Direct Effect of Aerosols Deduced from CERES TRMM SSF and AERONET Observations

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J.A. Coakley, Jr. and W.R. Tahnk

College of Oceanic and Atmospheric Science
Oregon State University
Corvallis, OR 97331-5509

By linking top of the atmosphere (TOA) radiative fluxes obtained by CERES/TRMM with surface measurements of aerosol optical depths obtained with the AERONET instrument at the Kaashidhoo Climate Observatory (KCO), Satheesh and Ramanathan (2000) derived emprical estimates of the direct aerosol radiative forcing for aerosols over KCO. The goal of this study is to extend the Satheesh and Ramanathan findings to other oceanic AERONET sites. The approach uses aerosol models in combination with CERES broadband radiances and fluxes and AERONET optical depths. An aerosol model is used to retrieve optical depth from the CERES broadband shortwave radiance and then the optical depth is used to generate a diurnally averaged radiative flux. Calculations and analyses were performed using various aerosol models in order to determine the range of estimates obtained with this approach. Ultimately, the fluxes derived using this approach will be compared with those obtained using the new CERES ADMS.

Estimates of aerosol burdens derived from satellite radiances are sensitive to the aerosol model used to link radiances with optical depths. For example, using CERES shortwave broadband bidirectional reflectances, optical depths derived for backscattered light and an average continental aerosol model (Hess et al. 1998) differ by as much as 30% from those derived using the same shortwave reflectance and the NOAA Phase 2 aerosol model (Stowe et al. 1997). The direct aerosol effect inferred from the reflected radiance, however, differ by less than 10%. This reduction in difference results from the nearly identical scattering phase functions for the two models. Even though absorption of sunlight by the average continental aerosol affects the accuracy of the retrieved optical depth obtained with the NOAA Phase-2 model, there is little difference in the direct radiative effect produced by the two models. On the other hand, when the scattering phase functions differ significantly, as is the case for the tropical marine and NOAA Phase 2 aerosol models, errors in estimates of the direct effect are comparable to those for the optical depth. The errors can be sizeable, > 50%. Unfortunately, the largest errors in the estimates of the direct effect stem from observations for the same viewing geometry that are used to retrieve the optical depths.

SSF Edition 1 for TRMM (January – August, 1998) was analyzed to obtain shortwave radiances and fluxes, along with the collocated VIRS radiances, that fell within $\pm$ 50 km of an AERONET Site for which AERONET observations provided a surface measurement of optical depth within $\pm$ 1 hr of the TRMM overpass. The SSF observations were restricted to fields of view for which retrievals of aerosol optical depth were performed for more than 50% of the VIRS pixels within the CERES FOV. To reduce cloud contamination in the retrieved aerosol optical depths, SSF observations were further restricted by requiring that the standard deviation of the VIRS channel 1 reflectances within the CERES footprint was also small. With this additional restriction, fields of view for which aerosol optical depth retrievals were performed for only 25% of the VIRS pixels appeared to be suitable for analysis.

To verify that estimates of the TOA radiative forcing were relatively insensitive to the choice of the aerosol model, optical depths were retrieved using both the average continental and tropical marine aerosol models. The optical depths and their corresponding models were then used to estimate the diurnally averaged reflected shortwave fluxes. The diurnally averaged fluxes were combined with the AERONET observations of optical depths to derive the diurnally averaged aerosol direct effect sensitivity. For Kaashidhoo, the derived aerosol effect was –31 Wm^{-2} per unit optical depth at 0.5 μm for the average continental aerosol and –34 Wm^{-2} per unit optical depth for the tropical marine aerosol. With the additional screening for cloud contamination, these sensitivities dropped to –24 and –28 Wm^{-2}. Satheesh and Ramanathan (2000) reported –25 Wm^{-2}. The direct effect for Kaashidhoo is similar to that obtained for Dry Tortugas in the Gulf of Mexico. The sensitivity is approximately equivalent to that of a polluted continental aerosol, like that observed during INDOEX. For Bermuda and San Nicolas Island, the direct effect sensitivities are much larger, with cloud-screened values ranging from – 60 to – 70 Wm^{-2}. Such large values are possible only for small, nonabsorbing aerosols.

Optical depths retrieved using the broadband, shortwave reflectances were also compared with those obtained by AERONET. Comparisons between the SSF optical depths and those derived using the CERES broadband radiances with the AERONET observations were comparable.

These results are still plagued by the small number of fields of view that meet all the criteria for aerosol retrievals and collocation with AERONET observations. We intend to check our collocations against those using the subset SSF observations constructed by Norman Loeb and the ADM Working group. Trends in retrieved optical depths with solar reflectance angle have been observed. Work is underway to include effects due to the angular dependence of the surface reflectance in the retrievals of optical depths and the estimates of the radiative fluxes. The fluxes generated here will also be compared with those generated using the new CERES ADMs.

References

Hess, M., P. Koepke, and I. Schult, 1998: Optical properties of aerosols and clouds: The software package OPAC. *Bull. Amer. Meteor. Soc*. **79**, 831-844.

Satheesh, S.K. and V. Ramanathan, 2000: Large differences in tropical aerosol forcing at the top of the atmosphere and Earth's surface. *Nature*, **405**, 60-63.

Stowe, L.L., A.M. Ignatov, and R.R. Singh,. 1997: Development, validation, and potential enhancements to the second-generation operational aerosol product at the National Environmental Satellite, Data, and Information Service of the National Oceanic and Atmospheric Administration. *J. Geophys. Res*., **102**, 16,923-16,934.

Aerosol Direct Effect from CERES and AERONET Observations

J. A. Coakley, Jr. and W.R. Tahnk

College of Oceanic and Atmospheric Sciences

Oregon State University

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GOAL: **Deduce aerosol direct effect using CERES SSF radiances and AERONET optical depths following Satheesh and Ramanathan (2000).**

Motivation

- Results obtained during INDOEX suggested that relationship between broadband and narrowband radiances were relatively insensitive to the aerosol model used to generate the radiances.

- What errors might be incurred by using an arbitrary model to deduce aerosol direct effects from CERES broadband radiances?

- How might direct effect estimated by Satheesh and Ramanathan change with location and season?

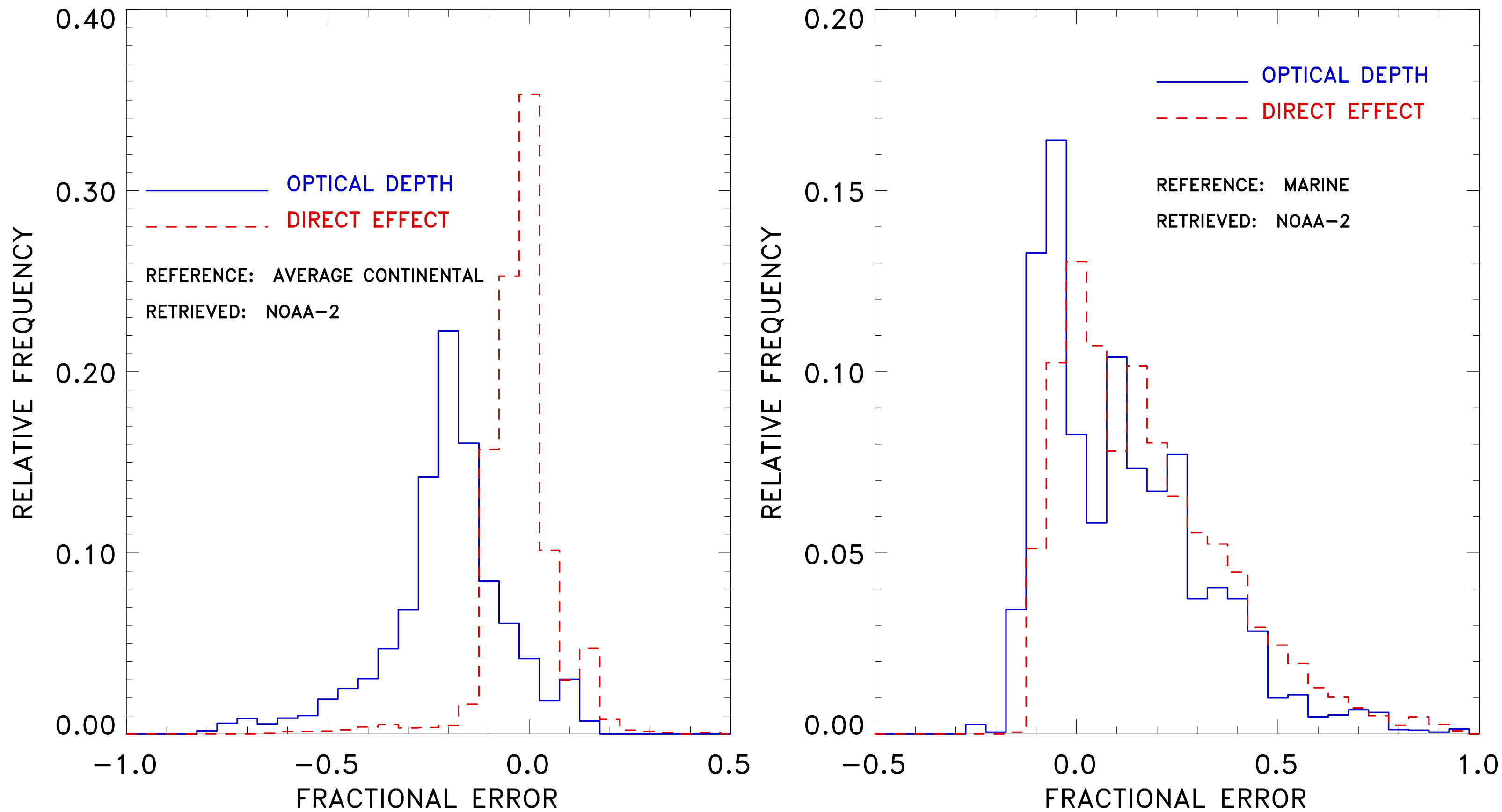
Method

- Use broadband radiances to retrieve aerosol optical depth for cloud-free CERES FOVs.

- Use retrieved optical depth to deduce aerosol direct effect:

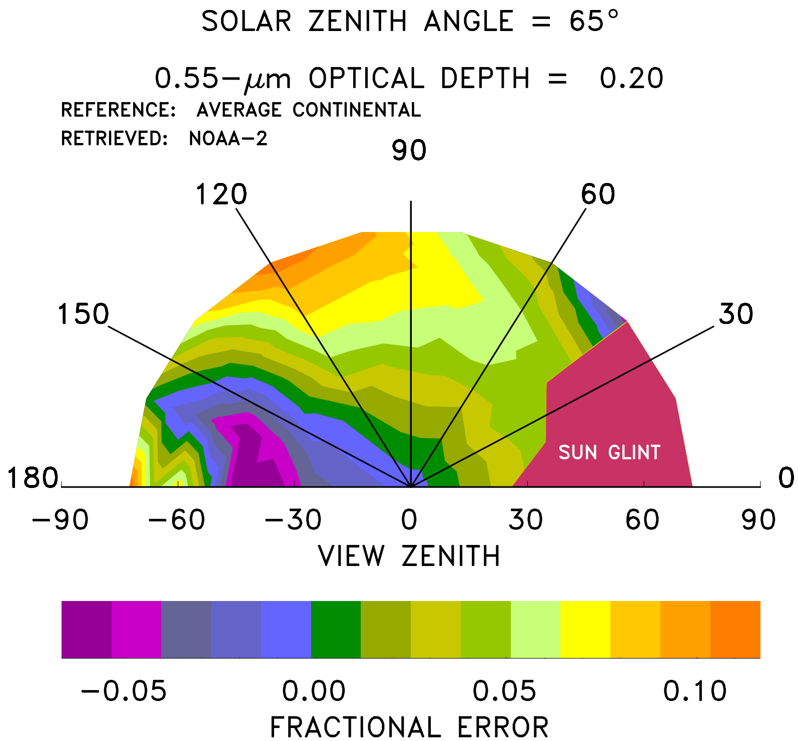
Direct Effect = Cloud-Free Net Radiative Flux –
Aerosol-Free Net Radiative Flux

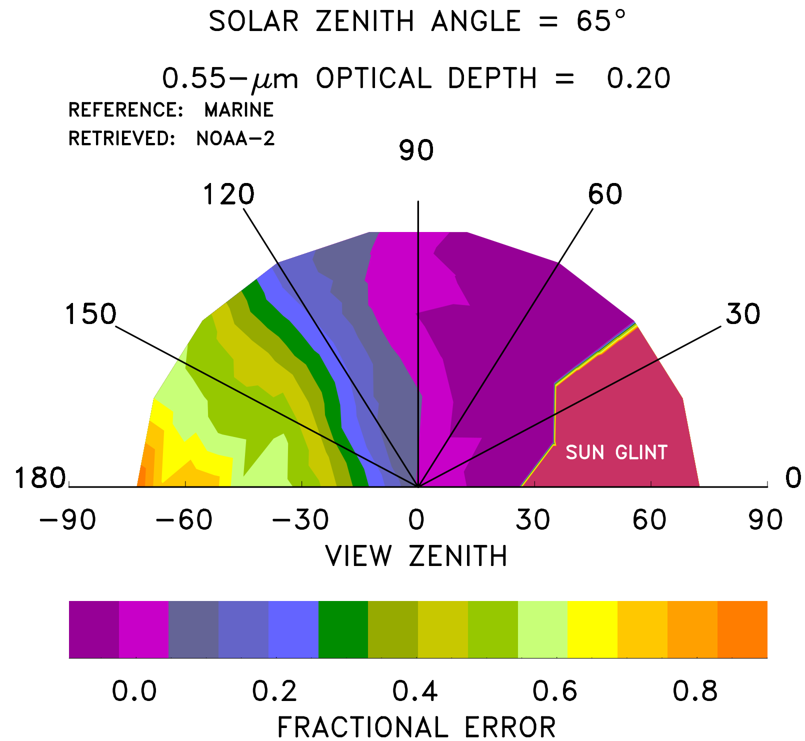
Compensation of Errors



Radiances and radiative fluxes generated using marine and average continental aerosol models. Optical depths and aerosol direct effect derived using NOAA Phase 2 model. Results are for viewing geometries used to retrieve aerosol optical depths: solar reflection angle > 40°, relative azimuth > 90°, and for $0.1 < \tau < 0.9$.

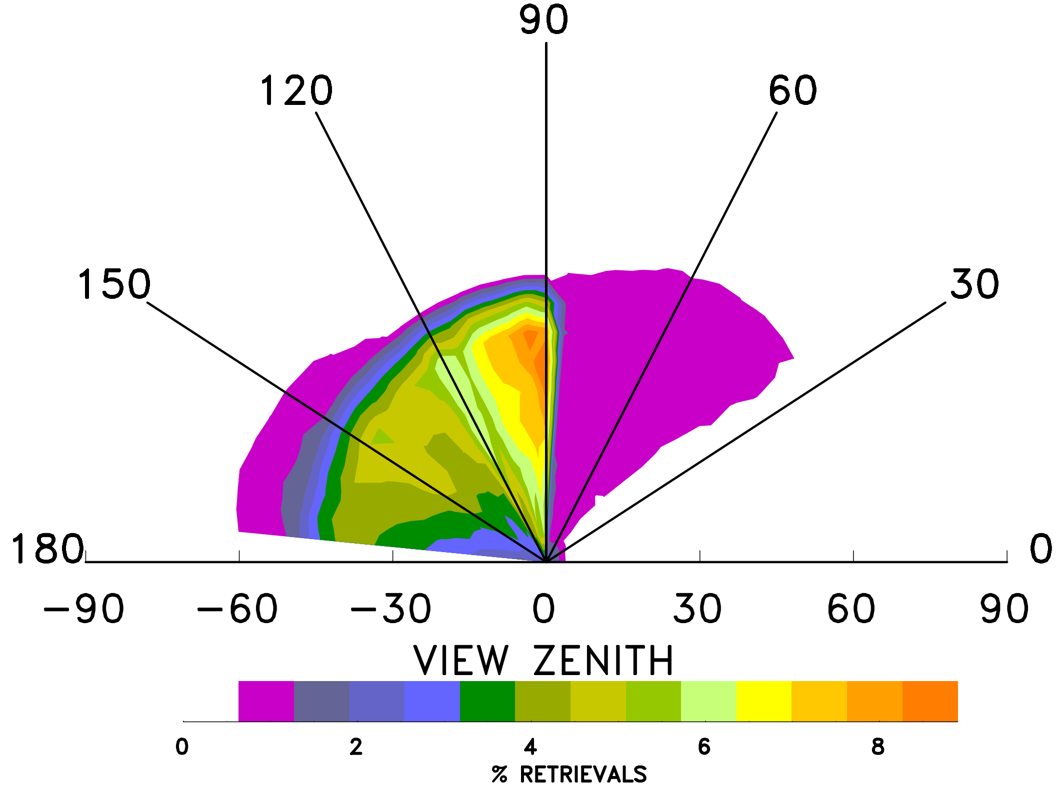
Fractional Errors in Direct Effect and Viewing Geometry





Radiances and Radiative fluxes calculated using average continental and marine aerosol models. Optical depths and aerosol direct effect derived using NOAA Phase 2 model. Results are for an aerosol with a 0.55-µm optical depth of 0.2.

Viewing Geometries for SSF Aerosol Optical Depth Retrievals



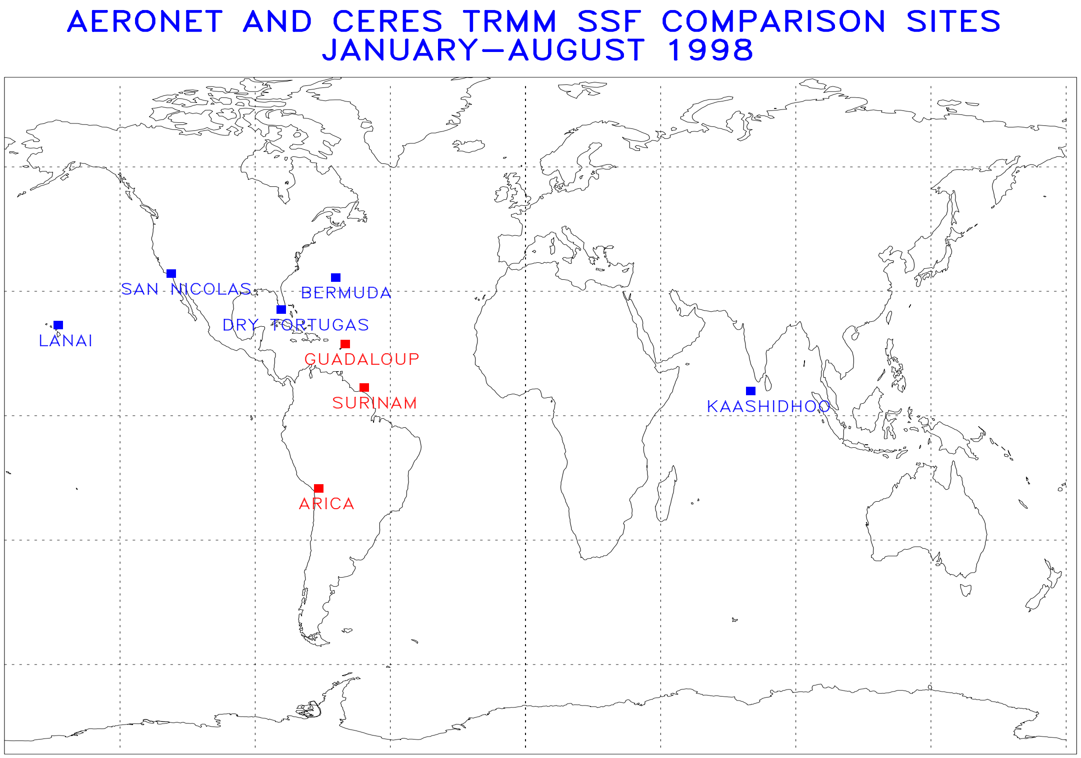
Viewing geometries for SSF aerosol optical depth retrievals, January-March 1998.

Lessons Learned….

- For Top-of-the-Atmosphere direct effect, errors in retrieved aerosol optical depths can compensate for errors in aerosol properties to produce reasonable estimates of direct effect, e.g. an absorbing aerosol modeled with a nonabsorbing aerosol having similar scattering properties.

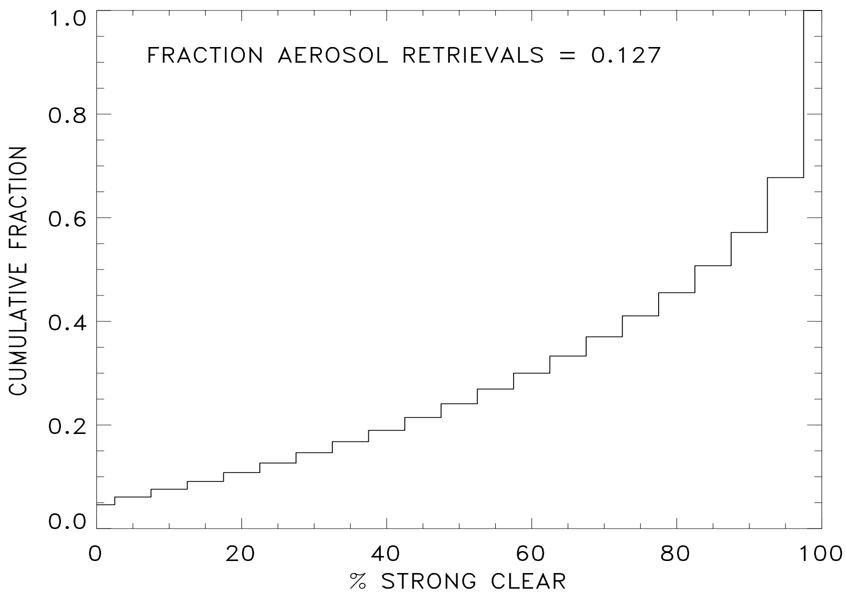
- *Nonetheless*, fractional errors in estimated direct effect can be large (50%) depending on differences in anisotropy of modeled radiances.

Collocation of SSF and AERONET Observations

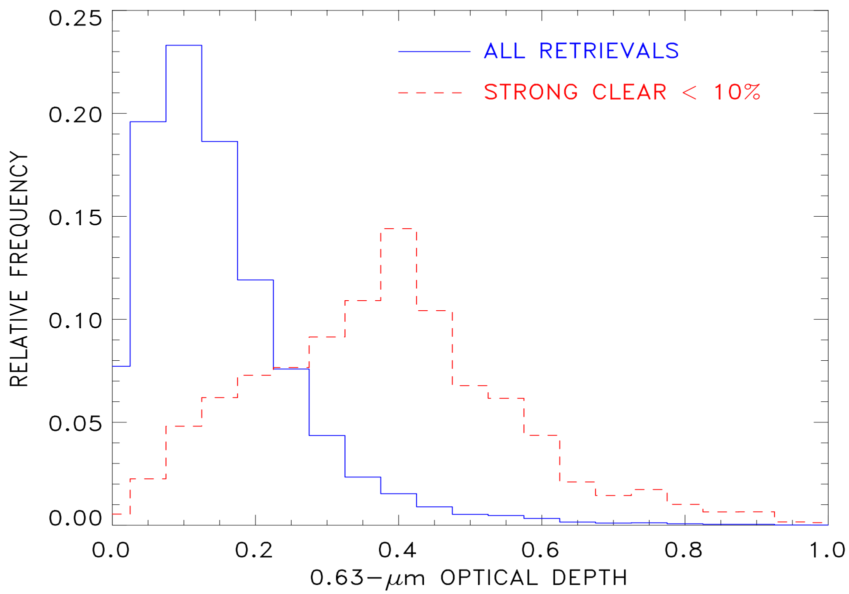


AERONET sites with matching CERES aerosol retrievals in 1998 are shown in blue. Collocations are ± 50 km and ± 1 hr.

Scene Identification for SSF Aerosol Retrievals

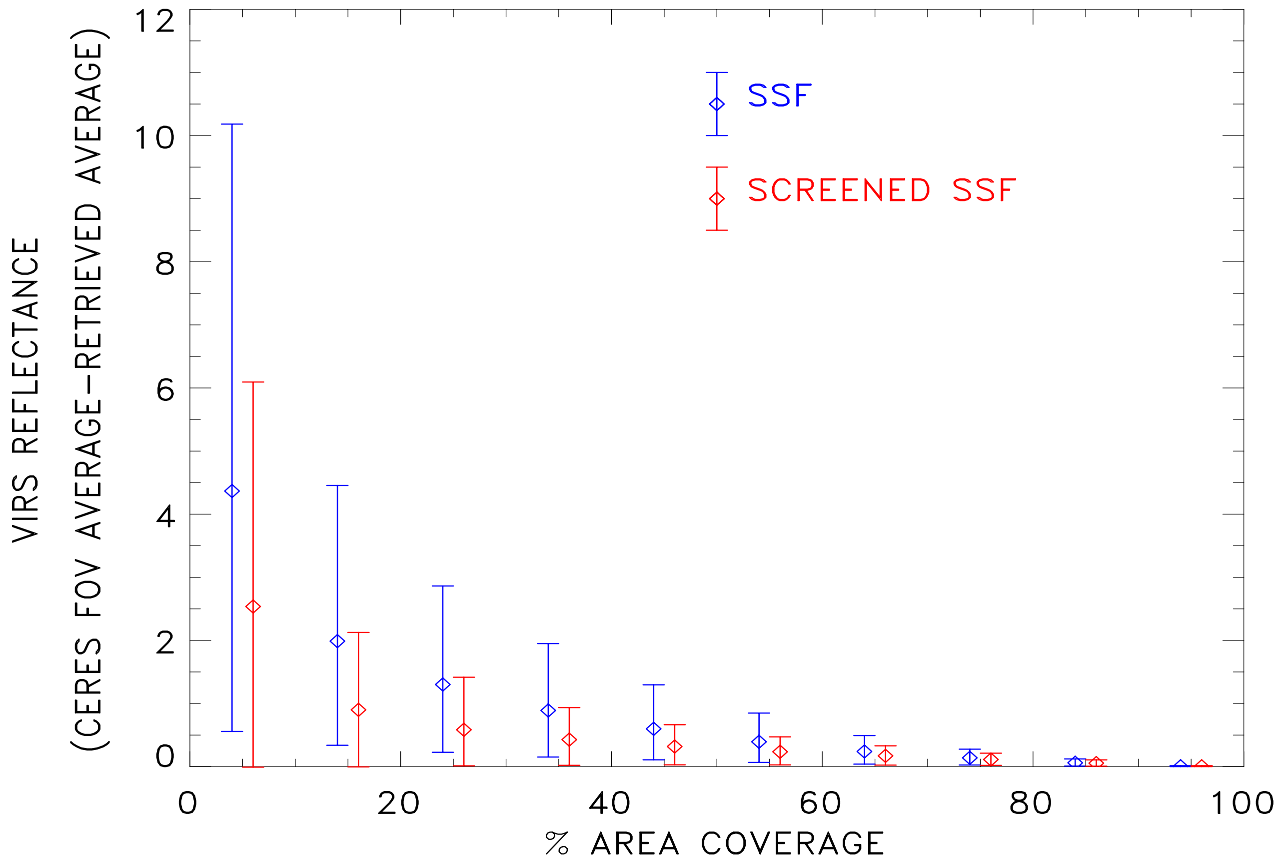


Percent area SSF CERES FOVs with aerosol optical depths covered by strong clear VIRS pixels.



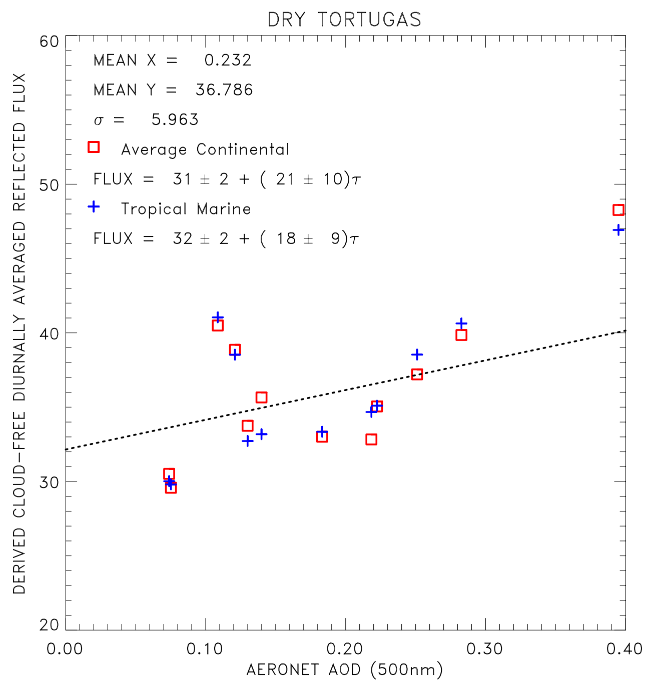
Distribution of optical depths for all retrievals and for CERES FOVs with less than 10% coverage by strong clear VIRS pixels.

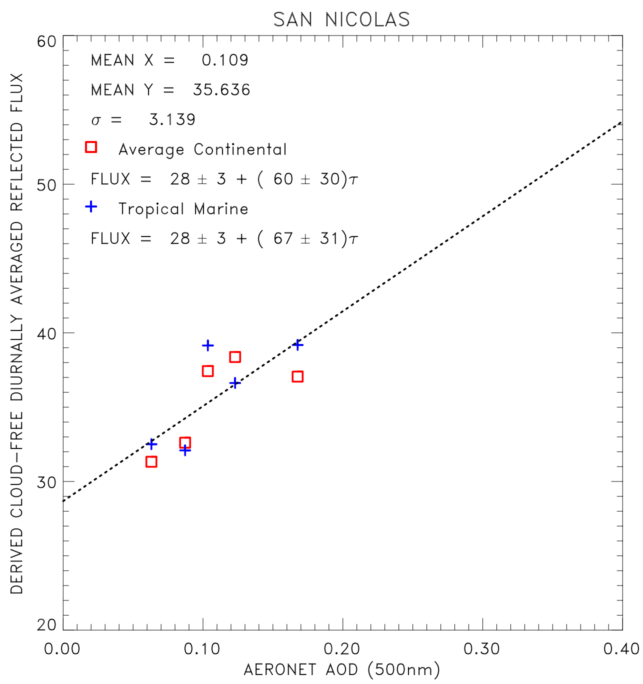
POTENTIAL CLOUD CONTAMINATION IN SSF AEROSOL RETRIEVALS



Mean, 10th, and 90th percentiles of VIRS Channel 1 (FOV average-aerosol retrieval average) reflectance for every 10% of retrieval area coverage. SSF retrievals screened using spatial uniformity for VIRS channel 1 reflectances.

Diurnally Averaged Flux and AERONET 0.5-μm Optical Depth



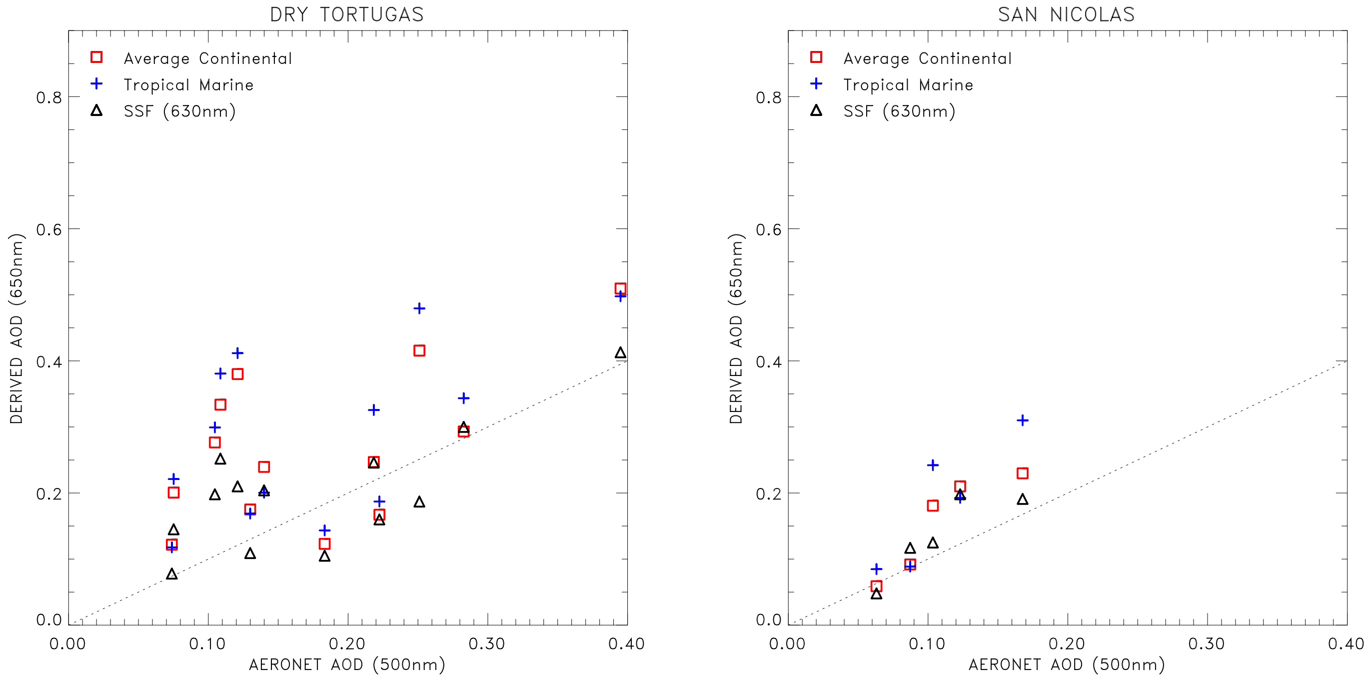


Direct effect sensitivity for Dry Tortugas similar to that of Kaashidhoo, and is similar to that for polluted continental aerosol. Sensitivity for San Nicolas Island similar to that for Bermuda and is similar to nonabsorbing aerosol with small particles. Observations are for cloud-screened SSF FOVs.

Summary of SSF-AERONET Direct Effect Estimates

Site	SSF			Cloud Screened-SSF		
	Number	Average Optical Depth	$dF/d\tau$ ($Wm^{-2}\tau^{-1}$)	Number	Average Optical Depth	$dF/d\tau$ ($Wm^{-2}\tau^{-1}$)
SAN NICOLAS						
Continental	6	0.18	49±35	5	0.15	60±31
Marine	6	0.20	69±39	5	0.18	68±32
KAASHIDHOO						
Continental	14	0.24	31±16	11	0.18	24±12
Marine	14	0.24	34±16	11	0.18	28±12
BERMUDA						
Continental	5	0.17	74±42	4	0.21	67±16
Marine	5	0.22	77±47	4	0.27	69±17
DRY TORTUGAS						
Continental	13	0.28	19±10	12	0.26	22±10
Marine	13	0.30	16±10	12	0.27	18±10
LANAI						
Continental	13	0.20	---	9	0.12	---
Marine	13	0.20	---	9	0.12	---

Retrieved 0.63-μm and AERONET 0.5- μm Optical Depths



Aerosol optical depths retrieved using broadband SSF radiances with average continental and tropical marine aerosol models compared with retrieved optical depths on SSF and AERONET 0.5-μm optical depth.

Broadband and Narrow Band Optical Depth Retrievals

	N	Average Optical Depth	Standard Deviation	BIAS	RMS	r
San Nicolas						
Continental	5	0.15	0.08	0.04	0.04	0.91
Marine	5	0.18	0.10	0.07	0.06	0.89
SSF	5	0.14	0.06	0.03	0.03	0.89
AERONET	5	0.11	0.04			
Kaashidhoo						
Continental	11	0.18	0.09	0.00	0.09	0.51
Marine	11	0.18	0.10	0.01	0.09	0.59
SSF	12	0.14	0.06	-0.02	0.06	0.70
AERONET	12	0.17	0.09			
Bermuda						
Continental	4	0.21	0.10	-0.03	0.05	0.82
Marine	4	0.27	0.11	0.03	0.06	0.81
SSF	4	0.18	0.09	-0.06	0.04	0.85
AERONET	4	0.24	0.08			
Dry Tortugas						
Continental	14	0.26	0.16	0.03	0.14	0.53
Marine	14	0.27	0.15	0.04	0.15	0.45
SSF	14	0.21	0.12	-0.02	0.13	0.56
AERONET	14	0.23	0.15			
Lanai						
Continental	9	0.12	0.08	0.05	0.08	-0.08
Marine	9	0.12	0.07	0.05	0.07	-0.02
SSF	9	0.10	0.04	0.04	0.03	0.40
AERONET	9	0.06	0.02			

Summary

- Direct effect sensitivity different for different sites.
- Cloud-screening SSF aerosol retrievals improves consistency of optical depth retrievals and estimates of direct effect.
- Accuracy of optical depths retrieved using broadband CERES radiances comparable to single channel retrievals on SSF.

Remaining Work…

- Seek more collocations.
- Add effects of sun glint to estimates of radiative fluxes and retrievals based on broadband radiances.
- Compare with estimates of direct effect obtained using new CERES ADM.