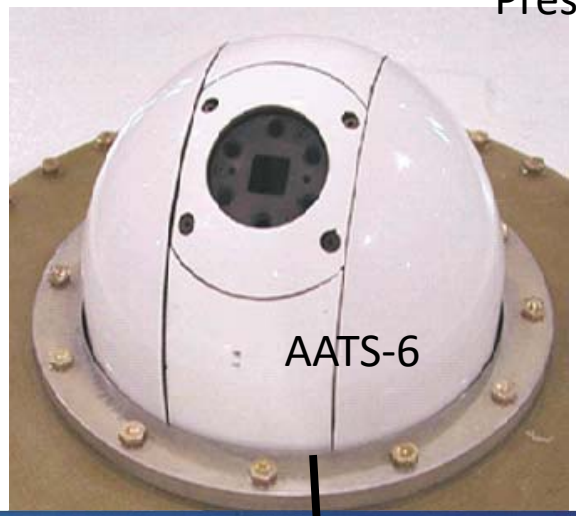
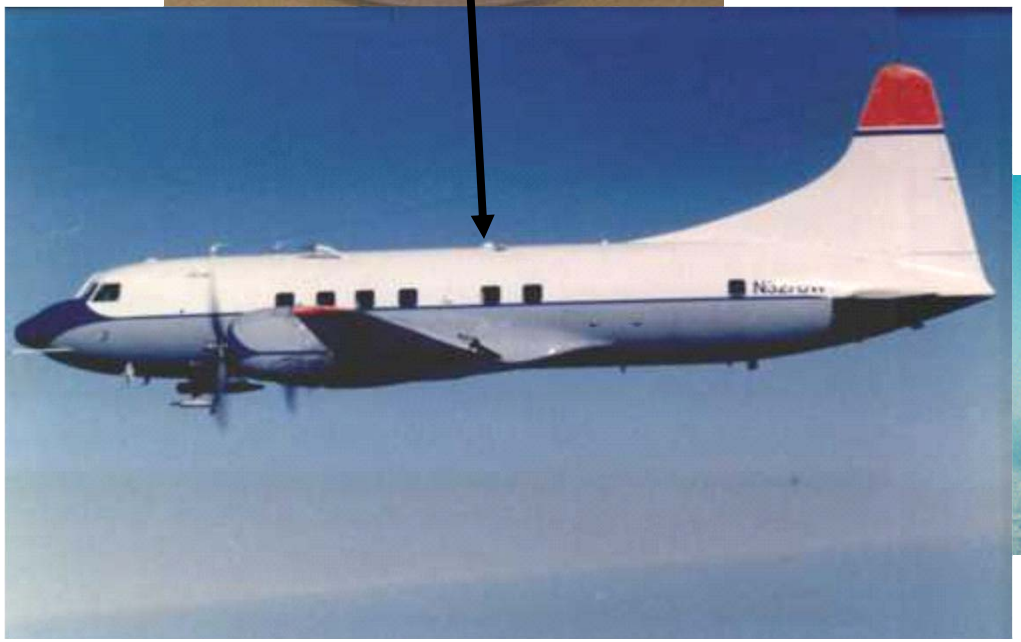
NASA Ames Airborne Tracking Sunphotometers (AATS-6 & AATS-14) and 4STAR (shown later)

NASA Ames Sunphotometer-Satellite Team
Presentation by Yohei Shinozuka





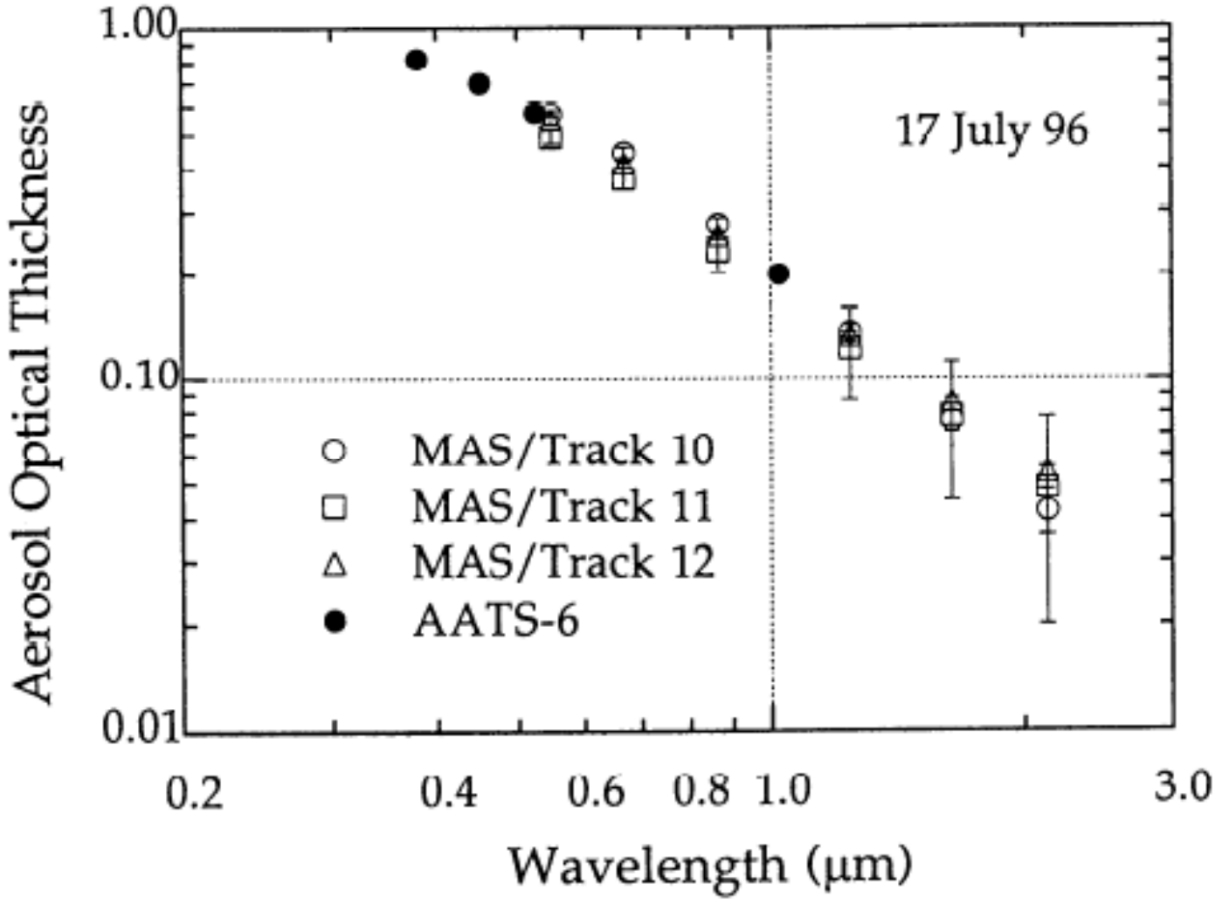
Objectives of Airborne Sunphotometers

- to validate and supplement satellite retrievals of stratospheric and tropospheric constituents (aerosols, water vapor, ozone),
- to validate airborne and ground-based lidar data products,
- to characterize horizontal and vertical distributions of gas and aerosol properties,
- to study closure with in situ samplers aboard many aircraft,
- to test chemical-transport models, and
- to study the radiative effects of atmospheric constituents and Earth surfaces that are important to both climate and remote measurements.

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 104, NO. D2, PAGES 2261–2278, JANUARY 27, 1999

Retrieval of aerosol optical thickness and size distribution over ocean from the MODIS airborne simulator during TARFOX

D. Tanré,[1] L. A. Remer,[2] Y. J. Kaufman,[2] S. Mattoo,[3] P. V. Hobbs,[4]
J. M. Livingston,[5] P. B. Russell,[5] A. Smirnov[6]



Comparison of aerosol optical properties and water vapor among ground and airborne lidars and Sun photometers during TARFOX

[JGR, 2000]

R. Ferrare,[1] S. Ismail,[1] E. Browell,[1] V. Brackett,[2] M. Clayton,[2] S. Kooi,[2] S. H. Melfi,[3] D. Whiteman,[4] G. Schwemmer,[4] K. Evans,[3] P. Russell,[5] J. Livingston,[6] B. Schmid,[7] B. Holben,[4] L. Remer,[4] A. Smirnov,[8] and P. V. Hobbs[9]

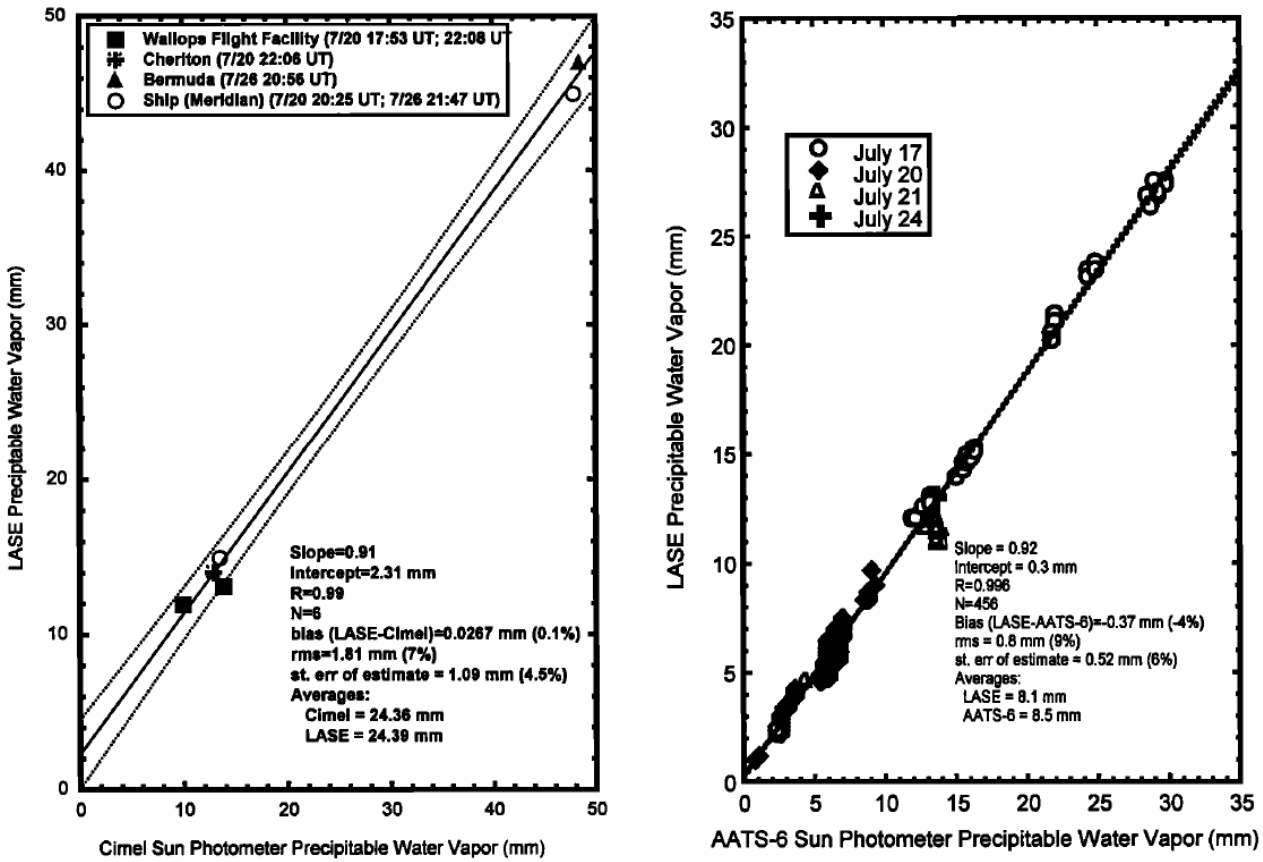
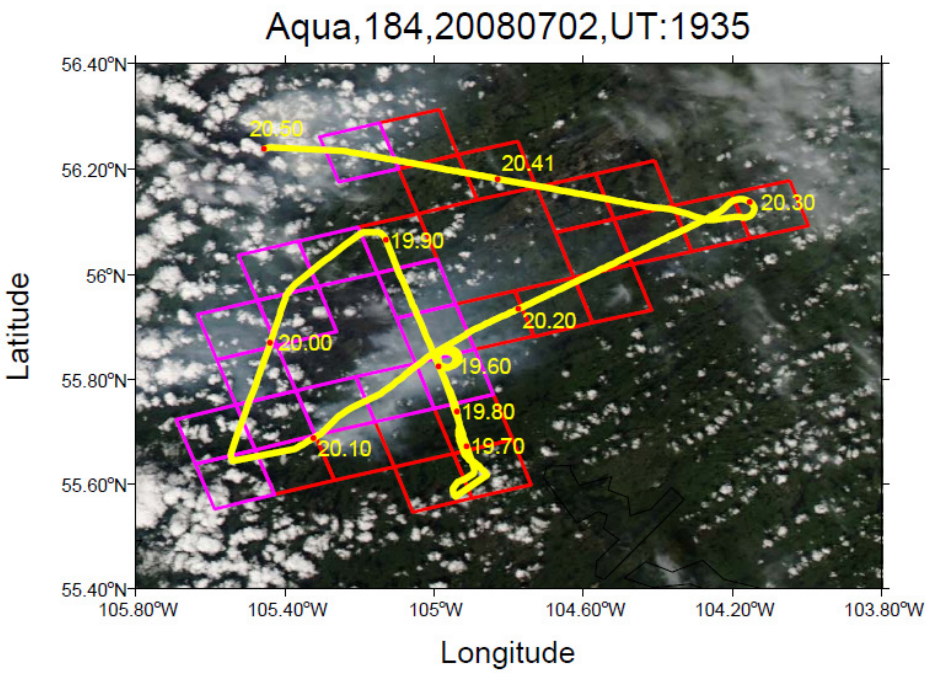


Figure 10. (left) Comparison of precipitable water vapor (PWV) measured by LASE and Cimel Sun photometer during TARFOX. (right) Same except for AATS-6 airborne Sun photometer flown on the UW C-131A aircraft.

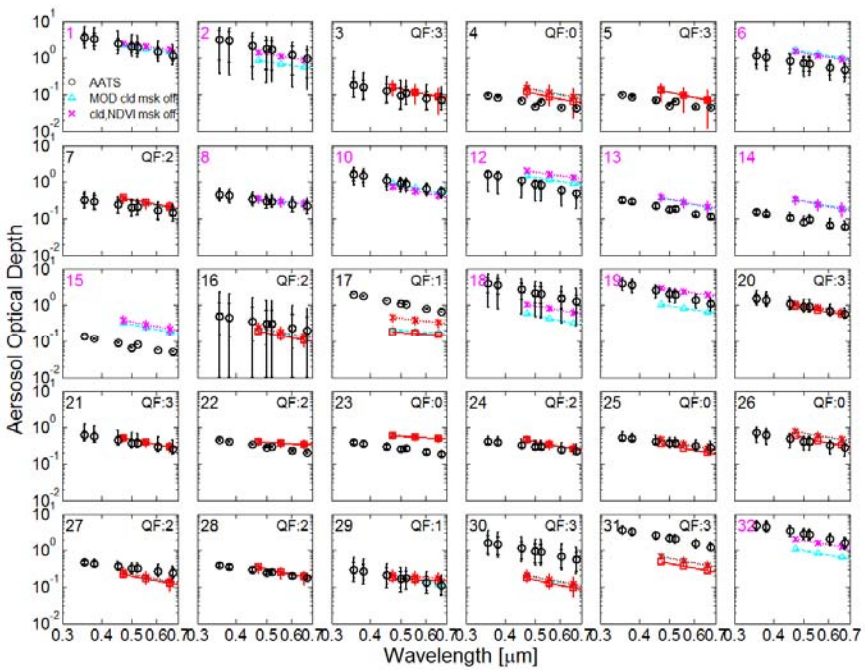


Comparison of MODIS 3 km and 10 km resolution aerosol optical depth retrievals over land with airborne sunphotometer measurements during ARCTAS summer 2008

J. M. Livingston[1], J. Redemann[2], Y. Shinozuka[3,4], R. Johnson[2], P. B. Russell[2], Q. Zhang[3,4], S. Mattoo[5,6], L. Remer[7], R. Levy[5], L. Munchak[5,6], and S. Ramachandran[8]

[JGR, 2014]

High resolution, near clouds

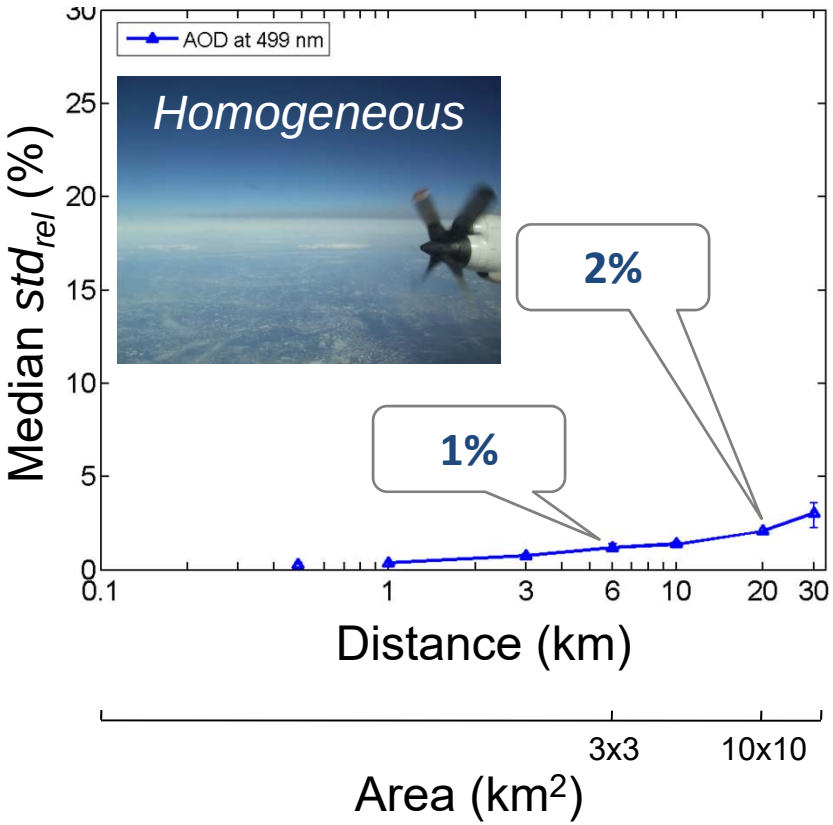


AATS-14

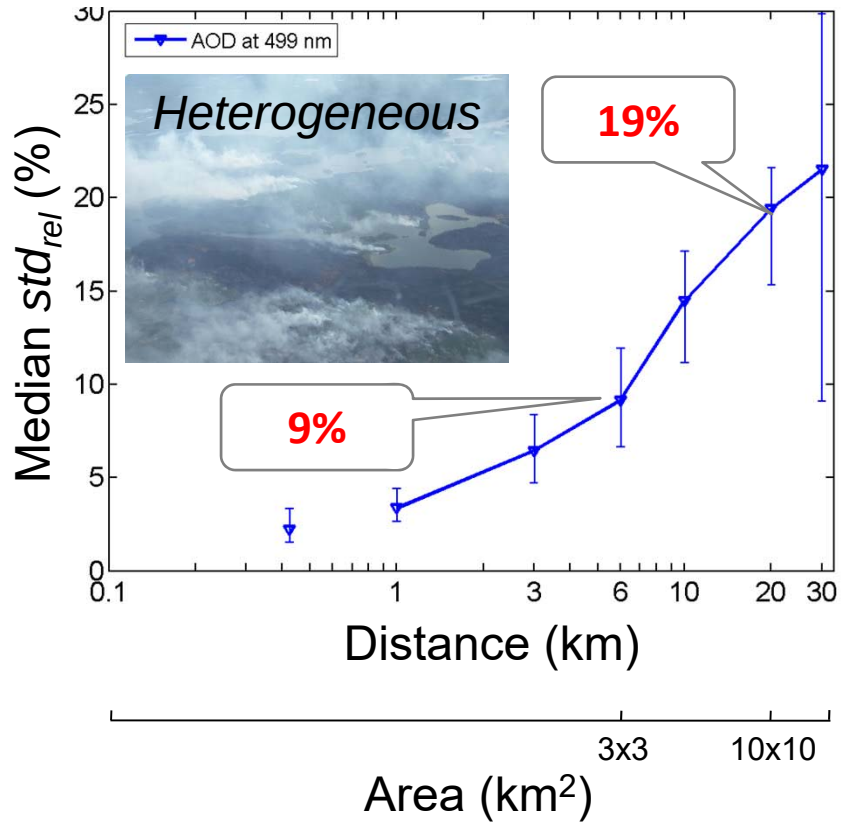
Horizontal variability

[Shinozuka and Redemann, 2011]

Asian outflow over Alaska



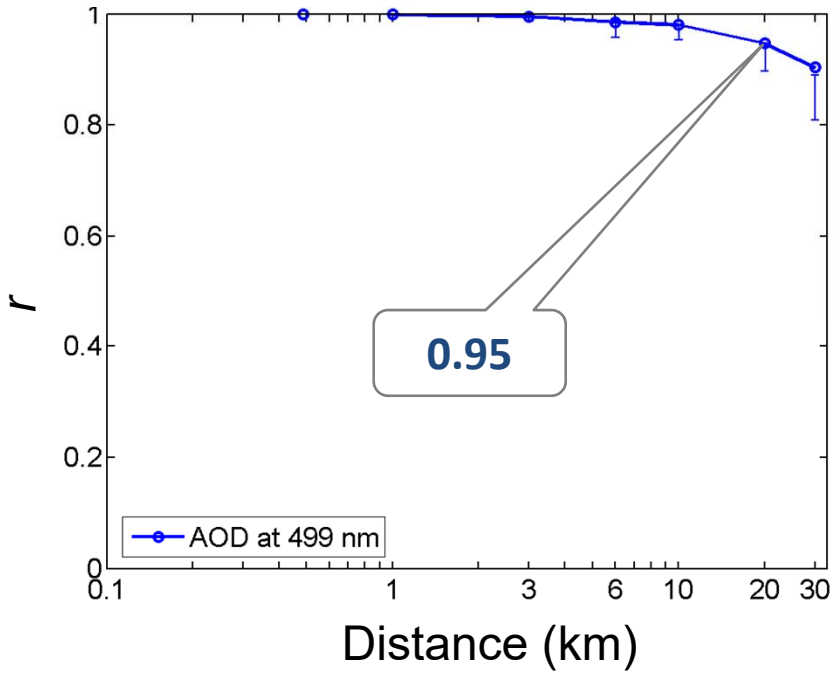
forest fire smoke over Canada



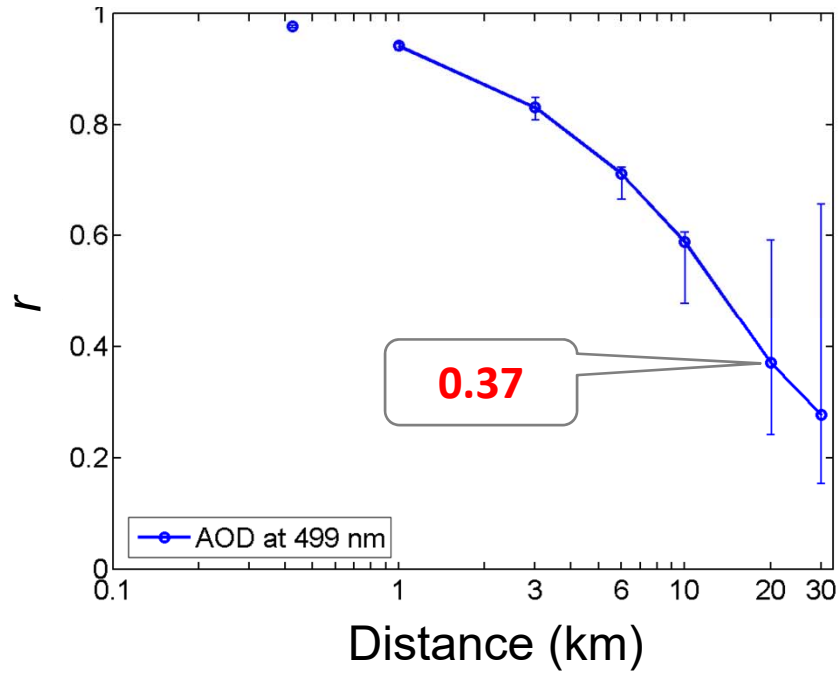
Our statistics help optimize observation strategy and model resolution.

r of AOD_{499}

Asian outflow over Alaska



forest fire smoke over Canada



Our statistics help optimize the locations of monitoring/validation stations.

Extending "Deep Blue" aerosol retrieval coverage to cases of absorbing aerosols above clouds: Sensitivity analysis and first case studies

[JGR, 2016]

A. M. Sayer[1,2], N. C. Hsu[1], C. Bettenhausen[1,3], J. Lee[1,4], J. Redemann[5], B. Schmid[6], and Y. Shinozuka[7]

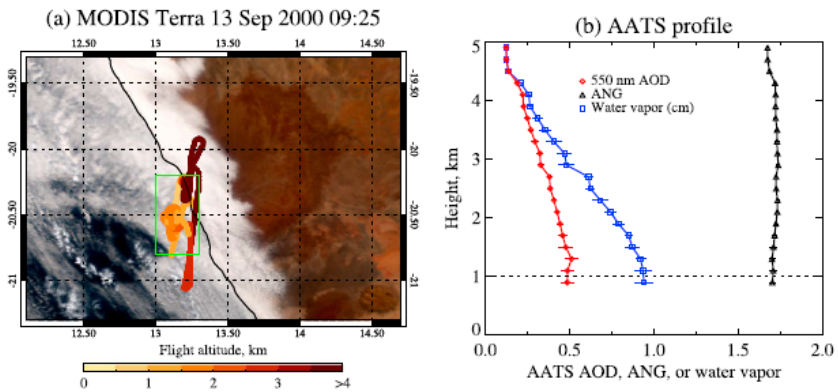


Figure 12. Summary of flight location and AATS profile from the 13 September 2000 case study during SAFARI-2000. (a) The aircraft altitude during the relevant portion of the flight. The green box indicates the region over which MODIS and AATS data are compared. (b) The AATS vertical profiles (cumulative from that altitude to TOA) of AOD at 550 nm, ANG, and CWV. Error bars indicate the standard deviation of AATS data over 200 m vertical bins. The dotted horizontal line indicates the average height of the cloud top.

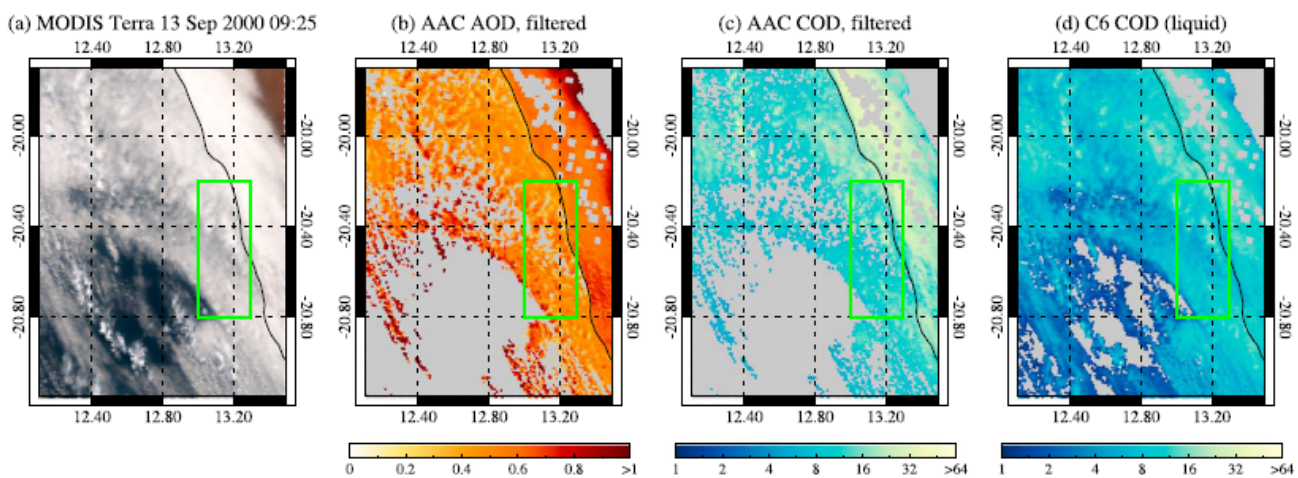


Figure 15. Filtered output of AAC retrieval for the SAFARI-2000 case study. (a) MODIS true color image, (b) the retrieved AAC AOD, and (c, d) the AAC and standard MODIS C6 COD, respectively. Pixels without valid retrievals are shaded grey. The green box indicates the area of the AATS spiral (cf. Figure 12).

Validating MODIS Above-cloud Aerosol Optical Depth Retrieved from 'Color Ratio' Algorithm using Direct Measurements made by NASA's Airborne AATS and 4STAR Sensors, [Jethva et al. AMTD, 2016]

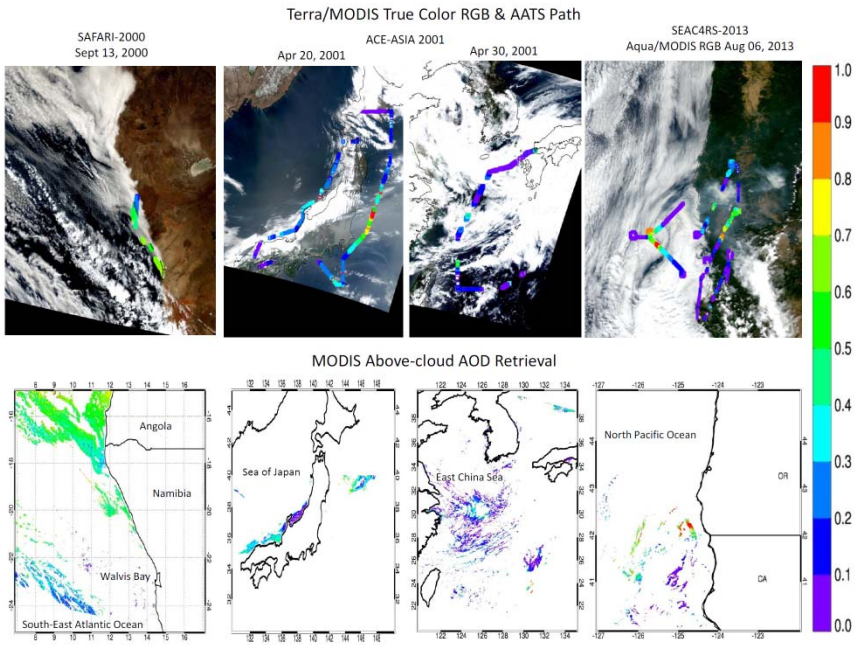


Figure 1. (Top) True-color RGB images captured by MODIS superimposed with AOD (500 nm) measured by AATS-6,-14/4STAR on Sept 13, 2000, April 20, 30, 2001, and Aug 06, 2013 during SAFARI-2000, ACE-ASIA 2001, and SEAC4RS-2013, respectively. (Bottom) Above-cloud AOD (500 nm) retrieved from MODIS above events.

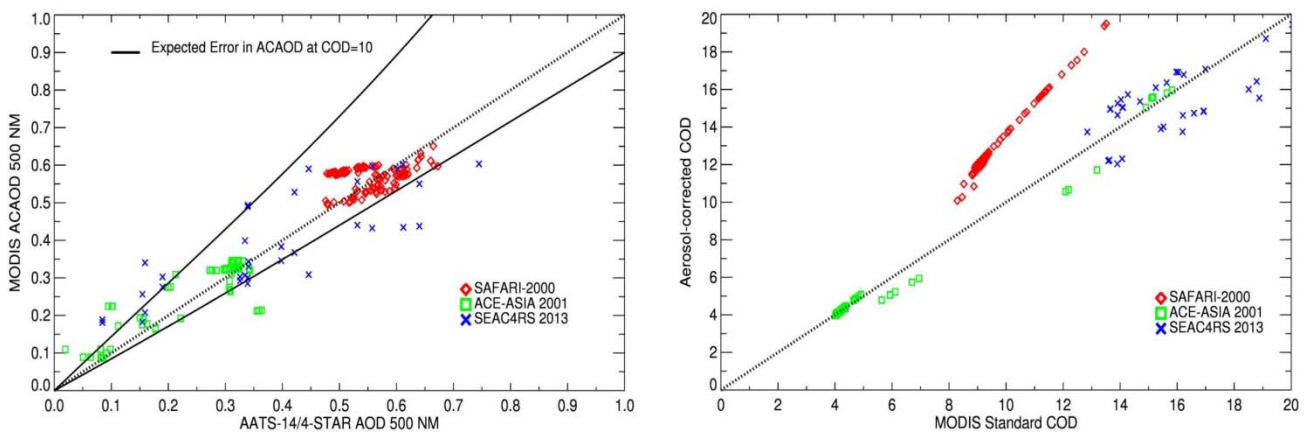


Figure 2. (Left) Scatter-plot of above-cloud AOD retrieved from MODIS (y-axis) and that measured by AATS-6,-14/4STAR (x-axis) for the five events discussed in the text. (Right) A comparison of aerosol-corrected COD retrieved from the CR algorithm with those provided by the MODIS standard algorithm (MOD/MYD06).

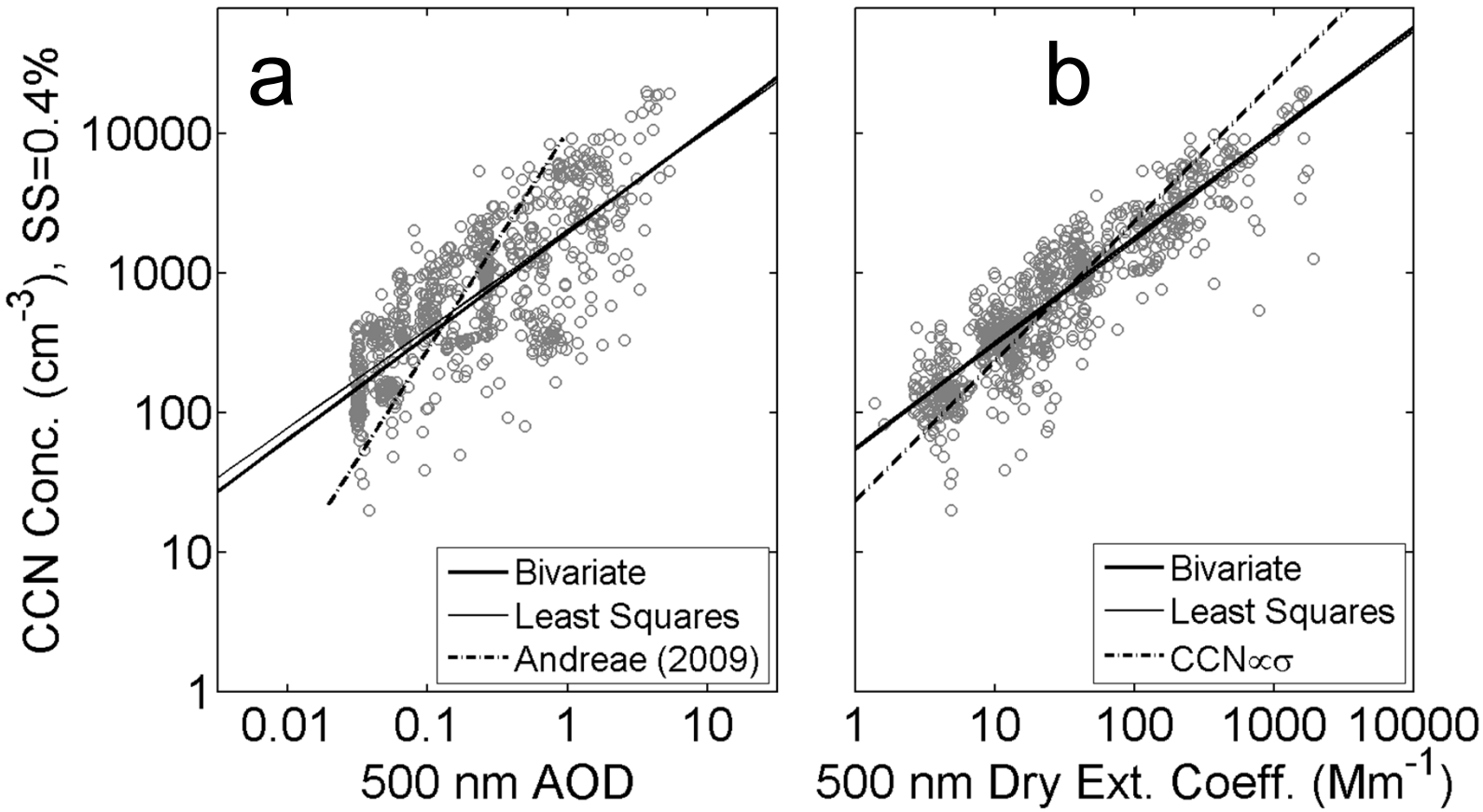
CCN surrogates

$1.03\times10^{4}AOD_{500nm}^{1.56}$	*Andreae*, 2009
AOD	*Kaufman et al.*, 2005; *Koren et al.*, 2008; *Bellouin et al.*, 2013
AOD×α ("aerosol index", α=Angstrom exponent)	*Nakajima et al.*, 2001; *Bréon et al.*, 2002; *Sekiguchi et al.*, 2003; *Quaas et al.*, 2004; *Penner et al.*, 2012
$4.57\times10^{8}(AOD\times\alpha)^{0.869}$	*Nakajima et al.*, 2001
MODIS ocean algorithm	*Gassó and Hegg*, 2003
$2.3397(\sigma_{sp,450nm}\times\alpha)^{1.5178}$	*Liu and Li*, 2013
$10^{0.3\alpha+1.3}\sigma_{dry,ext,500nm}^{0.75}$	*Shinozuka et al.*, 2015

See also Feingold and Grund [1994], Jefferson [2010].

The relationship between CCN and AOD, dry extinction

Airborne observations

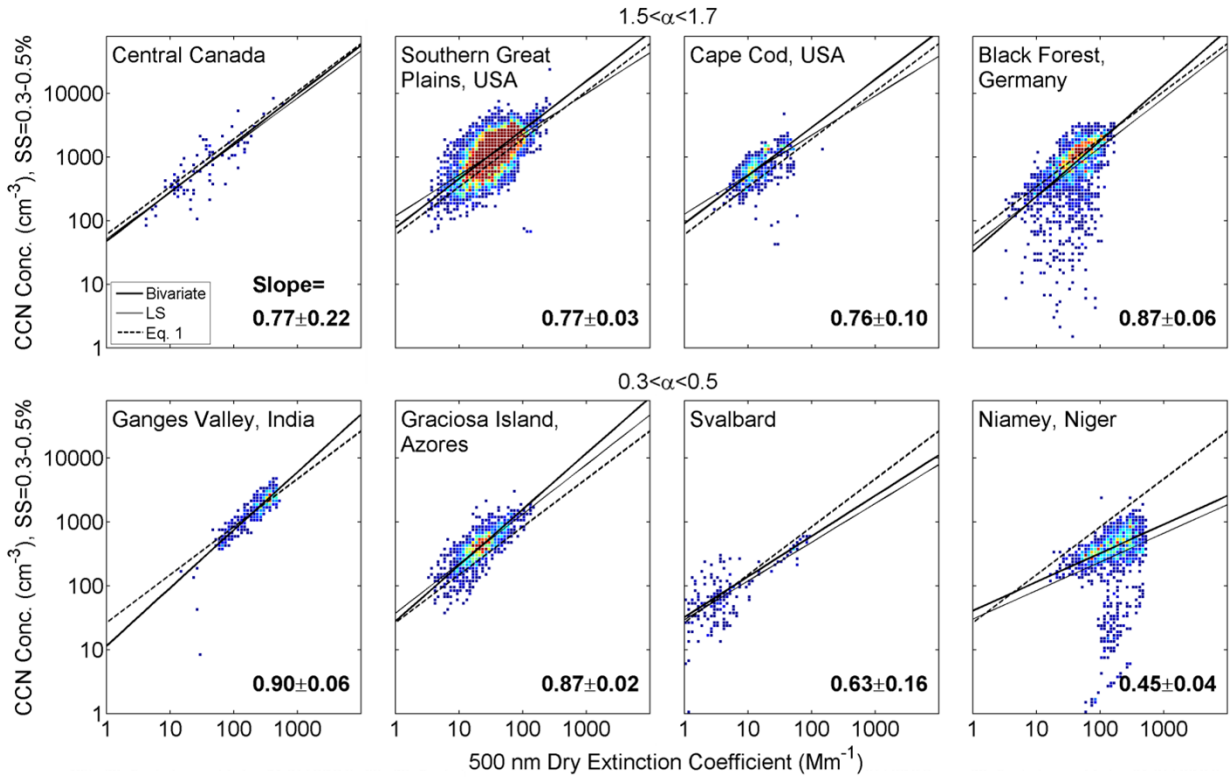


Shinozuka et al., ACP 2015

The relationship between CCN and dry extinction

- **The slope is less than unity**. Condensation increases extinction but not number.

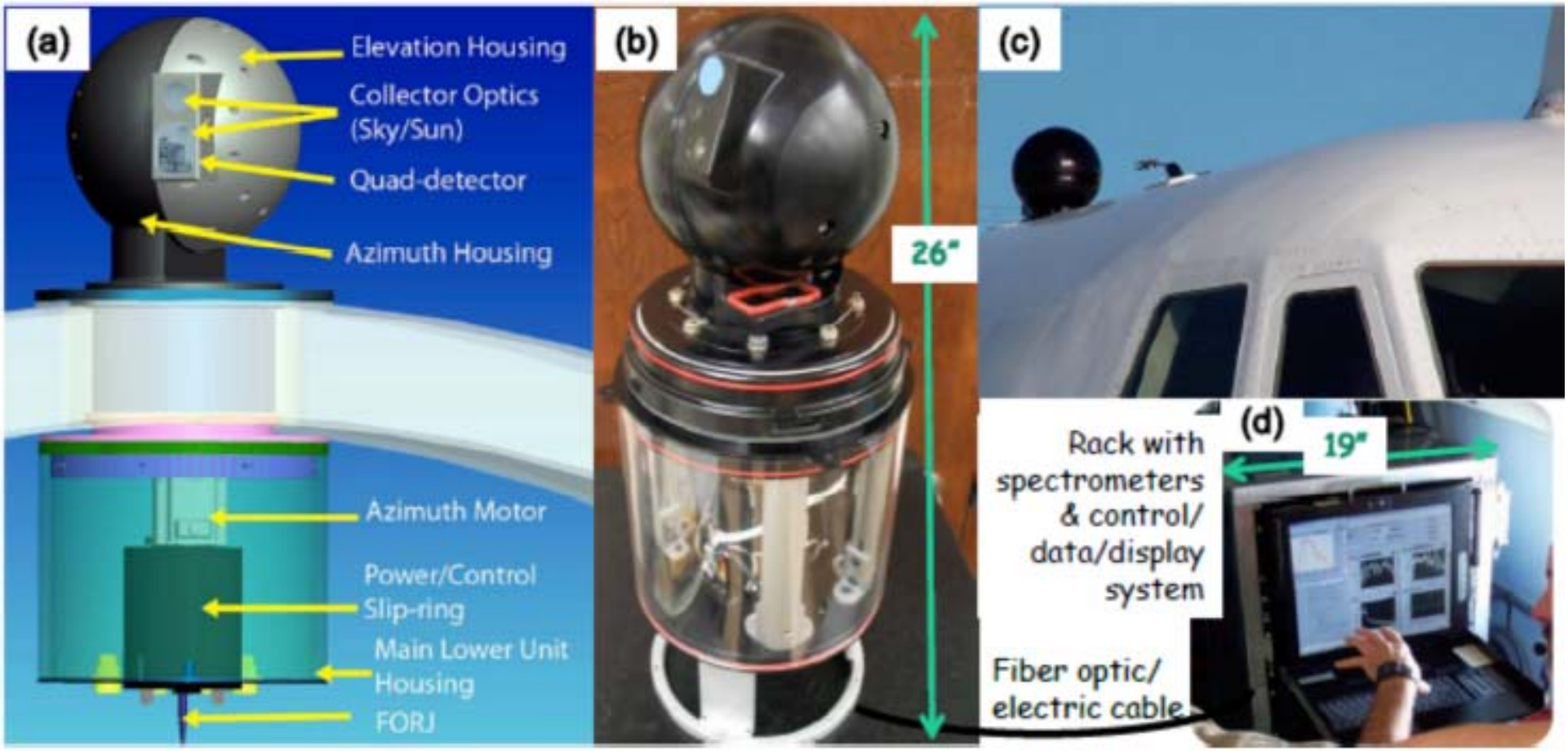
- $CCN_{SS\sim0.4\%}(cm^{-3}) = \mathbf{10^{0.3\alpha+1.3}\sigma^{0.75}}$
  σ: dry ext. (Mm^{-1}),
  α: Angstrom exp.
  RMS deviation is a factor of 2.0.



Ground-based

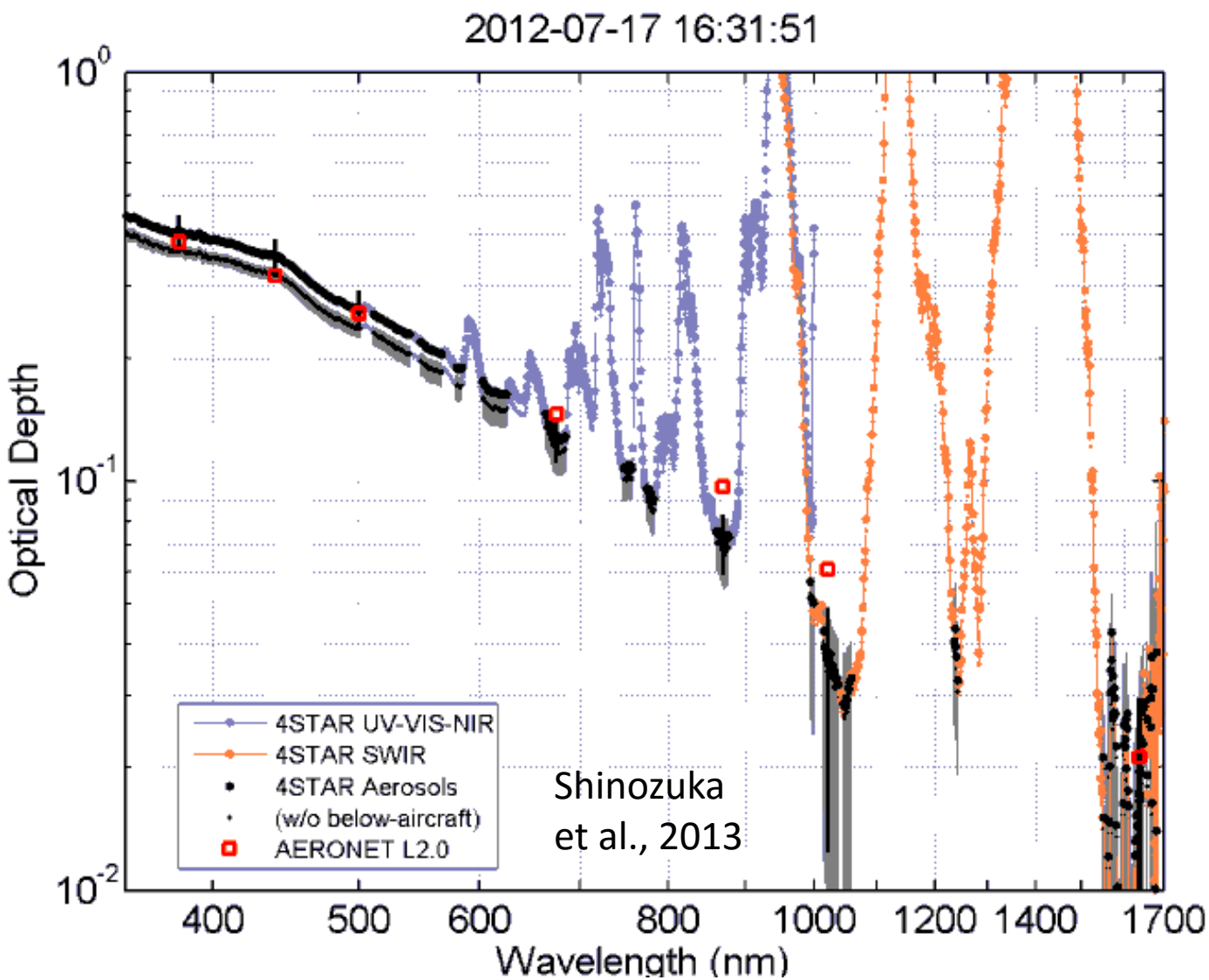
Shinozuka et al., ACP 2015

4STAR (Spectrometer for Sky-Scanning, Sun-Tracking Atmospheric Research)



Yohei Shinozuka, Jens Redemann, Beat Schmid, Roy Johnson, Steve Dunagan, Connor Flynn, Michal Segal-Rosenheimer, Samuel LeBlanc , Meloë Kacenelenbogen, John Livingston, Phil Russell - NASA Ames Research Center and Pacific Northwest National Laboratory
Many collaborators – Thank you!

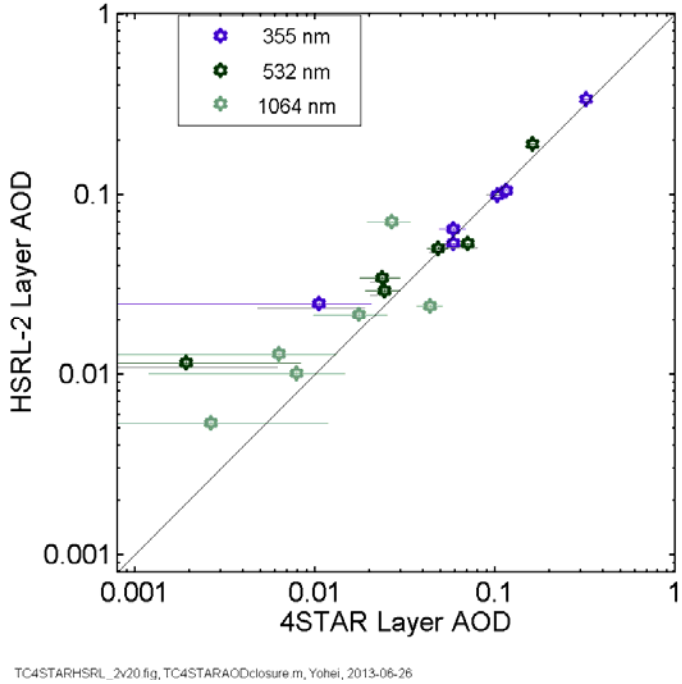
Hyperspectral AOD from 4STAR

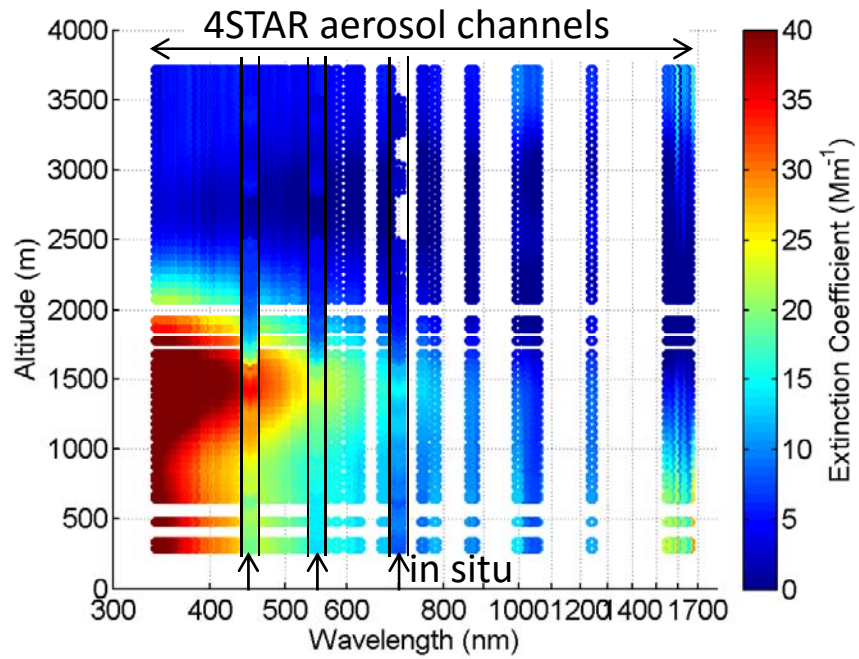


Layer AOD compared w HSRL-2

Extinction compared with in situ

Rogers, Ferrare, Hair, Hostetler, Burton





Hyperspectral aerosol optical depths from TCAP flights

Y. Shinozuka,[1,2] R. R. Johnson,[3] C. J. Flynn,[4] P. B. Russell,[3] B. Schmid,[4] J. Redemann,[3] S. E. Dunagan,[3] C. D. Kluzek,[4] J. M. Hubbe,[4] M. Segal-Rosenheimer,[3] J. M. Livingston,[5] T. F. Eck,[6,7] R. Wagener,[8] L. Gregory,[8] D. Chand,[4] L. K. Berg,[4] R. R. Rogers,[9] R. A. Ferrare,[9] J. W. Hair,[9] C. A. Hostetler,[9] and S. P. Burton[9]

[JGR, 2013]

4STAR O_3 & NO_2 retrievals compared to Pandoras at GSFC

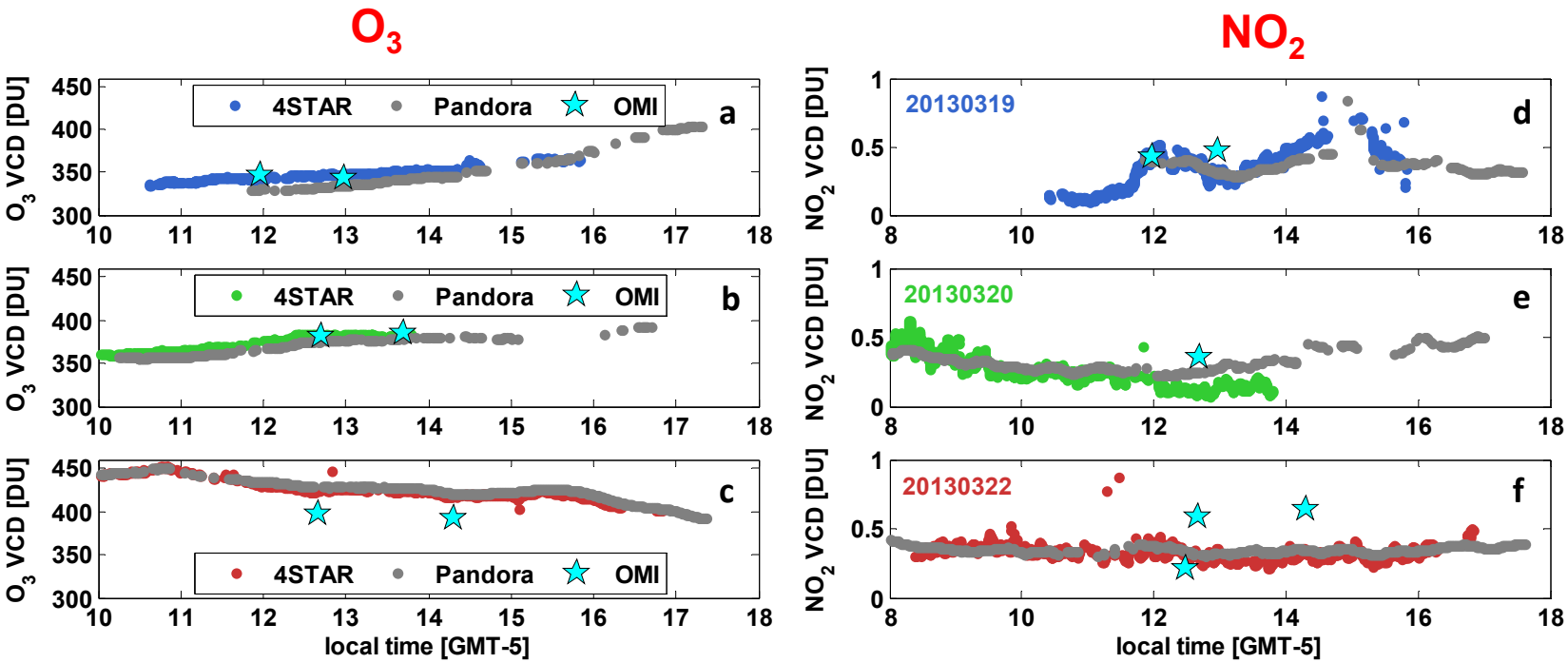


Figure 7: 4STAR O_3 (a-c) and NO_2 (d-f) retrieved vertical column densities (VCD) compared with collocated, averaged values of four Pandora instruments (#27,29,34,36) during the March 2013 Goddard ground-based inter-comparison period and with OMI overpass values (in cyan stars).

Segal-Rosenheimer et al., *JGR* 2014:

O_3: 1% RMSD, 0.1% bias. **NO_2:17.5% RMSD, -8% bias.**

4STAR: Operating Modes

Direct sun tracking:
- **Aerosol Optical Depth**
- **Column Water Vapor, O_3, NO_2** (demonstrated); CO_2, CH_4, OH, Formaldehyde (desired)
- Thin cirrus cloud properties

[Shinozuka et al., 2013; Segal-Rosenheimer et al., 2014]

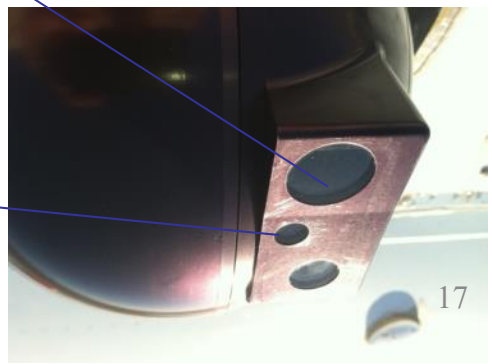
Sky scanning:
Almucantar and Principal plane
- **Sky Radiances**
- **AERONET-like retrieval of aerosol** size distribution, index of refraction, SSA, asymmetry factor, sphericity

[Kassianov et al., 2012]

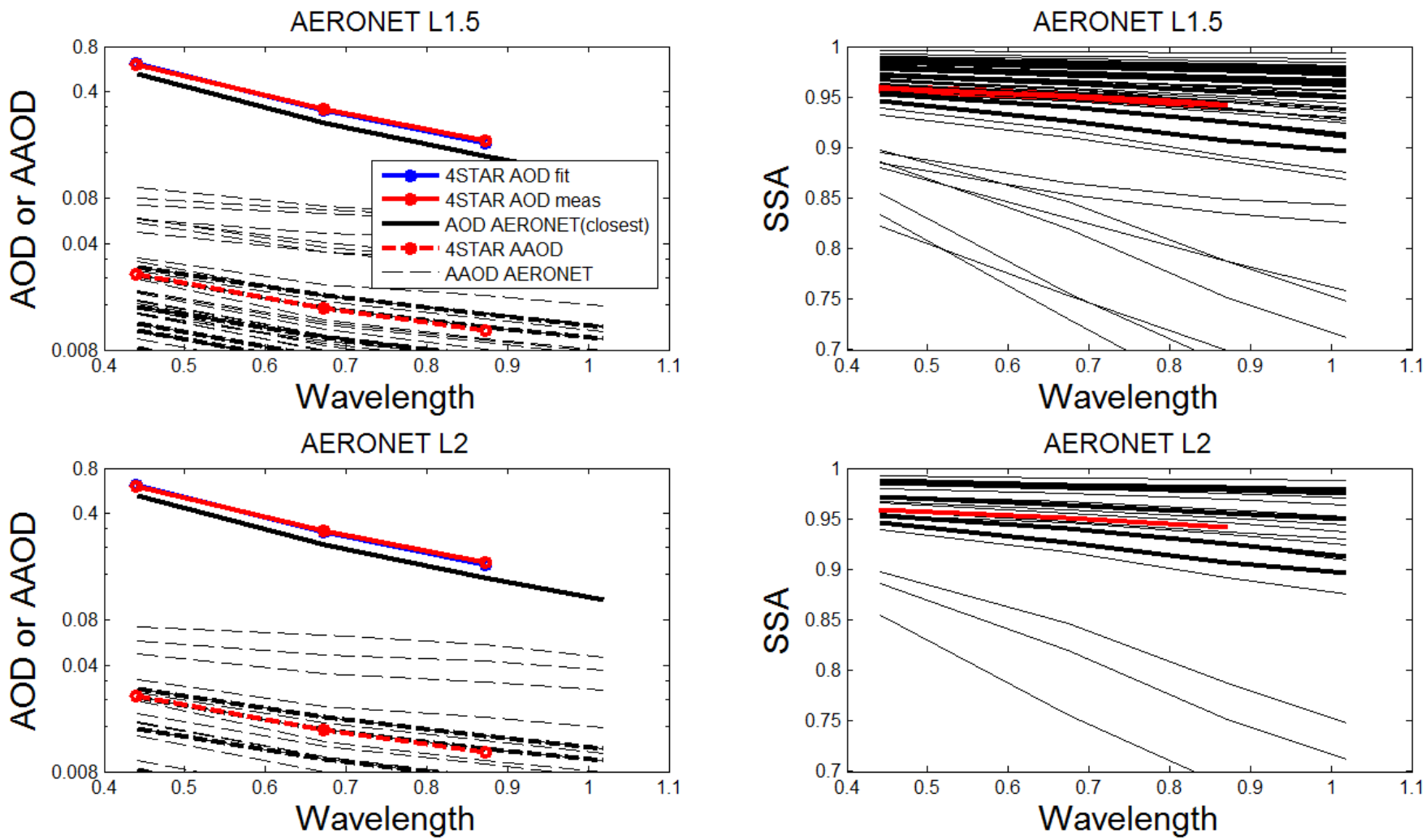
Zenith viewing:
- **Cloud property retrievals** (COD, cloud droplet effective radius)* * With SSFR

[LeBlanc et al., 2015]

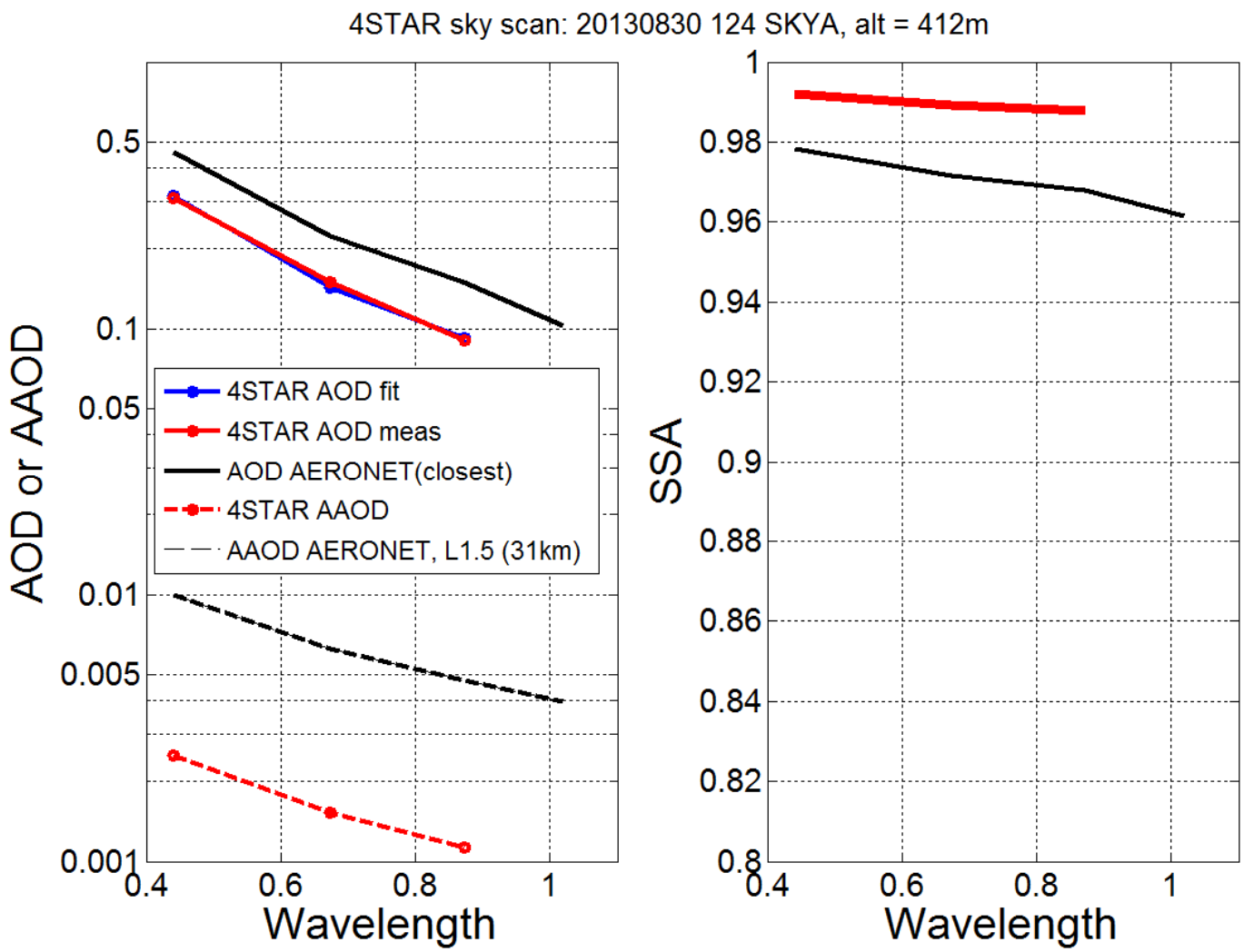
For instrument technology, see Dunagan et al. [2013]



4STAR: Ground-based comparisons to nearby (100km & 2hrs) AERONET retrievals during SEAC4RS, August 16, 2014



4STAR: Airborne comparison to nearby (30km) AERONET retrievals during SEAC4RS, August/September, 2014



Underway: airborne comparison to in situ measurements

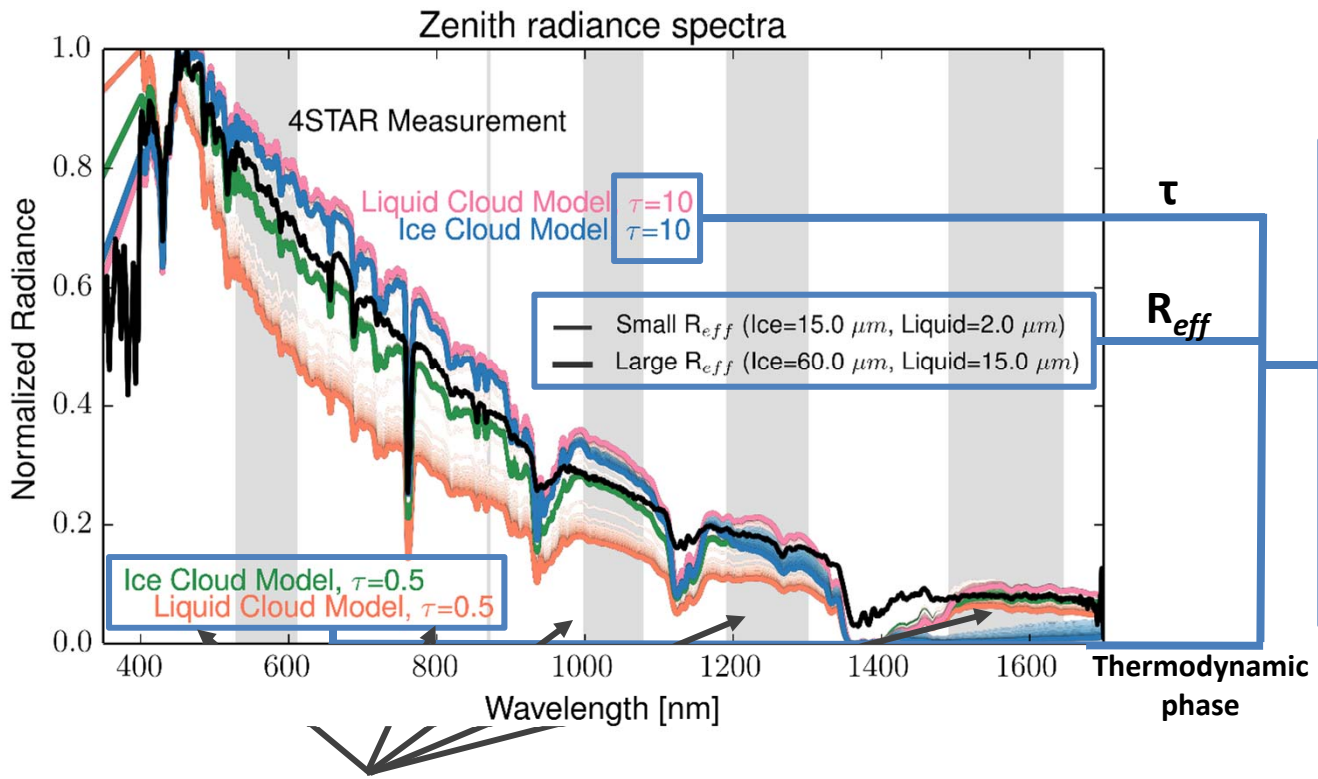
Cloud retrieval

Science question

Under cloudy skies, can measurements of transmitted light lead to less uncertainty in surface radiation budget than reflected light?

Expected Research outcome

Comparison of cloud properties from transmitted and reflected light and impact on below cloud energy budget. **Synergy with**: RSP, HSRL, MODIS, GOES, CERES



τ

R_{eff}

Thermodynamic phase

Retrieved Cloud properties

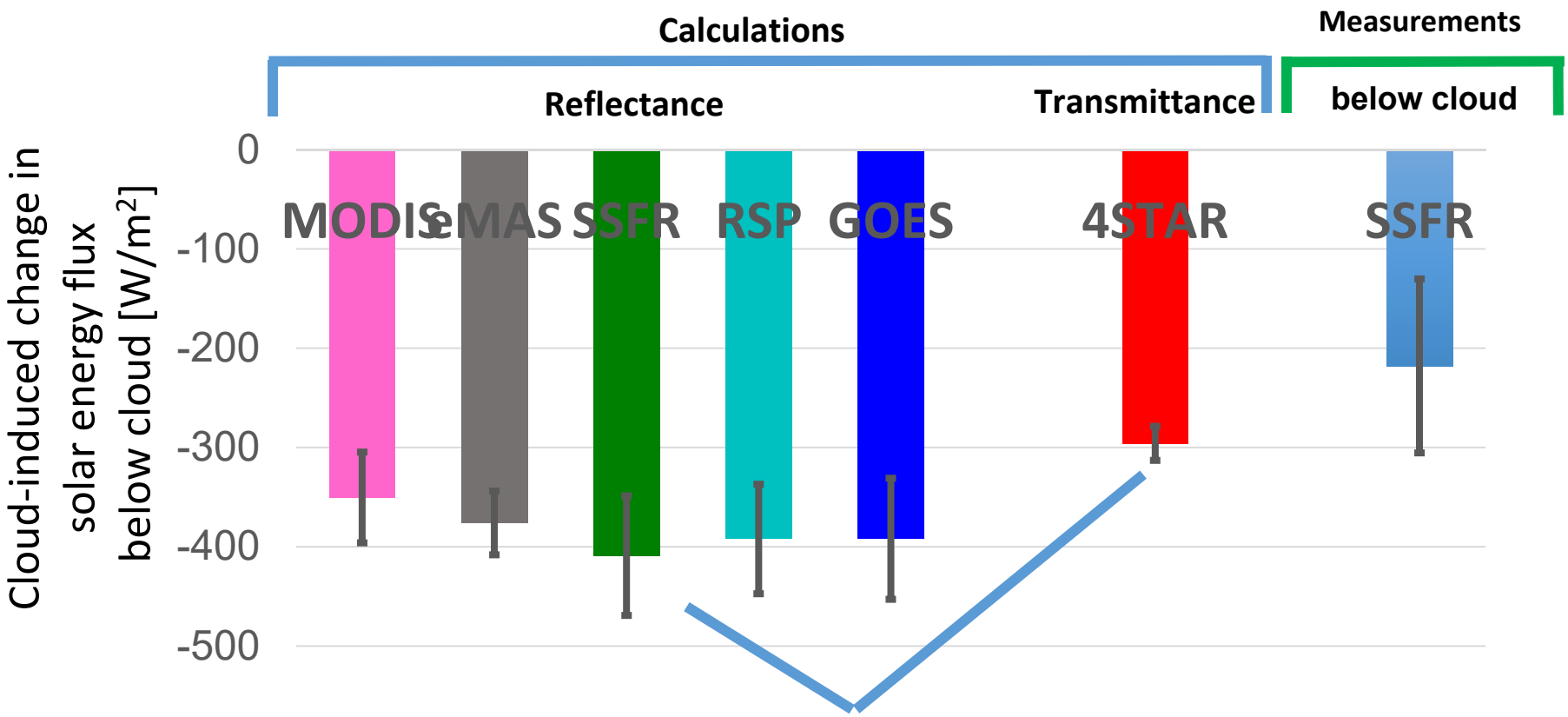
- Optical thickness
- Particle effective radius
- Thermodynamic phase (ice cloud or liquid water cloud)

Theoretical basis

Uses **15 Spectral shapes** of normalized zenith radiance (slope, ratios, derivatives, curvature) in 5 wavelength regions

LeBlanc et al., 2015, *AMT*

Cloud radiative effect below cloud is calculated to be smaller when using transmitted light



Differences of:
54.5 – 113.0 W/m²

Mechanically & electrically, 4STAR performed very well in TCAP, SARP, SEAC4RS, ARISE, NAAMES #1 and KORUS-AQ

4STAR is a flight-certified instrument under revision control

TCAP, DOE G-1

July 2012 and February 2013: 4STAR operated successfully on all science flights
- Science analyses in Shinozuka et al., 2013, Segal-Rosenheimer et al., 2014

SARP, NASA DC-8

- July 2013: 4STAR operated successfully on 4 of 5 flights

SEAC^{4}RS, NASA DC-8

- Aug-Sep 2013: 4STAR operated successfully on all 23 flights
- Data archived. Analyses underway.

ARISE, NASA C-130

- Aug-Sep 2014: 4STAR operated successfully on all 16 data + 3 transit flights.
- Analyses underway.

NAAMES, NASA C-130

- November, 2015, (May 2016 with AATS-14), 2017 and 2018

KORUS-AQ and SARP, NASA DC-8

- April – June, 2016

ORACLES, NASA P-3

- August/September 2016, also in 2017 and 2018