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

Functional Requirements Document

Version 2c (6/18/2010)

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REVISION HISTORY

DRAFT 6-14-2007 First Draft borrowing from AATS14 requirements, many open questions regarding science objectives and related functions

DRAFT1 8/23/2007 Incorporates comments from Phil and Beat

Version 1 10/2/2007 Incorporates comments from team review telecom

Version 1a 12/4/2007 Minor revisions: pointing accuracy language

Version 1aCDR 4/21/2010 Cleaned up for Critical Design Review (CDR)

Version 2a 4/28/2010 Posted to server as supporting documentation for CDR

Version 2b 6/1/2010 Cleaned up all residual questions, added requirement 5.5 for window protection from dirt and rain, added appendices A and B for Software Modes and Data Format.

Version 2c 6/18/2010 Incorporated corrections/clarifications re 4STAR maximum wavelength requirement and DC-8 ceiling. Minor spelling correction.

1.0. INSTRUMENT PURPOSE AND OVERVIEW:

This instrument will be used to measure optical properties of atmospheric aerosols and clouds and the amounts of H_2O, O_3 and NO_2 by observing both the direct solar beam and angularly resolved scattered radiation from the sky. It will build on previous multi-channel direct beam sun tracking design, and will incorporate sky scanning capability in the almucantar and principal plane directions, referenced to earth-fixed coordinates. Collected radiation will be separated into many component wavelengths. A very high level of radiometric precision is required in all measurements. The instrument will be deployed on an aircraft. A fast tracking system will permit the instrument to remain locked on the direct solar beam for extended periods, correcting for motions of the aircraft and sun. The sky-scanning mode will require additional navigation data to link the aircraft coordinate system to earth coordinates.

This instrument will be designed to operate on a variety of aircraft, some of which will be remotely piloted or autonomous. It will be able to locate and track the sun without input from an operator and will have a self-contained data storage system. In addition, it must interface to an aircraft-provided telemetry system, so as to receive and execute commands from an operator station, and transmit science and instrument-status data to that station. The operator station is an integral part of the 4STAR instrument and is covered by this requirements document.

The 4STAR instrument is intended to operate in a large variety of geographic locations, a wide range of temperatures, and a wide range of altitudes (from tropical sea level environments to very cold airborne environments), and must accommodate relatively rapid changes in operating environment. The instrument is intended to be lightweight, rugged and stable, and to need little maintenance or service over periods of several months. In particular, it must maintain its radiometric calibration (including window and filter transmittance, as well as detector responsivity and electronic gain) to within 1 % in each spectral channel for periods of several months.

To clarify the following requirements statements, the aircraft coordinate system is defined in figure.1.1

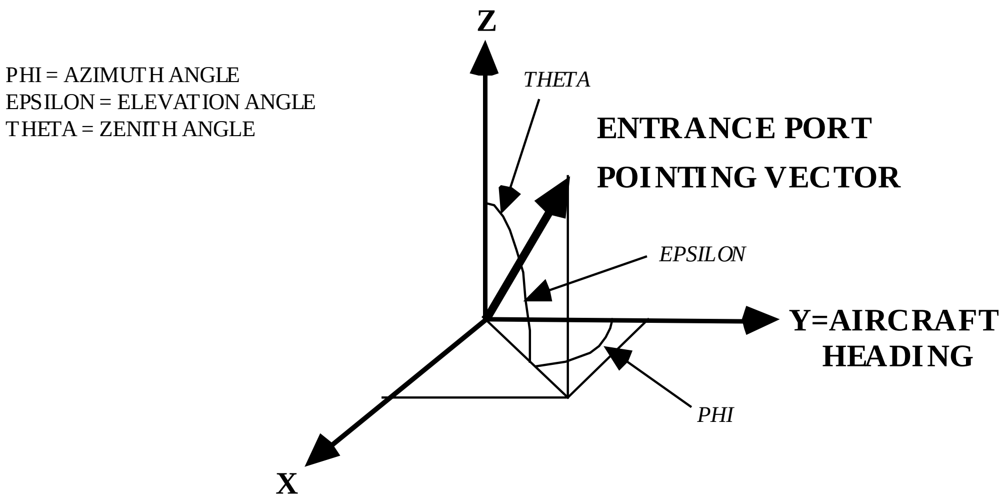

Figure 1.1. Aircraft coordinate system. $\varepsilon = 0.0$ and $\phi = 0.0$ occur when the Entrance Port Pointing Vector (EPPV) coincides with the aircraft heading. ϕ increases clockwise. ε increases upward from the XY plane.

The format of the functional requirements listing will begin with an objective statement of the required functionality, generally avoiding specific direction on a particular design or approach. *Following in italics will be comments that support or clarify the objective requirement statement.*

This document focuses on the functional requirements for an airborne prototype 4STAR, here called 4STAR-AirV1. The intent is that 4STAR-AirV1 will be the first airborne 4STAR, able to be built for reasonable cost while still being capable of performing field missions that demonstrate the scientific value of a spectrometer-based instrument that can measure both direct solar-beam transmission and skylight radiance from an aircraft over altitude ranges and geographic locations that are scientifically important with the primary purpose of investigating aerosol properties and trace gas concentrations. A secondary purpose could be the measurement of cloud properties – the feasibility of such measurements is to be determined based on observations with 4STAR-AirV1. It is anticipated that, after 4STAR-AirV1 has flown several scientific field campaigns, instruments (4STAR-AirV2, etc.) with extended capabilities (e.g., wavelength range or resolution, functional altitude range, weatherproofing, …) will be conceptualized based on that experience. Where appropriate, this document occasionally mentions how later versions might extend the capabilities of 4STAR-AirV1. However, the main focus is on 4STAR-AirV1.

Also relevant is the existing ground prototype, 4STAR-Ground. 4STAR-Ground was developed, and is currently being used and modified, to test the feasibility of various technological methods to be used in 4STAR-Air (e.g., entrance ports, fiber optics, couplings, spectrometers, motors, computer hardware and software). The current document is a working document that is strongly influenced by test results from 4STAR-Ground. Such test results indicate what technological approaches are affordable and likely to produce scientifically useful results from 4STAR-Air. Examples of 4STAR-Ground tests that have influenced, and may in the future influence, this document include measurements of 4STAR-Ground calibration stability, skylight measurements near the sun, spectrometer characteristics, and fiber optic couplings. The general philosophy regarding 4STAR-Ground and 4STAR-Air is that if any technological approach can be tested on the ground, it should be so tested before being incorporated in a 4STAR-Air design.

2.0 OPTICAL MEASUREMENT REQUIREMENTS

2.1 The instrument will measure spectral and radiometric qualities of the direct solar beam. *As an evolutionary enhancement of multi channel direct beam measurements, finer spectral resolution will permit gas retrievals and will improve aerosol measurements via better aerosol-gas separation. Vertical profiling requirements will ultimately require that we fly to DC8 altitudes, 41000 ft*.

2.1.1 Spectral span and resolution:

2.1.1.1 An ultra violet/visible/near infrared (UVVNIR) sensor will measure the range from 350 nm to 1015 nm with a resolution of 2 to 3 nm. *Very little light penetrates the atmosphere at wavelengths shorter than 330 nm. AATS 14 has a channel at 354 nm. Sensitivity at 350 is a firm requirement for many comparisons such as Raman Lidars and others.*

2.1.1.2 A short wave infrared (SWIR) sensor will measure the range from 900 to 1700 nm with 5-10 nm resolution, scaling with wavelength. *This broad range adds accuracy to aerosol retrievals, and permits comparison with retrievals from other (space) instruments. This comparison will be enhanced by matching of spectral channels.*

2.1.2 Spatial span and resolution

2.1.2.1 The instrument must be able to continuously track the sun in the azimuthal ϕ direction, as the aircraft flies in arbitrary heading patterns. The instrument must be able to access elevation angles from: $\varepsilon = 0$ degrees to +110 degrees. *The instrument must accommodate spiraling flight patterns and elevation scans from the horizon to zenith, plus bank angle.*

2.1.3 The instrument must resolve signal amplitudes across 3-4 orders of magnitude, from minimum detectable difference to saturation. Linear response is most desirable. *The biggest expected signal is at max altitude, with the sun at zenith on Jan 3. The smallest signal is flying low with the sun above horizon and an AOD of ~2. (We can't really work with data if color effects begin to show)*

2.1.4 The instrument sampling interval, coupled with the aircraft ground speed must combine to provide averaged data at a spatial sampling interval of 100 meters in earth coordinates. Each interval should consist of at least 5 individual samples with statistical data. *This will resolve spatial variability in aerosols, and permit cloud screening.*

2.1.5 The instrument will be capable of continuous operation for up to 11 hours duration. *This is driven by missions above the arctic circle.*

2.2 The instrument will measure spectral and radiometric properties of scattered light from the atmosphere (sky).

2.2.1 Spectral span and resolution

2.2.1.1. A visible/near infrared (UVVNIR) sensor will measure the range from 350 nm to 1015 nm with a resolution of 5nm. *AERONET is the standard. We will use similar data analysis algorithms.*

2.2.1.2 A short wave infrared (SWIR) sensor will measure the range from 900 to 1700 nm with 5-10 nm resolution. *These measurements will be useful for cloud analysis.*

2.2.2 Spatial (angular) span and resolution (in earth reference frame)

2.2.2.1 The instrument will perform scans in the almucantar direction over 360 degrees of range referenced to the sun and aircraft coordinate system, with angular position known to 0.2 deg accuracy. *The justification for the AERONET sky scan geometry is identified in Holben's paper "AERONET characterization of S. Asian aerosols: the view from version 2", presented at SPIE Asia-Pacific Remote Sensing Conference, 3–17 November 2006, Goa Marriott Resort, Panaji, Goa, India. Extensive discussions with Aeronnet team indicate the need to sample to within 2-3 degrees scattering angle*.

2.2.2.2 The instrument will perform principal plane scan over an elevation range from $\varepsilon = 0$ degrees to +180 degrees referenced to the sun and aircraft coordinate system, with angular position known to 0.2 degree accuracy. *No additional margin is included here for parking the sensor (see environmental requirements) or aircraft bank angles (see aircraft motion requirements)*

2.2.3 The sky radiance measurements must resolve signal amplitudes across 4 orders of magnitude, from minimum detectable difference to saturation. Linear response is most desirable. In clear skies, *the maximum signal is just off the sun in heavy aerosol atmosphere. The smallest signal is at 90 degree side scatter in a very clean atmosphere.*

2.2.4 The instrument will complete a pair of almucantar and principal plane scans within 10000 meters of aircraft motion. *This will resolve spatial variability in aerosols, and permit cloud screening. The MODIS 10km pixel is a point of reference for this requirement. Jens Redemann proposes this criterion to contain data collection within an atmospheric volume where OD does not change by more than 0.02 over the sampling volume. This volume is subtended by the angular range of the view angle passing through the ~3km sheet of lower atmosphere. A test criterion for this condition* *will be the symmetry of right and left almucantar scans. In addition, intermittent direct beam measurements between almucantar and principal plane scans will be performed to assess variability.*

3. TRACKING SYSTEM

3.1 The instrument will be fitted with a (2-axis or more) pointing system capable of keeping the instrument pointing on the central plateau of the FOV scan. The slope of the plateau can be up to 2% per deg. *This enables radiometrically accurate direct beam measurements.*

3.2 The instrument will interface to a subsystem to provide reference data to transform the pointing vector of almucantar and principal plane scan data from aircraft to earth referenced coordinates, to within 0.2 degree accuracy. *This subsystem (e.g. inertial navigation unit) may run its own clock and record the transformation data stream at appropriate update rates to achieve the angular error specification, with an occasional time stamp passed to the tracking system to permit coordinate transformation in post processing. This approach will not produce true almucantar and principal plane scans owing to aircraft motion, but scattering angles can be accurately computed in post processing. A related requirement for data synchronization is described in section 4.2.2.*

4. DATA ACQUISITION SYSTEM (DAS)

4.1 The Instrument will be fitted with onboard instrument controller software to enable the operations listed below. *Instrument control will be initiated and monitored by an instrument operator during all airborne missions.*

4.1.1 Initiate and terminate acquisition of direct beam sun tracking data.

4.1.2 Execute principal plane sky scan.

4.1.3 Execute almucantar plane sky scan.

4.1.4 Park instrument.

4.1.5 Field of view scan, principal and almucantar.

4.1.6 Manual position to arbitrary angle.

4.1.7 Abort and park. *Emergency stop*.

4.1.8 Tune initialization parameters (gains, scan parameters etc.) *All gains, limits, data processing parameters, etc. will be initialized in software through initialization files which will be edited in pre-flight or in-flight to modify system performance.*

4.1.9 Monitor status and health (including temperature) of key instrument subsystems

4.1.10 Execute pre-programmed flight plan. *This is low priority for the initial instrument checkout but will need to be an expansion path for future missions.*

4.2 The instrument will be fitted with a separate onboard data storage partition adequate to capture continuous raw and processed data for mission duration as specified in section 2.1.5. *A separate data partition is recommended to avoid cross-contamination of the boot partition in the event of in-flight crashes.*

4.2.1 All raw data will be saved.

4.2.2 The data acquisition system will import a timing synchronization stamp with better than 1 msec accuracy to permit post processed position and attitude correction. *The instrument will not include an inertial navigation unit (INU) but will rely on an aircraft system (e.g. Applanix Pos-AV) to provide accurate position and attitude data. An interface process running on the DAS will manage this time registration. A time code stamp (e.g.Net 106: IRIG-B over UDP) may be useful in this context.*

4.3 The instrument will perform onboard data processing. *Automatic "quick look" processing will be performed to display data to the operator for evaluation of target acquisition and data integrity and to interface with the mission manager in a timely way to maximize mission productivity.*

4.3.1 Operator initiated software will automatically calculate retrievals of AOD, water vapor, and potentially O_3. *AATS experience is the precedent for this.*

4.3.2 A background process will read and process systems health data, and will send an alarm to the operator console when systems health parameters are out of range.

5. ENVIRONMENT

5.1 The instrument will operate at altitudes from 0 to 41000 ft. MSL at all latitudes. *The instrument must operate reliably in the pressure, temperature, and relative humidity levels corresponding to the maximum expected variability from the standard atmosphere over these altitude and latitude ranges. 41000 ft is ceiling of DC-8.*

5.2 The instrument will operate reliably within the vibratory environments measured on the following aircraft. *These vibration spectra identify particular resonances that need to be avoided in the instrument structure. Shake table testing at the resonances shown in the figures below will identify potential vibration problems, which can be mitigated with isolation and damping elements.*

5.2.1 NASA DC-8 aircraft

5.2.2 NASA Wallops P-3 aircraft

5.2.3 PNNL G-1 aircraft

5.2.4 C-130 aircraft

5.2.5 Twin Otter aircraft (CIRPAS)

5.3 The instrument and all components will be capable of sustaining the emergency landing loads identified in the ARC Aviation Management Office JO-5 manual . *These are crash-worthiness requirements for NASA manned laboratory aircraft.*

5.4 The pointing system must maintain the pointing accuracy specification in section 3.1 subject to aircraft platform motion consistent with cruise and maneuvering flight. The following attitude limits and rates are consistent with previously successful designs. *This environmental specification is a function of aircraft wing loading, airframe inertia, flight control parameters, pilot inputs, and atmospheric forcing.*

5.4.1 Roll: 25 degree bank angle; 6 degrees/sec rate. *Roll is the least stable for most aircraft owing to high control surface forces and low fuselage inertia about this axis. AATS 14 is 4-6 deg/sec. Turbulence will be problematic. Will want to track the sun through a spiral but probably not low on the horizon.*

5.4.2 Pitch: 25 degree climb/descent; 3 deg/sec rate. *Pitch rates are lower owing to higher fuselage inertia.*

5.4.3 Yaw: continuously variable heading; 6 degrees/sec rate. *Yaw rate is derived from turning radius.*

5.4 Instrument components and materials will be selected to be compatible with operation in a pressurized aircraft (i.e. human-occupied confined space). *This is a safety requirement and will impact motor type, wiring insulation, and other materials that might out-gas. Beware of brushed motors*

5.5 Protect instrument window from water and dirt deposition during takeoff and through rain and clouds (in parked mode).

6. INTERFACES

6.1 The instrument head will be mounted into a port in the top surface of the aircraft. An accompanying half-height 19 inch instrument rack will interface to the head via a wire/fiber optic cable.

6.1.1 The instrument head weight will not exceed 50 lbs. The accompanying instrument rack will not exceed 200 lbs. If instrument is built as a can design (such as AATS-14) then the total weight shall not exceed 140 lbs. *The target weight is much lighter.*

6.1.2 The instrument head volume will not exceed a cylindrical envelope 12" in diameter and 24" high. *Mounting into previously used aircraft will be complicated and expensive if we exceed the mounting hole required for AATS-14, so we don't want to exceed the 8" diameter of the AATS head.*

6.1.3 The instrument head mounting interface will conform to a 10 inch bolt circle of 5/16" clearance holes, 16 holes equally spaced.

6.1.4 The instrument rack-mounted components will fit into a standard 19" wide by 22": deep rack and will not take more than 60" of vertical height. *Target is half rack.*

6.2 The instrument will draw electrical power from the host aircraft.

6.2.1 The operating voltage will be nominally 110 VAC, 60 Hz.

6.2.2 The instrument current draw will not exceed 15 amps in startup and 5 amps steady state.

6.2.2 The instrument will operate with electrical power noise levels on the order of the electrical power grid specifications for ripple and surge.

6.3 An Instrument Operator interface will be implemented over a network connection to the DAS. *When manned aircraft are used the operator will be aboard the aircraft. For UAS missions, control must be accomplished over a telemetry link using a network process. For simplicity of implementation and consistent operation, direct console connections for keyboard, mouse, and monitor are not recommended. This will require a separate laptop for flight operator mode.*

7. OPERATIONS

7.1 Aircraft flight track requirements: Primary data acquisition mode for sky scanning will be during constant altitude, wings-level flight legs.

7.2 Special operations:

7.2.1 Repetitive patterns (circles, squares, or racetracks) permit spatially localized measurements.

Appendix A

4STAR-Air Expected Operating Modes

Version 2a (12/9/2008)

REVISION HISTORY

DRAFT, V1	11-7-2008	First Draft
UPDATE	11-10-2008	Yohei’s input
UPDATE	11-12-2008	Phil’s corrections
V2	11-18-2008	Phil’s incorporation of email comments
V2a	12-9-2008	Phil’s incorporation of webcon discussion

1.0. PURPOSE AND RELATED DOCUMENTS:

This document is a supplement to the 4STAR Functional Requirements Document and the 4STAR Flight Software Plan (Appendix B). Its purpose is to provide guidance to the further development and refinement of the 4STAR Flight Software Plan.

2.0 EXPECTED OPERATING MODES FOR 4STAR-Air

2.1 4STAR-Air will have several operating modes. It is expected that the 4STAR-Air operator will change operating modes during any given flight or ground operation on the basis of the goals of the flight or ground operation plan plus the atmospheric conditions and 4STAR performance encountered during the flight or ground operation. It will be desirable for some mode changes to be made without parking the instrument. Some modes will be mandatory for inclusion in the 4STAR-Air prototype (as proposed to NASA ROSES in July 2008), whereas other modes can wait for implementation until after developing experience with the 4STAR-Air prototype. The following sections describe both prototype-mandatory and post-prototype modes, with an indication of which is which. The rationale for describing both types now is that it is useful to reserve space or structure for post-prototype modes in the basic software structure.

2.1.1 Park. This mode points the entrance ports to a stowed position that protects entrance optics from deposition of particles (cloud or aerosol) by the air through which the aircraft is flying and allows dark measurements (see also 2.1.2). Prototype-mandatory. We will consider post-prototype addition of a calibration source in the parked position.

2.1.2 Darks. This mode measures detector output while the entrance ports are blocked to prevent entrance of outside light. Prototype-mandatory.

2.1.3 Onboard Calibration. In this mode the sky and/or sun barrels point at an onboard calibration source. Source needs to be stable to 1-2% for sky barrel & 0.1-0.2% for sun barrel. Post-prototype. This mode would be valuable even if restricted to pre-or post-flight operation.

2.1.4 Sun Tracking. This mode provides data on the Sun’s direct-beam transmission through the atmosphere. It is expected to be 4STAR-Air’s most commonly used mode in flight. Since it requires tracking the sun, it will be used when the 4STAR-Air aircraft has a clear view of the sun for several minutes or more (i.e., conditions cloud-free or partly cloudy above 4STAR, or under clouds thin enough to transmit a Sun disk distinct enough for 4STAR to track). Prototype-mandatory.

2.1.5 Search for sun. Implemented automatically when Sun tracking mode loses Sun tracking for a period that exceeds x seconds, where x is user defined during operation. Prototype mandatory implementation will use AATS-like scans of sky (360 deg in azimuth at enough elevation angles for quad FOV to cover all of sky. Post-prototype implementation could use imaging detection of large portion of sky. A different post-prototype implementation could use ephemeris combined with A/C pitch, roll, yaw readout to point near sun.

2.1.6 Field of View (FOV). This mode is used to measure the field of view of both the Sun and sky channels, typically in two directions: principal plane (elevation) and almucantar (azimuth). It operates by sweeping the 4STAR entrance ports across the sun, starting several degrees away from the Sun on one side and ending an equal distance away on the other side. It will be desirable to switch from Sun Tracking to FOV mode without parking 4STAR. Prototype-mandatory. Spectral data not necessary; one selectable channel is sufficient.
[We can't really measure the FOV of the sky barrel without attenuator which in the current configuration will require getting outside the aircraft in flight. But this is not critical and the document is OK].

2.1.7 Sky. This mode is used to measure sky radiance in one of four sub-modes:

2.1.7.1 Almucantar Scan. This sub-mode sweeps the 4STAR entrance ports through 360˚ of azimuth at constant elevation passing through the sun. It is expected that the operator will choose this mode when sky conditions are such that most or all of the sweep will view clear sky (rather than clouds) and homogeneous properties of aerosols and the aircraft is flying nominally straight and level. It will be desirable to switch from Sun Tracking to Almucantar Scan mode without parking 4STAR. Prototype-mandatory.

2.1.7.1.1 Detail on possible Almucantar Scan: Start a few (TBD) degrees to one side of the sun, scan towards, across, and past the sun all the way out to 180 degrees azimuth. Then go back to the sun (briefly) before jogging few (TBD) degrees to the other side of the sun, scan towards, across, and past again but on the other side of the sky from the first one. The slightly overlapping shallow angles, repeated FOV scans, and temporally close direct beam measurements will be valuable.

2.1.7.2 Principal Plane Scan. This sub-mode sweeps the 4STAR entrance ports through ~180˚ of elevation (horizon to horizon) at constant azimuth passing through the sun. It is expected that the operator will choose this mode when sky conditions are such that most or all of the sweep will view clear sky (rather than clouds) and homogeneous properties of aerosols and the aircraft is flying nominally straight and level. It will be desirable to switch from Sun Tracking to Principal Plane Scan mode without parking 4STAR. Prototype-mandatory.

2.1.7.2.1 Detail on possible Principal Plane Scan. We should restrict our principal plane scans mostly to the portion with elevation angles higher than the sun like AERONET does. For example, AERONET only goes six degrees below the sun. There are definite advantages to doing the PP scans by dropping several degrees below the sun and then scanning up to, across, and past the solar disk (with short integration times since the sky near the sun is bright) and then continuing to larger scattering angles with commensurately longer integration times.This gets the near-sun scattering angles measured close in time to the direct beam measurement and provides a quick FOV scan with the sun barrel as part of the scan to confirm good registration of our angles for these shallow scattering angles where it matters most.

2.1.7.3 Zenith View. This sub-mode keeps the 4STAR entrance ports pointing as close as possible to the zenith. Data from this mode (supplemented by upwelling flux measurements from another instrument such as SSFR or Hydrorad 3) are useful for cloud studies. Thus it is expected that the operator will choose this mode when 4STAR is underflying extensive or broken clouds when Sun may not be visible. It will be desirable to switch from Sun Tracking or other sky viewing modes to Zenith View mode without parking 4STAR. A Zenith View mode that points to aircraft zenith (useful for cloud studies in nominally straight and level flight) is prototype-mandatory. A Zenith View mode that uses aircraft attitude information (pitch, roll, yaw?) to point to geo-referenced zenith is post-prototype.

2.1.7.4 Hemispheric Scan. This mode scans the sky in a pattern designed to provide a good estimate of downwelling hemispheric flux (i.e., the integral of downwelling radiance from all downwelling directions, weighted by cosine of zenith angle). Kaufman et al. (2002) describe using principal plane scans for this purpose; however, it would be desirable to preserve the option of using other patterns to improve accuracy. Post-prototype.

2.1.8 Manual Pointing. This mode is used to control manually 4STAR's pointing direction, using angles (with respect to aircraft frame) entered by the operator.

2.2 Immediate execution of mode commands. 4STAR-Air needs to include display buttons that execute a selected mode NOW without delay even if otherwise engaged in another mode. Prototype-mandatory. [PLEASE CHECK]

2.3 Stacking or queuing mode commands. The burden on the 4STAR operator can be reduced if the operator can stack (queue) commands to the program in advance of the actions. Example: having a scan automatically start right after another, without having to keep staring at the screen waiting for the end of the first scan. The queue should remain modifiable at any point, just like the coach can send a pinch hitter, a modification to the line-up, at any point of the game. A blank queue would mean back to sun-tracking. If that is too complicated, it would at least be useful to fine-tune settings for one mode while another mode is on. Example: changing the angles for an upcoming PPL scan while an ALM scan is going on. Post-prototype.

3. REFERENCE

Kaufman, Y. J., B. N. Holben, S. Mattoo, D. Tanre, L.A. Remer, T. Eck, and J. Vaughn (2002). Aerosol radiative impact on spectral solar flux reaching the surface, derived from AERONET principal plane measurements. *J. Atmos. Sci., 59*, 633-644.

Appendix B

4STAR data files: file types, content, and descriptions

4STAR will produce multiple types of data files:

- spectrometer files: This format applies to sun tracking, sky scans, and FOV modes for both VIS and NIR spectrometers.
- auxiliary files: If possible, absorb this content into the spectrometer files.
- tracking files: Rapidly sampled data saved only when tracking sun.

Design elements common to all file types:

Header rows: an arbitrary number of header rows with a leading "%". The header rows will be populated at least the following fields: "mission" (text input), "operator" (text input), "detector_type" (VIS/NIR), "detector_SN" (text input), "collection_code_version" (numeric value), "file_format_version" (numeric value), "Observer_note:" (text input, 400 char max?)

Label row: immediately following the header rows is a single row of column labels identifying the subsequent data content.

Data content common to all files:

Date: One of two date formats is requested as illustrated below.

Format 1: Date specified by y/m/d h:m:s ms components.

YYYY MM DD HH_UTC mm ss msec

2010 01 29 23 58 51 012

Format 2: Date specified by year, day of year, h:m:s ms components

YYYY DOY HH_UTC mm ss msec

2010 29 23 58 51 012

Note that the quantities are all integer quantities.

Shutter_state: An integer value for the shutter state should be reported.

0: view closed

1: view sun

2: view sky

Because we're writing ASCII files every digit, space, or decimal takes up room in our data file, so we should review the use of decimals using only as many digits as meaningful.

Data content of the spectrometer files:

Mode: Integer value reporting the following states:

0: Parked

1: sun tracking

2: FOV_PPL

3: FOV_ALM

4: sky_PPL

5: sky_alm

6: Manual

7: Seek (finding sun)

Num_pixels: Integer value indicating the number of pixels reported in this file. This is a function not only of the spectrometer (VIS or NIR) but also of the mode of operation (FOV has 1 pixel only but could potentially have more.)

Pixel_1, Pixel_2, Pixel_3, ... Pixel_N: one heading for each pixel reported in the file. For FOV files the label will indicate the number of the pixel selected for the FOV scan.

Zone: An integer value reporting the zone of sky for measurement. A negative value indicates below horizon for PPL or east of sun for ALM.

0. Sun
1. Solar disk
2. Very near sun
3. Near sun
4. Mid zone
5. Mid-far zone
6. Far zone
7. Very far zone

99. Not a zone (parked, manual, or seeking)

Data content of the track files: these are rapidly sampled values needed during sun-tracking mode. This file is only created during sun-tracking.

Az_deg: azimuth angle in degrees

Az_corr: correction from quad to azimuth in degrees

El_deg: elevation angle in degrees

El_corr: correction from quad to elevation in degrees

Az_step: azimuth motor position in steps

El_step: elevation motor position in steps

V_BT: Quad bottom voltage minus quad top voltage

V_LR: Quad left voltage minus quad right voltage

V_tot: sum of quad voltages

Auxilliary fields: these fields may inhabit a separate file ("AUX") or may be absorbed in the spectrometer files. In cases where both spectrometer files (VIS and NIR) are being produced this will incur some redundancy.

Lat, Lon, Alt: telemetry reported by aircraft or read from GPS with 4STAR.

AZ_step, EL_step, AZ_deg, EL_deg: azimuth and elevation position in steps and degrees (or ZA instead of EL).

SAZ_deg, SEL_deg: solar azimuth and elevation angle based on ephemeris (or SZA for solar zenith angle instead of SEL for solar elevation angle).

Quad voltages: voltages from quads.

AZ and EL corrections: effective azimuth and elevation corrections based on quad Vs.

Temperatures: ambient, instrument, and spectrometer temperatures and settings.

Scat_angle_deg: Scattering angle computed from AZ, EL, SAZ, SEL

File naming patterns: Files should be named according to the following pattern.

YYYYMMDD_NNN_TYPE_MODE.dat

YYYYMMDD: UTC date when collection starts
NNN: The Nth collection run of the day, irrespective of type or mode.
TYPE: "VIS", "NIR", "TRACK", (and maybe "AUX", but I hope not)
MODE: "SUN", "FOVP", "FOVA", "SKYP", "SKYA", "MANUAL".
So, for example, 20091120_004_VIS_SKYP.dat is the 4th data run collected on Nov 20, 2009 and represents a principle plane sky scan. The companion data from the NIR spectrometer would be named 20091120_004_NIR_SKYP.dat
If the 4STAR was returned to sun tracking immediately thereafter it would create the following three files:

20091120_005_VIS_SUN.dat
20091120_005_NIR_SUN.dat
20091120_005_TRACK_SUN.dat