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4STAR sky-scanning retrievals of aerosol intensive optical properties from multiple field campaigns with detailed comparisons of SSA reported during SEAC4RS

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Abstract

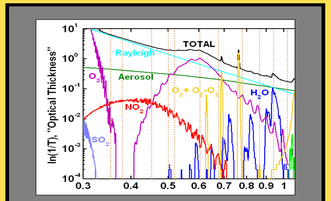
The 4STAR (Spectrometer for Sky-Scanning, Sun-Tracking Atmospheric Research) instrument combines airborne sun tracking capabilities of the Ames Airborne Tracking Sun Photometer (AATS-14) with AERONET-like sky-scanning capability and adds state-of-the-art fiber-coupled grating spectrometry to yield hyperspectral measurements of direct solar irradiance and angularly resolved sky radiance. The combination of sun-tracking and sky-scanning capability enables retrievals of wavelength-dependent aerosol optical depth (AOD), mode-resolved aerosol size distribution (SD), asphericity, and complex refractive index, and thus also the scattering phase function, asymmetry parameter, single-scattering albedo (SSA), and absorption aerosol optical thickness (AAOT).

From 2012 to 2014 4STAR participated in four major field campaigns: the U.S. Dept. of Energy's TCAP I & II campaigns, and NASA's SEAC4RS and ARISE campaigns. Establishing a strong performance record, 4STAR operated successfully on all flights conducted during each of these campaigns. Sky radiance spectra from scans in either constant azimuth (principal plane) or constant zenith angle (almucantar) were interspersed with direct beam measurements during level legs. During SEAC4RS and ARISE, 4STAR airborne measurements were augmented with flight-level albedo from the collocated Shortwave Spectral Flux Radiometer (SSFR) providing improved specification of below-aircraft radiative conditions for the retrieval.

Calibrated radiances and retrieved products will be presented with particular emphasis on comparisons between ambient SSA retrievals SEAC4RS and comparisions between 4STAR and AERONET.

What is 4STAR?

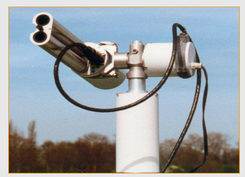
Spectrometer + **Sky-Scanning** + **Sun-Tracking** = **Atmospheric Research!**



Spectral Measurements…
- Improve H_2O, O_3…
- Provide NO_2
- Improve AOD

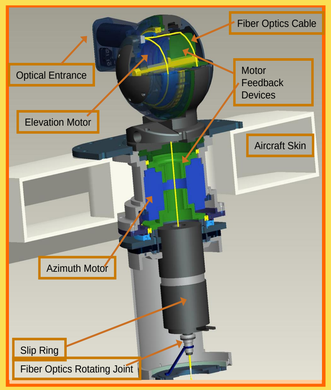
Goal: airborne profiles of trace gas + aerosol type via Aeronet-like retrievals

AERONET-like
- phase function
- size mode distributions
- $n_{re}(\lambda)$, $n_{im}(\lambda)$
- single-scattering albedo
- asymmetry parameter
- shape, hence aerosol type



Ames Airborne Tracking Sunphotometer

AATS-14-like
- column AOD
- column gases (O_3, H_2O)
- aerosol ext. profile
- profile of gaseous atmospheric components



4STAR's record of consistent achievement and continual development in the field.

2008 MLO, Sun Photometer InterComparison Experiement MLO: Developed hyperspectral Langley. Confirmed radiance calibration.

2010/11 PNNL, 4STAR airborne hardening and flight tests: Advanced TRL. Conducted airborne Langleys, retrieved AODs over vertical profile through ramped flight.

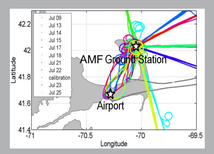
2012 July /2013 Feb. Cape Cod, TCAP-I & II: Flawless first field campaign series. Solid operation on ALL TCAP flights. Collected direct beam, AOD & Ext, gas retr. , and sky scans.

2013 (summer), SEAC4RS. Again outstanding operations. Aeronet overflights and collocation with SSFR provide means to assess sky scan retrievals.

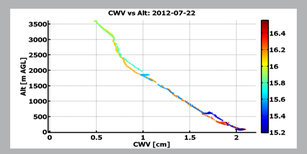
2013 (fall/winter) Alaska, ARISE: Direct beam, sky scans, cloud retrievals, airborne Langley. Collocated with SSFR again.

2015 (winter), NAAMES, just completed.

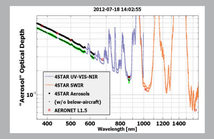
TCAP I Flights from Cape Cod



Gas Phase CWV Retrieval during TCAP I



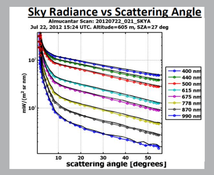
Segal-Rosenheimer, M., et al. (2014). Tracking elevated pollution layers with a newly developed hyperspectral Sun/Sky spectrometer (4STAR): Results from the TCAP 2012 and 2013 campaigns, J. Geophys. Res. Atmos., 119, 2611–2628, doi:10.1002/2013JD020884.



Hyperspectral AOD agrees well with AERONET during overflight when corrected for contribution below aircraft.

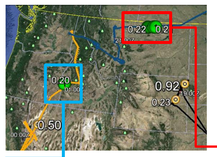
Shinozuka, Y., et al. (2013), Hyperspectral aerosol optical depths from TCAP flights, J. Geophys. Res. Atmos., 118, 12,180–12,194, doi:10.1002/2013JD020596.

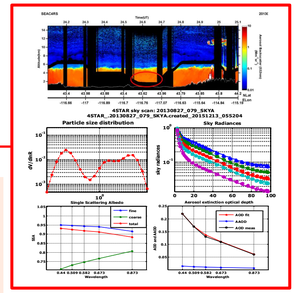
Sky Radiance vs Scattering Angle



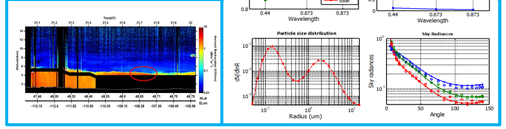
Hyperspectral airborne sky radiance scans show good pointing registration and stability, and sufficient signal to noise, but sky scan retrievals also require accurate calibration of direct beam (optical depth) AND sky radiance, knowledge of upwelling radiation or surface albedo, as well as "cooperative" homogeneious sky conditions. TCAP offered few opportunities to assess 4STAR airborne sky scan retrievals against Aeronet due to low aerosol burden and lack of Aeronet sites over the open ocean.

Selected SEAC4RS flights over diverse regions and varying aerosol burden and type. Numbers indicate 4STAR AOD at 440 nm.

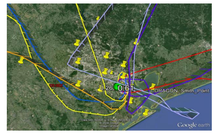




Note the strikingly different aerosol properties observed on Aug 27 at different locations despite similar AOD. The scan from scan 27 (red outline) is dominated by coarser particles yielding correspondingly weaker wavelength dependence than scan 13 (blue outline).

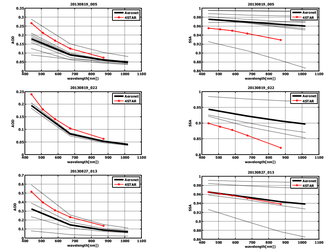


SEAC4RS flights over CONUS provide the opportunity to compare Aeronet and 4STAR sky scan retrievals with sufficient aerosol burden for multiple over-flights across widely separated locations differing aerosol types.



Scans per flight
- Aug 16 – 1(g)
- Aug 19 – 4(2g)
- Aug 21 – 1
- Aug 26 – 3
- Aug 27 – 3
- Aug 30 – 7
- Sep 9 – 6
- Sep 11 – 1

The examples below show the typical level of agreement observed between 4STAR and Aeronet during overflights, and likely illustrate sampling challenges. The bold black line is the average of all Aeronet retrievals within 50 km and 2 hours.



What is next for 4STAR?

- **Current AITT funding to improve calibration stability and implement mechanical/optical improvements**
- **Selected for KORUS-AQ 2016**
- **Selected for ORACLES 2016-2020**
- **Explore new calibration approach to eliminate relative bias errors between direct beam and sky radiance measurements.**
- **Implement vectorized radiative transfer code to speed sky scan retrieval for N-wavelengths.**
- **Hyperspectral cloud-properties retrievals in development (demonstrated in NAAMES)**
- **Build more 4STARS!**

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