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

Development and Results from First Test-flights

A collaboration involving:

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► **NASA GSFC**: B. Holben
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**AERONET-like capability**

Ground-based direct beam + sky scanning yields column-integrated properties:
- AOD
- Size distributions
- Single-scattering albedo
- Asymmetry parameter
- Sphericity
- Cloud OD

**AATS-like capability:**

AOD at 13 wavelengths
H₂O
horizontally and vertically resolved
4STAR Integration and test flights on PNNL/Battelle G-1, Aug-Sep 2010

- Elevation Housing
- Collector Optics (Sky/Sun)
- Quad-detector
- Azimuth Housing
- Azimuth Motor
- Power/Control
- Slip-ring
- Main Lower Unit Housing
- FORJ

[Image of 4STAR equipment and aircraft interior]
Anticipated 4STAR data products:

- **Solar Direct Beam**
  - Atmospheric Transmittance
  - Aerosol Optical Depth and Ångstrom exponent
  - Aerosol Extinction (via aircraft vertical profiling)
  - Gases: H$_2$O, O$_3$, NO$_2$, CO$_2$ (column and in profile)

- **Angularly-resolved sky radiance inversions**
  - Scattering phase function, asymmetry parameter
  - Aerosol size distributions, fine/coarse mode fraction
  - Aerosol sphericity
  - Aerosol absorption

- **Zenith radiance cloud retrievals**
  - Cloudy/clear transition zone (Marshak, Chiu)
  - Cloud Optical Depth, Droplet effective Radius (with auxiliary measurements, Barker et al.)
  - Water vapor, liquid water, ice water fractionation (Daniels et al.)
4STAR and its Use...

**Advantage:**

- Exact match in layers sampled by *airborne* sunphotometer & *in situ* instruments
- Tightens closure
- Key link
- Helps explain discrepancies
Key Technological Hurdles

- Entrance window contamination
- Fiber optic couplings with <1% calibration stability (Connections/Rotation)
- Irradiance calibration to 1% over a period of months.
- Radiance calibration to a few percent.
- Stray light rejection: measure skylight down to within 3° of sun
- Sky scan within 100 seconds (10 km in flight)
- Stray light inside spectrometers
Ground Prototypes (4STAR-G)
Rotating Fiber Optics Coupling Throughput Repeatability

Fractional variation after normalized by sinusoid

Normalized over angle and revolution vs. angle of rotation (degrees)
Radiance Calibration

AERONET Cimel

NASA Ames 30” Sphere

4STAR-Ground
4STAR-Ground

AERONET Cimel

Jens Redemann

Roy Johnson
4STAR and Aeronet principal plane scans on 2007-04-30, SZA=43.8 deg
Independently calibrated at NASA Ames and NASA GSFC

+ 4STAR
o Aeronet
440.8 nm
673.6 nm
869.3 nm
1005.6 nm
Stray light rejection close to Sun - old barrel
Size Distribution Retrieval using AERONET Code

Particle Radius, $\mu$m

$dV/d\ln R$
Sun Photometer Inter-Comparison Experiment
Mauna Loa, Aug. 24 - Sep. 2 2008
3 flights in Sep 2010:

1. Pilots only: Airworthiness certification
2. Science ops: Pasco, WA to San Jose, CA
3. Science ops: San Jose local

Flights met all goals (sun tracking only). Large data set to guide improvements & test/demo flights in 2011.
Sun Tracking Performance

9/28/2010; SJC t/o ~10 am

[Graphs showing data over time]
Vertical profile of optical depth
(normalized to top of layer)

9/28/2010
SJC ~10 am

Layer OD

wavelength [nm]

OD

alt [km]

λ (nm)
In FY11: bring 4STAR to full science capability
- Install/characterize skylight optics
- Improve FOV uniformity of sun optics
- Make tracking immune to glint
- Adding temperature-stabilized enclosure for spectrometers and electronics
- Apply correction of stray light inside spectrometer
- Full characterization in test-flight series on G-1 in April, Jul, Sep
  - Next flight April 11 focusing on sky scan and cloud-mode
- Mauna Loa Calibration

In FY12
- Hardening and retrieval algorithms
- 4STAR/AATS-14 intercomparison flight on NASA P-3
- DOE/ARM Mission on G-1, Cape Cod, Summer and Winter 2012