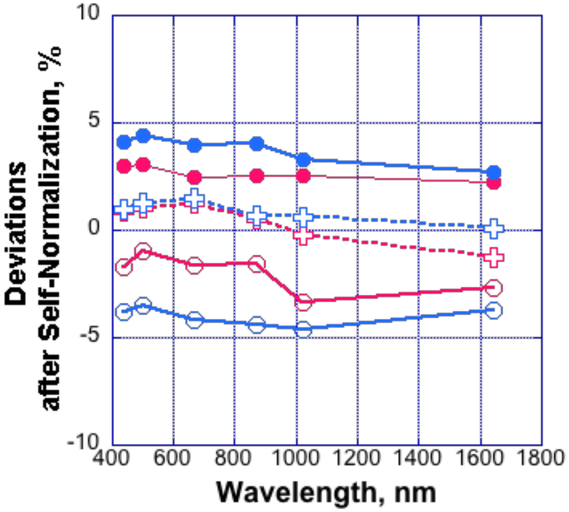
Spectral difference between instruments: before and after self-normalization

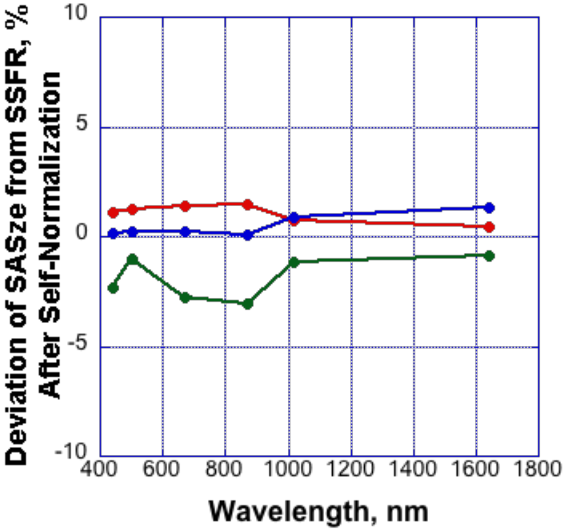
Before



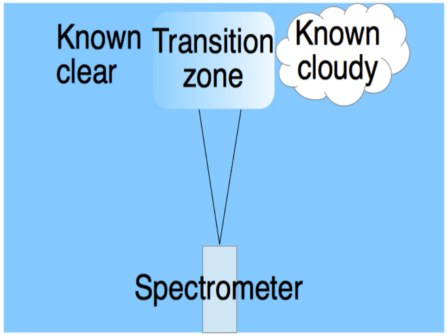


After





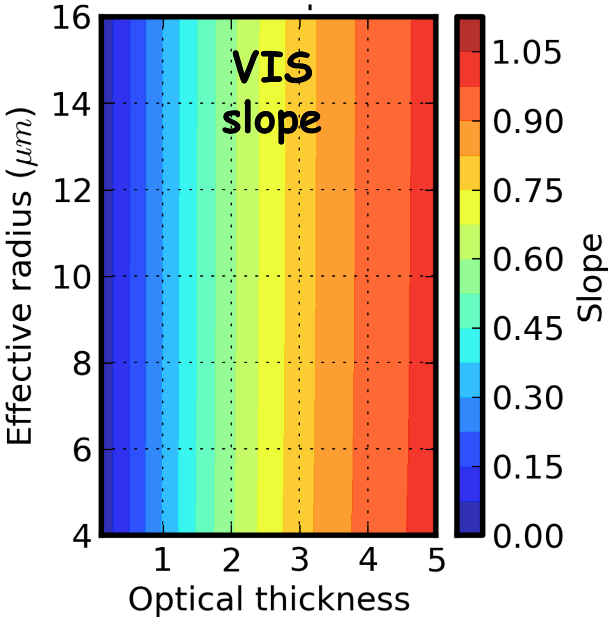
Understanding of cloud properties in the transition zone

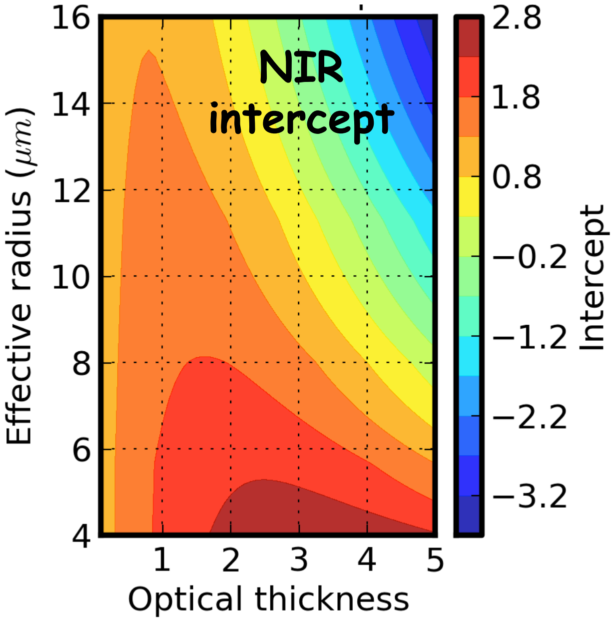


$$R_{transition}(\lambda) \approx aR_{cloudy}(\lambda) + bR_{clear}(\lambda)$$

$$\frac{R_{transition}(\lambda)}{R_{clear}(\lambda)} \approx a\frac{R_{cloudy}(\lambda)}{R_{clear}(\lambda)} + b$$

$$Y_{\lambda} \approx aX_{\lambda} + b$$

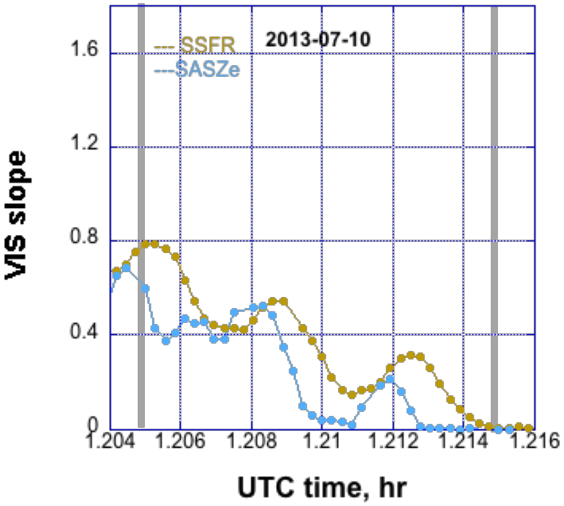


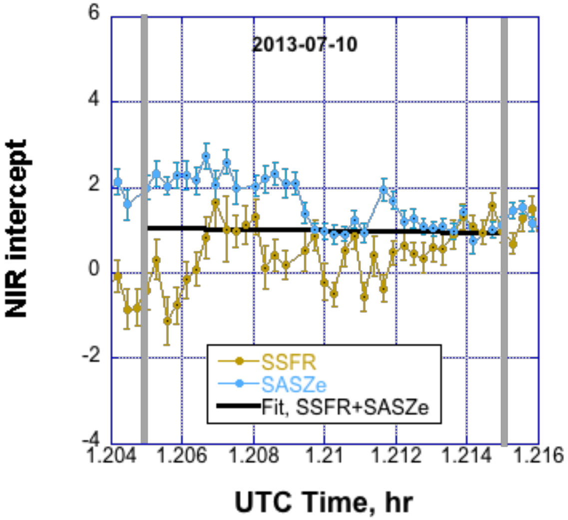


Slope *a* (for VIS) and intercept *b* (for NIR) contain information of cloud optical depth and droplet size.

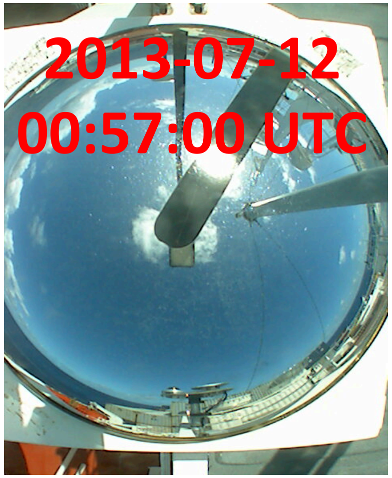
Transition zone between cloudy and clear air

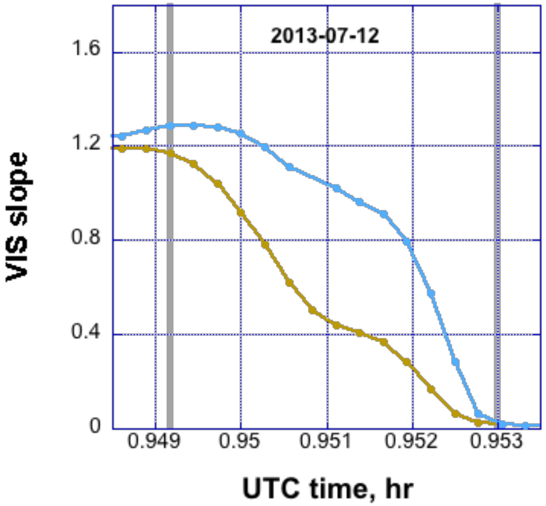
$$\frac{R_{transition}(\lambda,t)}{R_{clear}(\lambda)} = a(t)\frac{R_{cloudy}(\lambda)}{R_{clear}(\lambda)} + b(t)$$

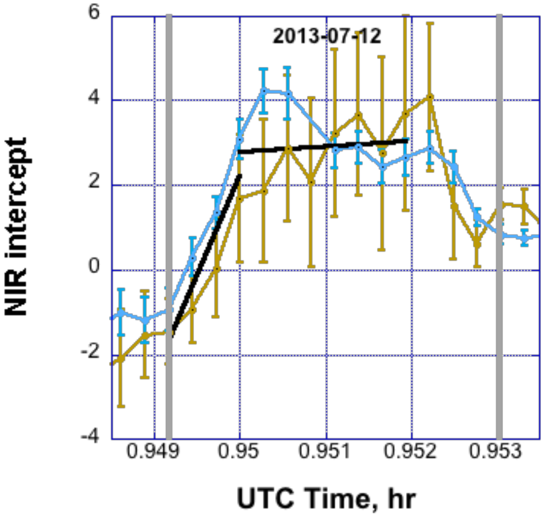




43 sec







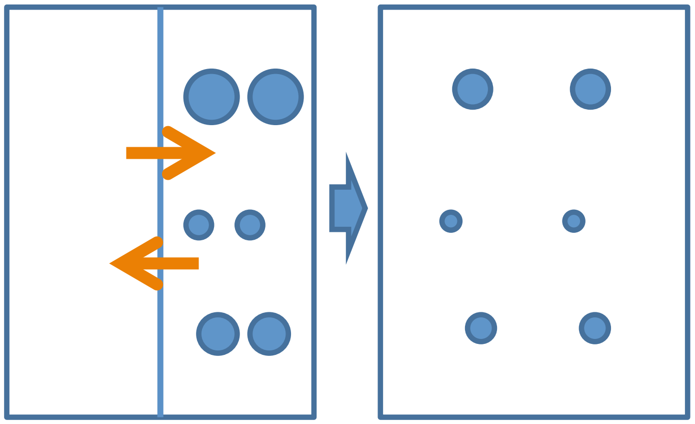
18 sec

Transition zone between cloudy and clear air

$$\frac{R_{transition}(\lambda,t)}{R_{clear}(\lambda)} = a(t)\frac{R_{cloudy}(\lambda)}{R_{clear}(\lambda)} + b(t)$$

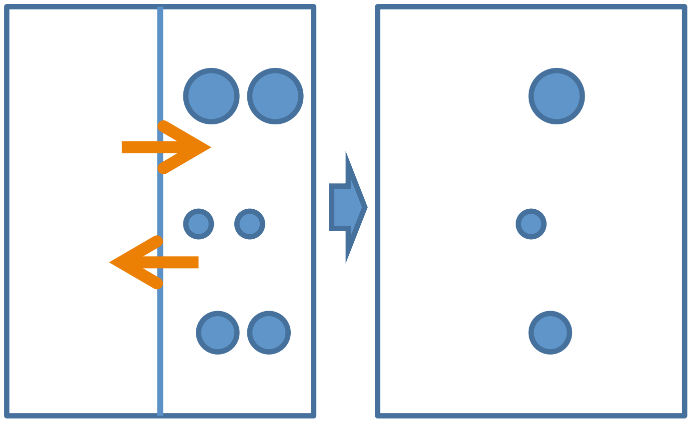
The consistency of the slopes and intercepts for two instruments tells us that the algorithm relying on the spectral ratios is not sensitive to different instruments and yield reliable results.

Two limiting scenarios in cloud and air mixing



Homogeneous Mixing
Drier air penetrates the cloud before cloud drop evaporates.

Reduction in size of *all* droplets but no substantial change in the number of cloud droplets.



Inhomogeneous Mixing
Cloud drop evaporates before dry air penetrates the entirety of the cloud.

Reduction in the droplet number concentration for droplets of *all* sizes but no change in the cloud drop spectrum.

e.g. Baker et al. (1980); Baker and Latham (1982); Lehmann et al., (2009); Lu et al., (2013)

Summary

- Differences in radiance measurements of the three radiation instruments (SSFR, SAS and CIMEL) can be large but spectral dependence of the differences is weak.
- The 'self-normalized' spectra are well consistent between SSFR and SAS.
- Analysis and retrievals of cloud properties based on the slopes and intercepts of the spectral invariance approach are robust.
- Analyzing the SAS and SSFR measurements of the cloud/clear transition zone during MAGIC, we found that inhomogeneous mixing dominates (no substantial changes in cloud drop size) near cloud edges.

Thank you

Reference details

Baker, M. B., Latham, J.,1982. A diffusive model of the turbulent mixing of dry and cloudy air. Q.J.R. Meteorol. Soc., 108: 871–898.

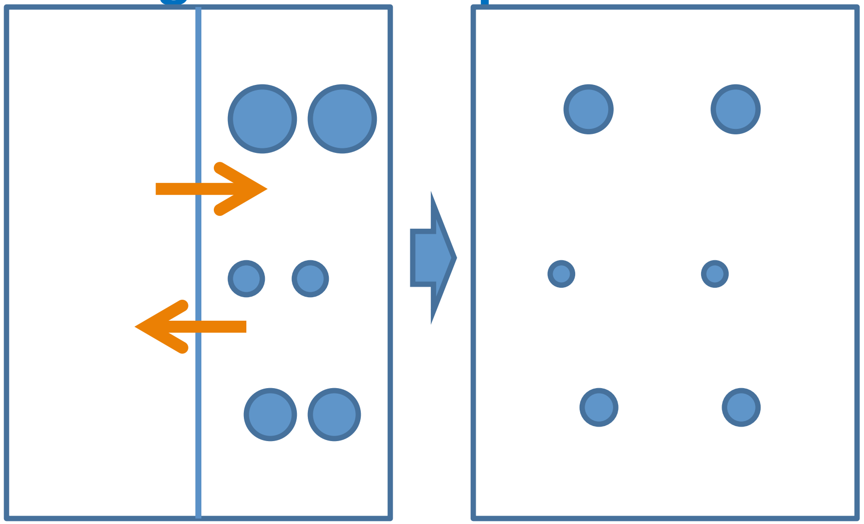
Baker, M. B., Corbin, R. G., Latham, J., 1980. The influence of entrainment on the evolution of cloud droplet spectra: I. A model of inhomogeneous mixing. Q.J.R. Meteorol. Soc., 106: 581–598.

Lehmann, K., Siebert, H., Shaw, R. A., 2009. Homogeneous and inhomogeneous mixing in cumulus clouds: Dependence on local turbulence structure, J. Atmos. Sci., 66, 3641–3659.

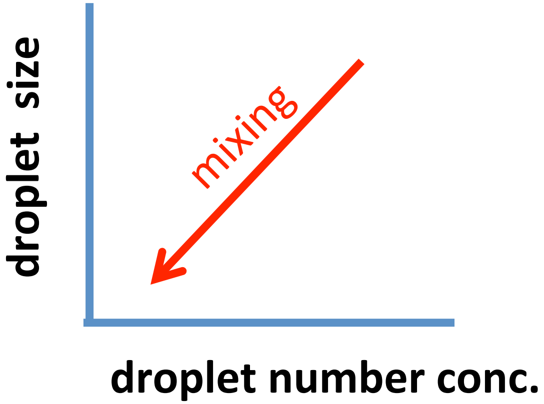
Lu, C., Liu, Y., Niu, S., Krueger, S. K., Wagner, T., 2013. Exploring parameterization for turbulent entrainment-mixing processes in clouds, J. Geophys. Res. Atmos., 118, 185–194.

Homogeneous mixing

Mixing first & Evaporate later

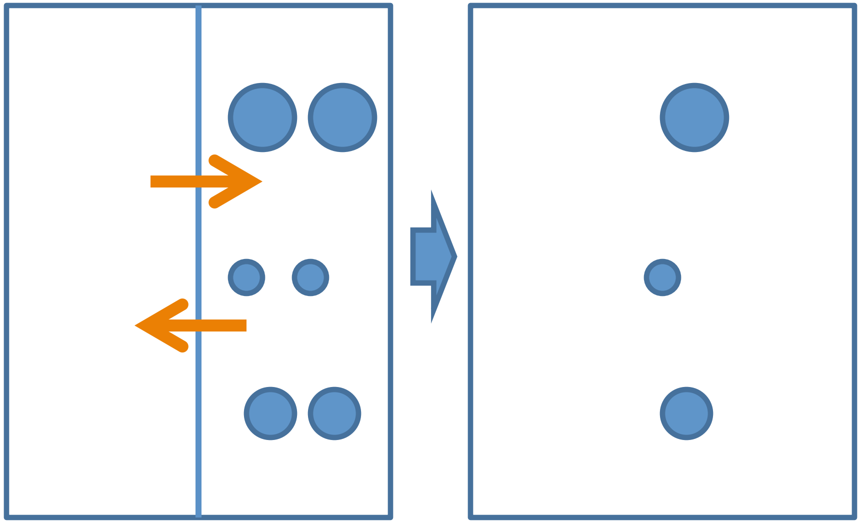


- The number concentration does not change/decreases.
- All droplets decrease their size because of evaporation

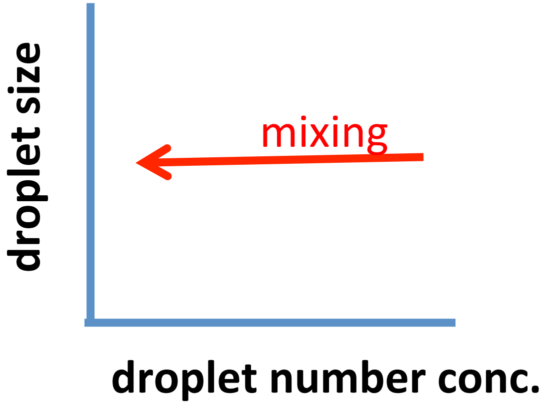


Inhomogeneous mixing

Evaporate first & Mixing later

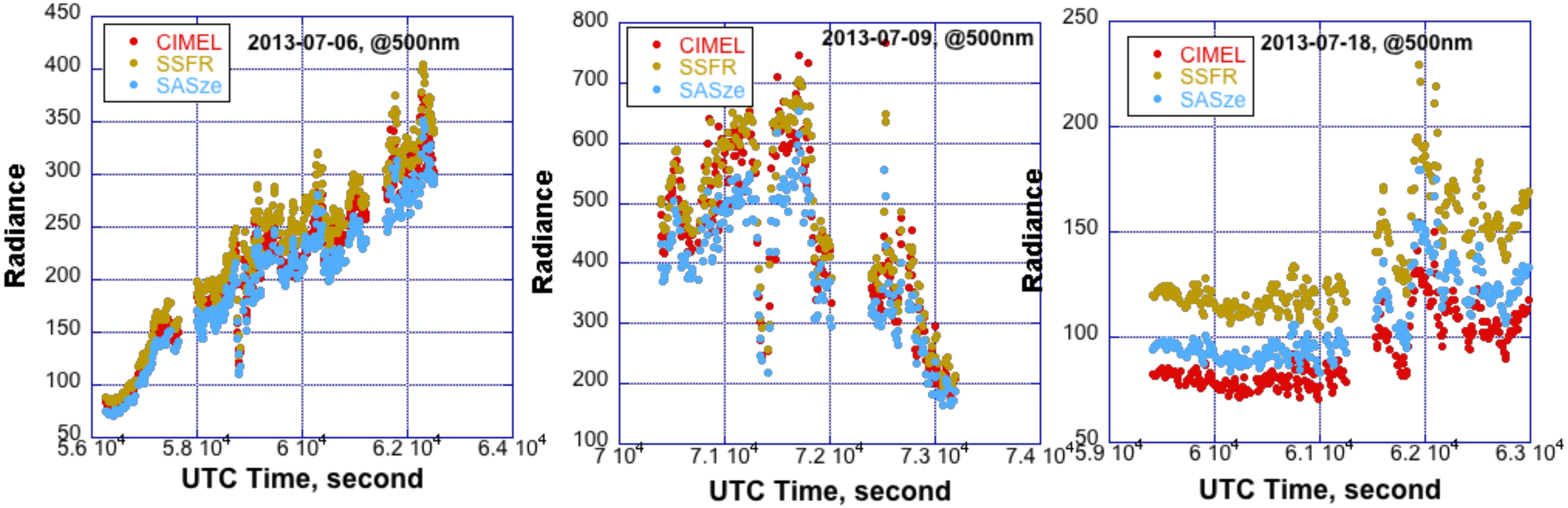


- The number concentration decreases even more.
- The surviving droplets keep their size.

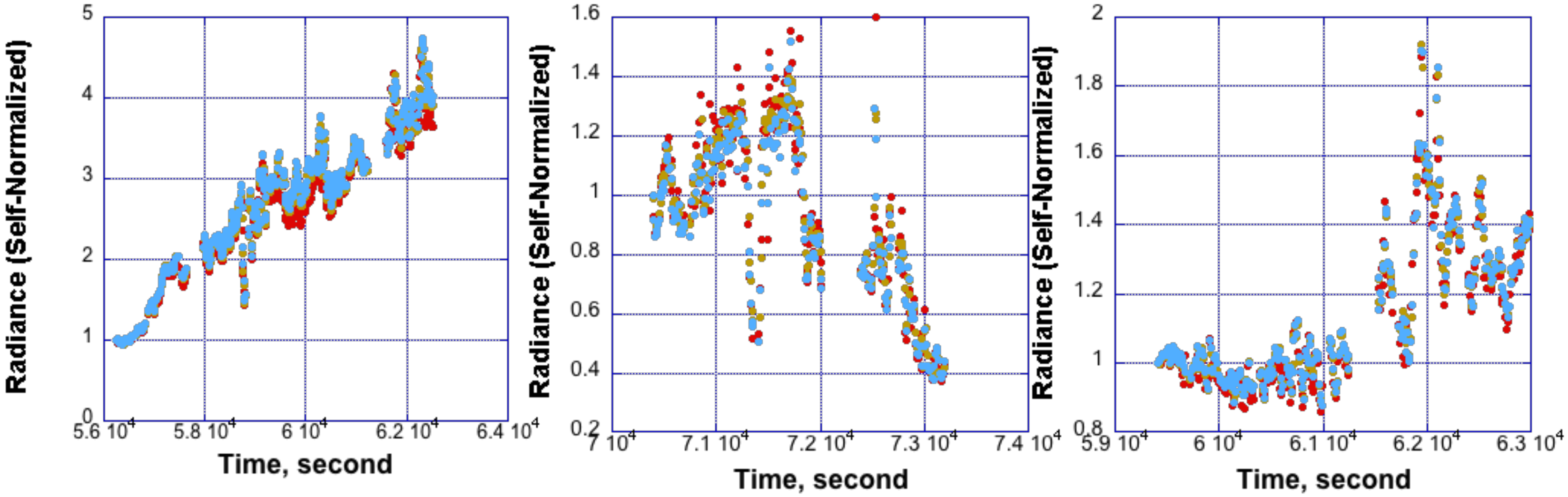


Three instruments comparison @500nm: before and after self-normalization

Before



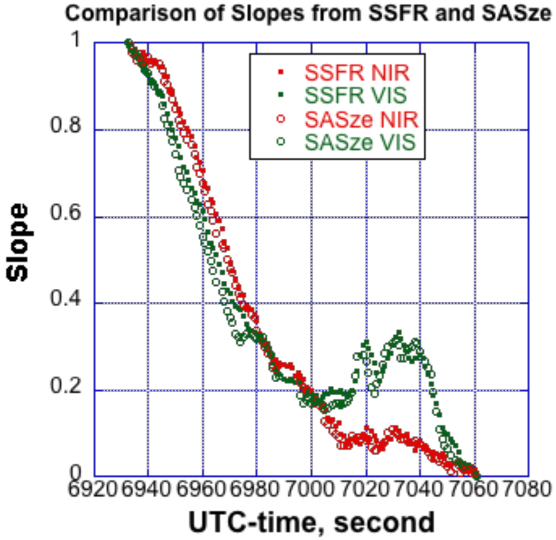
After



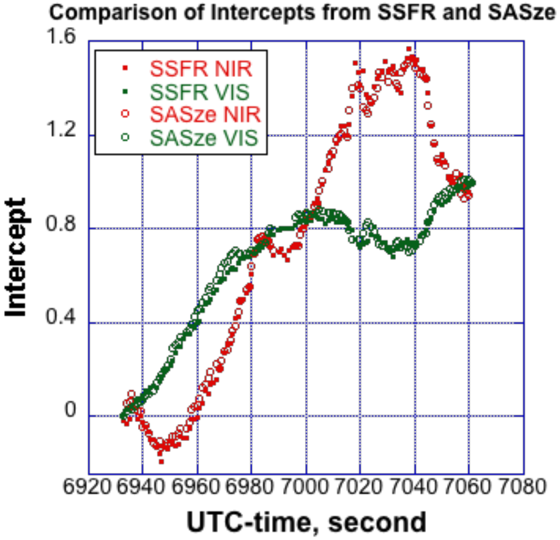
Transition zone between cloudy and clear air

$$\frac{R_{transition}(\lambda,t)}{R_{clear}(\lambda)} = a(t)\frac{R_{cloudy}(\lambda)}{R_{clear}(\lambda)} + b(t)$$

Slope $a(t)$



Intercept $b(t)$



- Slopes and intercepts in the VIS and NIR are used in the spectrally-invariant approach for understanding/retrievals of cloud properties in the transition zone (optical depth and droplet size).
- The consistency of the slopes and intercepts for two instruments tells us that the algorithm relying on the spectra ratios is not sensitive to different instruments and yield reliable results.