Spectrometer for Sky-Scanning, Sun-Tracking Atmospheric Research (4STAR) for SEAC^{4}RS: Instrument Description, Science Goals and Supplemental Information

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For SEAC^{4}RS, 4STAR (see images below) is offered as an option to replace AATS-14 on the DC-8 after initial science flights by AATS-14 during the Southeast Asia deployment. 4STAR has the sun-tracking capabilities of AATS and adds sky-scanning and zenith-viewing capabilities, all with spectrometers replacing the individual photodiodes of AATS [e.g., *Dunagan et al.,* 2011; *Schmid et al.,* 2011].

Left: 4STAR tracking/scanning head and slipring/FORJ cylinder.

Right: 4STAR rack-mounted components as flown on PNNL G-1, August 2011.
Top to bottom:
Motor controller box
Data system box
Operator pullout keyboard and screen
APC UPS
Spectrometer box
Chiller

Below: 4STAR rack & operators on G-1 flight, September 2010

4STAR has made several test flights on the PNNL G1, and its full capabilities are still being developed. When it achieves those full capabilities, we expect that, in addition to AATS-like direct-beam measurements of aerosol optical depth (AOD) and water vapor,

- 4STAR's sky-scanning capabilities will permit the first airborne AERONET-like retrievals of such aerosol properties as SSA, complex refractive index, shape, and multimodal size distribution,

- Its zenith-viewing mode will permit retrievals of cloud optical thickness and cloud particle effective radius (when combined with a measurement of upwelling flux at two solar wavelengths), and
- Its spectrometric resolution will permit improved aerosol-gas separation (hence improved aerosol retrievals) and possibly retrievals of additional gases.

Thus, 4STAR measurements in SEAC^{4}RS will support the goals of AATS-14 (see below) with a more diverse data set covering more conditions, including overcast skies. In particular, 4STAR's zenith-viewing cloud mode will provide cloud measurements when clouds prevent sun tracking, and its sky-scanning mode will permit AERONET-like detailed aerosol property retrievals away from and above clouds. For SEAC^{4}RS, 4STAR will be calibrated before and after the experiment at Mauna Loa Observatory (MLO) using the Langley plot technique.

For reference, the goals of AATS-14 in SEAC^{4}RS are to:

1. Provide the multi-spectral optical depth measurements listed in the Aircraft Payloads table of the SEAC^{4}RS Planning Document, plus simultaneous water vapor column measurements, in conditions away from clouds, above clouds, and near cloud-aerosol boundaries,
2. Perform integrated analyses of the aerosol optical depth (AOD), water vapor, and associated data sets from aircraft, satellites, and surface measurements in support of SEAC^{4}RS goals in:
   a. satellite validation, especially in the difficult environments of cloud-aerosol boundaries and aerosol above clouds,
   b. aerosol effects on radiative energy budgets and cloud remote sensing caused by aerosols from anthropogenic sources, wildfires and other natural sources (e.g., marine, volcanic) as affected by the monsoon circulation and ENSO state,
   c. aerosol-cloud interactions, and
   d. science definition of such NRC Decadal Survey-recommended missions as ACE and Geo-CAPE.

Further information on 4STAR is at

http://geo.arc.nasa.gov/sgg/NID/index.html .

References

Dunagan, S., R. Johnson, J. Zavaleta, R. Walker, C. Chang, P. Russell, B. Schmid, C. Flynn, J. Redemann, 4STAR Spectrometer for Sky-Scanning Sun-Tracking Atmospheric Research: Instrument Technology Development, Preprint, 34th International Symposium on Remote Sensing of Environment, Sydney, Australia, 10-15 Apr 2011.

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4STAR for SEAC^{4}RS: Supplemental Information

Parameters measured	Technique	Averaging or Integration Time	Expected Resolution/Accuracy
Multiwavelength optical depth (~350-1690 nm) Water vapor column Sky and cloud radiance Multiwavelength extinction and water vapor density when aircraft flies vertical profiles	Sky scanning, zenith viewing, and sun tracking spectrometry	Typically 0.1 s for AOD and CWV. ~100 s for sky scans.	Resolution: Slant OD ~0.002 Slant WV ~0.0005 to 0.006 cm^{-1} Accuracy: Aerosol optical depth (AOD) ~0.01 Column water vapor (CWV) ~10%

Instrument operational preferences and constraints

- Location on DC-8: Away from obstructions to viewing sun. Current planned location, 62º #3 viewport, is acceptable but not as good as the 62º #1 viewport where AATS-14 flew in SOLVE II.
- 4STAR window cleaning: The 4STAR entrance window must be cleaned before each flight and inspected after flight. If the 4STAR DC-8 mount, like its G1 mount, allows the 4STAR head to be dropped into the cabin between flights, this cleaning can be accomplished without access to the DC-8 roof.
- 4STAR bucket: Between flights the 4STAR head needs to be covered with its bucket. This prevents rain from entering 4STAR. The bucket needs to be removed before flight and replaced after flight. This requires access to the DC-8 roof by stairs or lift.
- Aircraft speed: No restrictions.
- T, P: No hard restrictions, but very cold conditions are challenging, especially after being exposed to moisture. The risk is freezing water in the 4STAR bearings, which prevents sun tracking, sky scanning, and zenith viewing.
- Ascent/descent rates: No restrictions.
- Bank angles: Prefer ≤30º.
- Smoke contamination: We need ~30 seconds warning before penetrating dense smoke or clouds, so we can park 4STAR. Usually the pilot gives us this warning.
- Clouds: 4STAR data on aerosol optical depth (AOD) are interrupted when a cloud blocks the 4STAR-to-sun viewing path. 4STAR column water vapor (CWV) data persist when 4STAR tracks the sun through thin cirrus. In overcast skies 4STAR's zenith-viewing mode provides cloud radiance data.
- High altitude sampling issues: As mentioned above, very cold conditions are challenging, especially after being exposed to moisture.

Critical observable to transmit in real time to ground planning teams

- I would suggest AOD at one or a few wavelengths, plus maybe CWV. We have not done this before, but these values are calculated and displayed onboard in real time. What is the procedure for getting these values into the telemetry stream?