Aerosol optical properties (…and so much more) measured using 4STAR

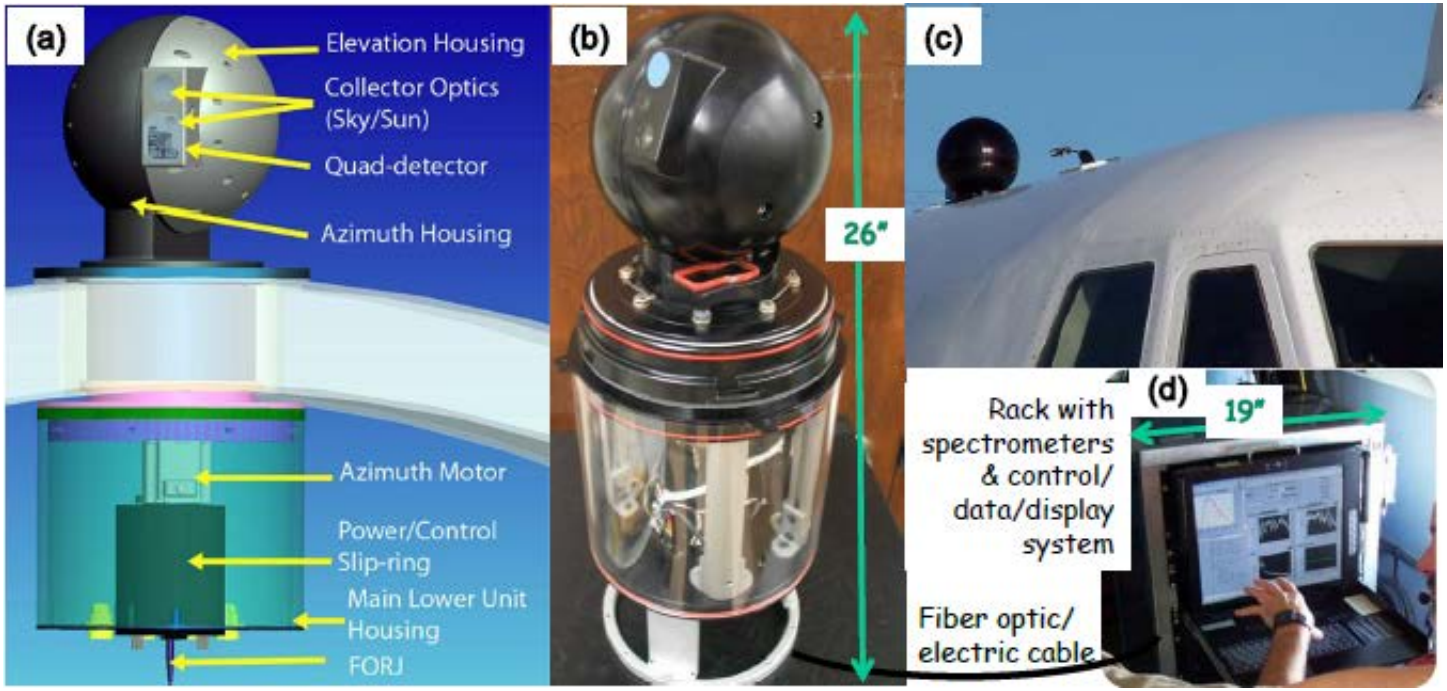
J. Redemann, Y. Shinozuka, M. Segal-Rosenheimer, C. Flynn, S. Dunagan, R. Johnson, M. Kacenelenbogen, K. Knobelspiesse, J. Livingston, P. Russell, B. Schmid

4STAR: a joint instrument development effort between NASA Ames and PNNL

Contents:

1) **Overview of 4STAR data acquired in TCAP-1 and TCAP-2**
2) **AOD and ext results**
3) **Trace gas retrieval results**
4) **Progress on sky radiance measurements**
5) **Example of cloud retrieval from zenith sky radiances**
6) **Outlook for future work**

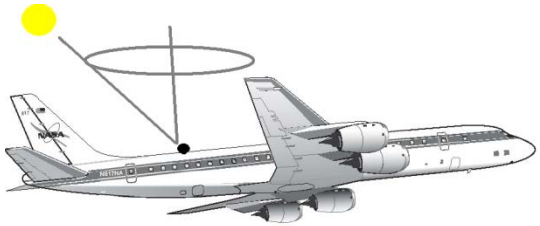
4STAR: SPECTROMETER FOR SKY-SCANNING, SUN-TRACKING ATMOSPHERIC RESEARCH

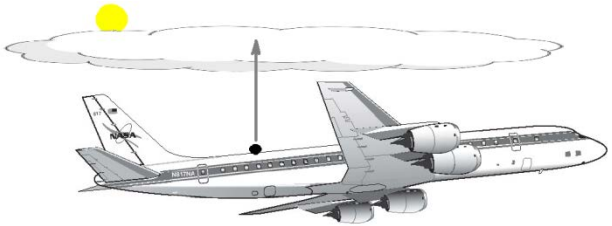


(a) Design for 4STAR tracking/scanning head and can.
(b) Head and can as built.
(c) 4STAR head on G-1 aircraft. (d) Rack and contents flying on G-1.

4STAR: SPECTROMETER FOR SKY-SCANNING, SUN-TRACKING ATMOSPHERIC RESEARCH

Operating modes





Direct sun tracking:

- **AOD** at 100s of wavelength, **Angstrom exponent**
- aerosol extinction profiles
- **O3**, NO2 and **CWV** (demonstrated); CO2, CH4, OH, Formaldehyde (desired)
- Thin cirrus cloud properties

Sky scanning:

Almucantar and Principal plane

- **Sky Radiances**
- AERONET-like aerosol size distribution, index of refraction, SSA, asymmetry factor, sphericity*

Zenith viewing:

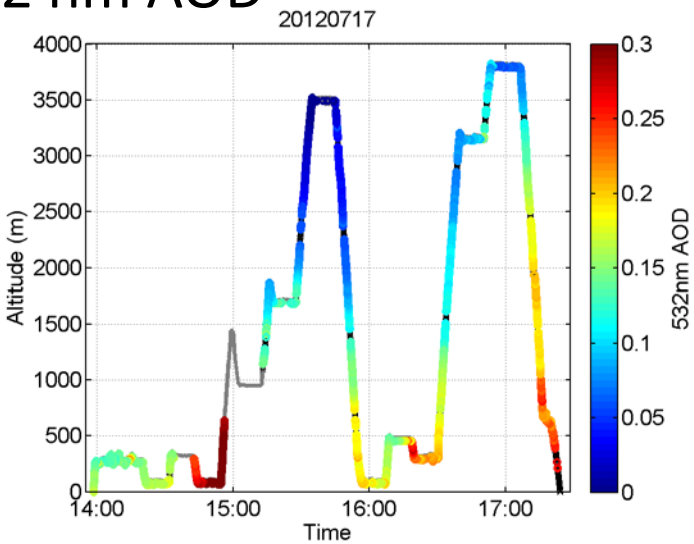
- Cloud property retrievals (**COD, cloud droplet effective radius**)*

* With SSFR measurements

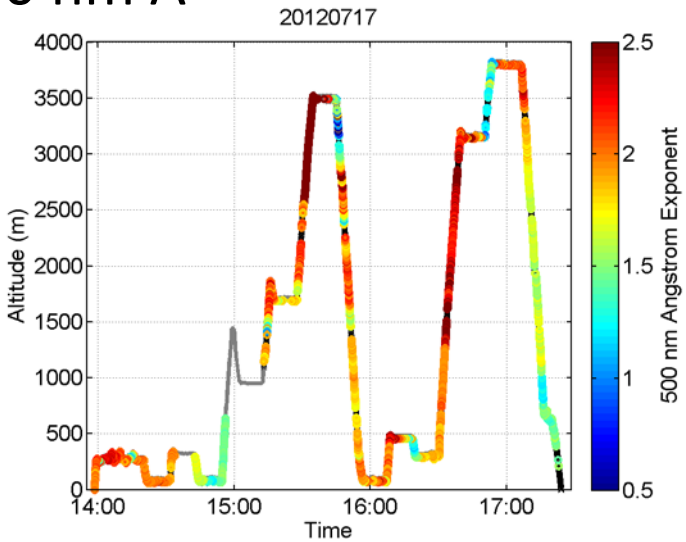
1215mins (screened)	46 scans	41 mins	TCAP-1
1107mins (screened)	157 scans	833 mins	TCAP-2

TCAP 1: AOD measurements

532 nm AOD

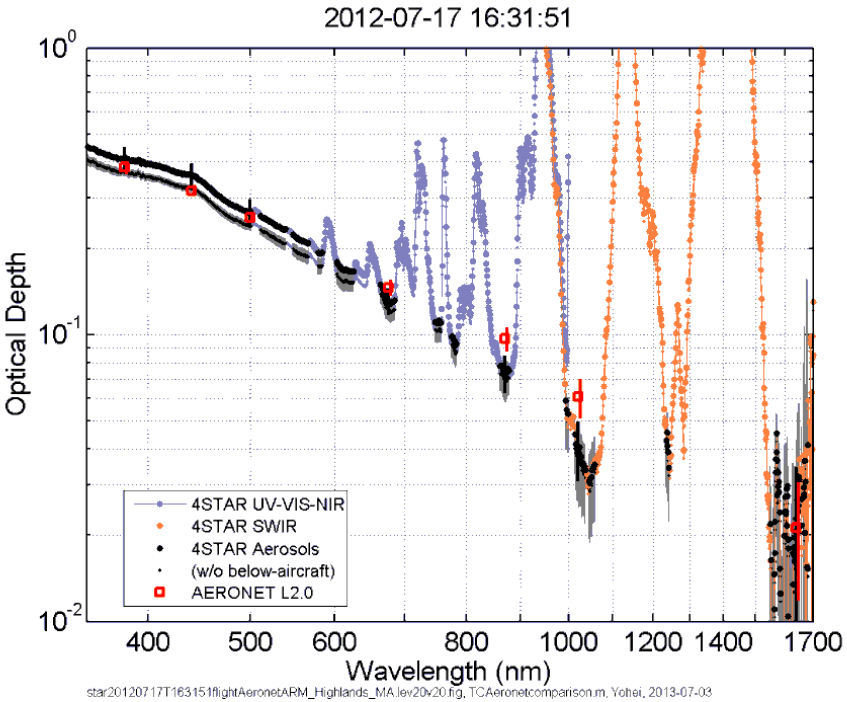


500 nm Å



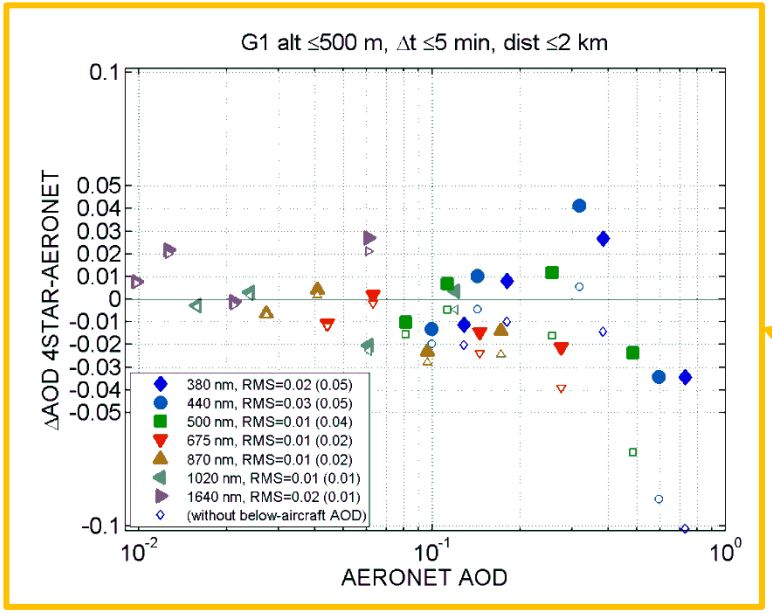
star20120717Time_Altitude__500nmAngstromExponentv11.fig, TCquickplots.m, Yohei, 2013-01-31

See also:
Shinozuka et al., 2013



star20120717T163151flightAeronetARM_Highlands_MA.lev20v20.fig, TCAeronetcomparison.m, Yohei, 2013-07-03

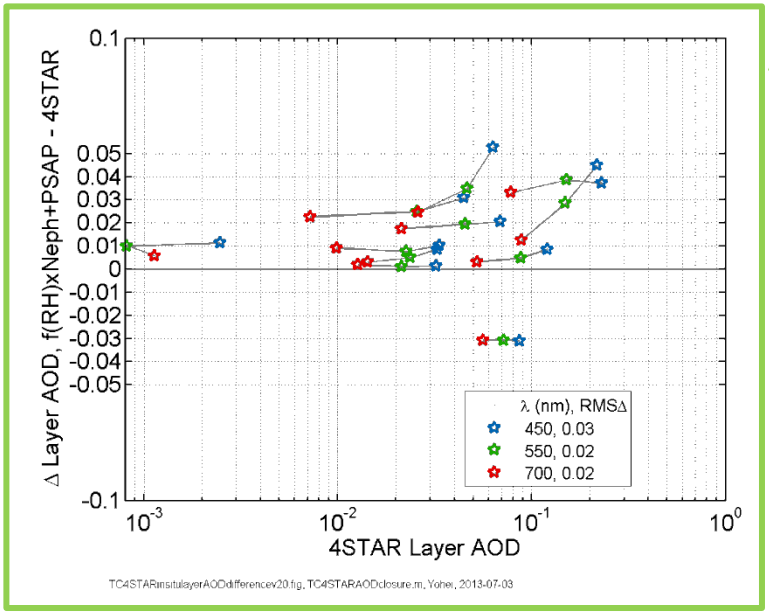
TCAP 1: AOD comparisons



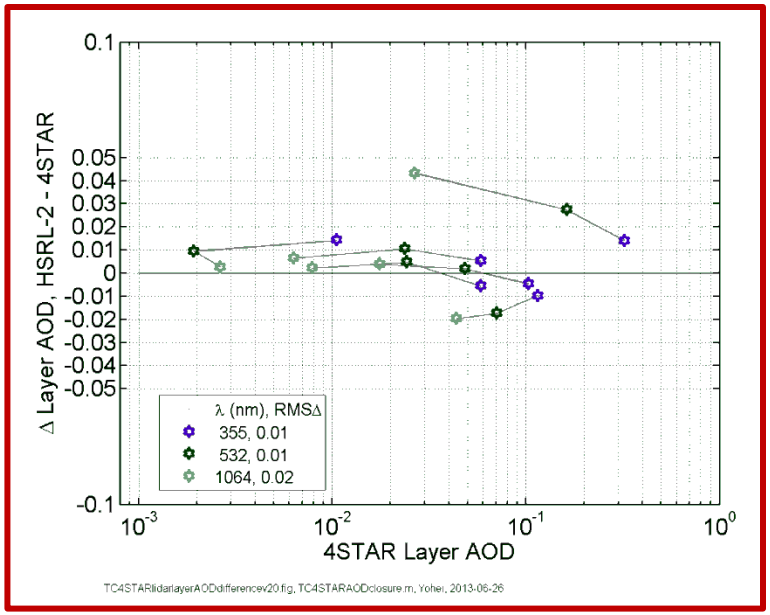
AERONET

See also:
Shinozuka et al., 2013

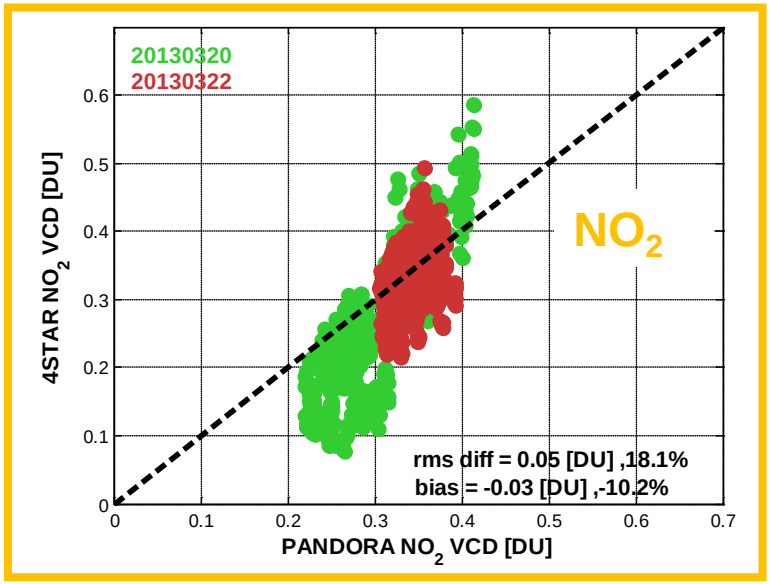
In situ



HSRL-2

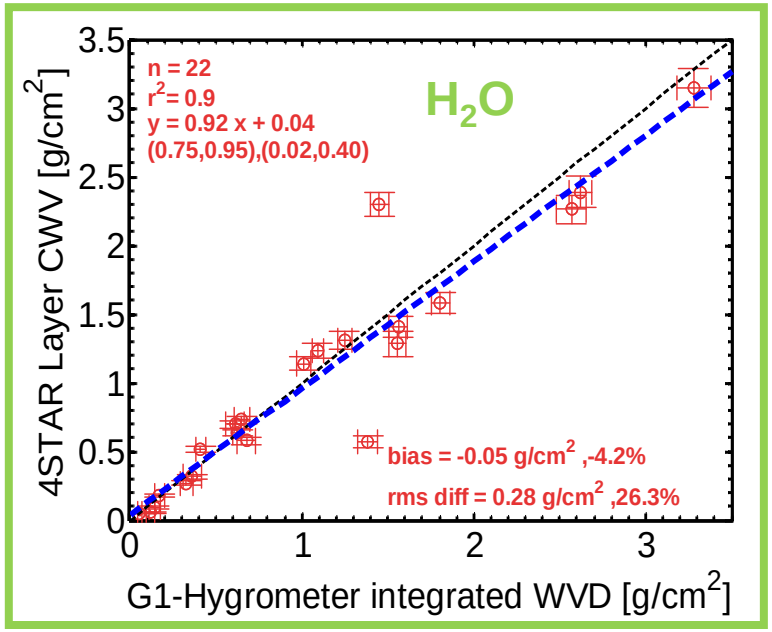


TCAP 1&2: Trace gas comparisons



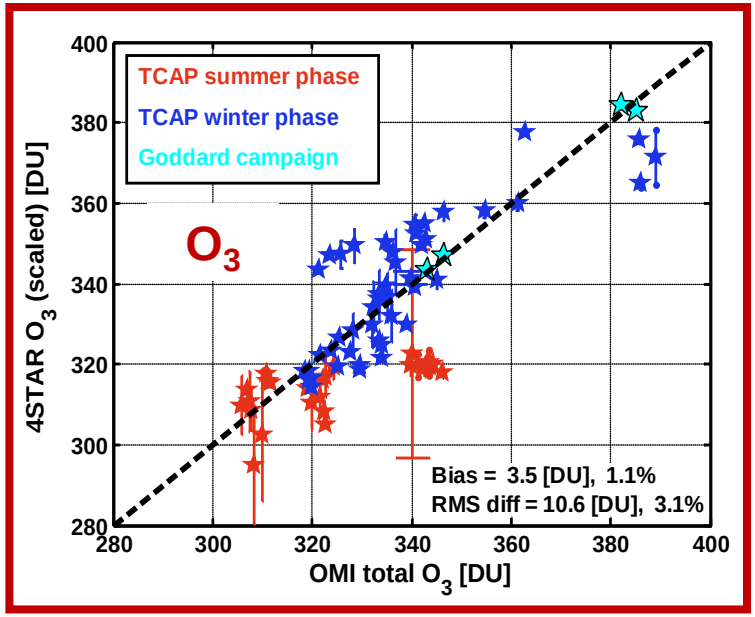
Pandora (Ground-based)

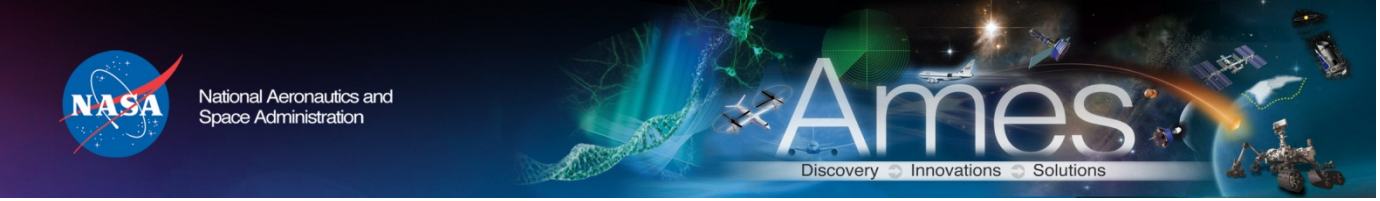
See also:
Segal-Rosenheimer et al., Tracking Elevated Pollution Layers with a Newly Developed Hyperspectral Sun/Sky spectrometer (4STAR): Results from the TCAP 2012 and 2013 campaigns, under review, *JGR-Atmos*, 2013

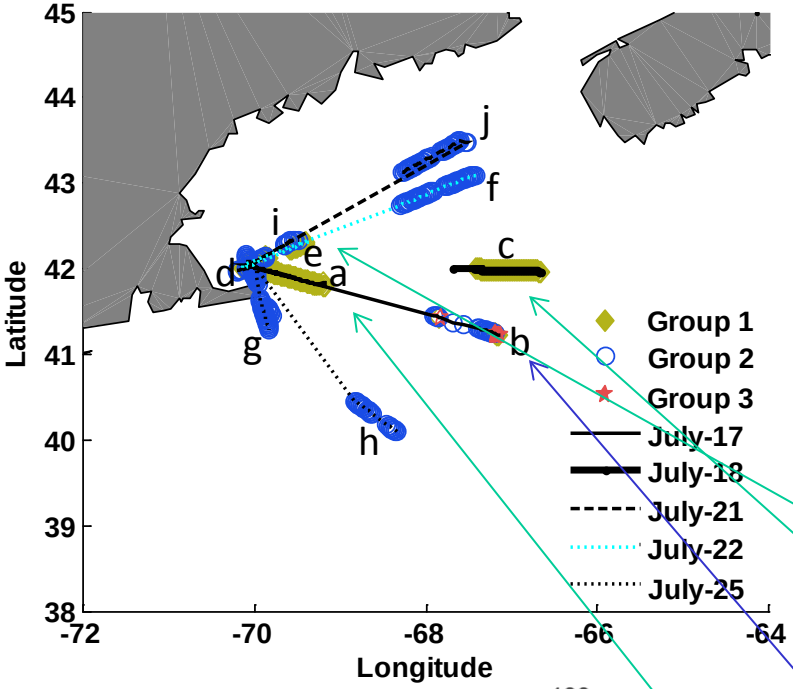


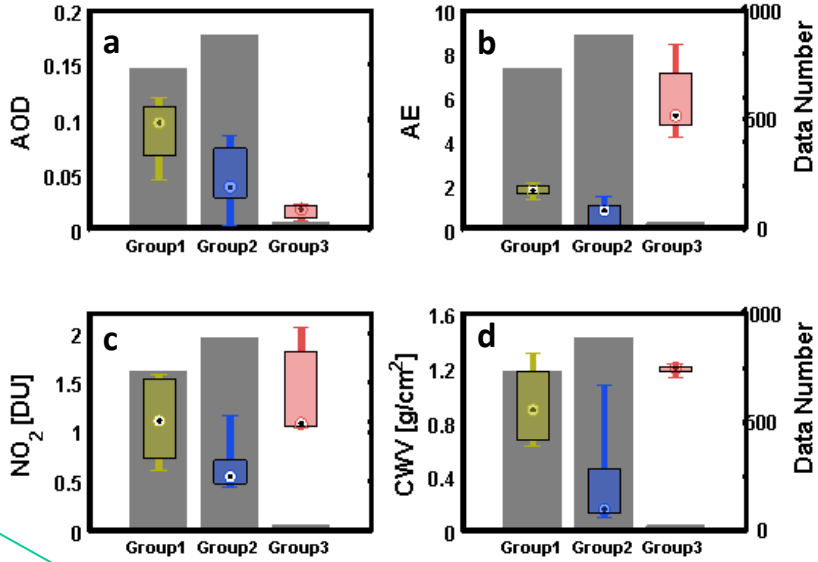
In-situ

OMI



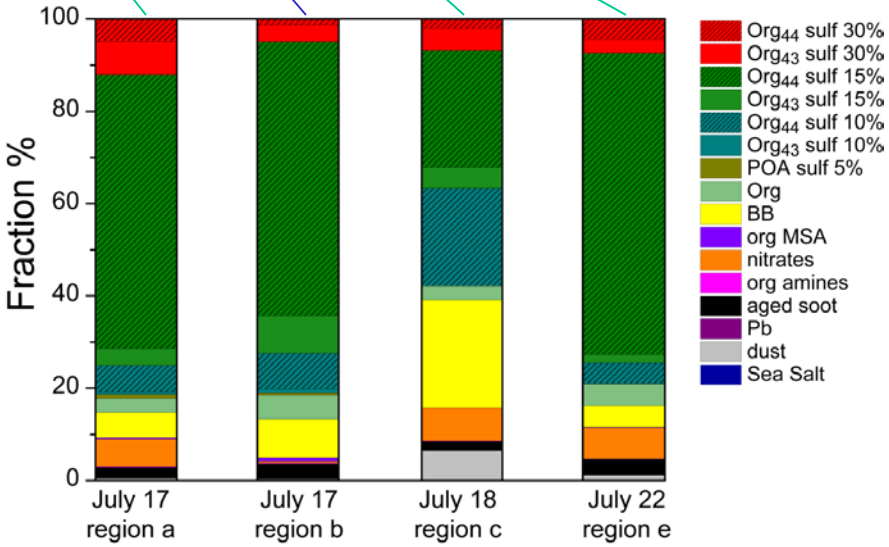






See also:
Segal-Rosenheimer et al., 2013

Clustering analysis resulted in three distinct groups, which corresponded well with miniSPLAT composition analysis. Group 1 contains BB and nitrates, while Group 3 contains BB and aged soot. Group 2 represents clean and dry airmasses from Canada

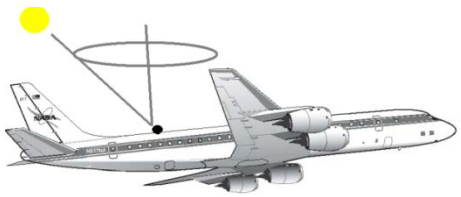


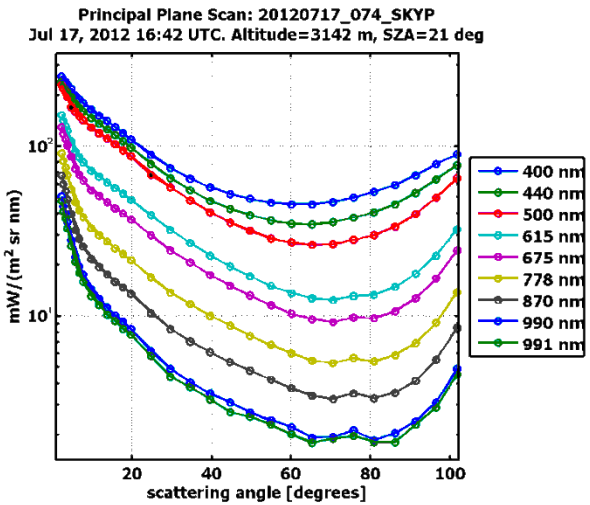
Such analysis can be instructive for elevated layers that were not sampled by in-situ instrument during flight. The combination of aerosol and gas composition allows identification of Group 2, which has very low AOD amounts that are difficult to classify by other (extinction only) remote-sensing platforms

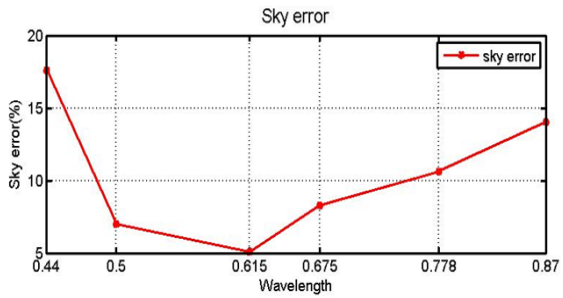
Preliminary

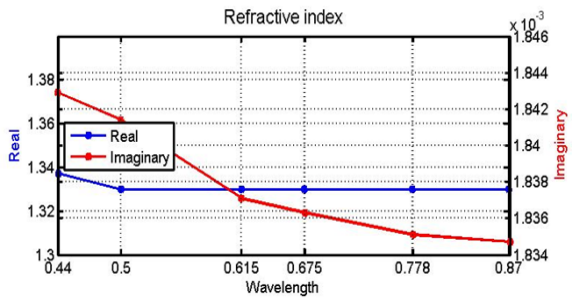
From radiances to intensive aerosol properties

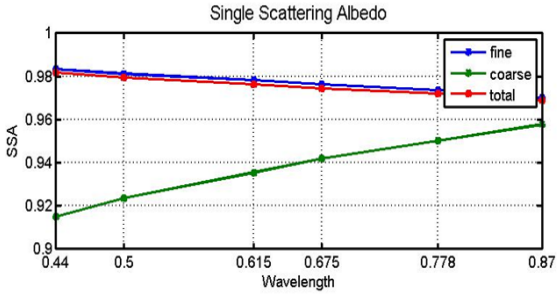
Size distribution, index of refraction, SSA, asymmetry parameter, sphericity.

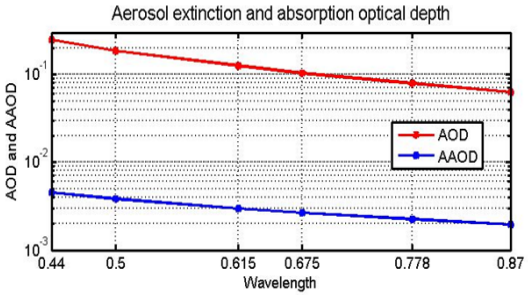










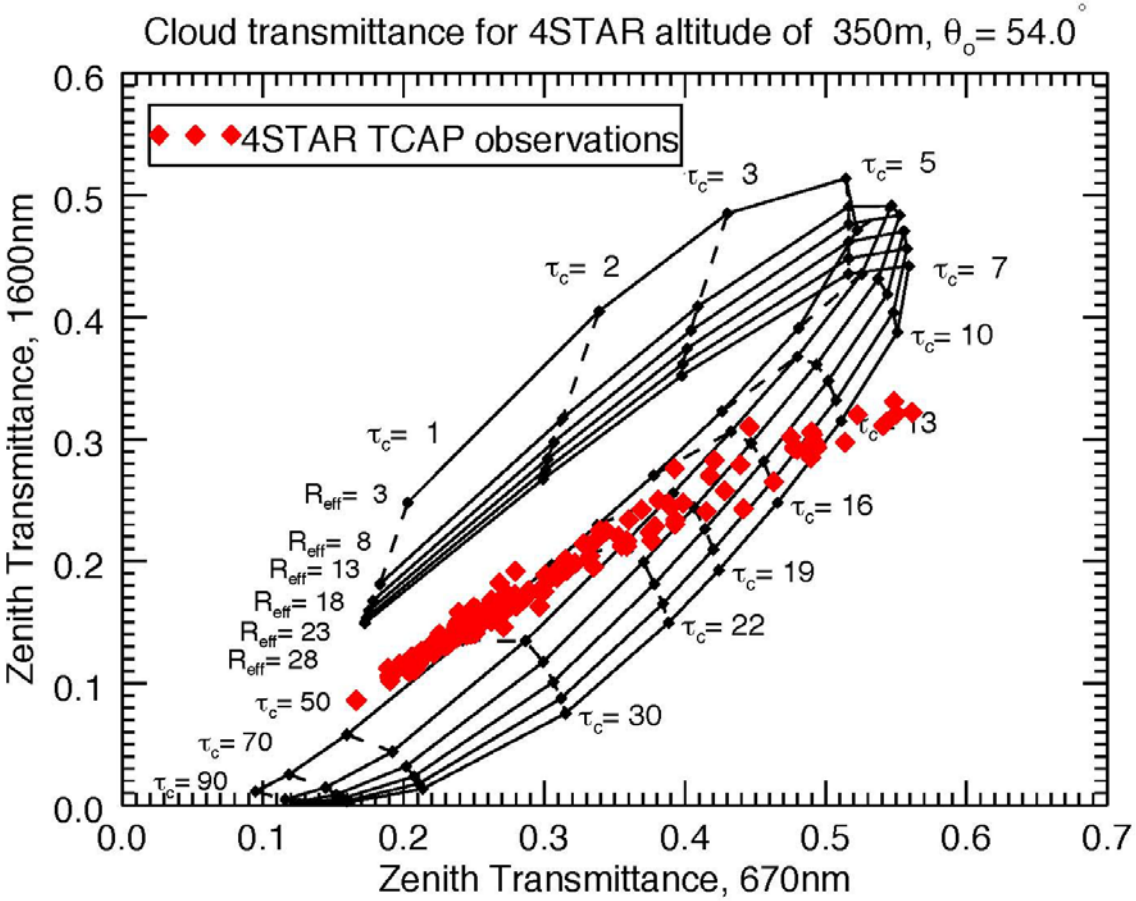


Analysis by Connor Flynn

Collaboration with AERONET, SSFR, potential comparison to collocated RSP, HSRL, AERONET and satellites

Preliminary

Cloud properties from 4STAR zenith radiances



The LUT is for:

- **TCAP-2, Feb 19, 2013**
- Over ocean with 5m/s wind
- Solar zenith angle
- water clouds only
- 1km slab
- A/C altitude
- No aerosols

Analysis by Knobelspiesse, Segal-Rosenheimer, Flynn

Papers re 4STAR & TCAP

Kassianov, E., C. Flynn, J. Redemann, B. Schmid, P. Russell, and A. Sinyuk: Initial Assessment of the **4STAR-based Aerosol Retrieval: Sensitivity Study**, *Atmosphere* **2012**, *3*, 495-521; doi:10.3390/atmos3040495 (Special issue: Advances in Studies of Atmospheric Aerosol and Clouds Using Remote Sensing Techniques).

Dunagan S., et al., 4STAR Spectrometer for Sky-Scanning Sun-Tracking Atmospheric Research: **Instrument Technology**, *Remote Sens.* **2013**, 5, 3872-3895; doi:10.3390/rs5083872

Shinozuka, Y., et al., **Hyperspectral aerosol optical depths** from TCAP flights, *J. Geophys. Res.,* accepted.

Segal-Rosenheimer, M, et al., **Tracking Elevated Pollution Layers** with a Newly Developed Hyperspectral Sun/Sky Spectrometer (4STAR): Results from TCAP 2012-and 2013 campaigns, for *J. Geophys. Res.* in review.

Future TCAP-4STAR work

- **Refine direct beam measurements -**
  - Provide refined measurements of 4STAR AOD and trace gas column concentrations for comparisons with climate model output and independent observations (TCAP RP 6 and 7);
  - Derive AOD-CCN relationships and study the information content in UV AOD (ASR Process Research focus 2.2.2 Microphysics and 2.3.1 Cloud Particle Formation, and TCAP RP 1);
  - Support the TCAP objective (RP 4) of passive AOD retrievals in the presence of clouds by scrutinizing the 4STAR near-cloud measurements and cloud screening of 4STAR AOD data.
- **Invert sky radiance measurements –**
  - Develop 4STAR algorithms for the retrieval of aerosol absorption, scattering phase function, asymmetry parameter, and size distribution;
  - Test the sensitivity of retrieved aerosol properties to aerosol loading and conditions (Θ, A_{S+atm});
  - Carry out radiative closure studies (TCAP RP 2) by comparing the measured sky radiances with radiances calculated using in situ aerosol properties and HSRL-2 retrievals.
  - Calculate aerosol induced changes in heating rate profiles from 4STAR retrieved aerosol properties (ASR Process Res. focus 2.1.3 Aerosol Direct Rad. Forcing and 2.2.3 Radiation).
- **Analyze zenith mode measurements –**
  - Develop 4STAR algorithmic capabilities to retrieve cloud optical depth and droplet effective radii from zenith mode operations;
  - Compare 4STAR cloud retrievals to independent observations (e.g., polarimeter retrievals, in situ measurements, satellites) in support of the TCAP aerosol-cloud interaction focus (RP 5).