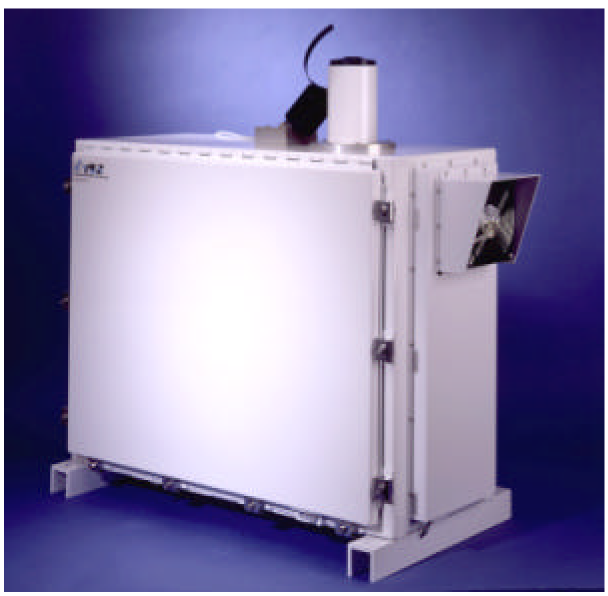
RSS/UVRSS-1024

Rotating Shadowband Spectroradiometer

Installation and User Guide

Version 2.1



RSS-1024/UVRSS-1024 Rotating Shadowband Spectroradiometer

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Contents

In This Manual

This manual provides information on setting up a Rotating Shadowband Spectroradiometer instrument, including how to maintain it. It covers two models of instruments: the Model *UVRSS-1024* that measures the UV-B and UV-A spectral range, and the Model *RSS-1024* that measures the visible/NIR range. Throughout this manual we refer to both models as the *RSS*, and only highlight differences between the two models when necessary.

What this manual covers

This manual covers the following topics:

CHAPTER		DESCRIPTION
1	Overview	Types of instruments, detailed specifications, and general principle of operation
2	Installation	Site requirements and procedure for setting up an instrument at the site
3	Interpreting the Data	Information on how to access the data and information on retrieving aerosol, optical depth, ozone and aerosol particle size distribution
4	Maintenance and Service	Routine maintenance tasks you should perform on the instrument; troubleshooting information
A	Ozone Absorption Coefficients and SSA	Table of calculated coefficients for ozone optical depth, and Single Scattering Albedo (SSA) procedure
B	References	Published papers on the RSS
C	Comparisons	Comparing data to other instruments

Related manuals

This manual describes setting up and operating the instrument. Please also refer to the *YESDAQ Data Visualization Engine User Guide* for information on setting up remote database replication. For more detailed information on interpreting and using the data you may wish to refer to published and unpublished scientific papers on the instrument, please contact YES Technical Sales.

Technical support

If you have a question about operating the shadowband instrument and cannot find the answer you need in this manual, contact YES Technical Support using any of the following methods:

- **E-mail:** support@yesinc.com
- **FAX:** 413-863-0255
- **Phone:** 413-863-0200

CHAPTER 1

Overview

The Rotating Shadowband Spectroradiometer (RSS) is a field instrument that measures the global, direct, and diffuse components of solar spectral irradiance, via 1024 individual narrowband CCD pixels (or channels). A microprocessor-controlled shadowband alternately shades and exposes the instrument's input diffuser, enabling the system to measure all three irradiance components with only one detector. A precision optical slit located directly beneath the diffuser permits light to pass through two fused silica (quartz) prisms where light is refracted onto a thermoelectrically cooled, astronomy-grade CCD detector. The CCD images the refracted solar spectrum, and a CPU core calibrates and stores spectra into an internal database for later retrieval and further analysis on any remote workstation equipped with a web browser.

RSS instrument family

The YES family of rotating shadowband spectroradiometers consists of:

- **RSS-1024** Rotating Shadowband Spectroradiometer, covers approximately 360-1100nm over 1024 narrowband CCD channels
- **UVRSS-1024** UV Rotating Shadowband Spectroradiometer, with an additional optical stage and slit to increase out-of-band radiation rejection covers approximately 290-370 nm over 1024 narrowband CCD channels

Applications

The continuous, real time spectra provided by the RSS-1024 and UVRSS-1024 make them well suited to many applications:

- Long term scientific climate studies requiring calibrated, high accuracy spectral irradiance measurements required to establish a global climatology
- Providing ground truth for state-of-the-art remote sensing platforms
- Laboratory measurements of optical power and spectral irradiance
- Automated remote solar resource monitoring and renewable energy research
- High accuracy optical depth and aerosol retrievals via Langley Analysis
- Data from Model RSS-1024 channels near 940 nm can be used to measure column water vapor; those below 440 nm can be used to extract NO_2, and channels within the 602 nm Chappuis band provide column ozone
- Data from the Model UVRSS-1024 is comparable to legacy scanning UV monochromators and prism spectrographs (e.g. Brewer or Dobson instruments). As with these older instruments, the UVRSS-1024 extracts

ozone by calculating the ratios of channels within ozone absorbing spectral regions to those with little ozone absorption cross section

- Research and solar exposure studies on pharmaceutical degradation
- As a transfer detector at labs producing new FEL irradiance lamp standards

Benefits

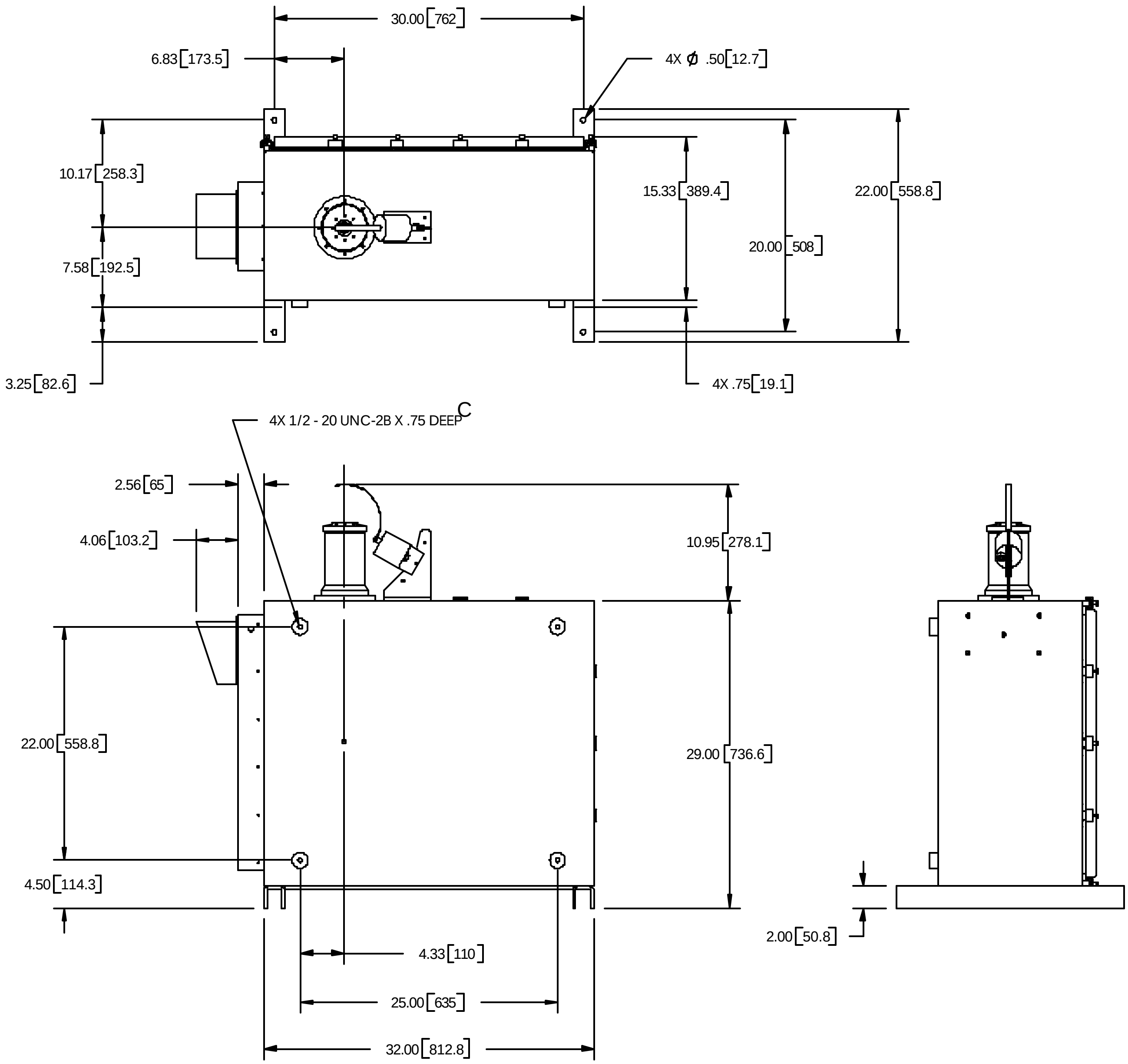
Several aspects of the RSS design make it unique among its competitors:

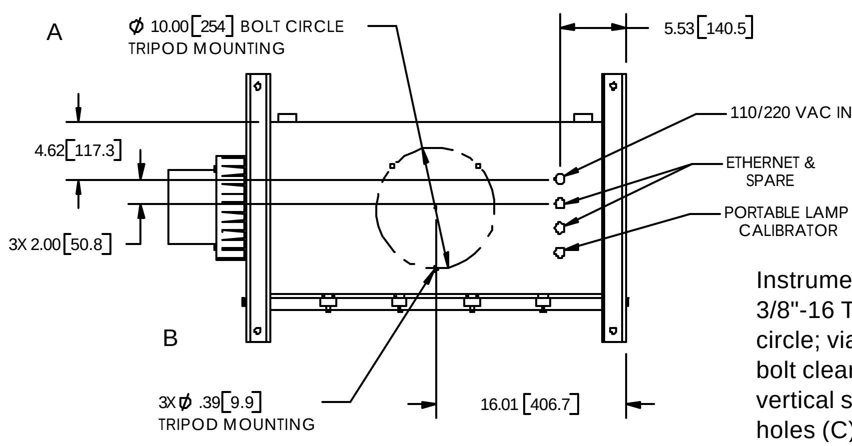
- Direct, diffuse and total components are each measured via a single detector, greatly simplifying calibrations. Previously, three separate instruments were required for solar assessment studies: a normal incidence pyrheliometer mounted on a two-axis tracker and two pyranometers, one with shading.
- The direct normal is cosine-corrected, eliminating the need to operate a two-axis tracker.
- CCD spectra are acquired nearly instantaneously, therefore eliminating the need to average multiple scans together to attain "representative scans" as was required with earlier scanning monochromator-based spectroradiometers
- State-of-the-art wavelength stability due to a lack of any moving parts that alter or control throughput and wavelength registration
- Unlike spectroradiometers using diffraction gratings, the RSS does not require order-sorting filters, which can change throughput or degrade over time and exposure. Fused silica is inherently ultra stable over both time and exposure.
- The solid state silicon CCD detector used is inherently more stable than vacuum photomultiplier tubes, which over time leak and change sensitivity
- Unlike scanning monochromators, the RSS can be absolute calibrated on its side, using conventional standard 1kw FEL lamps burning base down
- The RSS is fully automated and does not need constant supervision, making it ideal for larger monitoring networks

Options

You can order the following as optional equipment to enhance your RSS system:

- Heavy-duty folding aluminum tripod for mounting the system on flat ground
- A rugged, reusable hard shipping case for secure transport and storage
- Additional YESDAQ plug in software modules to process calibrated spectral irradiance data into value-added products such as optical depth, NO_2, aerosol size distribution, column water vapor and column ozone
- YES Model PFC-5001 portable NIST-traceable irradiance optical source for performing absolute instrument calibrations in the field
- YES 10/100-BaseT copper to fiber optic interconnect cable kit
- YES Model DSM-420 removable, non-volatile solid state data storage modules for sites without telephone PPP or Ethernet TCP/IP connectivity





Instrument mounts on optional tripod via three 3/8"-16 TPI bolt studs (A) on 10" (25.4 cm) bolt circle; via four holes (B) drilled through for 1/2" bolt clearance, or can be hung off suitable vertical supports at four blind 1/2"-28 tapped holes (C).

Figure 1. Mechanical Interface

Specifications

CHARACTERISTIC	DESCRIPTION
Spectral response	**Model UVRSS-1024:** covers UV-B+UV-A ≈290-370 nm*; **Model RSS-1024** covers visible/Near-IR ≈360-1100nm*
Cosine response	Within 5% @0-80° zenith angle; within 1% corrected
Detector type	Cooled, astronomy-grade 256x1024 pixel silicon CCD, column binned to 1024 channels, using dual slope integration
CCD temperature	**Model UVRSS-1024**: -5°C; **Model RSS-1024**: 0 to +5°C
Spectral Accuracy	**Model UVRSS-1024**: 0.1 pixel (±0.06nm); **Model RSS-1024**: 0.1 pixel (±0.2nm);
Sampling Interval	**Model UVRSS-1024**: 0.07 nm (0.3nm effective slit width) **Model RSS-1024**: 0.75 nm
Spectral Repeatability	**Model UVRSS-1024**: 0.005 nm RMS **Model RSS-1024**: Too small to be measured at all temps
Out-of-Band rejection	10^{-6}
Absolute calibration	±5% (over full temperature and wavelength range)
Scanning time	**Model UVRSS-1024**: 0.25 to 5 seconds (up to 25 spec. order) **Model RSS-1024**: 0.25 to 5 seconds
Effective Slit Bandwidth	**Model UVRSS-1024**: 0.3 nm FWHM @300 nm; optional 0.6 nm available but not recommended for most applications. **Model RSS-1024**: 0.6 nm @ 360 nm, up to 4nm @1100nm, 2.25 pixels FWHM. Bandwidth of each channel varies from one end of the spectrum to the other*
A/D bits	16 (=2^{16} or 65,535 counts, ≈40,000 counts typical DNR)
Temperature range	-50°C to +45°C. Internal optics are temperature controlled; can be adjusted to operate in environments hotter than +45°C
Power requirement	110/220 VAC, 50/60 Hz, 1800 watts maximum. Nominal power depends on ambient temperature, solar load and wind speed, but is typically on the order of 300 watts.
Weight	≈175 lb. (80 kg), not including optional tripod
Packaging	Powder-coated aluminum NEMA-4X chassis, designed for either indoor or continuous outdoor (above water) deployments

* Wavelength limits listed are *nominal.* Instruments are individually characterized, and each pixel is wavelength-registered via gas discharge lamps. The Model UVRSS lower limit is set to capture 292 nm, and its upper limit is a consequence of rapidly falling response due to out-of-band rejection filters in the second stage.

Principle of Operation

The RSS is a state-of-the-art CCD spectrograph with an external shadowband. RSS spectra are stored in a self-contained SQL internal database system, the Yankee Environmental Systems' Data AcQuisition database (YESDAQ). YESDAQ provides flexible data access via its Data Visualization Engine (DVE) component providing a web-based graphical data browsing environment.

YESDAQ

YESDAQ data are stored internal to the RSS on an environmentally hardened RAID-1 disk array. This disk subsystem holds approximately one year's worth of RSS data. Typically, the internal YESDAQ is replicated to a workstation running a mirrored YESDAQ system, and then back up the database from the workstation via user-provided workstation or available LAN backup service. Each RSS includes a software license for one replicated YESDAQ system.

YESDAQ contains a web server, permitting users to access data via the web. While the replicated YESDAQ system is typically located on a network with a fast Internet connection, data are also available directly from the RSS itself. If either the RSS or the replicated external YESDAQ system are situated on a LAN with an Internet gateway, worldwide "self-serve" access to near real time data are provided, freeing you from routine user requests for data and eliminating any need to install and then maintain special client software on user workstations.

YESDAQ data can be accessed or exported in a variety of ways. Any Java-enabled web browser provides users with either calibrated graphical plots or ASCII data. Control and monitoring of data collected from any number of multiple remote instruments is possible from anywhere on the Internet. This distributed data replication architecture provides installation flexibility tailored to your exact needs, as well as a robust, fault tolerant data handling environment.

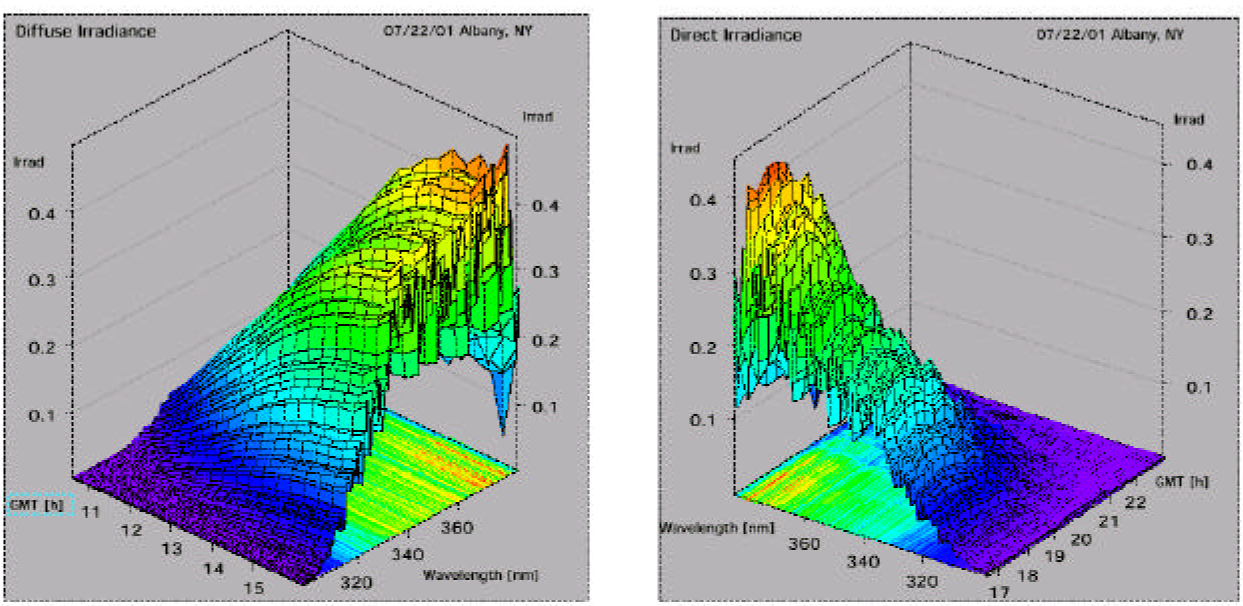


Figure 2. Typical morning and afternoon UVRSS-1024 spectral data (λ vs. time vs. watts/m^2-nm)

Core CPU subsystem

YESDAQ runs on the system's *Core CPU* which controls the various embedded subsystems and collects, calibrates, stores and presents data via a web server. The Core CPU contains the internal RAID-1 storage system, dial up modem and LAN interfaces, and monitors critical environmental parameters. Three communications configurations are supported for connecting your system to the Internet:

- TCP/IP, via the included RJ-45 10/100BaseT Ethernet connection
- PPP, via the included dialup V.90 telephone modem
- Physically, via optional removable non-volatile data storage modules (DSM)

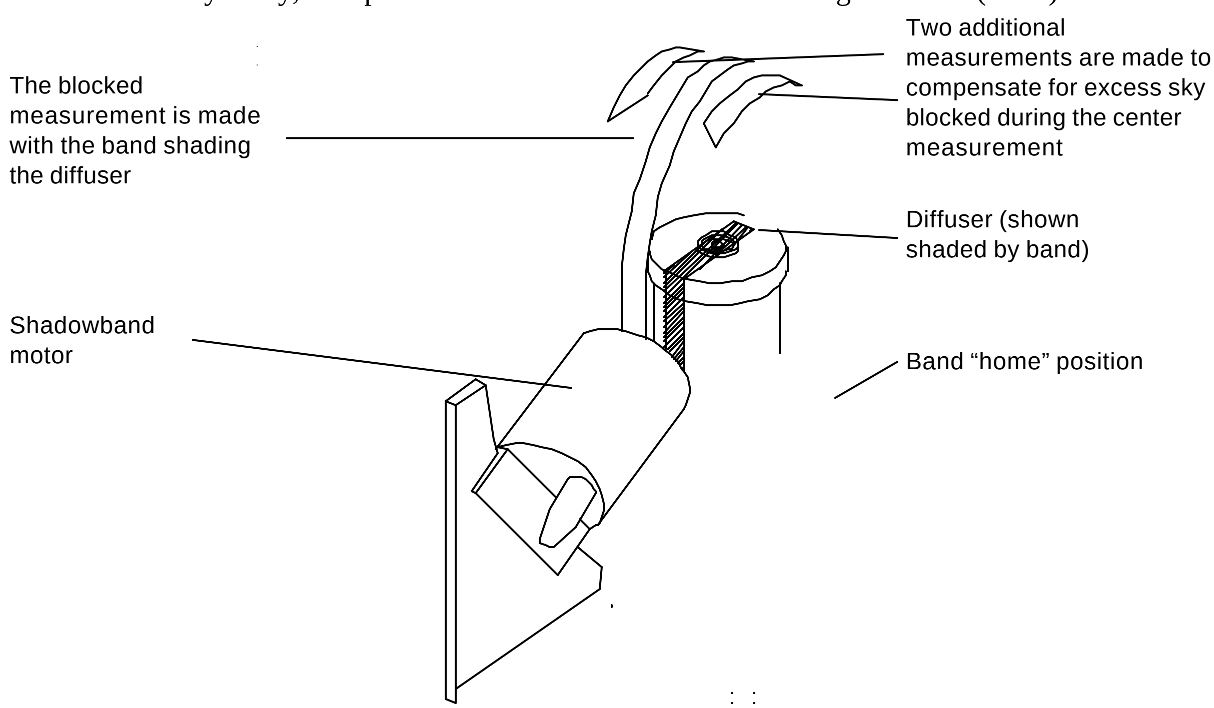


Figure 3. Shadowband operation, showing center (fully blocked) position.

The geometry of the rotating shadowband instrument is shown below. The shadowband is a strip of metal formed into a circular arc and mounted along a celestial meridian, with the instrument's entrance aperture at the center of the arc. The shadowband blocks a strip of sky with a 3.3° umbral angle, sufficient to block the sun. It can be positioned with an accuracy of 0.4° by a microprocessor-controlled stepper motor. The motor housing is positioned in one of three holes, adjusted to be closest to the latitude of the instrument site. The entire instrument must be azimuthally aligned to the local geographical North / South meridian. The orientation of the system depends on the hemisphere; the back of the motor (closest to you in the figure below) faces towards the equator. Finally, it must be carefully leveled. System time is precisely synchronized via NTN timeservers.

One embedded microprocessor in the instrument is dedicated to controlling shadowband operation. At each measurement interval, it computes the current solar position using a close approximation of the solar ephemeris. The shadowband is first rotated to a position out of the way of the field-of-view of the sky (also called the band *home* position) to permit a measurement of the global *or total* irradiance. The first measurement is made with the internal shutter closed for a dark-count subtraction. A second measurement is made with the shutter open, to obtain the total (or global) spectral irradiance. Next, the band is rotated to make a series of three more measurements, where the middle measurement (the diffuse horizontal irradiance) is made with the sun completely blocked; while two other measurements are made with the band rotated 9° to either side of the sun. The two side measurements permit the system to correct for excess sky blocked by the shadowband during the completely sun-blocked measurement.

The four RSS shadowband stops

These two side block measurements, the completely blocked, the unshaded and dark count measurements are sent to the Core CPU. It stores raw data and then averages the two side measurements and the fully blocked diffuse measurement to correct for the portion of the band that does not block the solar disc. It then subtracts this corrected diffuse component value from the unshaded global measurement (to obtain the *direct horizontal* component), divides the direct horizontal by the cosine of the solar zenith angle, to compute the direct *normal*

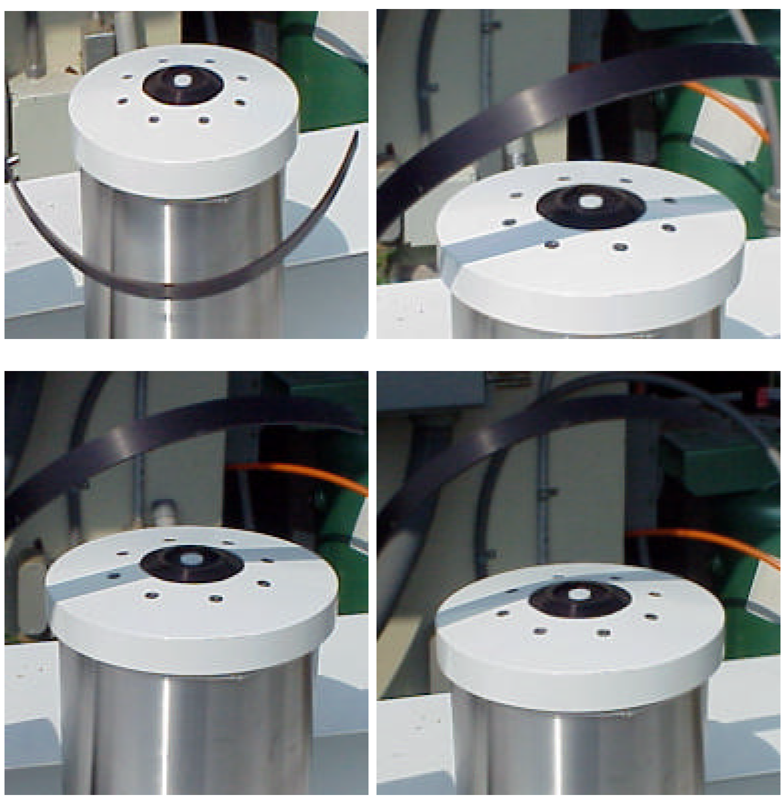


Figure 4. The four steps in shadowband operation: unshaded total (upper left), 1st side block (upper right), 2nd full block (lower left), and 3rd side block (lower right). The shadowband then returns to its home position as seen at upper left.

component, and finally cosine corrects it based on a factory angular diffuser characterization. Results are stored in the YESDAQ database.

Depending on the CCD auto-exposure time, the entire sequence completes in less than 20 seconds. Scans can be configured to take place as often as once every 30 seconds or as slow as every ten minutes (600 seconds). As with the angular correction of the direct normal, the wavelength registration and absolute calibration of each pixel is performed by the Core CPU, based on previously stored factory calibrations. While characterizations of the angular (cosine) response and wavelength registration require factory facilities, routine absolute calibrations are made via the optional Model PFC-5001 Portable Field Calibrator accessory.

RSS opti depth da

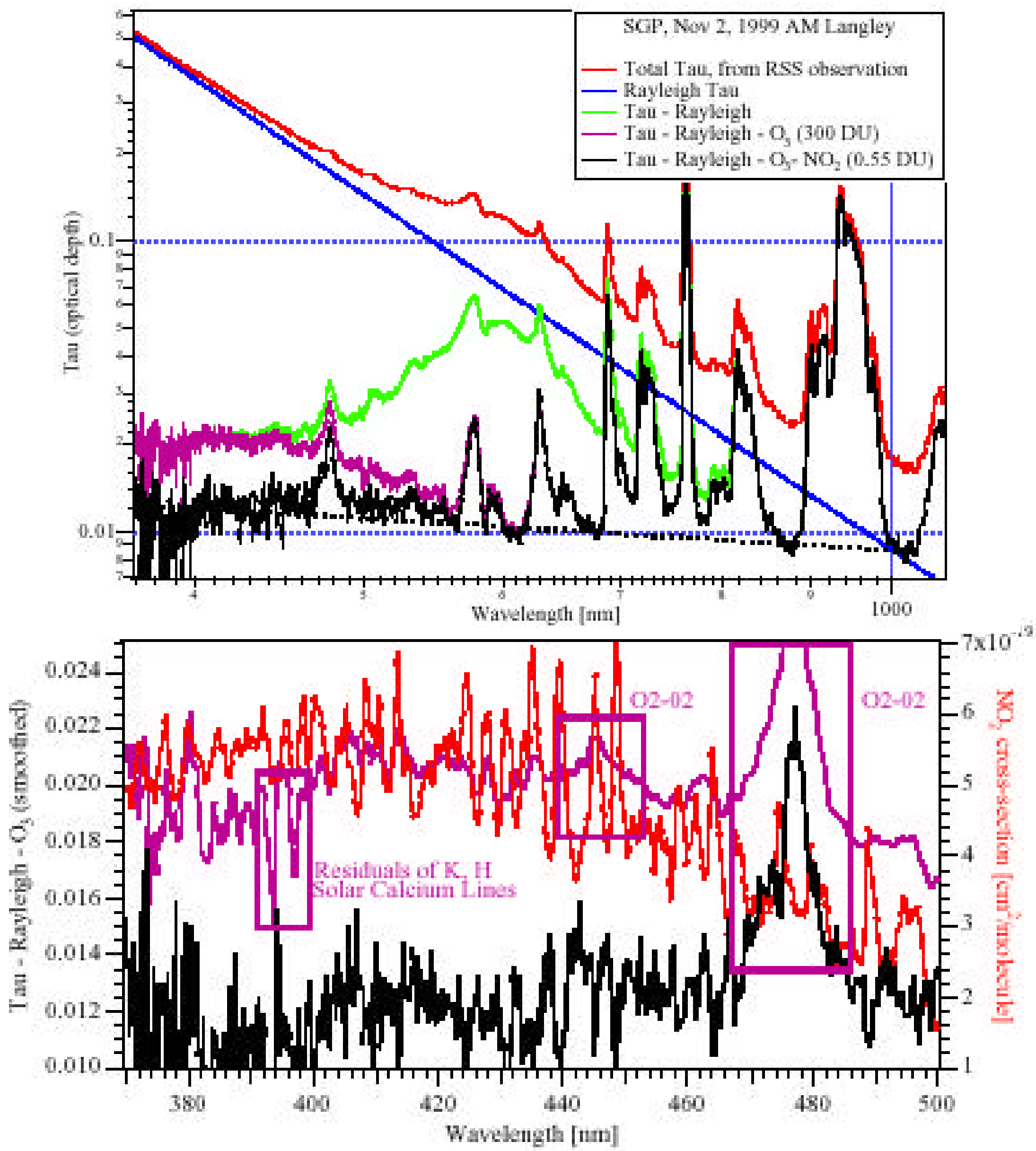


Figure 5. Optical Depth Spectrum log-log plot (top) and enlarged to show oxygen A band & NO_2

In the upper plot, spectra taken during absolute lamp calibrations are shown. In the lower plot, a false color CCD image taken during exposure to a gas discharge

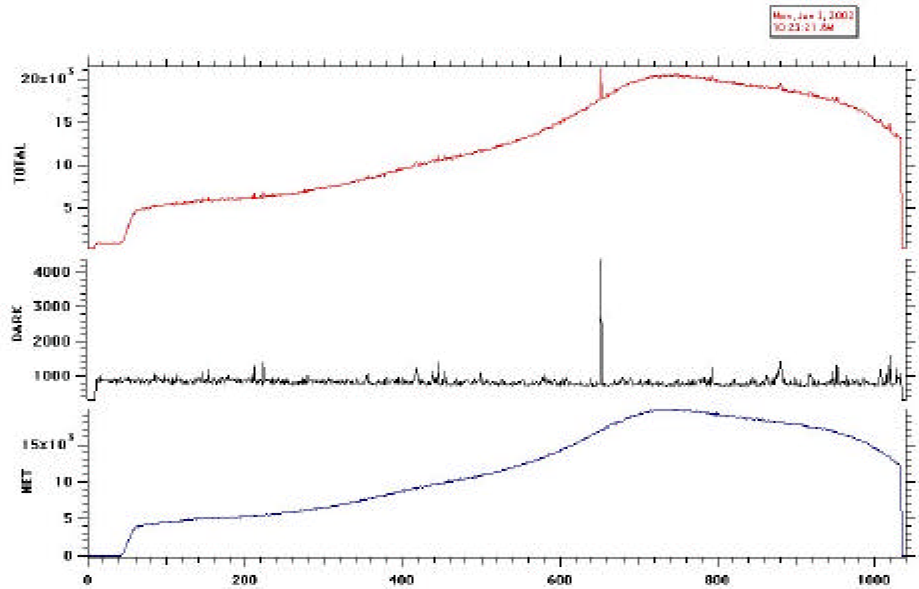


Figure 6. CCD data taken from a tungsten lamp exposure. Dark counts from center plot are subtracted from raw data at top to yield lower curve.

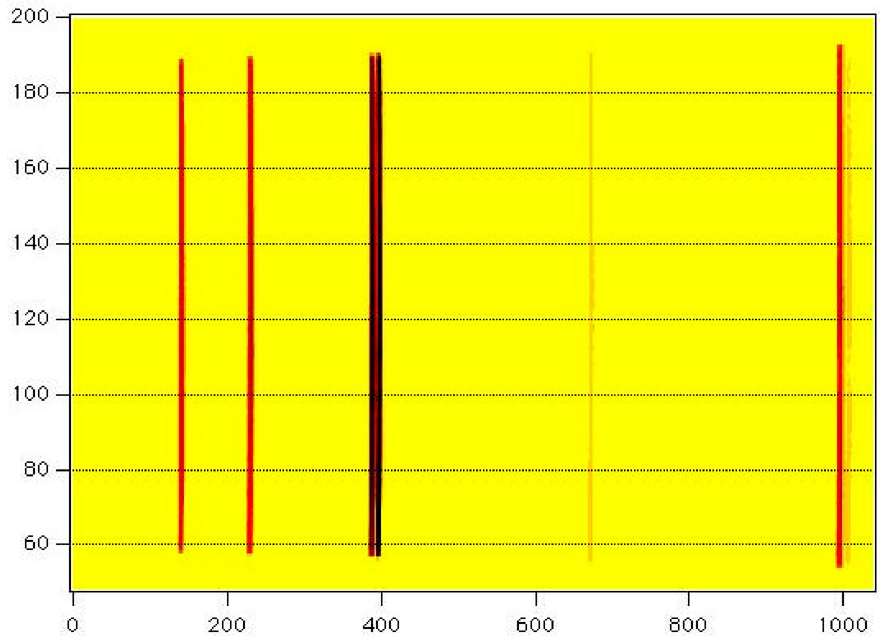


Figure 7. False color image of UVRSS two-dimensional CCD during exposure to a gas discharge-type line source (e.g. a mercury lamp.)

lamp is shown. These spectral lines are used for CCD pixel to wavelength characterizations.

Major Internal Systems

In this section we discuss the system electronics module-by-module as background information for later setup and maintenance procedures.

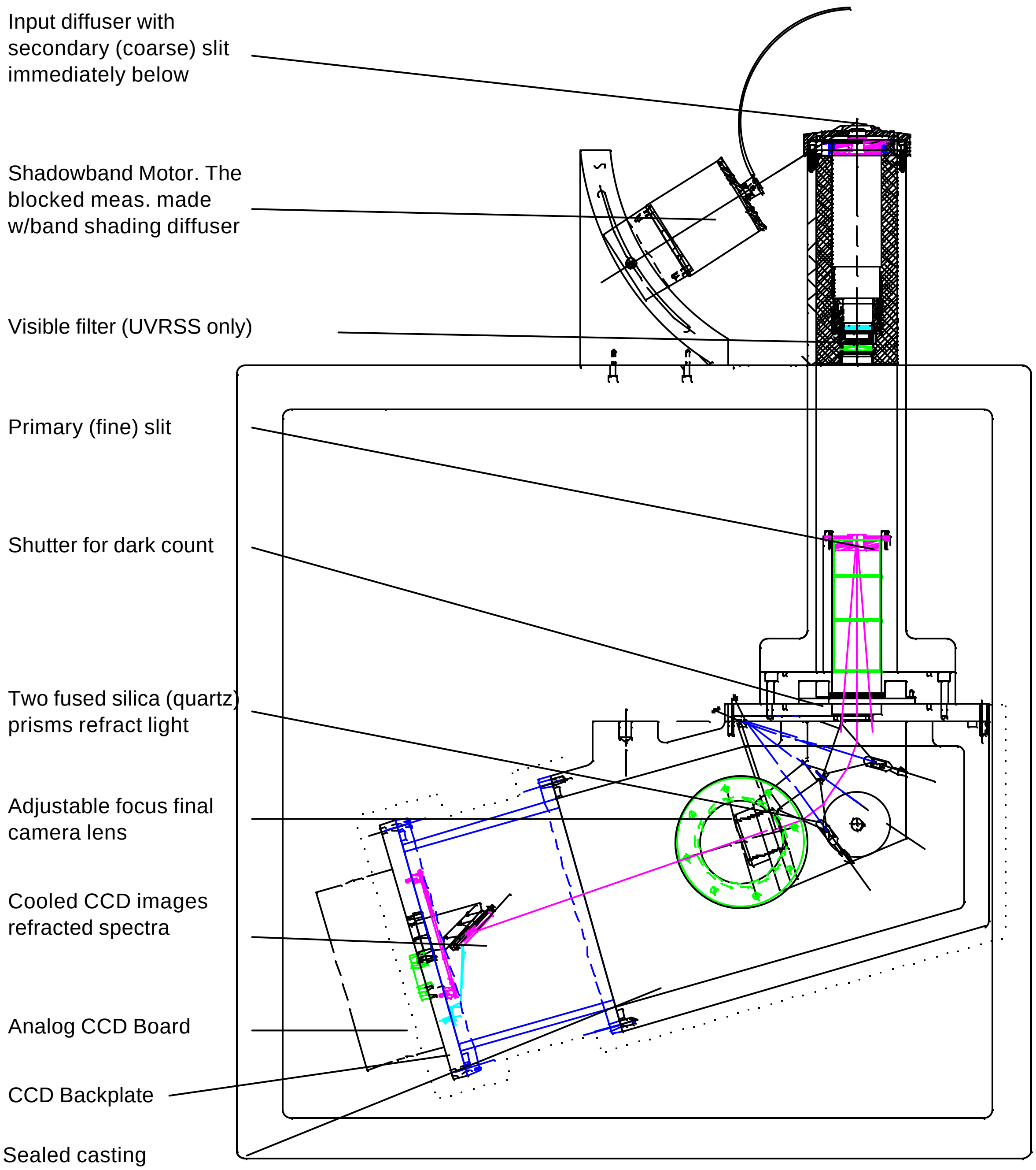


Figure 8. Side cutaway view of Model UVRSS-1024. Model RSS-1024 does not have upper stage optics but otherwise has a similar optical layout.

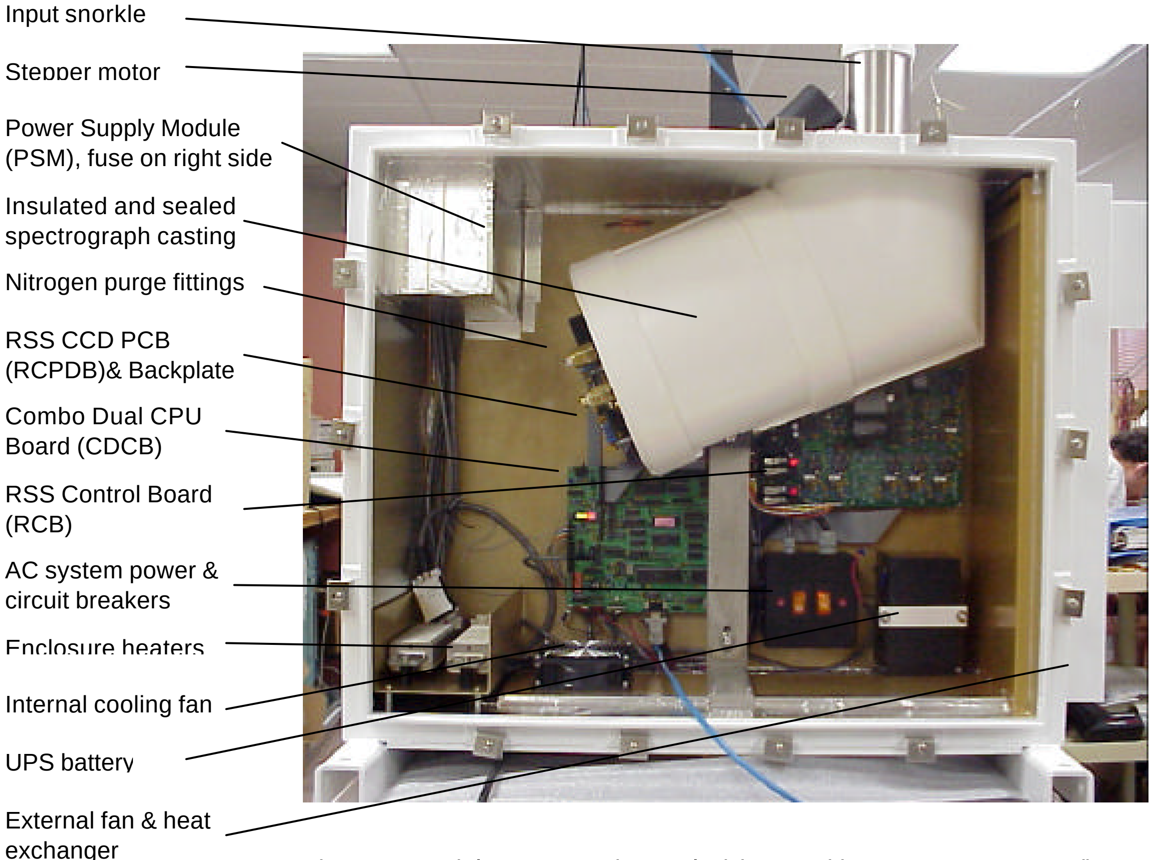


Figure 9. Model RSS-1024 internals (shown with Core CPU removed)

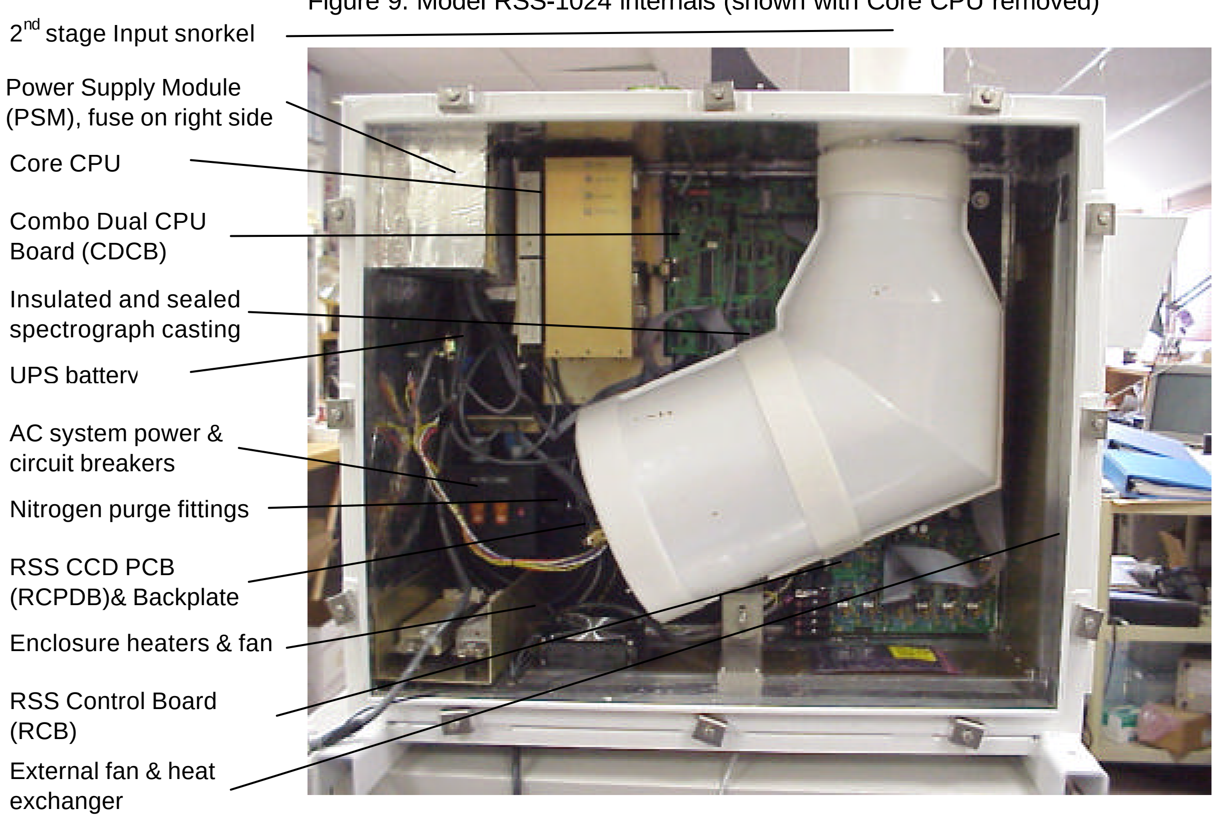
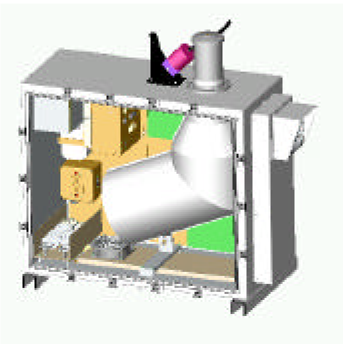


Figure 10. Model UVRSS-1024 internals. Note the taller spectrograph assembly.

Internal Subsystem Modules



Inside the system, you will find several subsystem modules:

- Insulated spectrograph pressure vessel casting, at center
- Insulated Power Supply Module (PSM), at upper left
- Core CPU, which links the system to the external world via 10/100Base T Ethernet or telephone, at left center
- RSS CCD PCB DSI Board (RCPDB), at lower left
- RSS Control Board (RCB), just below the insulated spectrograph casting
- RSS CPU Combination Board (RCCB), at lower right on the Model RSS-1024 or upper center on the Model UVRSS-1024
- Main AC switch junction box, at lower right on the Model RSS-1024 or lower left on the Model UVRSS-1024
- Sealed lead acid standby battery, at lower right on Model RSS-1024 and lower left on Model UVRSS-1024
- Enclosure heaters, at lower left

Opening the Enclosure Door

These internal subsystem modules are protected from the elements by a heavy duty, power-coated aluminum weather tight enclosure with a gasketed door. To gain access to the inside of the cabinet, use a medium-sized flat bade screwdriver to loosen each door clamp. Note that it is not necessary to remove each clamp screw completely, simply loosen them all and slide them to clear the door lip. Finally, grasp the door with two hands, pull it off and set it aside.

WARNING: Your instrument was designed to be turned on and left on indefinitely, in any weather conditions found worldwide. It is extremely important to keep power applied and the enclosure door tightly clamped to keep rain, moisture and insects out of the electronics *at all times*. The door must be tightly closed under all conditions except pressure service. Be especially careful to fully tighten all hold down clamps on the enclosure door to prevent wind-blown precipitation from entering the system. Leaving the door loose will destroy the system electronics and void your warranty.

Power Supply Module (PSM)

The *Power Supply Module* (PSM) converts AC line power to the various voltages required by the subsystems, and also manages AC power via an integrated on line UPS subsystem. The PSM is linked to the Core CPU such that when AC power fails, it notifies the Core CPU of the failure after about 8 minutes. The Core CPU will then initiate a controlled system shutdown procedure, which when finished, will completely turn off the instrument. The PSM is designed to ride out short AC power glitches lasting up to 8 ½ minutes.

If the AC line power fails for longer than this period (e.g. either the system is unplugged or the AC switches are turned off), a controlled shutdown of the system will follow that will take ≈3 minutes. During the time when AC power is absent, the CCD's thermal-electric cooler (TEC) that normally keeps it cold will slowly ramp back up in temperature. An opposite slow ramp down process also takes place after AC power is restored, during the first 10 minutes of operation. This behavior avoids thermally shocking the TEC and damaging the CCD.

Startup of the PSM is further governed by a failsafe thermal override via a thermistor physically attached to the Core CPU chassis, which continuously monitors the internal air temperature within the enclosure. At power on, if the internal air temperature is below 0°C or exceeds +58°C, the PSM will lock out system startup until the internal temperature is between ≈+11°C and ≈+51°C. If it is too cold, the enclosure heaters quickly warm-up a cold soaked system. If it is too warm, the heat exchanger will cool down an overheated system.

This failsafe startup temperature limit is designed to allow the hard drives to reach a reasonable operating temperature before attempting to write data to them. Note that this high/low limit protection does not affect the operation of the cooling fans, the enclosure heater or the heating pads that keep the instrument casting warm. Only the Core CPU, RCPDB and RCCB electronics are affected.

UPS Battery

The PSM backup uninterruptible power supply battery is secured with a heavy-duty strap. It has a life expectancy of several years, and is a special extreme-duty service part used in the CATV industry. Nevertheless, battery life will depend on ambient temperature, where hotter environments will shorten battery life.

The PSM contains battery charge current sensing circuitry to prevent the system from turning on until the battery has been sufficiently charged to support a system shutdown in the event of an AC power failure. In the event the system is turned on with an essentially fully discharged battery, a red LED on the DCB lights during this *charging hold* period. In addition, if the battery develops a shorted cell, the system most likely will never come on, because the charge current will remain too high. In this case, you must replace the battery before the system will start.

The PSM contains one user-accessible fuse that protects the DC buss, five Amp 3AG fast-blow type fuse. It is located on the side of the PSM and is accessible by removing the vertical 4"x10” insulation panel facing the shadowband motor. To access the fuse, cut the shiny metal tape along the edges of this insulation panel using a razor blade. This panel and the one below it must be removed if the PSM ever needs servicing. Depending on the Model, you may wish to first remove the RCCB in order to access the PSM's insulation panel.

> **Warning:** Unlike many commercial UPS systems, the battery does not need to be disconnected during shipment or long term storage. It is very dangerous to run the system without a good battery, because there will not be sufficient battery power to turn off the Core CPU properly. The state-of-the-art journalling file system (JFS) used on the RAID-1 storage array should not be damaged by improper hard AC power shutdowns, but it is still not a good idea.

RSS Control Board (RCB)

The *RSS Control Board* (RCB) is a trapezoidal-shaped board located just below the spectrometer on the rear panel of the enclosure. The RCB is largely an analog subsystem that precisely controls the temperature of the instrument in either five separate zones on the Model UVRSS-1024, or four zones on the Model RSS-1024. Incoming 36 Vac power provided by from the transformer in the PSM feeds each heater zone. The RCB also controls the temperature of the CCD's TEC, and controls both cooling fans and the internal dark count shutter.

Thermal zones

It is critical to maintaining wavelength stability that the instrument keeps all wavelength-selection components above expected ambient temperatures. Each heating zone on the instrument is controlled by an individual PID channel to keep it at a precise temperature that is independent of ambient diurnal variations. Each PID channel has a separate monitor thermistor as well as a control thermistor. Heaters are glued to the exterior casting and the input foreoptic, as well as embedded in the prism mounts. Together these zones maintain the prism optics inside the pressurized casting at a very constant temperature above ambient. Since thermally-induced wavelength shifts are dominated by the refractive index of the prisms, they are thermally isolated from the main casting and set to a warmer level, ≈50°C. In extreme cases such as a dousing summer rain on a hot system, the input optic can drop in temperature a bit, but throughout the interior prisms are is maintained at a stable temperature.

On the left, narrower end of the RCB are opto-isolated output drivers that control the flow of AC power to the heaters. Each opto-isolator acts as a solid state relay and has its own protection fuse (located under a metal clip). A red LED lights when AC power is being used to heat that zone. Under normal operating conditions, these LEDs will appear to "flicker", some faster than others depending on the current thermal load and external environmental conditions. When the instrument is starting cold, these LEDs will be on continuously until the instrument reaches temperature and stabilizes. When they are near control temperature they may appear to flicker or appear to glow dimly—this represents normal operation. An LED full on after normal warm up indicates a blown fuse.

Note: The RCB, including spectrometer heaters and fans will not operate during brief AC power losses; the PSM operates just the Core CPU, RCCB and RCPDB

The various setpoints for the heaters were selected for the expected target ambient environment where the instrument is to be operated. The higher the maximum ambient temperature the instrument is likely to be subjected to, the higher the typical setpoint. This setpoint decision represents a classic engineering tradeoff between overall power requirements (the higher the setpoint the more power is required), CCD thermal depression (the Peltier can depress the temperature of the CCD only so far), and electronic component life (components such as electrolytic capacitors last longer at lower temperatures).

CCD PID zone

Also located on the RCB is the PID channel that controls the CCD's Peltier-type thermoelectric cooler (TEC) temperature. The CCD is typically set to ≈-5°C for the Model UVRSS-1024 or between zero and +5°C for the Model RSS-1024. Because the CCD is cooled, the inside of the sealed spectrometer casting needs to be maintained as a very dry environment, as any condensation on the CCD will cause it to fail. The casting, which holds the spectrograph optics and the CCD is carefully sealed, leak tested, purged and then slightly over-pressurized with dry nitrogen gas to a few PSI. In addition, desiccant inside the casting helps to keep it as dry as possible, to avoid unwanted condensation of water or contaminants on the CCD's cool surface.

Maintaining the seal of the spectrograph pressure vessel

Two independent internal pressure and RH environmental monitoring sensors inside the pressure vessel casting permit long term monitoring of the integrity of the pressure vessel seal. If the pressure falls below a preset level (≈0.5 PSI) or the RH rises above 60%, the TEC will be turned off automatically, and the CCD temperature will rise to the environment that surrounds it, or +45°C. If the RH threshold setpoint is tripped, the TEC coolers will be turned off *and locked out until the power to the RCB is cycled*. However, if the casting pressure setpoint is triggered, this lockout will not occur, and if the pressure returns to a high enough level, the coolers will be reactivated. When illuminated, a single red LED in the upper center of the RCB indicates that the TEC is off due to one of these fault conditions. If this LED comes on you must find the fault and as soon as possible re-purge the instrument with dry nitrogen gas via the two purge fittings on the CCD backplate, or return the system to the factory for service.

WARNING: There are no user-serviceable parts inside the RSS' spectrograph pressure vessel and special fixtures are required for proper reassembly. *Never open the casting up for either inspection or for simple curiosity*. Doing so will permit water vapor to enter the casting and will permanently damage the CCD. Repair of this condition will be enormously expensive.

Maintaining a low relative humidity (RH) inside the instrument casting is critical. A package of desiccant inside the casting is designed to absorb water vapor over the life of the system assuming the casting is never opened. The RH depends on several factors, as well as on how dry the desiccant is. It is therefore crucial to never allow atmospheric water vapor to enter the casting. Contact the factory immediately if you suspect that the instrument has lost pressure, and do not power down the heaters.

The RCB also includes the variable speed fan controllers for the internal and external heat exchanger fans. The internal fan tends to operate over a much wider speed range than the external, which switches on at ≈31°C. If the external fan is on, the internal one will be running as well. Note that the external fan is a specialized water/weatherproof model that is not commonly available but should last several years; contact the factory to order a replacement fan kit as needed.

Each thermal zone on the RCB has two thermistors associated with it, one for its PID control and one that acts as a separate, isolated temperature monitor. In addition to the heater zones, a thermistor monitors the inside box temperature and the incoming air to the outside heat exchanger. The pressure sensor plus RH sensor inside the casting are paired with a barometric pressure sensor and RH sensor inside the enclosure for general meteorological use. A door open detector also records when the enclosure door is open. This suite of sensors permits you to remotely monitor all environmental conditions in the system (such as tampering by unauthorized personnel) via the web, in real time.

> **Note**: On the web view of the *Aux Data* parameters for the Model RSS-1024, there is no reading given for *lower snorkel*. This control zone is found only on the Model UVRSS-1024 that has an additional optical stage requiring it. There will also be a small unpopulated section of the RCB on the Model RSS-1024.

The two trim pots in the upper right corner of the RCB control the internal casting pressure and RH protection setpoints. If either the casting pressure drops below a threshold or the RH exceeds its setpoint; the CCD's TEC cooler is automatically turned off to protect it and the CCD from condensing water vapor. *These setpoints are factory adjusted and should not be touched*. All of the PID circuits have fixed setpoint resistors and are thus non-adjustable. Finally, keep in mind that your instrument's wavelength response depends critically on its internal thermal stability and that changing these setpoints will necessarily result in a loss of wavelength registration and accuracy.

Polar Operation

Like the several other thermal zones in the system, the enclosure heaters are also controlled by Proportional-Integro-Differential (PID) thermal regulation. However, unlike the spectrometer, the enclosure air is not maintained at a precise temperature. Enclosure air is kept warm but is only coarsely controlled where the internal air temperature will generally track the external air temperature during operation. The boost heaters will only be activated once the temperature inside falls below ≈0°C in order to keep the air warm enough for the RAID-1 disk drives.

RSS Combo CPU Board (RCCB)

The *RSS Combo CPU Board* (RCCB) is rectangular and is mounted like the RCB on the rear enclosure panel. On the Model RSS-1024, the RCCB is located below the spectrometer while on the Model UVRSS-1024 the RCCB is located immediately above the spectrometer casting. It serves two purposes: to calculate the solar ephemeris (controlling the external shadowband motor), and digitally clock the RCPDB board that manages the CCD.

Humidity and pressure sensors

On the RCCB, a single linear 10-segment LED display monitors various parameters on the board. The five green LEDs should all be lit, as they monitor the five DC voltages that power the various electronics sections. These are in order, from the edge of the display to the inside, +5 Volts, +12 Volts, +15 Volts, -15 Volts and +26 Volts. If only the +5 Volt LED is lit, then you can assume the 5-Amp fuse in the power supply that protects the main +12 Volt supply is blown. See the PSM section later in this section for how to replace this fuse.

RCCB LED Status Indicators

The next four LED segments are red, and monitor CPU processing activity on both the RCCB and in the Core CPU. The last LED segment is a yellow, and it lights up to indicate when the shutter is open during an exposure cycle.

Because there are two microprocessors on the RCCB, there are two programmable read-only memory chips (EEPROMS) that control them, the *RSS EEPROM* located in the center of the board and the *CCD EEPROM*, which is near the bottom. Normally there is no need to service these chips, but should changing one be necessary, the system must be fully powered down.

The RCCB also contains a Relative Humidity (RH) sensor to measure humidity inside the box, a solid state electronic barometer, and a photocell that detects when the door to the instrument is opened and closed. The RCCB has 32 auxiliary analog channels that measure various other instrument parameters, which are collected and stored on the hard drives in the CPU. Not all of these channels are used—some are reserved for future applications. The RH sensor is identical to the one inside the casting and measures the RH inside the enclosure, which can be used as a diagnostic if the enclosure has a serious water leak, or can be used as a surrogate for the RH of the outside ambient air.

Note: If this RH sensor is exposed to reasonably strong sunlight, it will rail out at its lower end and produce a negative RH reading. This will happen, for example, if the cover is removed and the sensor exposed to direct sunlight. This is yet another reason that you should keep the enclosure door tightly closed.

Barometric Pressure Sensor

The system pressure sensor measures barometric pressure and is very accurate if calibrated against a co-located device. To adjust it, determine the local barometric pressure in millibars from a high quality, calibrated co-located electronic pressure sensor. Next adjust trim pot "R1", which is located on the upper edge of the board nearest the top of the enclosure. Adjust it such that the reading displayed in the instrument interface for barometric pressure corresponds to the external reading from the calibrated barometer. Keep in mind, strong winds blowing across the box might distort the reading, since no baffle is being used in conjunction with the sensor at this time. If high accuracy is important, such as for doing aerosol particle size distributions, an external pressure baffle can be connected to the sensor via the spare strain relief and some flexible PCV tubing. The linearity of the pressure sensor should also be checked for accuracy. In reality, however, the enclosure acts as a fairly good pressure baffle, as barometric data seems to be relatively unaffected by air movement outside the enclosure.

Next to R1, the barometer offset adjustment, is a two-wire header that connects to a thermistor mounted close to the CPU’s two RAID-1 hard drives. This thermistor controls the high/low temperature limits of the instrument, and prevents CPU boot at very low temperatures until the enclosure heaters warm the RAID-1 hard drives to about 0°C. Note that if this thermistor is disconnected or defective, the instrument electronics will not power on, even if plugged in and switched on.

WARNING: Disconnecting the internal air thermistor while the system is operating will immediately cut all power to the Core CPU and electronics. This hard shutdown is not advised and can possibly cause irreparable damage to the journalling file system on the RAID-1 disk array that holds your YESDAQ data!

You should normally never press the white reset button (next to the six pin power supply input). This button resets the RCCB dual microprocessors, but without affecting the Core CPU. The Core CPU also has the ability to perform this reset, if it ever detects the RCCB has locked up and needs to be reset.

UPS battery charging LED

A single red LED near the reset button illuminates when the UPS battery is being charged. Once it turns off, power will then be applied to the rest of the system. See the PSM description for more information. If this LED ever comes back on during normal operation, *replace the UPS battery immediately!* This battery charging current can be remotely monitored via the web interface.

RSS CCD PCB DSI Board (RCPDB)

The square *RSS CCD PCB DSI Board* (RCPDB) is located on the backplate of the instrument pressure vessel casting, directly underneath the CCD cooler's "hot side" heat sink. A 34-conductor ribbon cable connects it to the RCCB. The RCPDB precisely digitizes analog output signals from the CCD and provides the necessary clocking signals and bias voltages required to manage the minute electrical charges generated by light falling on the CCD to an ADC preamplifier. The design for this almost entirely analog circuit board centers on the use of Dual Slope Integration (DSI), which is done in the analog domain. Analog DSI is very effective at removing reset noise from the CCD analog signal output. A precision 16 bit analog-to-digital (A/D) converter with serial output digitizes the CCD analog signal at a rate of ≈40 kHz. A pair of optical isolators connects the A/D output to the RCCB's digital shift register input.

There are a number of adjustments on the RCPDB board, none of which should be touched with the exception of R17, which provides an offset adjustment for the analog signal after it has passed through the DSI circuitry but before it is digitized. R17 is the trim pot in the group of four closest to the corner mounting hole. This adjustment faces up from the board towards the side of the enclosure, making it somewhat easy to access. To adjust the offset, cover the diffuser so that no light enters the instrument. Then take a 10ms exposure, the shortest exposure the system can make. The offset trim pot should be adjusted so that the CCD noise hovers around 300 counts or so when the instrument is at normal operating temperature. The CCD must also already be at its proper operating temperature.

Warning: It is highly unlikely that the CCD offset adjustment will change over time. Consult the factory before attempting to make such an adjustment.

The other trim pots should not be touched *under any circumstances* as they can damage the CCD invalidating your warranty. These trim pots include the bias voltage VSS substrate (R16, next to the screw mentioned above), VRD (R15) and VDD (R14). The remaining trim pot is a little distance away from the group of four and adjusts the amplitude of the CCD clocking pulses. Because every CCD has its own unique analog personality, each requires a unique set of adjustments that will enable it to operate quietly and with good linearity. If these adjustments are altered, calibration of the instruments will, in many cases, be irreversibly invalidated and the CCD permanently damaged.

Core CPU Module

The *Core CPU* module is a major subsystem enclosed in its own aluminum chassis mounted to the rear of the enclosure on four "captive screws." It is located on the left side above the enclosure heaters. By removing interlocked

cables, the entire Core CPU module is easily removable for repair or replacement.

The Core CPU contains an 800 MHz or faster Intel Pentium™ processor, 256 Mb RAM, 10/100BaseT Ethernet RJ-45 interface, and a RAID-1 disk subsystem containing two 30 GB or larger IBM hard drives which store data. These drives are mirrored via RAID-1 and support full operation if either drive fails. A 1.44 Mb floppy disk drive can be used to load a boot disk (if inserted) if you are instructed by the factory to debug trouble in the CPU Core itself. A PCMCIA type III slot provides support for the optional Model DSM-420 Data Storage Modules.

The Core CPU is directly linked to the PSM via a cable. Should the system be unplugged or power lost for more than ≈8 minutes, a controlled, orderly shutdown will take place. The CPU Core contains the YESDAQ database and web interface for the instrument, calibrating digitized CCD scans that the RCCB feeds to it.

Communications ports

The Core CPU has three serial ports; one connects to the RCCB, one is allocated to an internal V.90 Hayes-compatible modem to support PPP dialup access, and a third port (COM2) serves as a console port to support initial assignment of TCP/IP parameters. Finally, a 10/100BaseT RJ-45 auto-switching Ethernet connection provides a connection to a LAN for real time access via a web browser. You typically connect this port to a fiber converter that is connected to your LAN.

IMPORTANT: Because of Ethernet cabling rules, copper wire Ethernet connections to hub/switches cannot exceed 100 meters. Outdoors, to provide lighting immunity and to extend this distance limitation, *we strongly urge the use of fiber optic connections*, via a pair of RJ45-to-ST fiber media converters. Using copper CAT-5 or CAT-6 Ethernet cable is very risky, and we can't stress enough how important it is to use an optical connection to your local network. Please protect your precision instrument with fiber optic voltage isolation technology!

CHAPTER 2
Installation

Using the RSS as a spectroradiometer in an indoor lab environment requires significantly less installation effort than outdoor use. This chapter focuses on the details of how to set up system hardware and software. Indoor laboratory users must still configure TCP/IP networking parameters, but can skip the third step involving system hardware installation in the field.

Installation process

To set up the system, you will perform the following tasks in this order:

1 Perform initial instrument TCP/IP setup via the console port

2 Check that you can remotely access the system via a web browser, finish web configuration and startup data collection

3 Install YESDAQ on suitable workstation for data replication

4 Installing the system hardware at the field site:

- **a** Prepare the site by installing power and communications equipment and a suitable mounting platform
- **b** Mount the instrument on the platform or the optional tripod
- **c** Precisely align the system to the north/south meridian
- **d** Precisely level the system using the diffuser shade ring as reference
- **e** Connect power and communication cables and apply power

This chapter explains tasks one, two and three. For details on installing and setting up data replication to a host, see *the YESDAQ User's Guide*.

Unpacking the system

The instrument is shipped in a heavy container that should be carried by at least four people. Before accepting the shipment from the carrier, carefully examine the exterior of the case for signs of shipping damage. If you see any suspicious marks request that you open the box to inspect before accepting it. Contact your carrier if you fear damage may have occurred to make an insurance claim.

If you ordered the optional reusable flight case shipping container, do not store it outside. Unlike the RSS itself, prolonged exposure to precipitation will ruin it. Store the shipping container in a cool, dry place so it is ready to use when you return the RSS to the factory for routine recalibration or service. To prevent damage, always use a hard shipping container when moving the system.

Configuring critical system TCP/IP settings

Before you connect the RSS to your network, you must configure it to use the proper TCP/IP settings. Once completed, the Core CPU will restart. Later, we will check the configuration is correct by connecting the system's 10/100 Base-T Ethernet port to your LAN and accessing the system's web interface via a local workstation. After verifying the TCP/IP configuration is active, you use your web browser to specify other information such as latitude/longitude and site name. At that point, it is ready to be installed in the field.

In this section we specify the TCP/IP settings and the network time server.

Note: The RSS does not support Dynamic Host Configuration Protocol (DHCP). Because the system contains a web server, it requires a *static address*, which you must obtain from your local system administrator who coordinates them.

Core CPU Console & VGA ports

If you specified your desired TCP/IP settings at time of order, your system will arrive pre-configured with the proper network address and DNS settings and all you need to do to proceed to the next step is to plug it in to your network. If your system was not pre-configured at the factory, a unique TCP/IP address, net mask, DNS, etc. must be entered using one of two methods:

- Using a null modem cable, connect an external laptop to the Core CPU's 9 pin RS-232 console port. Run a terminal emulation program such as *Hyperterm* or *Tera Term*, configured for 38,400 baud, 8-N-1, and setup to use ANSI screen control characters, or
- Connect both a VGA monitor and AT-style PC keyboard to the Core CPU

Either method enables you to specify your site-specific TCP/IP configuration.

With the enclosure door open, begin by plugging the RSS into AC line power and turn on the two large orange switches. Once the battery is sufficiently charged, the electronics are allowed to come on (approximately 60 seconds after the charging period ends), the Core CPU will beep once during the power on self test and the system will begin its startup sequence. After system startup is complete, a log-in screen will appear.

Logging in to the system console port

The login name to access YESDAQ, (all in lower case), is:

```
install
```

In addition, the default password, (all in lower case) is:.

```
install/yesdaq
```

In the following steps, you will generally follow down the blue screen menus in order.

WARNING: You should change the default password, and record the new one.

You an use arrow keys or the highlighted characters. These steps will complete initial configuration of critical TCP/IP settings involving time and physical address. Please start by reviewing the software license agreement screen:

Software license agreement

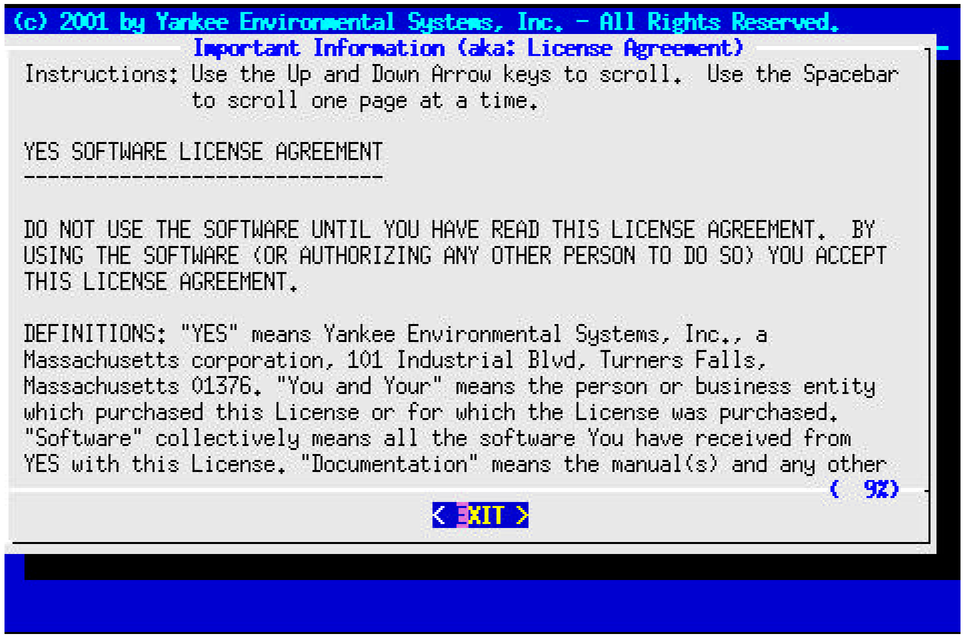


Figure 11. Please read the software license agreement.

Next, close this screen and use the arrow keys to select Ethernet Communication Configuration:

TCP/IP Ethernet Configuration

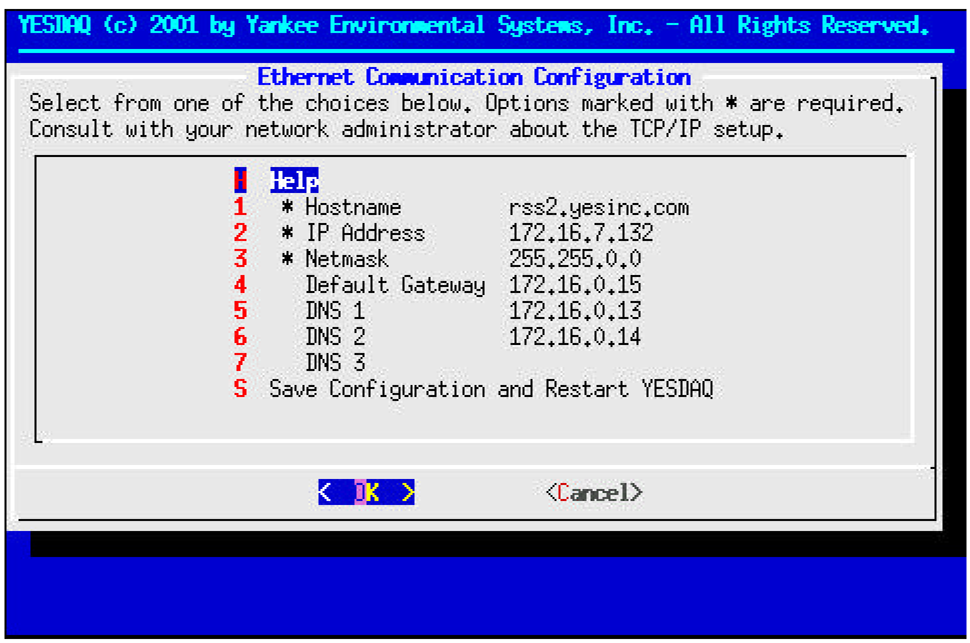


Figure 12. Main Ethernet configuration screen. NOTE: The settings shown here are for demonstation purposes only, DO NOT ENTER THESE SETTINGS! Instead, obtain a fixed TCP/IP address from your local network administrator.

Warning: Entries 1-3 that have an asterisk are *required* fields, and it is extremely important to enter these settings accurately to prevent network disruptions. *If you are not sure what these setting should be, do not try to guess them!* If you are working on a stand alone network without a DNS server, DNS is not required.

At any menu, you can generally type *H* to view a help screen, as shown below. We highly recommend you read all help screen information as you proceed.

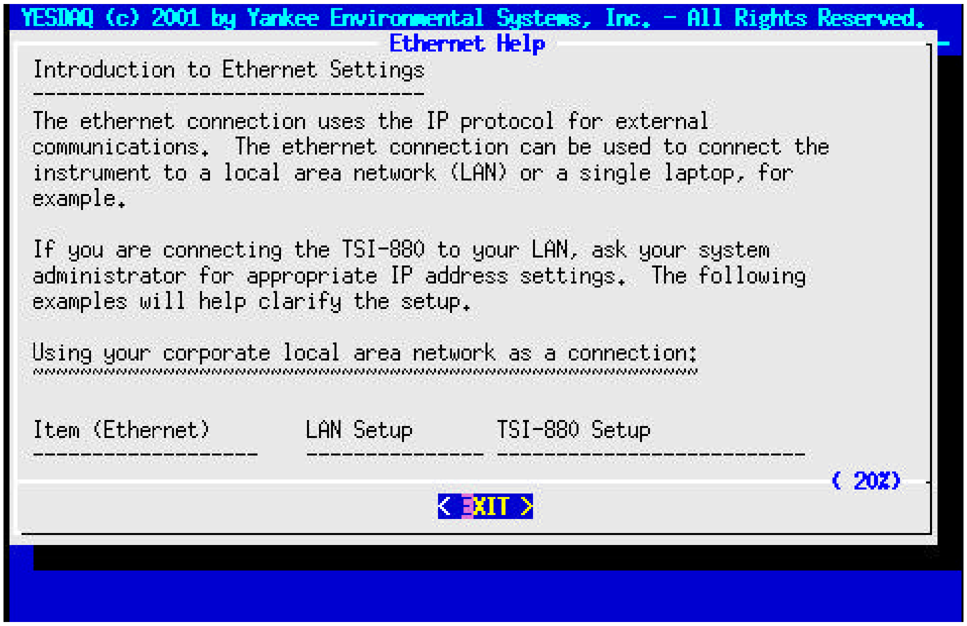


Figure 13. Ethernet Configuration Help screen.

Several other informational status screens are available, for example Core CPU voltage, fan and temperature status. Note that due to BIOS incompatibility issues there may be voltage alarm indications—it is safe to ignore these alarms.

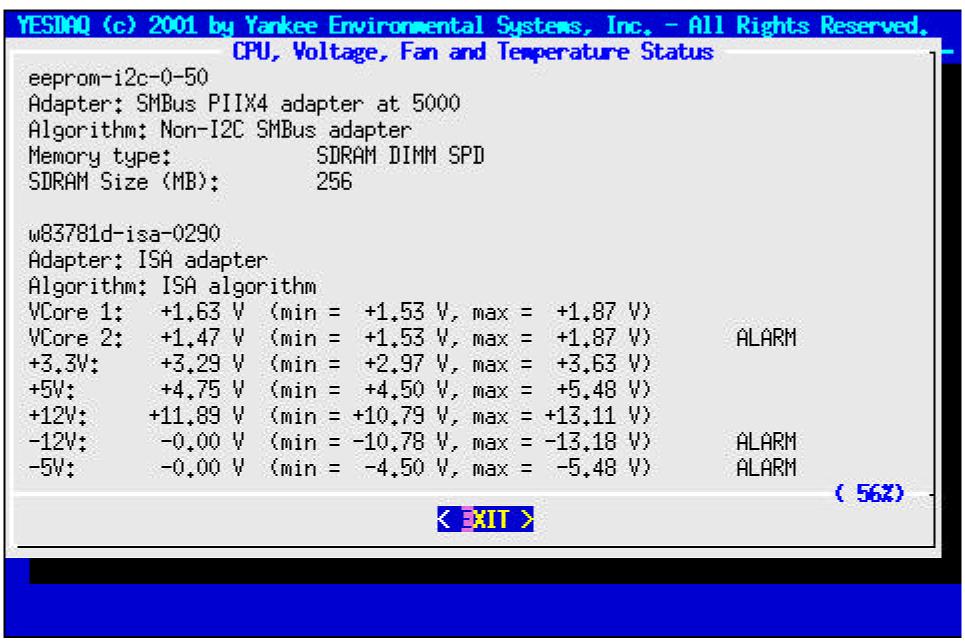


Figure 14. CPU BIOS level status - it is safe to ignore alarms.

Another screen indicates the current amount of RAID-1 disk storage space in use.

Checking disk usage

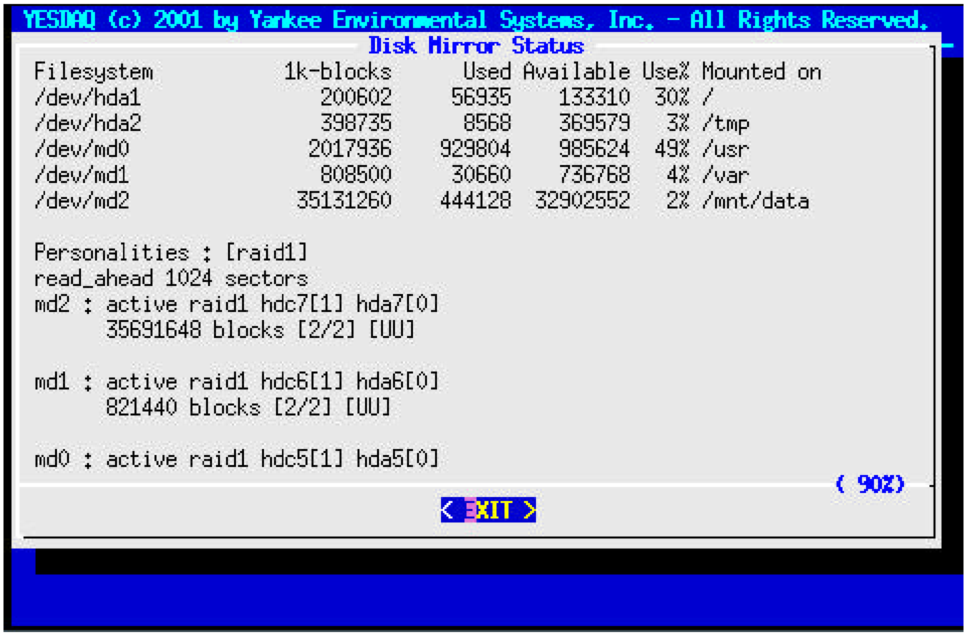


Figure 15. Internal RAID-1 disk array mirror status. Although you can view disk space via the web interface remotely, this status screen is the only way to determine if a hard drive has actually failed.

Do not alter the YESDAQ license screen unless directed to do so by the factory.

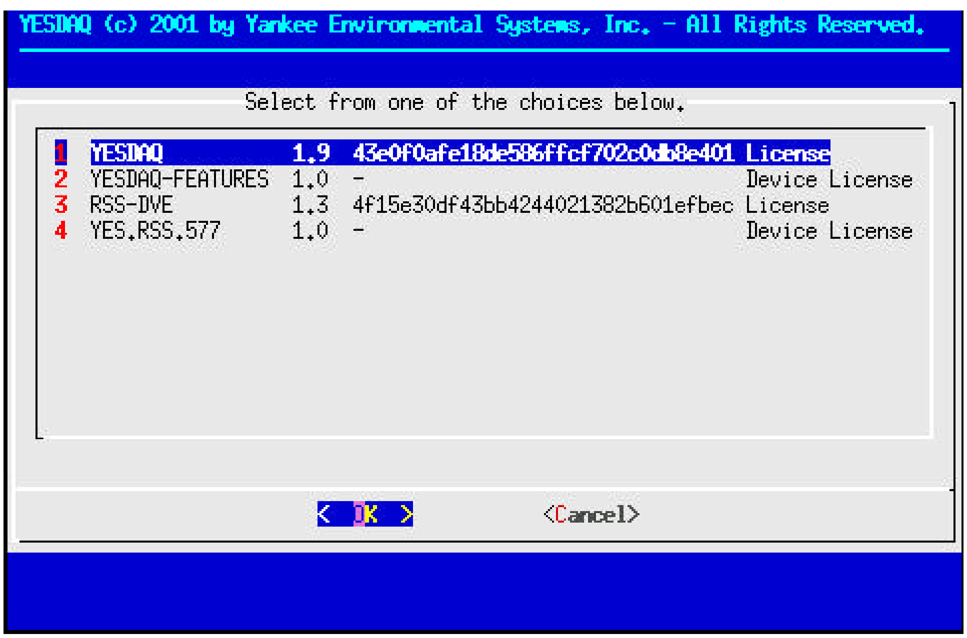


Figure 16. YESDAQ licenses. Your system software was pre-installed at the factory and this license information is for information purposes only.

Configuring dial up remote PPP access

We recommend that you use the built-in 10/100 Base T Ethernet interface for optimum performance and usability. However, a V.90 modem exists to support telephone line dial up access via the PPP protocol. Follow the screens to specify a dial up TCP/IP address, a PPP user name and password. The telephone interface is also helpful for remote software updates and emergency backup connections.

You will need to enable remote administration to permit factory technicians to install future system software updates into your RSS. If you have an active support contract for your RSS, these updates are free of charge and automatic. The updates do not alter the stored data on your drives, but rather update and improve the internal operating system.

Figure 17. Configuring Point-to-Point Protocol for dial up networking.

Note: As they can be changed, keep a log of all system passwords. There are three critical passwords to protect: the install password, the PPP password and the YESDAQ admin password. User ODBC passwords allow read only access only.

The telephone line cannot be a digital PBX line and must be a standard analog (POTS) telephone line. Incoming calls will be auto-answered. Although the system will never make outgoing calls by itself, you may want to consider setting up a toll-restricted line to ensure that no unauthorized calls are made from a remote site.

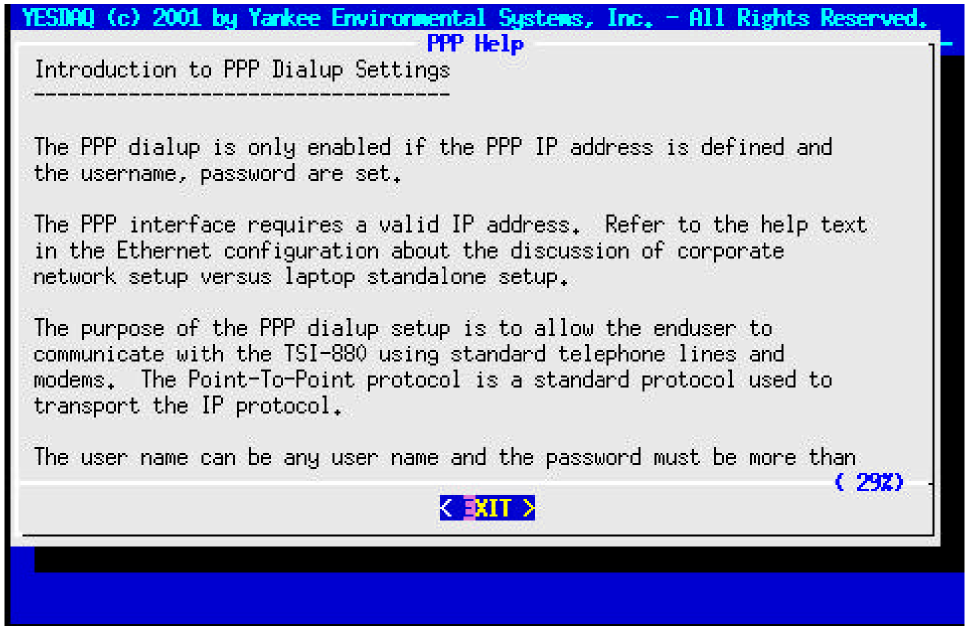


Figure 18. PPP setup Help screen.

There are several methods supported for software updates, which are covered in the Software Update Help screen.

Setting up remote software update capabilities

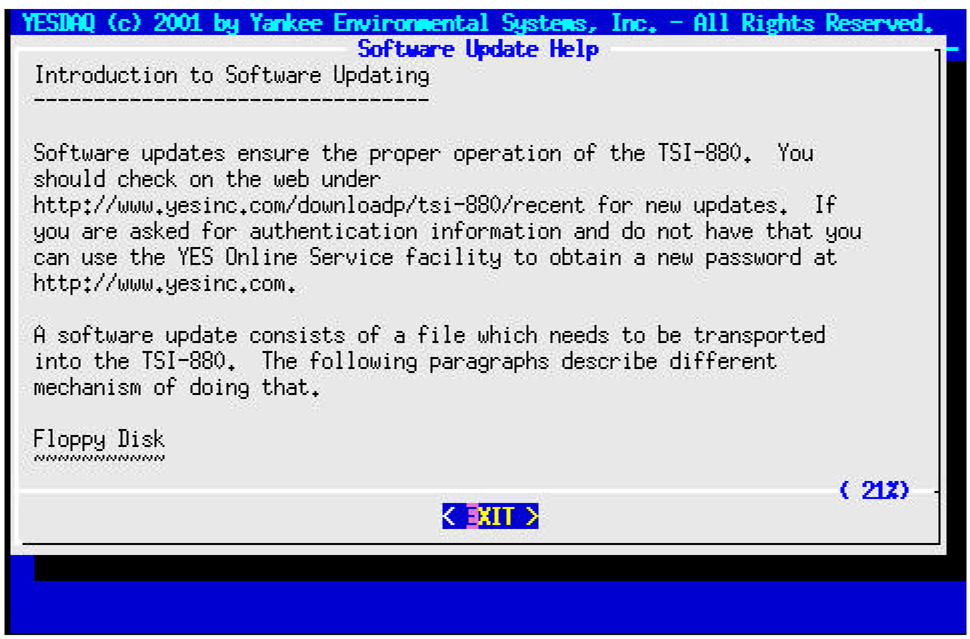


Figure 19. Software update Help screen.

Note that the web URL listed on the help screens may change over time based on models, follow the help instructions and use your browser to locate the latest software updates.

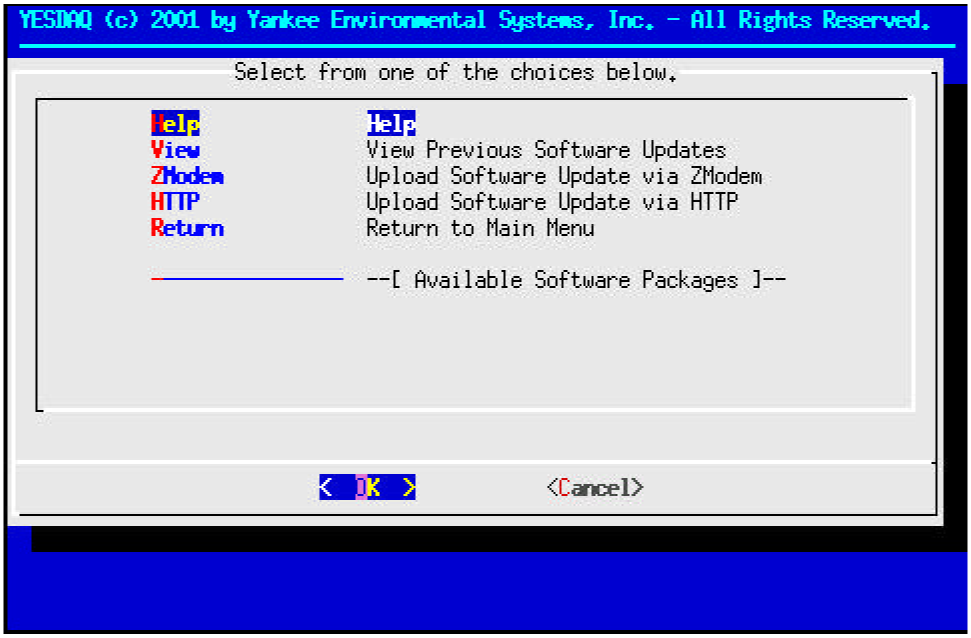


Figure 20. Selecting upload software method: ZModem (dialup) or http (web).

You can also review exactly which software updates were applied to your system:

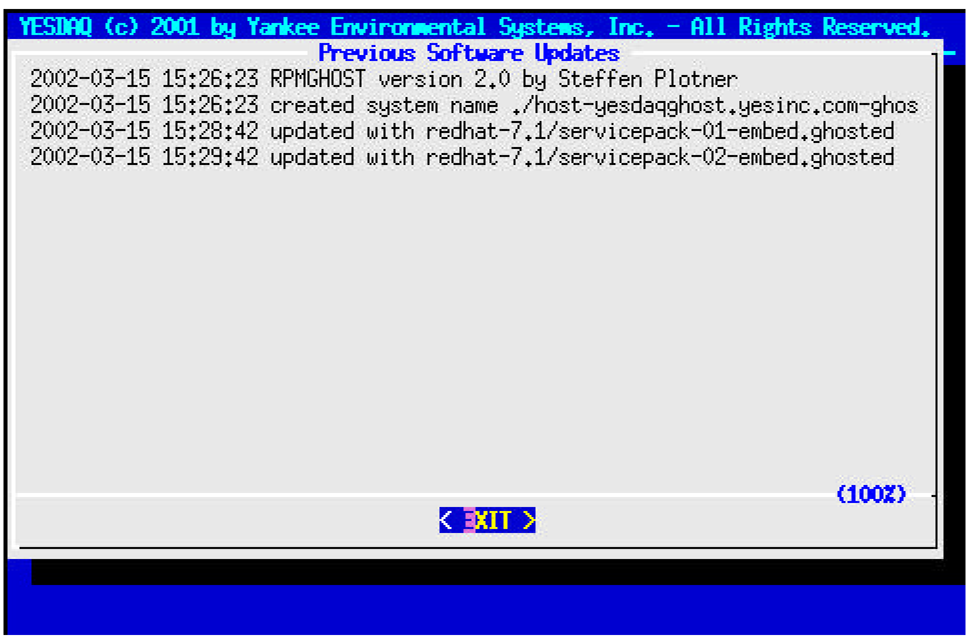


Figure 21. Viewing previous software update log.

Setting up NTP Time Services

The RSS uses Universal Coordinated Time (also called GMT or UTC) to support worldwide network operation. For proper shadowband operation, it is extremely important that this internal time is precisely maintained. Thankfully, the RSS supports *Network Time Protocol* (NTP) synchronization to NIST/PTB/NPL

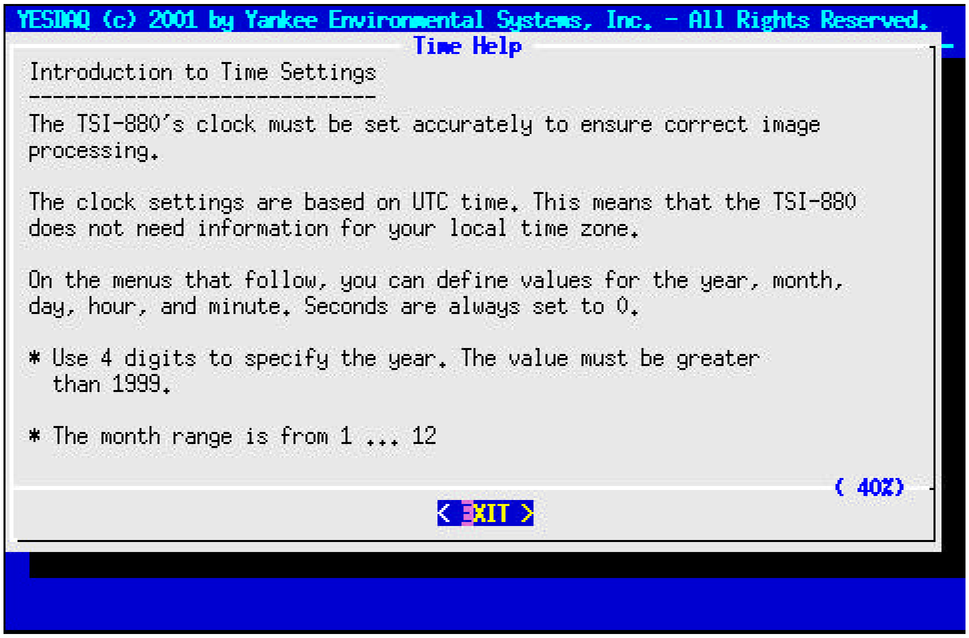


Figure 22. Time server setup Help.

atomic quality Internet time servers for "set-it-and-forget-it" timekeeping. Assuming your RSS system is on a LAN with an Internet gateway, you only need to specify a suitable Internet time server.

Figure 23. Main UTC Time Configuration Screen. If you setup time server, you do not need to set the time manually.

Manually setting the system time

If the system time is not accurate, the shadowband will not properly shade the RSS diffuser. However, once internet time synchronization is setup, you can forget about keeping the time accurate as it is automatically checked.

Specify a NTP timeserver host

WARNING: Due to the need to maintain accurate timekeeping, YES does not recommend installing the RSS on a stand alone network without access to a time server, unless the system time can be remotely checked on a weekly basis. If you need truly stand alone operation off the internet, you must provide a local hardware-based atomic clock time server such as those made by Datum, Inc (now part of Symmetricom) at http://www.datum.com or http://www.symmetricom.com

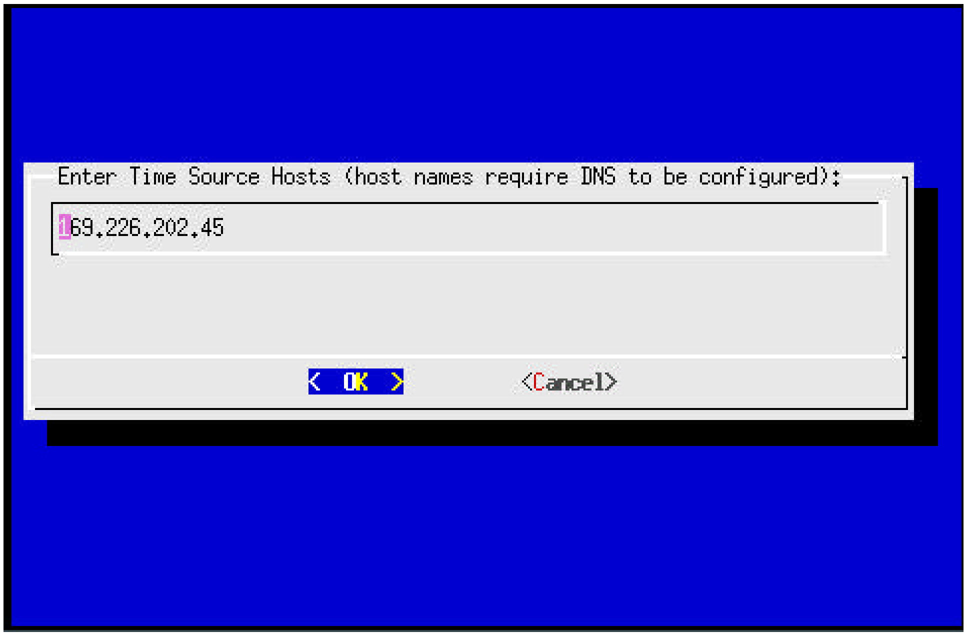
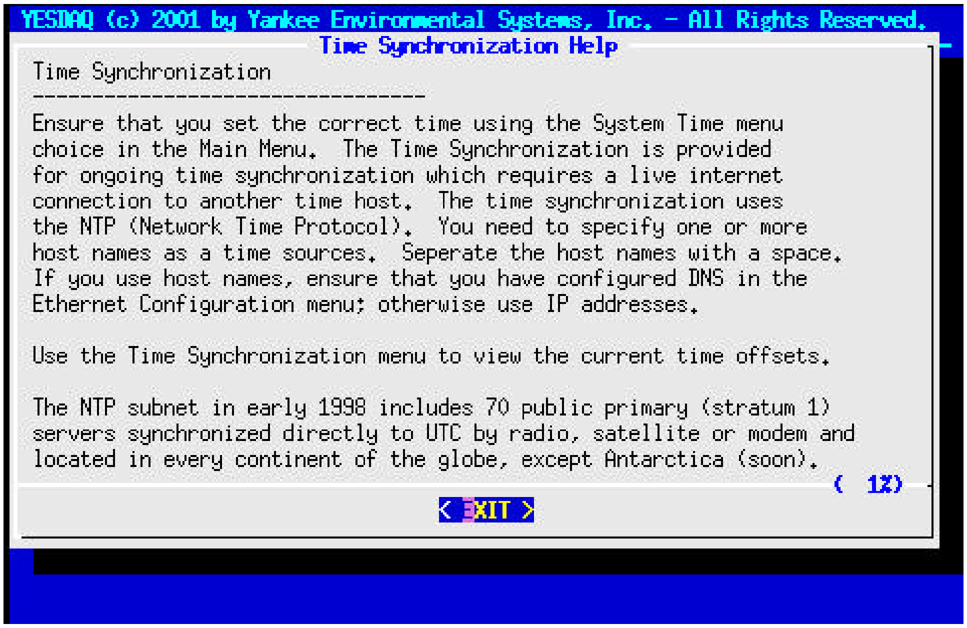


Figure 24. Specifying the time server host to use. See the Time Synchronization Help screen for suggested Internet time hosts. Although you can enter a hostname, use an actual IP address unless you have already setup DNS.

Note that the help screen suggests a long list of potential NTP timeserver hosts.

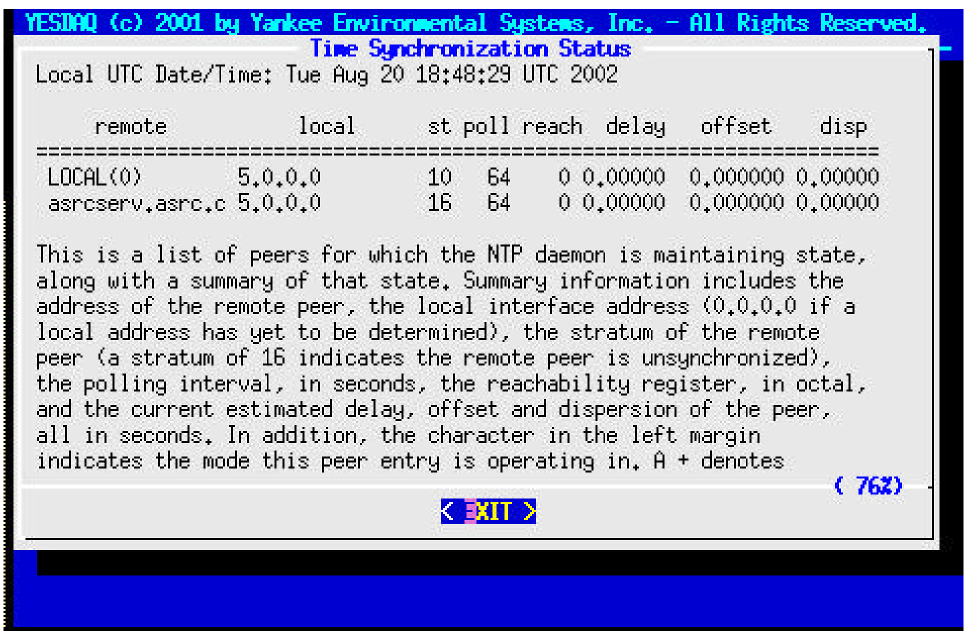


```
YESDAQ (c) 2001 by Yankee Environmental Systems, Inc. - All Rights Reserved.
                         Time Synchronization Help
Time Synchronization
---------------------------------
Ensure that you set the correct time using the System Time menu
choice in the Main Menu.  The Time Synchronization is provided
for ongoing time synchronization which requires a live internet
connection to another time host.  The time synchronization uses
the NTP (Network Time Protocol).  You need to specify one or more
host names as a time sources.  Seperate the host names with a space.
If you use host names, ensure that you have configured DNS in the
Ethernet Configuration menu; otherwise use IP addresses.

Use the Time Synchronization menu to view the current time offsets.

The NTP subnet in early 1998 includes 70 public primary (stratum 1)
servers synchronized directly to UTC by radio, satellite or modem and
located in every continent of the globe, except Antarctica (soon).
                                                                ( 1%)
                                 < EXIT >
```

Figure 25. Time Synchronization Help. This screen has several suggested remote atomic quality time servers to select from.

Observing the time synchronization start

After you enter the address of a time server, check the status screen to verify it is active by selecting time synchronization status.



```
YESDAQ (c) 2001 by Yankee Environmental Systems, Inc. - All Rights Reserved.
                        Time Synchronization Status
Local UTC Date/Time: Tue Aug 20 18:48:29 UTC 2002

     remote           local      st poll reach  delay   offset    disp
=======================================================================
 LOCAL(0)        5.0.0.0        10   64     0 0.00000  0.000000 0.00000
 asrcserv.asrc.c 5.0.0.0        16   64     0 0.00000  0.000000 0.00000

This is a list of peers for which the NTP daemon is maintaining state,
along with a summary of that state. Summary information includes the
address of the remote peer, the local interface address (0.0.0.0 if a
local address has yet to be determined), the stratum of the remote
peer (a stratum of 16 indicates the remote peer is unsynchronized),
the polling interval, in seconds, the reachability register, in octal,
and the current estimated delay, offset and dispersion of the peer,
all in seconds. In addition, the character in the left margin
indicates the mode this peer entry is operating in. A + denotes
                                                               ( 76%)
                                 < EXIT >
```

Figure 26. Time Synchronization Status screen. After synchronization is setup, verify that communications with the remote time server was established. Initially the status screen will appear similar to this.

Successful time synchronization

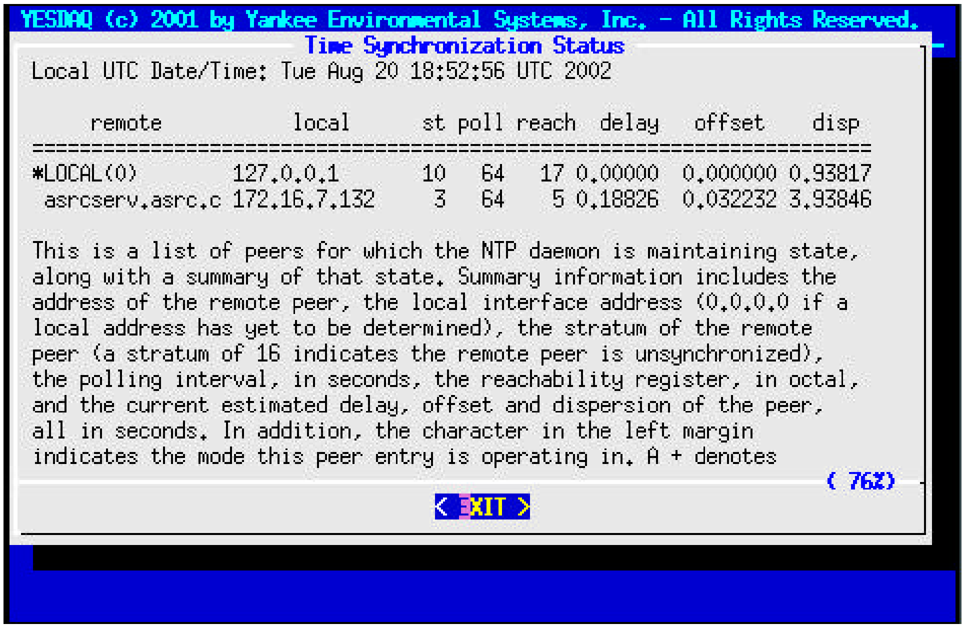


Figure 27. After a few minutes, the time status window will appear similar to this.

Once all TCP/IP parameters have been stored, the system will need to be restarted.

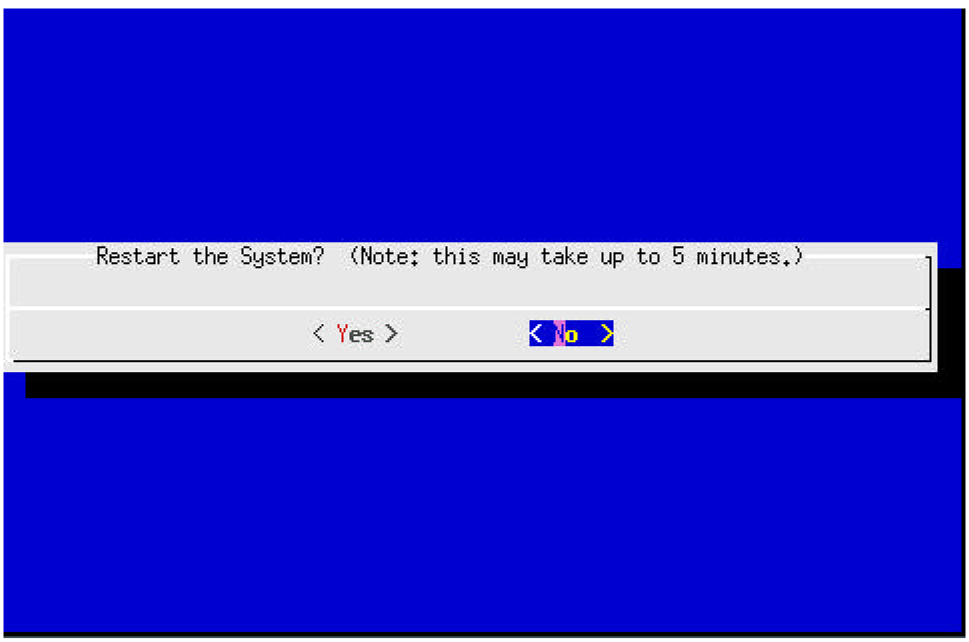


Figure 28. Now that the parameters are entered, the system needs to be restarted.

Configuring system parameters via the web

Now that basic settings are in place, verify that TCP/IP parameters are correct by plugging the instrument's 10/100-BaseT cable into an active port on your local area network hub and verify the activity LEDs are operating as you would expect. Using a known-working workstation with a different TCP/IP address, try reaching it by entering the TCP/IP address for the system into a local web browser.

Warning: If you cannot see the system, you must ascertain what the setup problem is before proceeding. For example, ensure the test workstation does not share the same TCP/IP address as the system's address you installed on the RSS!

Additionally, if you have Domain Name Services (DNS) running on your local area network, you can simply enter the hostname of the RSS system, rather than the numeric TCP/IP address. DNS adds considerable convenience to users.

If your networking parameters are configured correctly, the system verifies that

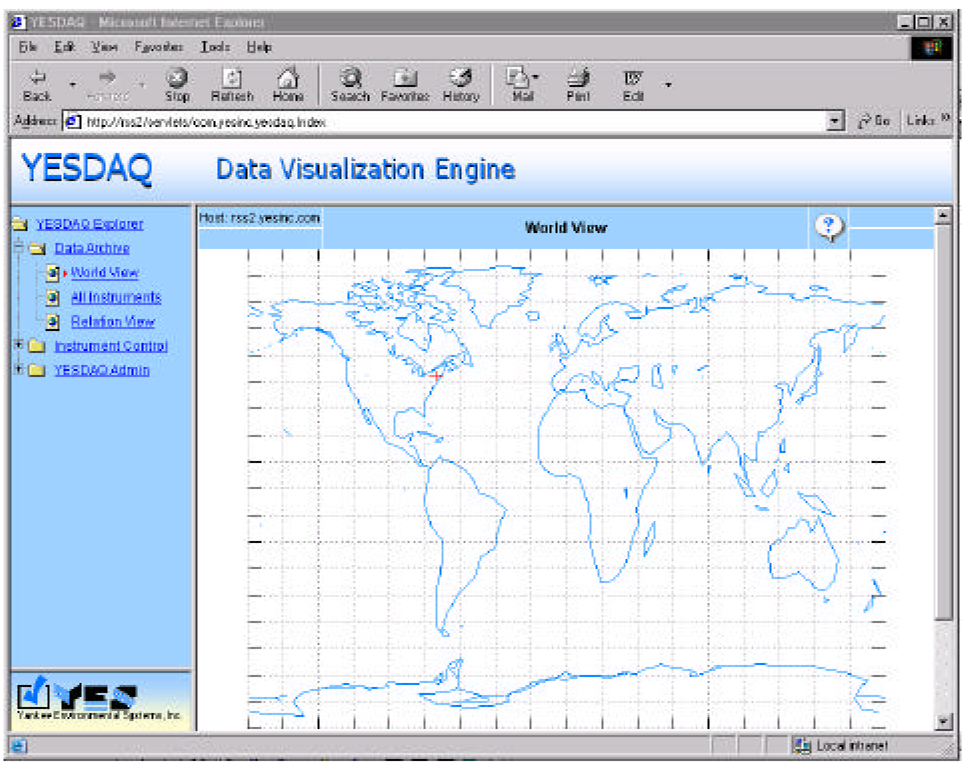


Figure 29. Initial home page shows a map of the globe.

Java is enabled in your browser and a map of the world should appear. When you see the world map appear, you have properly configured the TCP/IP settings.

If you do not see the map of the world (the system home page), try issuing a ping command to the system's TCP/IP address from the Unix or MS-DOS command prompt. Observe the LAN activity LED on the RSS' Core CPU to see if you can see network segment traffic. If you see activity, try swapping the Ethernet cables first, taken form a known working LAN device. Next, try connecting a known-working TCP/IP device into the Ethernet cable initially connected to the RSS and see if that device functions properly. Finally, if all else fails, seek help from your local network system administrator.

If you can't see the world map

Note: Java must be enabled within your web browser to use the RSS. The exact method you use to enable Java varies with version and browser manufacturer. For example, in MS-Internet Explorer, look under Tools | Internet Options , click on the Advanced tab, scroll down to the "VM" section and look for the Java section. The menus differ slightly with Netscape. If you are using an older browser version, we strongly recommend that you upgrade. MS-Internet Explorer V.5 (or later), Netscape 6 or later have been tested. It is not possible to use the RSS via a browser unless Java is enabled.

Assuming you can see the world map, click on the *All Instruments* tab at left and select the instrument corresponding to your RSS. (Note the system name will differ from the screens shown in the examples shown).

Now select the site name, in this case ASRC/National Weather Service Office:

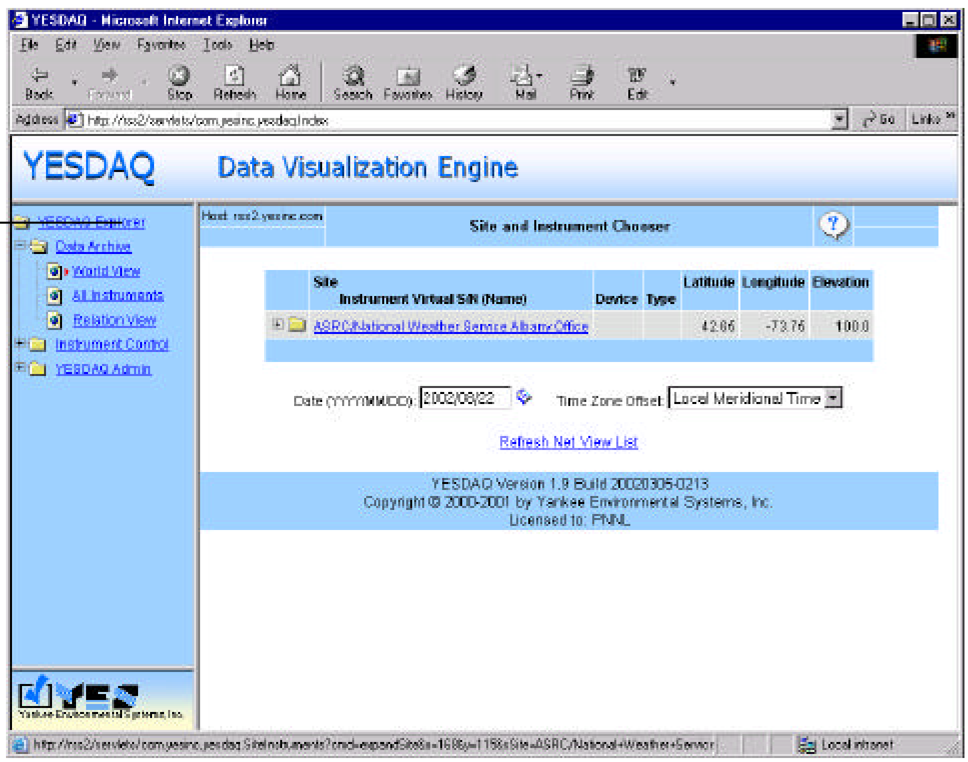


Figure 30. Selecting the site, note that your screen will look different!

Once the site is expanded to show the system (in this case YES.RSS.577) select the RSS control icon under the center *Device* column:

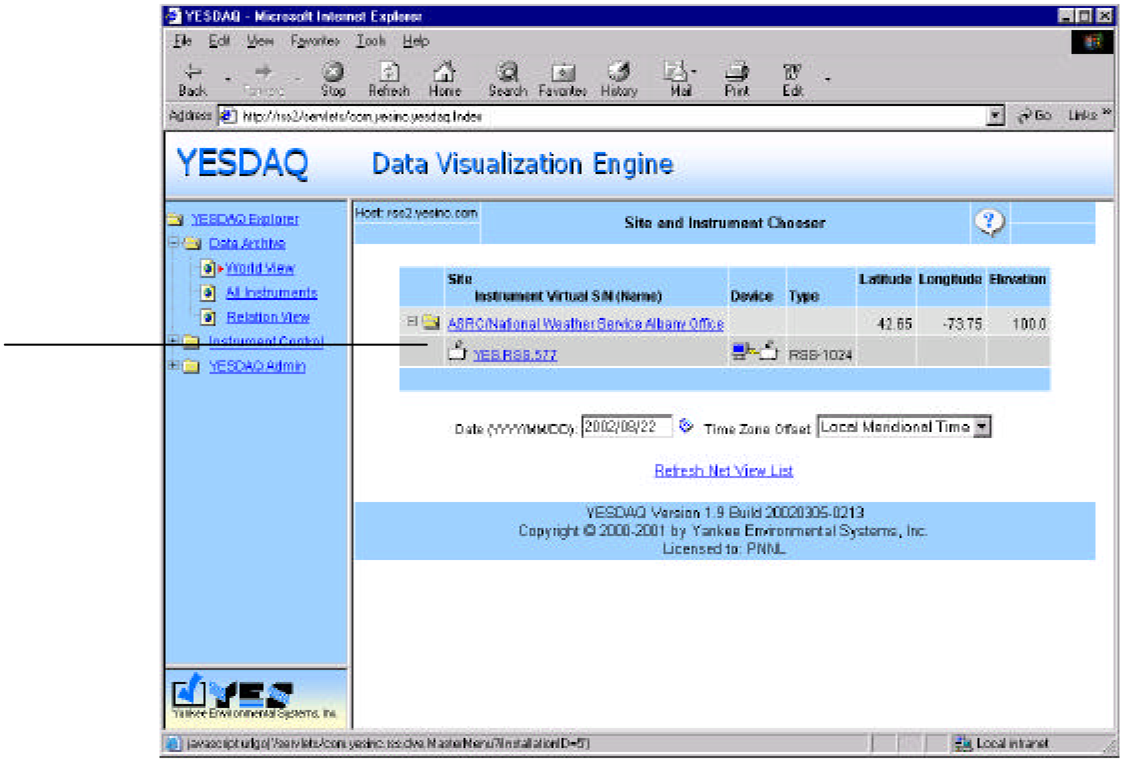


Figure 31. Selecting the device control icon to access configuration parameters.

A YESDAQ administrator authentication dialog appears. Login as (all lower case):

```
admin
```

Logging in as admin the first time

In addition, use password (again, as all lower case):.

```
sqladmin
```

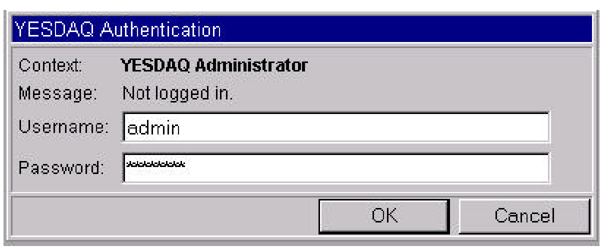


Figure 32. YESDAQ login prompt. Initially, use the default password.

WARNING: Change the default YESDAQ admin password above, by selecting the YESDAQ Admin menu (on the left of the main page). Write down the new password. Note it is not as necessary to set the RS-232 serial port passwords as they are not accessible via the web and require physical access to the system. Modem access is further protected via the PPP password, which you should also change if you ever connect the system to a telephone line.

Stopping RSS data acquisition

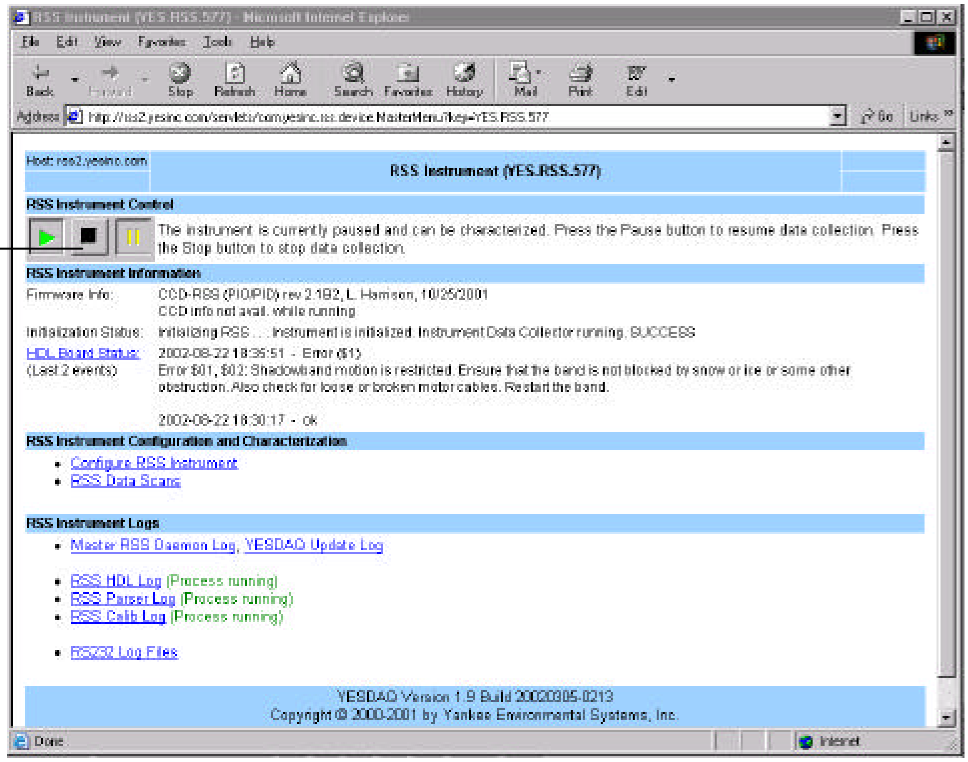
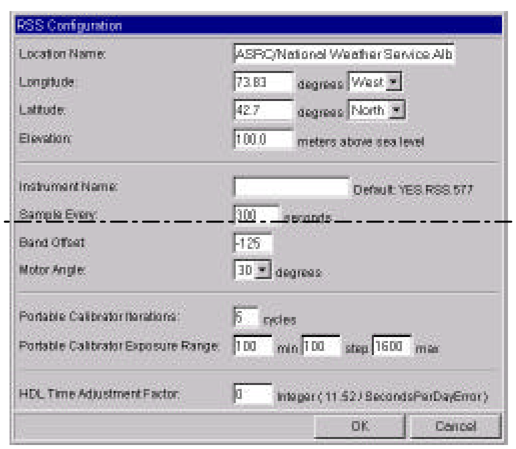


Figure 33. RSS Instrument control screen.

Click on the black square stop button to verify that the system is stopped and not collecting data. Click on OK when it warns you it will take up to 2 minutes.

Setting the location and site name

Now specify your unique site parameters by clicking on *Configure RSS Instrument*. Change the system Location Name, Latitude/Longitude all the way down to *sample every n seconds*, but leave the lower settings alone. *Location name* is typically the geographical site name and *instrument name* is left as the default. These names will appear in the web browser view of the system. Hit OK when you are ready to proceed.



Ý **OK to adjust** Ý

ß **Do not change** ß

Figure 34. RSS Configuration screen.

WARNING: We strongly recommend that you do not alter any RSS Configuration settings below *Sample Every* unless directed by YES technical support. The band offset was set at the factory and should not need adjustment.

Using the system as a CCD spectrograph

In this section, we discuss using the system as a conventional spectrograph. The RSS is an excellent tool for transferring spectral irradiance calibrations from FEL lamp standards, using the RSS as a conventional spectroradiometer.

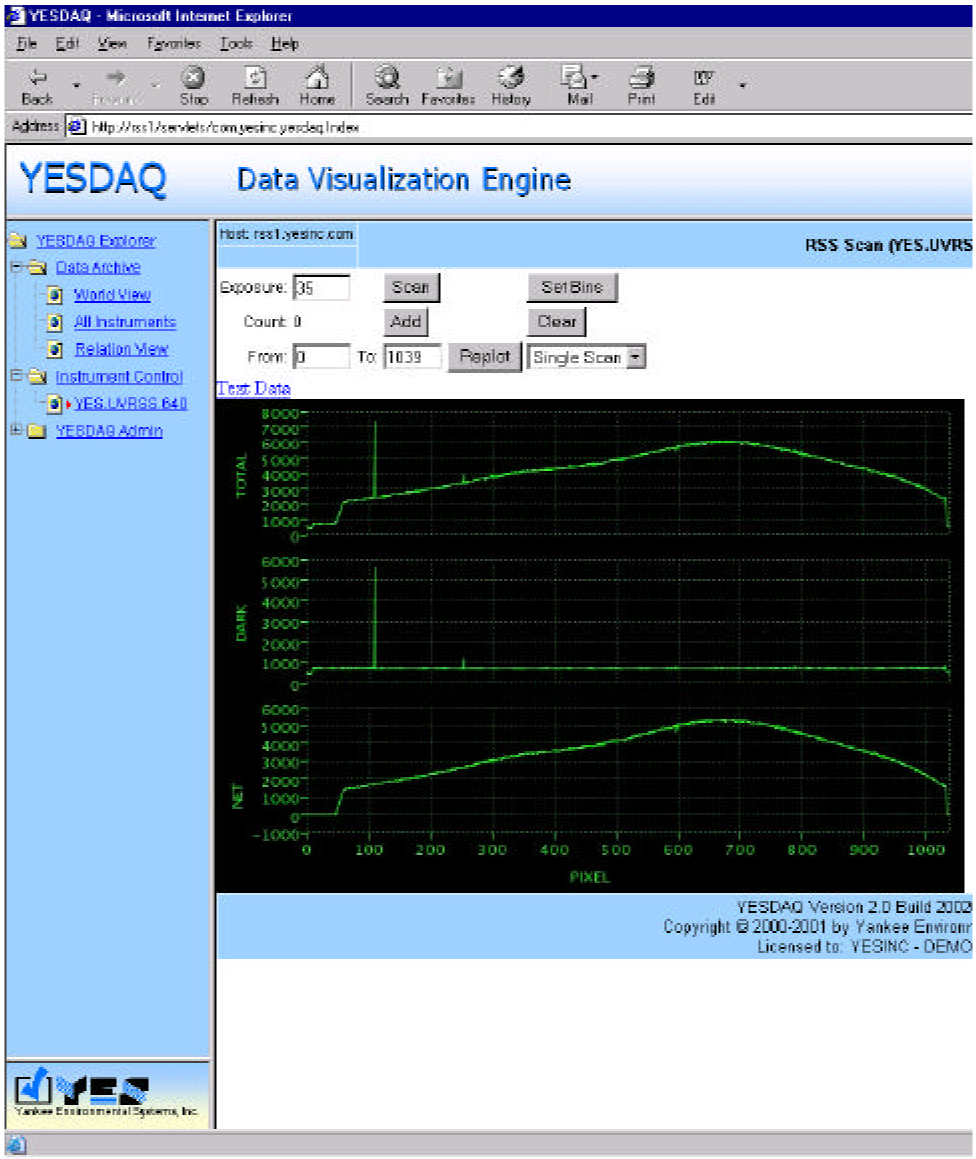


Figure 35. RSS scan screen, which permits you to take individual scans, for example, in front of an irradiance standard lamp. The top plot is the raw CCD data not corrected for dark count (note “hot” pixel near 100), the center plot is a dark count shuttered measurement, and the bottom plot represents the top-minus-dark measurement. Note that data in individual scans is in ADC counts and is *not* absolute calibrated in engineering units. The scans shown here were taken using a UVRSS-1024 in front of the 500 watt Hg-Xe arc lamp on the cosine characterization facility bench, to testing CCD linearity.

From the RSS control screen, click on *RSS scans* to view the RSS Scan screen:

In *RSS Scan* mode, you can take one scan or averages of *n* scans. Averaging multiple scans together is a traditional method for improving signal-to-noise levels.

> **Note:** Scan data are not calibrated. In addition, *RSS Scan* mode is only available when the instrument is in *stopped* mode and not taking shadowband data.

The center plot represents *dark counts* and is simply a shuttered measurement. It is subtracted from the top *total* scan to get a dark-count-corrected *net* reading at bottom. You can also manually set the CCD exposure and the start/stop CCD bins that are used for column binning operation. Normally, you will not want to alter the bin settings. The from/to limits represent the CCD pixels and is normally left from 0-1039. The upper 16 CCD pixels are always blanked off, and the actual spectra underfills the CCD's active 1024 pixels.

> WARNING: There is an option to set the bins permanently but, do not alter these CCD bin settings unless you have a very good reason to do so. Your instrument settings are factory set and any alteration when the RSS is operating manually will alter its absolute calibration and noise floor. RSS Scan mode is only available when the system is not taking data.

Acquiring single scans from the RSS

From the main YESDAQ web-page:

Understanding the scan mode plots

1. Click on *Instrument Control*
2. Click on your RSS instrument
3. If you are not already logged in, log in as user *admin*
4. Stop the instrument by clicking on the square *stop* icon
5. Click on *RSS Data Scans*
6. Select the exposure you want. Note that getting it right the first time may take some experimentation depending on the FEL lamp you are using
7. Click on *Scan*
8. If the scan looks OK to you, click on *Add* to add it to the set to be averaged
9. Repeat steps 7 and 8 until you have enough scans to average to get the noise to an acceptable level, typically twenty is adequate. The *current count* is displayed on the screen

> **Note**: You can't change the exposure once the averaging process has started.

10. Choose Average *of Scans* in the drop-down list box
11. Click on *Replot*

12 For text data click on *Text Data* button at the upper left of the plot area. To get the data in downloadable form copy/paste the data into your favorite text editor. Note that data are presented in 4 columns: pixel number (0 .. 1039), ADC light counts, ADC dark counts, ADC net counts

Characterizing RSS absolute response using traceable FEL lamp irradiance standards

There are three ASCII input data files required to perform absolute RSS characterizations:

- *Absolute responsivity* file, consisting of 1040 raw counts, one per pixel
- FEL *lamp characterization*, with two columns of data: wavelength in nanometers, and irradiance in $Wm^{-2}nm^{-1}$ (note these units MUST be correct!)
- *Wavelength characterization*, consisting of 1040 wavelengths, one per pixel

1 The *absolute responsivity* file is the average of the raw scans generated by the RSS Data Scan web interface. You then must edit the file to contain only the last column (net count). Note the exposure setting used during the averaging steps.

2 The FEL *lamp characterization* file comes from the irradiance curve data supplied to you by the manufacturer of your FEL lamp.

> **Note**: you must convert the FEL lamp manufacturer's units to $Wm^{-2}nm^{-1}$. Note also that FEL lamps have a finite calibration lifetime, typically 50 hours.

3 The *wavelength characterization* file can be downloaded from the instrument with the perl script program *rsscaldownload*.

> **Note:** The wavelength response in the RSS should not change, due to its locked down optical design and internal thermal control, so use the factory-supplied wavelength response file. If you wish to check the wavelength response, you can expose the RSS to a line source lamp.

For documentation on the syntax, simply type:

```
rsscaldownload -?
```

These three data files, plus the exposure you used, is then fed to the command line executable program *respchar*. This program has the following command line arguments, for help on using the script simply type:

```
respchar -?

   -r respfile 1040 counts

   -e exposure sec/100

   -w wavefile 1040 wavelengths (nm)
```

```
-l lampfle wavelength (nm), irradiance (W/m^2 nm)

-a auditpxl dump specified pixel data to stderr

-? this help message
```

By default, output from the *respchar* program goes to *standard out* on your workstation, which is the display. You will want to redirect the output to a text file via the *redirect* operator (>).

For example, using the response file **MyRes.txt**, the wavelength file **MyWave.txt** and the FEL lamp response curve file **MyFEL.txt**, sending the result to a text response file **r.txt** you would type from your command line:

```
respchar –r MyRes.txt –e 40 –w MyWave.txt –l MyFEL.txt > r.txt
```

Finally, upload the resulting response file **r.txt** file to the RSS using the perl script *rsscalupload*. For documentation on how to run the script, simply type

```
rsscalupload -?
```

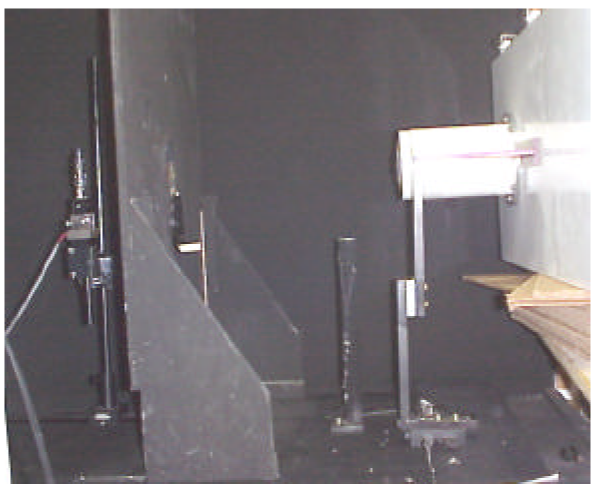


Figure 36. Absolute optical calibration setup using a base-down-burning, 1 kW FEL irradiance standard lamp. The lamp source is precisely fixed 50 cm from the diffuser per convention. Operation of the RSS on its larger flat side provides the most mechanically safe orientation.

Looking at System Logs

Master system log

Next, close this window and click on *Master Deamon* log to get a view of the internal messages from the OS running the RSS. These logs can be helpful in diagnosing various internal system problems.

Click on *RS-232 logs* to see the raw data directory. These ASCII text files are

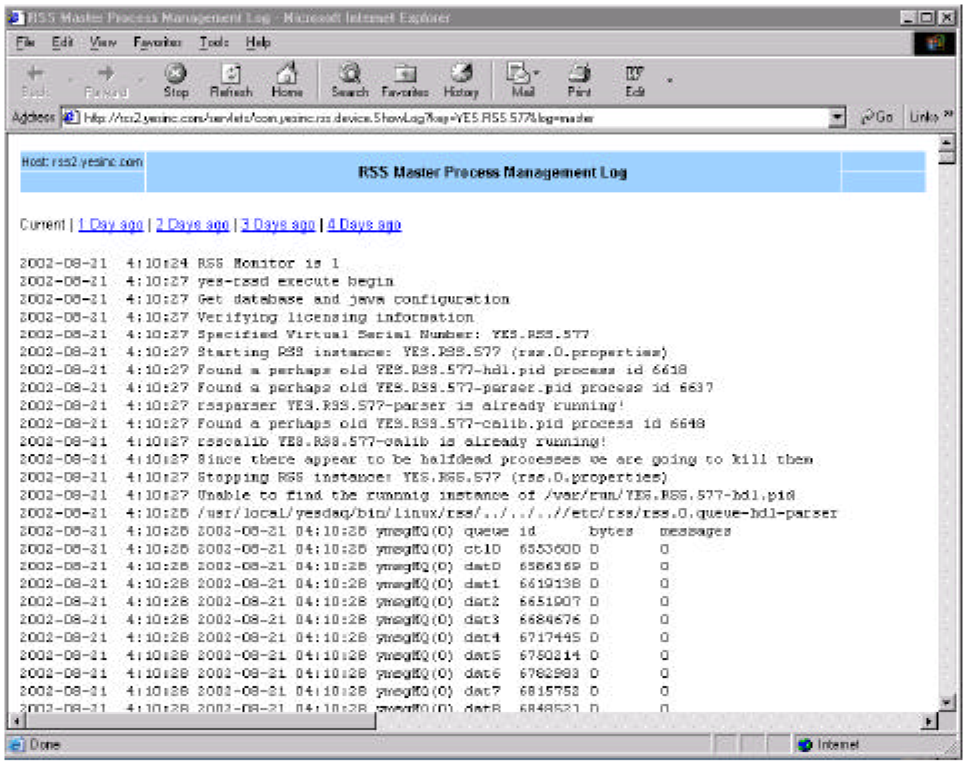


Figure 37. Master system log.

RSS scan ASCII data

the actual raw analog-to-digital converter scans produced by the Dual Combo CPU board that are sent on to the Core CPU. You can use a web based utility using http protocols such as *wget* to fetch these files from this directory if you wish. Close this window when you are ready.

> **Note:** System logs are generally only needed if the system develops internal problems. For TCP/IP security reasons, the RSS does not support legacy direct ftp connections, but there are a number of http-based solutions for moving files from the system such as the *wget* set of open source http protocol web fetch utilities.

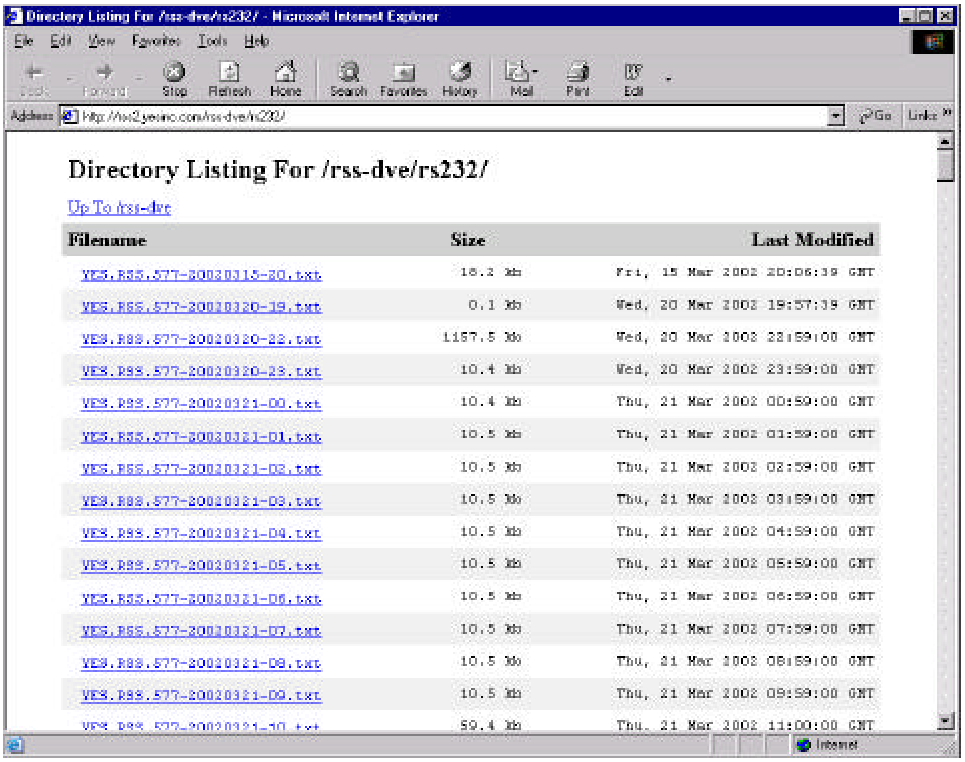


Figure 38. Viewing the raw CCD scan data directory.

Restarting RSS data acquisition

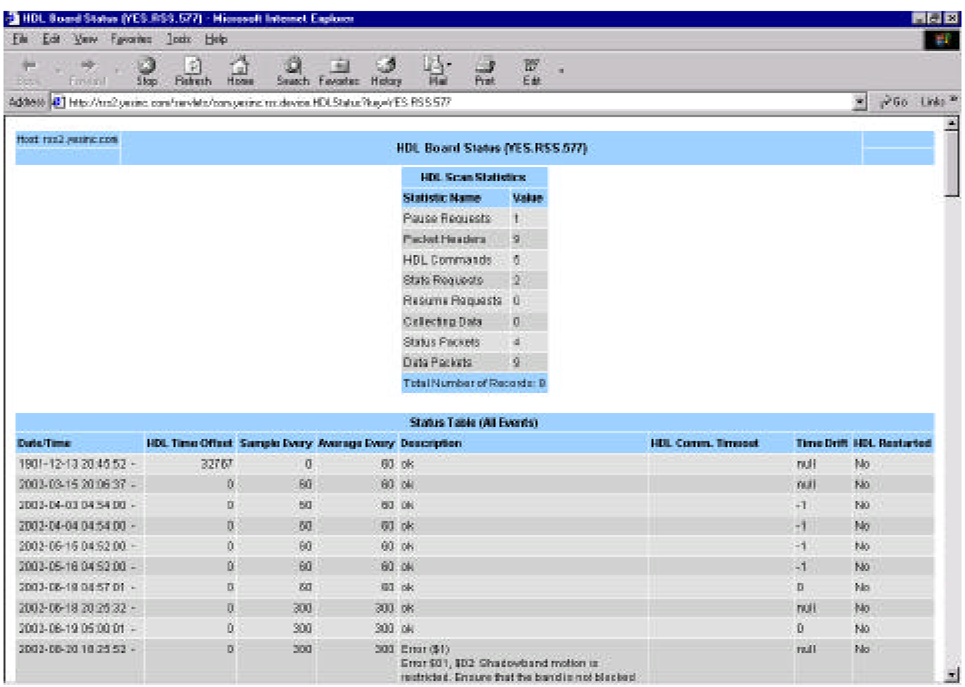


Figure 39. Reviewing the embedded control system status log. (Scroll to the bottom of the window to see the latest commands.)

Back at the main *RSS Instrument Control* window, start the RSS taking data by clicking on the play button arrow, then OK to acknowledge the warning. After a minute or so, check the “HDL status” link to observe the commands, noting the right hand column “HDL restarted” in the status table. The RSS is taking data and you should observe the shadowband moving at the sampling interval you selected.

Installing the System Hardware at the Site

Laboratory users can skip to the next section. Outdoors, locate a suitable site for the system, hopefully with an open, unobstructed view of the horizon to eliminate local environmental bias. An open field or rooftop is a good choice. In heavily wooded areas, install the system on an elevated walk-up platform.

Once you have found a site, ensure that it has the necessary power and communications equipment. The system is typically powered from the AC line via a single 15 amp 110 or 220Vac outlet. This section explains how to install and align the instrument at the site.

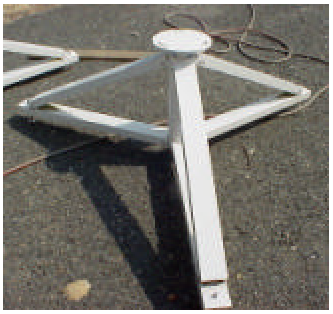
Mounting platform

The instrument must be securely mounted so it cannot move, or worse, fall over, under any wind conditions. Ensure that adequate drainage exists as erosion can affect the mounting platform's stability. Also check the plumb of the mounting platform with a level — it should be roughly within 2° or better of vertical. You can alternately bolt the four feet of the enclosure to a suitable sturdy flat surface such as a metal table. The RSS can operate on its side (supporting absolute irradiance calibrations via 1 kW FEL lamps burning base-down), but to do this in the field you will need to provide a suitable mounting scheme. Field absolute irradiance calibrations are typically performed via the Model PFC-5001 accessory and tilting the system is not necessary.

Optional tripod

The optional tripod provides an excellent solution for pad mounting at installations where digging is not practical, such as on rooftops. Take care to secure it to the ground and secure all bolts. A typical tripod field installation is shown below.

Figure 40. Side view of RSS, shown mounted on optional tripod.



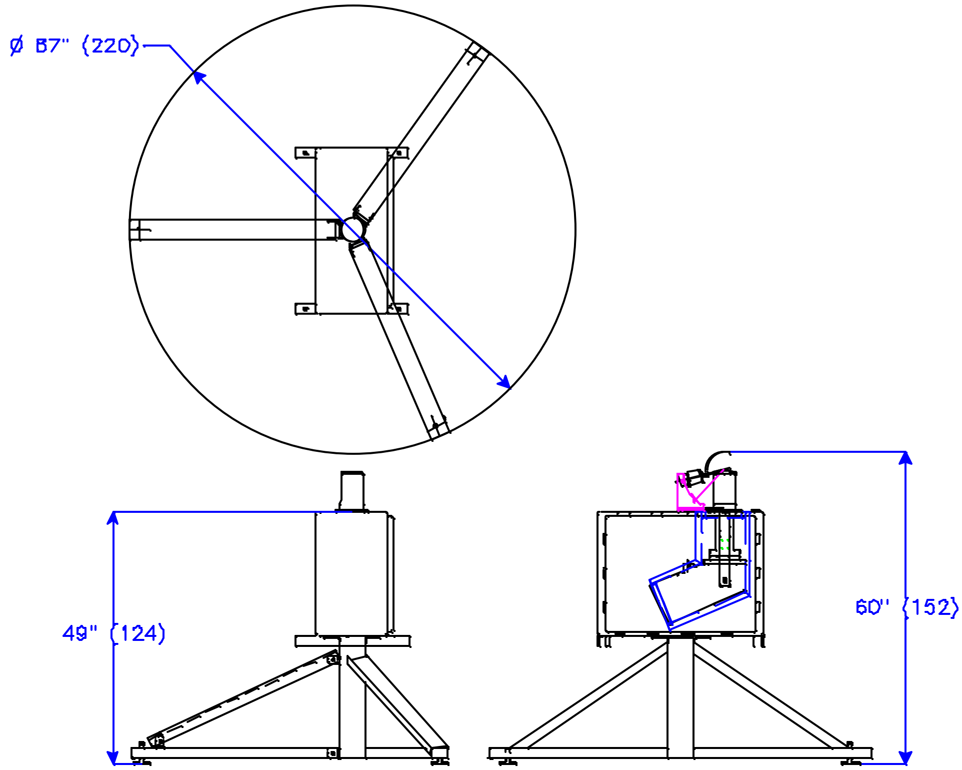


Figure 41. RSS shown mounted on optional tripod. Dimensions in inches (cm).

AC Power Considerations

While the RSS contains an integral on line UPS, providing stable AC power is critical to system performance, as well as achieving rated specifications. If you are operating at extremely remote sites with generator power it is a good idea to provide a suitable on-line UPS between the generator and the RSS to support operation during generator refueling.

> **Note**: While the RSS is normally used with AC line power, 48 volt DC versions are available for remote sites with solar power. Your solar panel and battery array will need to provide 48 Volts DC at ≈500 watts continuously *day and night*. The DC input option must be specified at time of order—contact YES for details.

Changing the AC line voltage

Inside the enclosure you will find two orange AC circuit breaker/switches and line voltage selection switches. Both AC switches are typically left in the "on" position. The system can operate on either 120 or 240 VAC, 50 or 60hz, via two selector switches. When changing the system line voltage, be sure to switch both selector switches with the AC power off. The switch on the left side controls the AC to the enclosure's internal boost heaters and the right switch controls the system electronics. Both AC switches illuminate when on and line power is present.

> **WARNING**: The right hand AC switch runs the RSS electronics and casting heaters and *must match the incoming line voltage*!

The right switch controls the system electronics *and must be set to the correct local line voltage*. The left switch controls the enclosure heaters and while it can be set to either 120 or 240 Vac, it is usually set to match incoming line voltage.

However, at extremes of temperature you may wish to set the enclosure heaters to the opposite position. For example, at 120 Vac installations, you might want to select the 240 Vac heater switch setting if the system is installed in a very warm environment (where ambient temperatures are unlikely to drop below 0°C in the wintertime). Similarly, if the system is used in very cold regions, a 120 Volt setting might be appropriate at 240 Vac line voltage to boost output of the enclosure heaters. Note that in this case a new heater circuit breaker will be required, as the provided AC circuit breaker is rated at only 5 Amps; and the draw will be roughly 1800 watts requiring a 10 Amp version of the breaker.

Typically, at 120 Vac, the system will consume ≈600 watts of power if turned on in a sub-zero environment from a cold start. Note that if the heater switch was set to 120 Vac and the system was being supplied with 240 Vac, start-up power in a sub zero environment could be as high as 1800 Watts, but is closer to 1000 Watts if the heater switch is properly set to 240 Vac and the system is being fed 240 Vac. Once the instrument is warmed up, power consumption is much lower, assuming operation in environments when the ambient temperature is above 15°C.

System Grounding and AC Power

For safety reasons, the system enclosure is connected to the AC ground wire in the power cord. It therefore relies upon the quality of that AC ground connection, which might not always adequate. Additional ground rods local to the instrument site is helpful, but some sites in dry regions have poor-conducting dry soil and/or rocky ground. In these situations, you will need to bury a radial array of copper wires around the instrument, as deep in the ground as you can dig.

Fiber Optic Cable

While you can use copper cable to connect the 10/100BaseT connection, we highly recommend using fiber optic network connections. Using hard wire (copper) CAT-5 or CAT-6 Ethernet cable is risky, particularly if there is any distance to the Ethernet hub/switch. Lighting hits nearby will enter the system and destroy it, even with shielded cable.

IMPORTANT: Play it safe and protect your investment; use fiber optic connection technology to connect to your LAN. The best protection from electrical disturbances is a fiber optic cable connection to the instrument. Also plug the instrument’s AC cord into a line voltage conditioner (a ferro-resonant type device, not a power strip-like MOV surge protector) with at least a 600 VA rating, minimum(or 2 KVA in arctic environments). Do not use an external UPS supply; this instrument has its own built-in UPS circuitry.

Likewise, permanent RS-232 serial connections to the console port are not recommended or required. At setup, you can use a laptop to initially assign the TCP/IP address. Having a permanent serial line can create ground loops and provides another path for lighting to enter the system. Electronics inside the cabinet are grounded to the cabinet, (e.g., "DC ground" is "AC ground"). Hence, there is a potential for ground loops and lightning damage via connections to the instrument, (apart from AC ground).

AC line conditioners and power protection

AC Line Conditioners will help keep dangerous surges from damaging the RSS and its power supply. Place a sufficiently large enough AC line conditioner at the instrument end of the AC feed. This precaution will go a long way to protecting your system from nearby lightning strikes. If the system is to be installed in an arctic-like environment and more power is needed to keep it warm, be sure to use a line conditioner with at least a 2000 VA rating.

Incoming AC power is protected internally with type AC-120L gas discharge devices, located just behind the two circuit breakers in the AC junction box inside the enclosure. These gas discharge devices can be accessed by removing the four screws that hold the junction box cover in place.

> **Note:** If an incoming AC surge/spike is strong enough, the AC-120Ls might short out in a desperate attempt to protect the electronics. If that is the case, the circuit breaker will not engage, requiring a replacement of the AC-120L components. Although the AC-120Ls will work at 240 Vac, it would be best to replace them with AC-240Ls if the instrument is being supplied with between 210 and 240 Vac.

Connect ground wire and cables

Connecting a ground wire from the enclosure or optional tripod to a ground rod is an excellent idea to reduce the chance that lighting will hit the system.

To install the instrument on a table:

Bolt instrument to platform

You should perform this procedure on a sunny day to ensure that the instrument is aligned properly to the north/south meridian.

1 Place the instrument on the platform as close as you can aligned to the north/south meridian.

2 Align the four hold-down holes in the instrument base over holes in the platform and loosely secure it with heavy duty stainless steel hardware. Finger tighten only, since the alignment and leveling procedures that follow require some freedom of movement of the base.

Align the instrument

The shadowband instrument’s motor bracket must be parallel to the local *geographical* north/south meridian in order to work properly. We recommend that you do this on a clear, sunny day to obtain the highest accuracy results.

> **Note**: By north/south we mean *geographical* north (the earth’s rotational pole), not *magnetic* north (the earth’s magnetic pole). You cannot use a magnetic compass to determine geographical north. You can derive geographical north most accurately by sighting known objects using a transit, or to less accuracy by waiting until solar noon and checking the motor bracket casts no shadow.

1 Obtain the solar noon time for your location. Solar times can be calculated using the mean of published local sunrise and sunset times.

2 You can obtain accurate Universal Coordinated Time (UTC) broadcasts at 5.000, 10.000 and 15.000 MHz on short-wave, or via Internet time servers.

3 At solar noon, rotate the entire system so that the motor bracket faces the same direction as the sun, such that the motor bracket does not cast a shadow to either side of the shadowband motor assembly. In the northern hemisphere, the motor bracket must point southward (i.e. the side the motor cable's connector is on); in the southern hemisphere, it points northward.

Band motor

At solar noon, the motor bracket should not cast a shadow to either side when the system is properly north/south aligned

Level the instrument

Proper diffuser level is critical to obtaining accurate results. The optional tripod base has three leveling screws. Gently place a machinist's level on the diffuser's black shadow ring. Be careful not to make contact with the white diffuser. Adjust the screws until the bubble level shows level in both planes. Once the instrument is level, secure the tripod platform with adequate hold down bolts.

Check band shape

The shadowband can be bent during shipment and we recommend that you check its shape to ensure that it was not bent out of alignment.

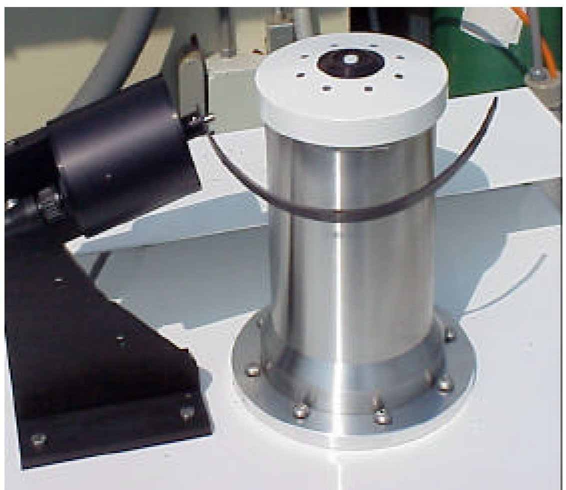


Figure 42. Observing the shadowband.

Once you have started data acquisition, you should observe the following band stops during each shadowband measurement cycle:

- **Band stopping positions**. The band pauses three times during a measurement cycle. At the second stop, the diffuser-blocked measurement is made—the diffuser should be completely shaded. If it is not, you must physically realign the system to north/south meridian as described previously. The two off-center measurements compensate for the excess sky that is blocked when the diffuser-blocked measurement is made.
- **Band return motion to home position.** Ensure that the band does not strike the canister when it returns to the stopped position. If it does, you must physically adjust the band as described below. The band home position should be ≈0.5 cm from the outer canister.
- **Data results displayed via the web.** Examine the real-time data via YESDAQ. If the band is shading properly, the direct-normal component should be greater than zero, assuming it is a clear day. If the direct

component is zero and the sun is out, this indicates the band must be adjusted.

> **Note**: *Proper system alignment to geographical north is critical.* At any time of the day, if the diffuser is even partially shaded during either side block, and/or is not fully shaded during the center stop, the instrument will incorrectly measure diffuse and direct irradiances. Do not simply check for proper shading once during the day and conclude that the alignment is correct—check it at a variety of sun angles. Check it early and late in the day, at mid morning, and at solar noon. Once the system is properly aligned and is suitably mounted, you can generally rest assured that the alignment will stay accurate.

Normally, you will not need to adjust the band unless it becomes loose. Before attempting this step, be sure that the system has been properly leveled and is oriented to *geographical* north/south.

Readjusting the band

To adjust the band, you need a 0.050 Hex driver. This procedure must be performed while the system is running. The procedure assumes you have specified –125 for the band offset and that the instrument is leveled and properly aligned along the North/South meridian. See the section Configuring system parameters via the web on page 2-16 for more information.

1 First, observe the measurement cycle for the instrument. The second stop must fully shade the diffuser, including its sides. You adjust the band so that the band is centered on the diffuser during the blocked measurement.

2 When the band is in the stopped (home) position, carefully insert the Hex driver in the band hub's set screw. Then loosen the set screw ½ turn. The band should swing freely on the shaft when the motor runs; otherwise, loosen it a little more.

3 While holding the Hex driver on the set screw with one hand, gently rotate the band with the other hand until the band's shadow is centered on the diffuser. When you hear the motor run for the second measurement and pause for the diffuser-blocked measurement, tighten the set screw ½ turn, taking care not to overtighten it. Remove the wrench and observe a few measurement cycles. If the band strikes the canister when it returns home, you must increase the gap between the band and canister by loosening the set screw and rotating the band away from the canister. Usually a gap of 0.5 cm works well. If you increase the gap, repeat the procedure starting with step 1.

Repeat this procedure as necessary. Because you have only a few seconds, it may take a few tries before you get the timing right.

> **Note**: If you must loosen the shadowband on the motor shaft, first note the air gap between the face of the motor and the hub of the band near the set screw. Try to recreate this gap. Do not overtighten the set screw. Again, check for proper shading at a variety of solar zenith angles.

Before leaving the site, be sure the enclosure door is securely tightened. You are now ready to take the system for a test drive.

Deleting YESDAQ Data

Depending on your data sampling rate, eventually, your RSS internal RAID-1 disk storage will completely fill up, requiring you to manually delete data. Depending on hours of sunlight at your site and assuming one minute sampling rates, the drives will not fill up until more than a year has passed. Normally, you will setup YESDAQ to replicate all data to an external mirrored YESDAQ system on a remote server, such that you can then safely delete data on the RSS. To view the status of disk space usage, click on Status from the link on the left

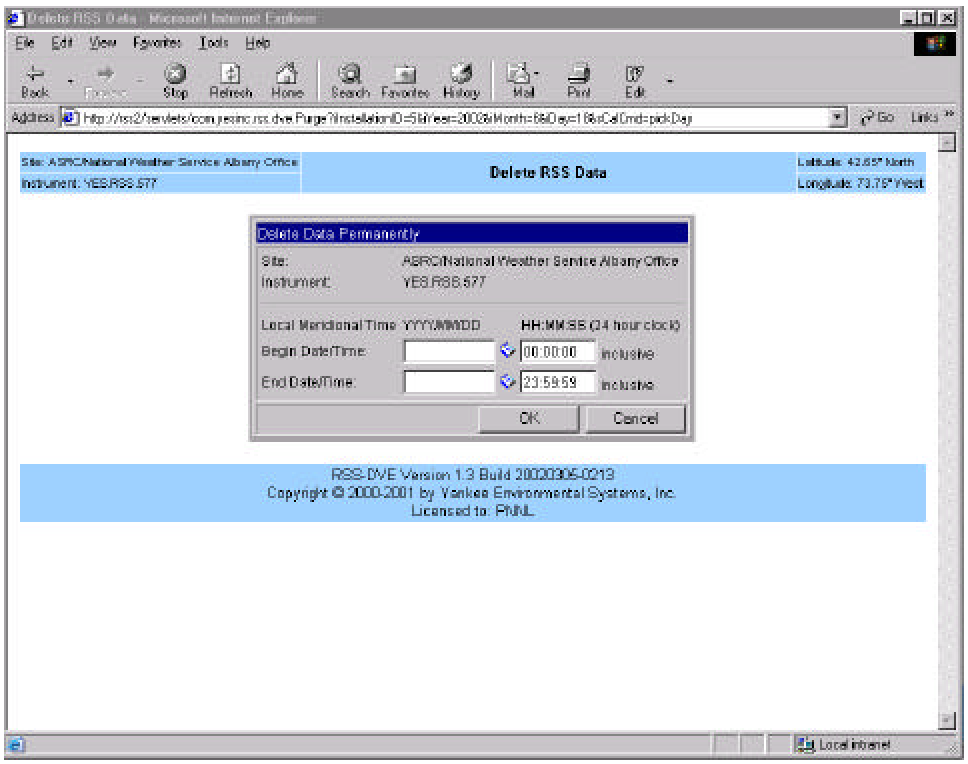


Figure 43. Delete data dialog.

side of the DVE page.

Click on the “X” (delete data) icon at the upper left on the main YESDAQ window to show the *Delete Data Permanently* dialog:

Warning: Deletion is a *permanent* operation. It is therefore essential to backup all YESDAQ data before actually deleting it, *as there is no undo function to the delete data function!* Check the dates and time ranges carefully before proceeding with data deletion. In addition, while convenient, the ability to remotely delete system data further underscores the importance of why you should always change the default YESDAQ admin password to one only known by trusted system administrators.

A brief tour of the Data Visualization Engine

The Data Visualization Engine (DVE) is a web-based data browser for instrument data. It offers quick and easy access to anyone with a Java-enabled web browser.

Note: For optimum performance, use MS-Internet Explorer V.5 (or later), or

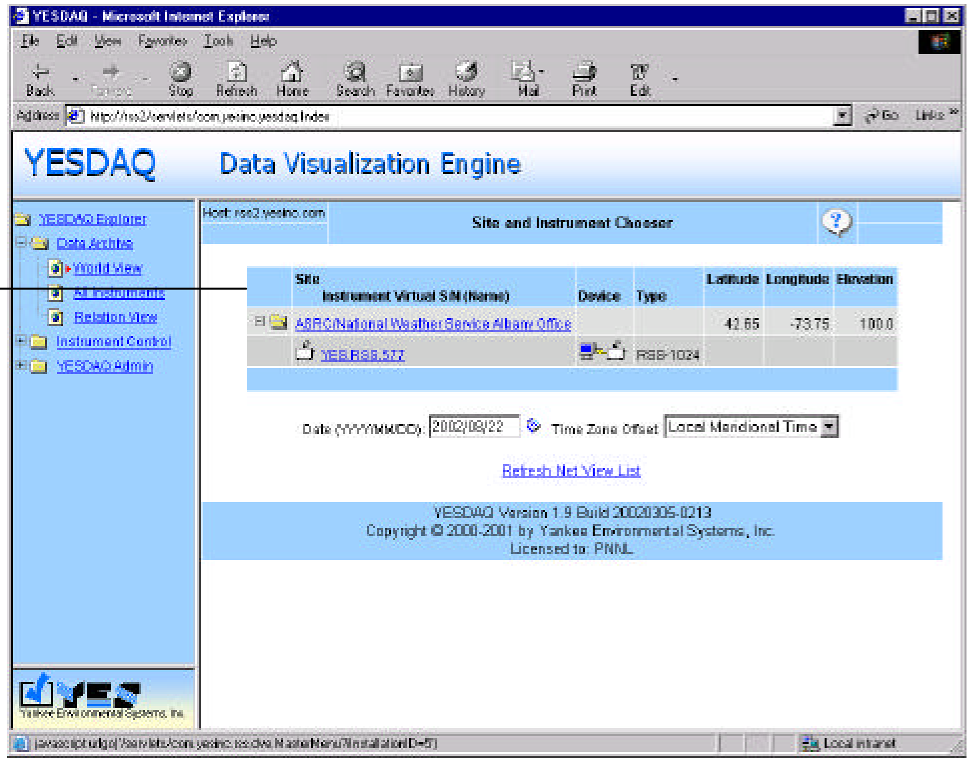


Figure 44. Click on the RSS icon under *Site* to open the data browser window.

Netscape V. 4.7 (or later).

To begin, click on the site via the map, and then on the appropriate instrument icon. Note that the hierarchical design of the DVE permits an arbitrary number of sites with an arbitrary number of instruments and instrument sites at each site. Other YES instruments such as the Automated Radiosonde Launcher (Model ARL-9000) and Total Sky Imager (Model TSI-880), as well as the Vaisala Model CT-25K ceilometer are supported via a common, unified network web view.

Once you select an instrument, an overview window appears showing you a long term "bird's eye view" of the stored data timeline for the RSS. This gives you an overview of the dates when RSS data are stored in YESDAQ. You use the calendar view to browse to dates of interest over time, or simply type in a date. If you have just started the RSS for the first time, leave the date set to today. Assuming it is during daylight hours (RSS data are not collected after sundown), with the instrument collecting data, you should see scans appear in the list box at lower left. You may need to refresh your browser to update the list box as it fills up throughout the day.

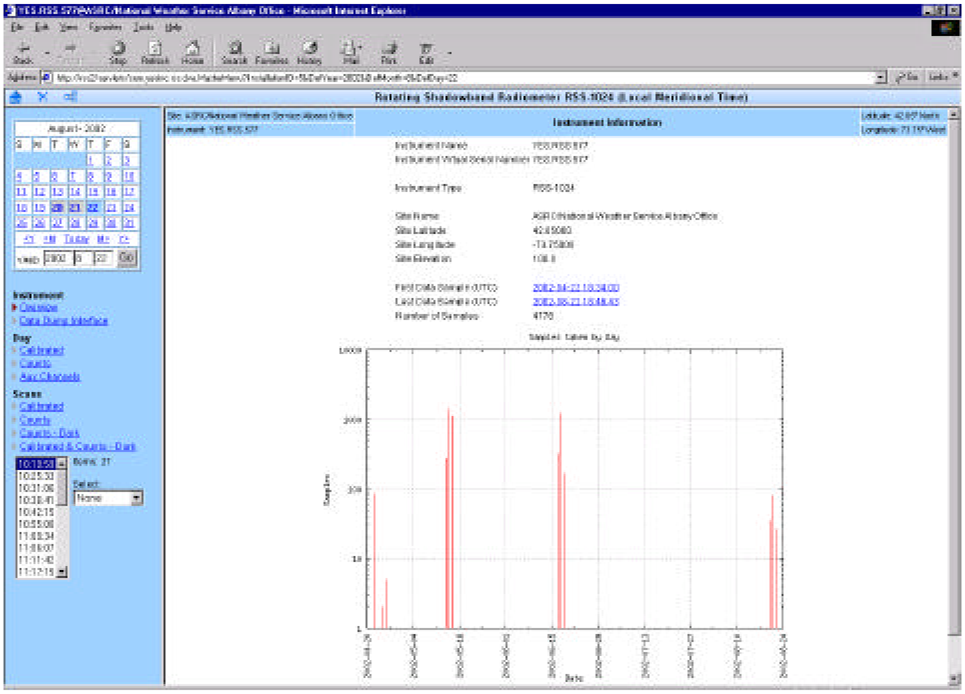


Figure 45. Initial Overview window. Red lines indicate dates with stored data.

Under **Scans**, click on *Calibrated & Counts* to view some raw spectral data.

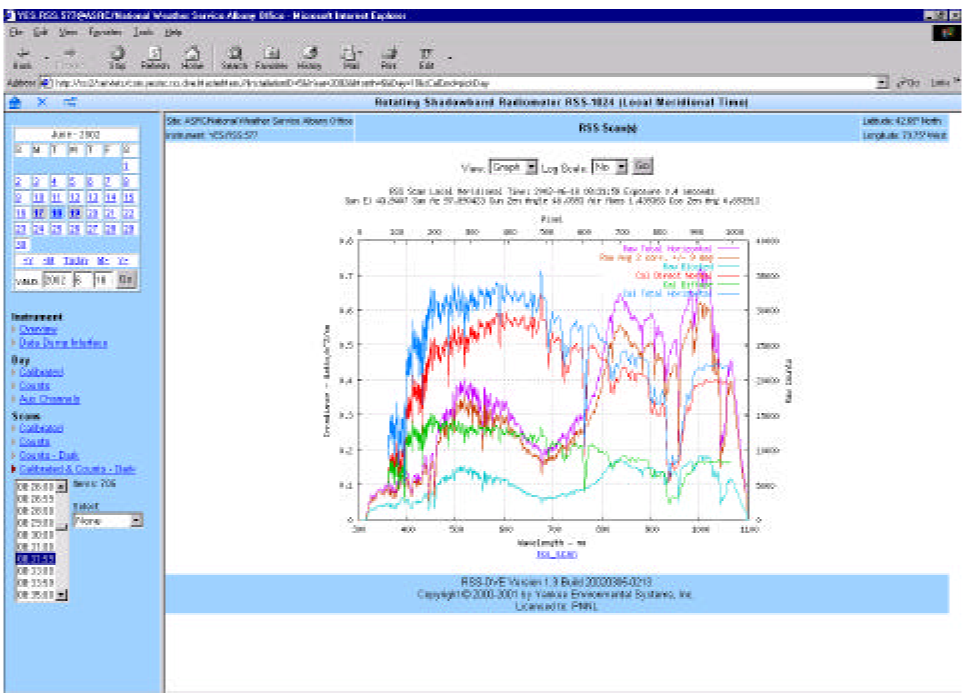


Figure 46 Sample of calibrated and raw RSS data, including dark counts.

Now under **Day**, click on **Calibrated** to view the scan as calibrated data.

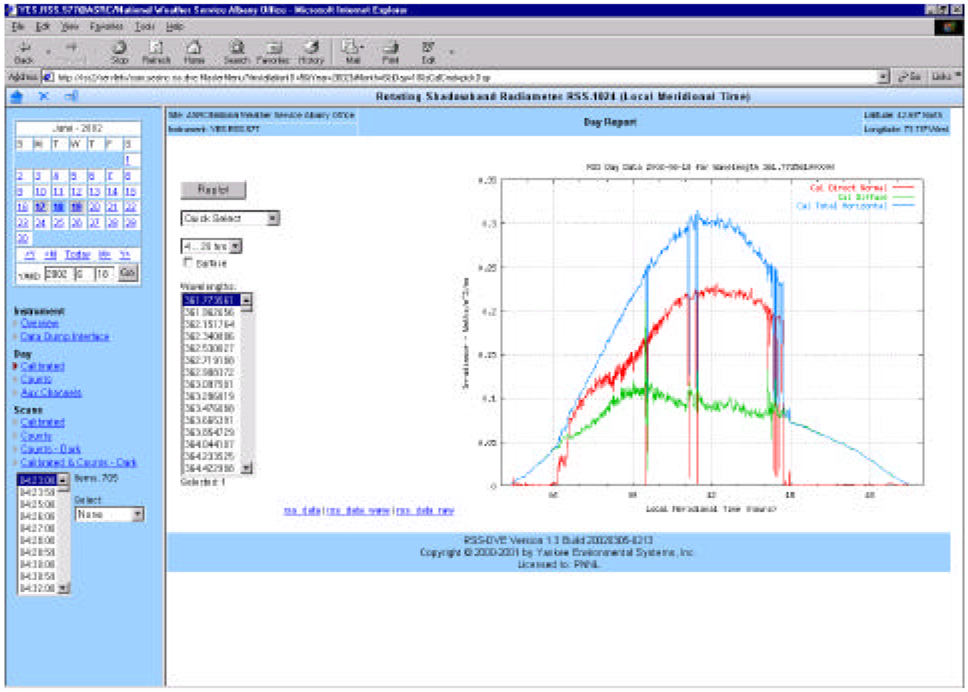


Figure 47. Typical Day Report plot showing a solar plot for a single RSS pixel.

Users of solar data will find the Day report useful for ascertaining general cloud conditions. This shows a single RSS wavelength in the time domain as direct-normal, diffuse and total spectral irradiance. **Wavelengths** selects other pixels.

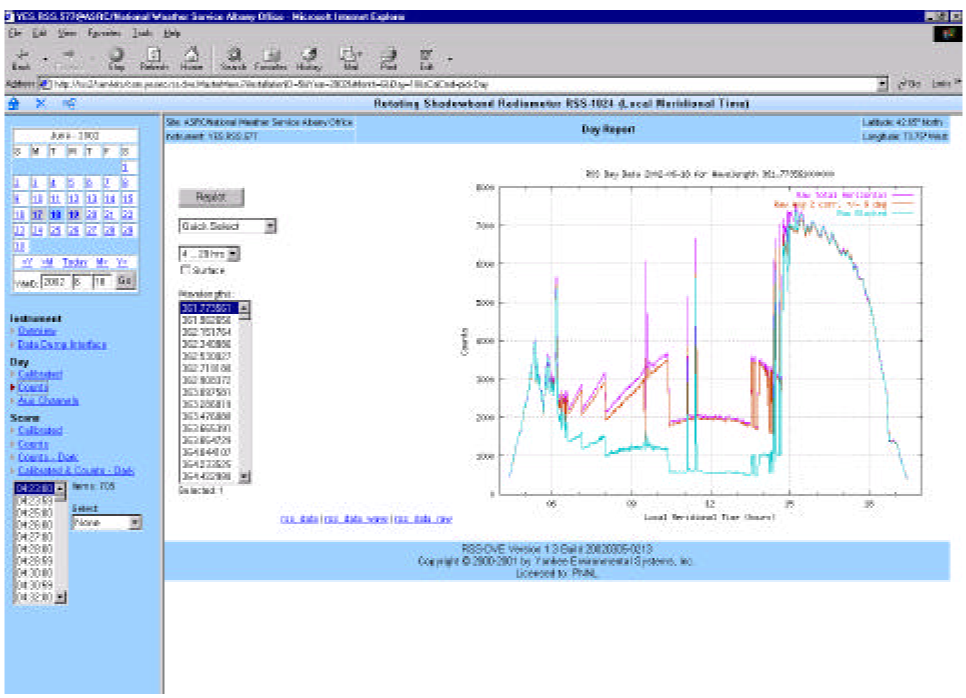


Figure 48. A "under the hood" view of raw ADC counts for a single pixel over a day. Note that CCD auto-exposure adjustments are constantly taking place throughout the day based on sky brightness, which accounts for the step changes.

Under **Day**, **Counts**, observe how the autoexposure algorithm works over the day.

Viewing Internal System Sensor Data

A variety of internal RSS parameters are constantly monitored on over 20 auxiliary data channels. Under *Day*, Click on *Aux Channels* to see a list, and try

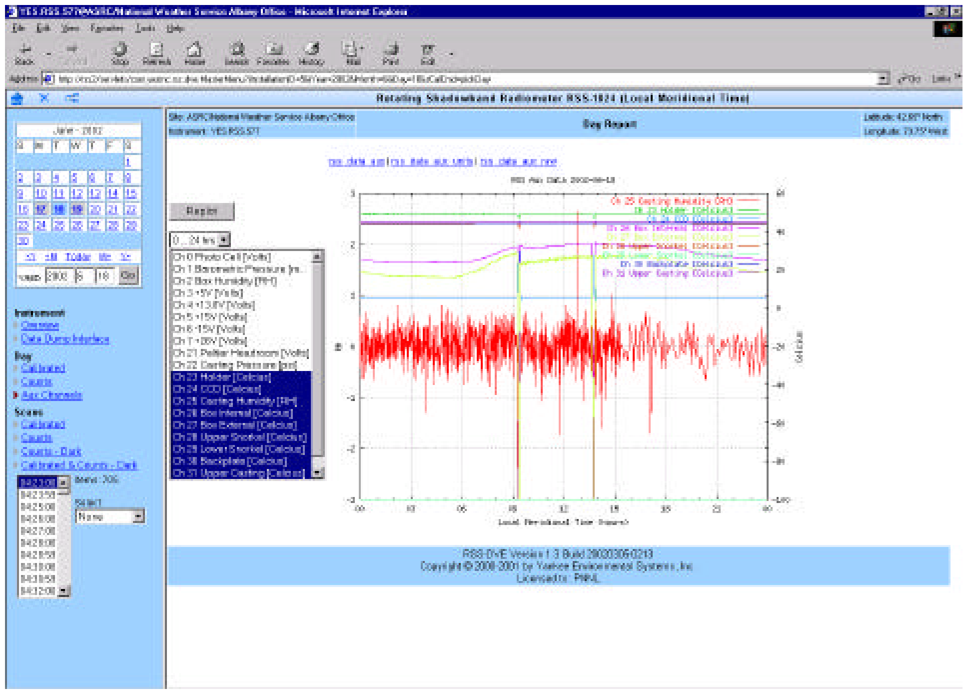


Figure 49. Observing RSS auxiliary monitoring channels. Note how a group of similar channels were selected and then plotted together, by holding down the shift and/or control keys and selecting channels of interest with the mouse.

selecting a few at a time. In the example below eight different temperatures are plotted together with spectrograph pressure vessel internal relative humidity.

Note: Channel 32, *exposure*, is actually *pseudo data* that indicates the CCD exposure time when the scan was acquired. Depending on light conditions this exposure will vary to optimize the dynamic range of the ADC subsystem. Because end users typically want calibrated data, this internal artificial gain scaling is not important.

Viewing RSS Spectra with the DVE

The Data Visualization Engine for the RSS is a component of YESDAQ provides several plotting options covering both the time and wavelength domains.

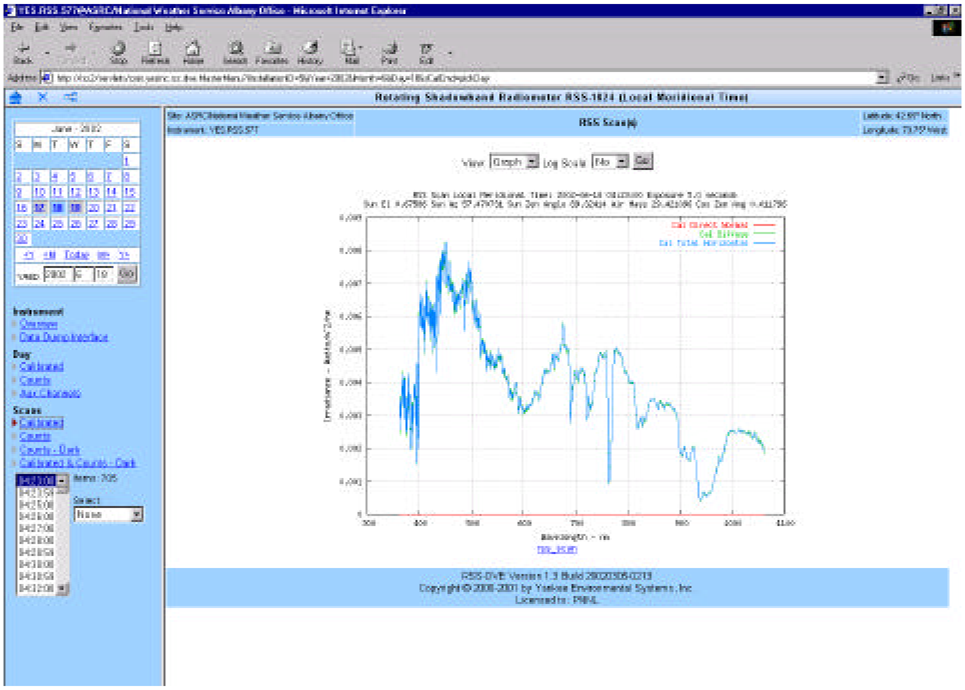


Figure 50. Sample spectrum from early in the day (no direct-normal data yet).

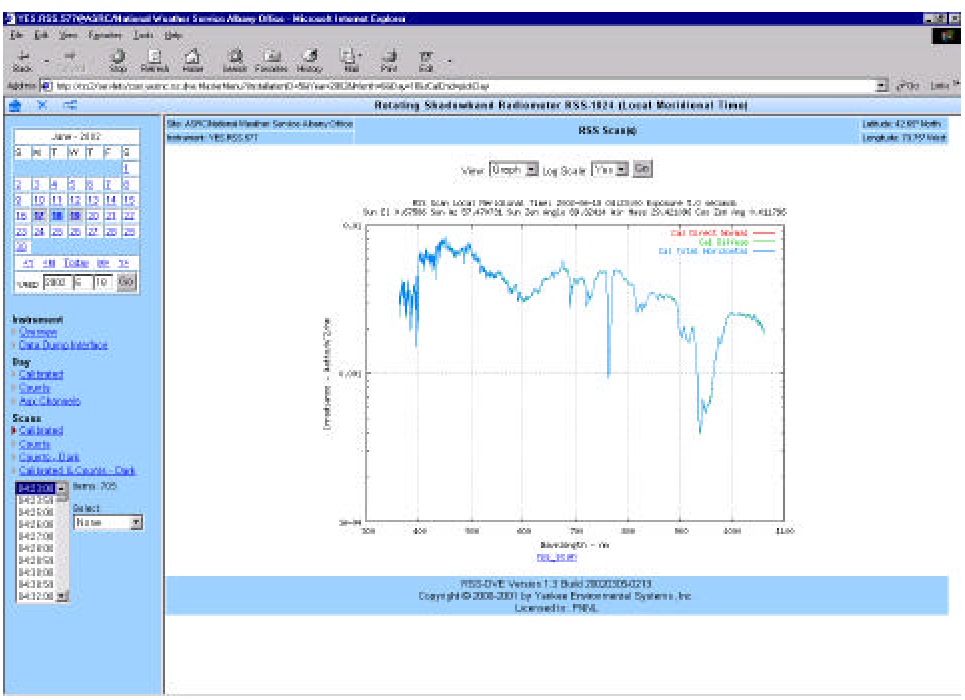


Figure 51. Viewing the same twilight spectrum using a log scale view.

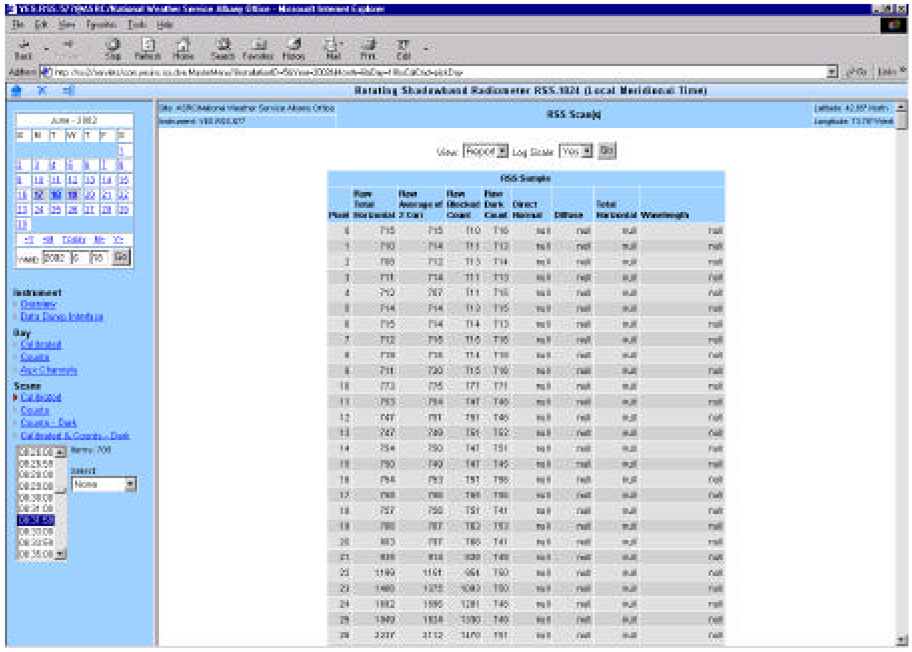


Figure 52. Viewing a spectrum via report mode to see ASCII data.

In addition to plots, a *Report* view provides cut-and-paste access to ASCII data.

Two dimensional *month plots* and three-dimensional *day plots* are also available via the DVE interface. These are particularly useful for getting an overall idea of the data, so that you can then drill down further and analyze periods of interest.

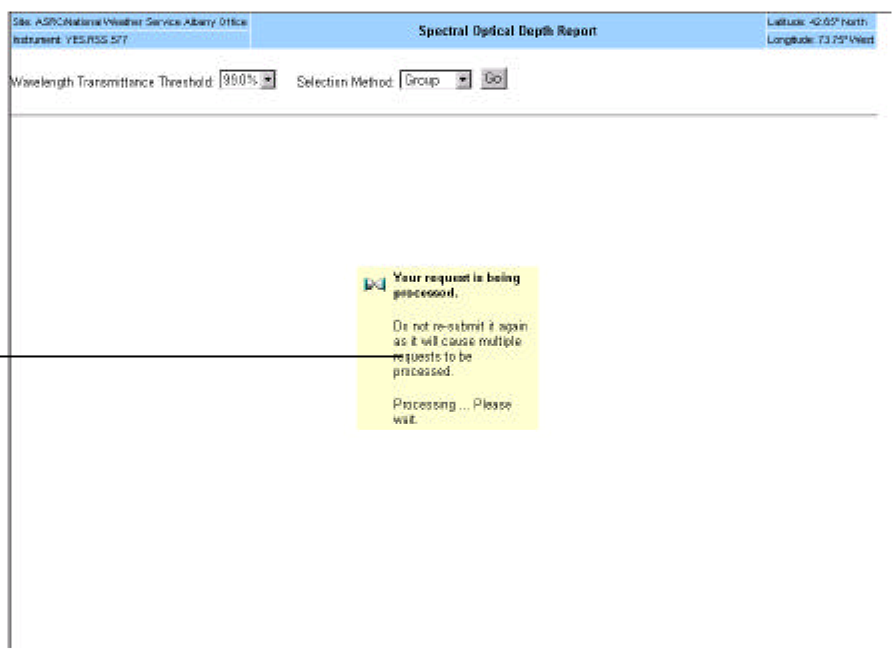


Figure 53. Waiting for results while the YESDAQ database query completes.

Please be patient as certain operations can take several seconds to render and display up to the ≈20 Mb of data.

Setting up Remote YESDAQ Database Access

You can connect your own data analysis or storage software to YESDAQ via Microsoft's *Open Database Connectivity* (ODBC) or *Java Database*

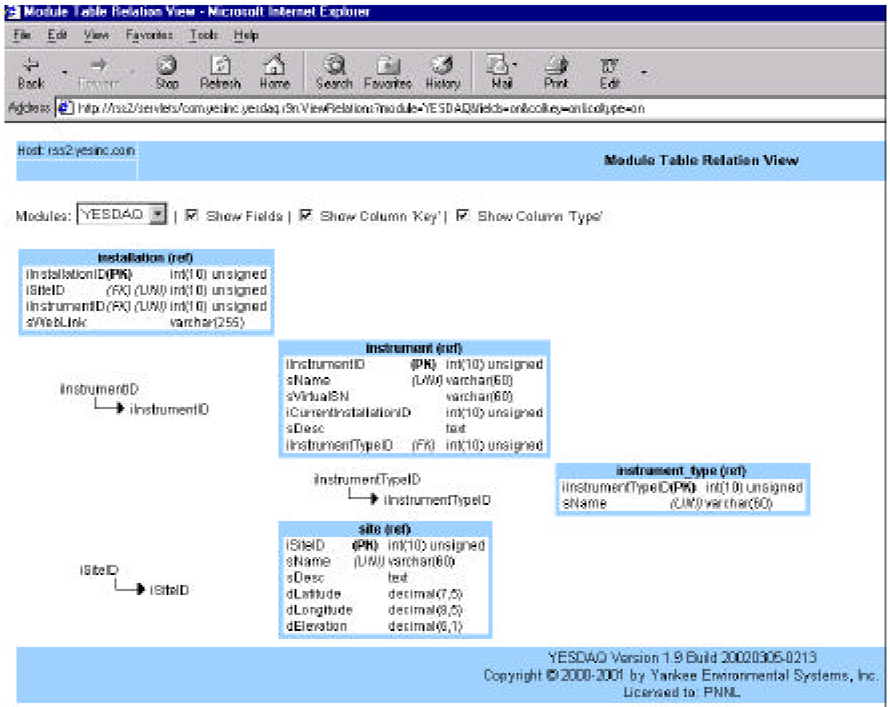


Figure 54. Table view of YESDAQ database, showing all fields and types.

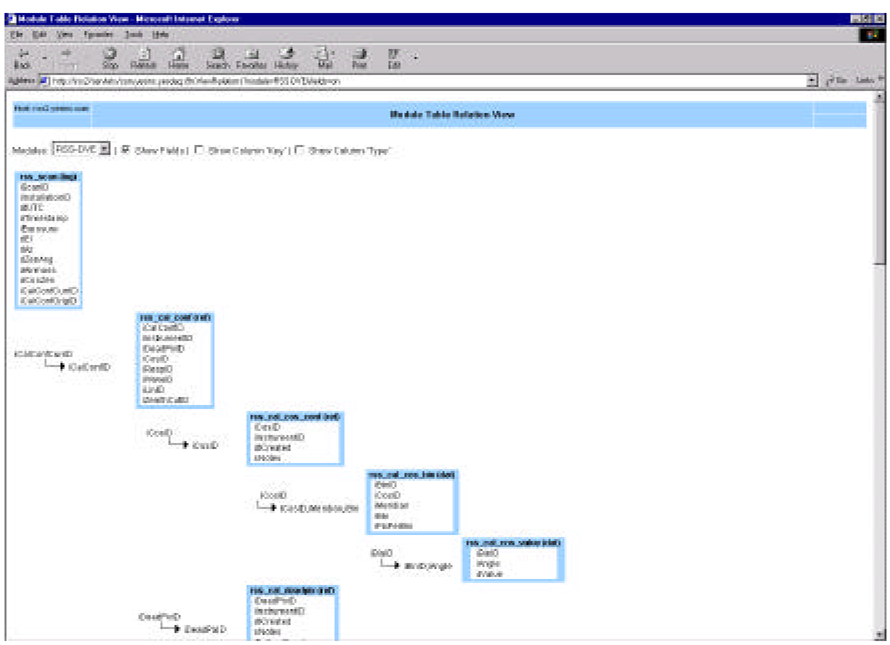


Figure 55. Viewing the RSS-DVE database table structures. By studying these, you can link data into downstream programs via ODBC, JDBC or native clients.

Connectivity (JDBC) links. In addition to supporting ODBC and JDBC YESDAQ also supports several native language data access clients (such as Python or Perl). YESDAQ stores both calibrated and raw RSS data. You can use a web browser to interact with the system (as described in the previous chapter), or you can retrieve stored data from it via ODBC, JDBC or http protocols supporting direct file transfers.

Note: To learn more about the database structures used by the system, click on the table icon at the upper left corner, to access the module table relation view.

YESDAQ collects RSS data via a *WEBCOLLECT* job (see *YESDAQ Admin*, Scheduled Jobs). This collection job runs automatically in the background to provide real time data availability. The RSS system, which contains a YESDAQ, also sends data to a second YESDAQ, typically installed on a Windows NT4/2000 Pro/XP Pro host.

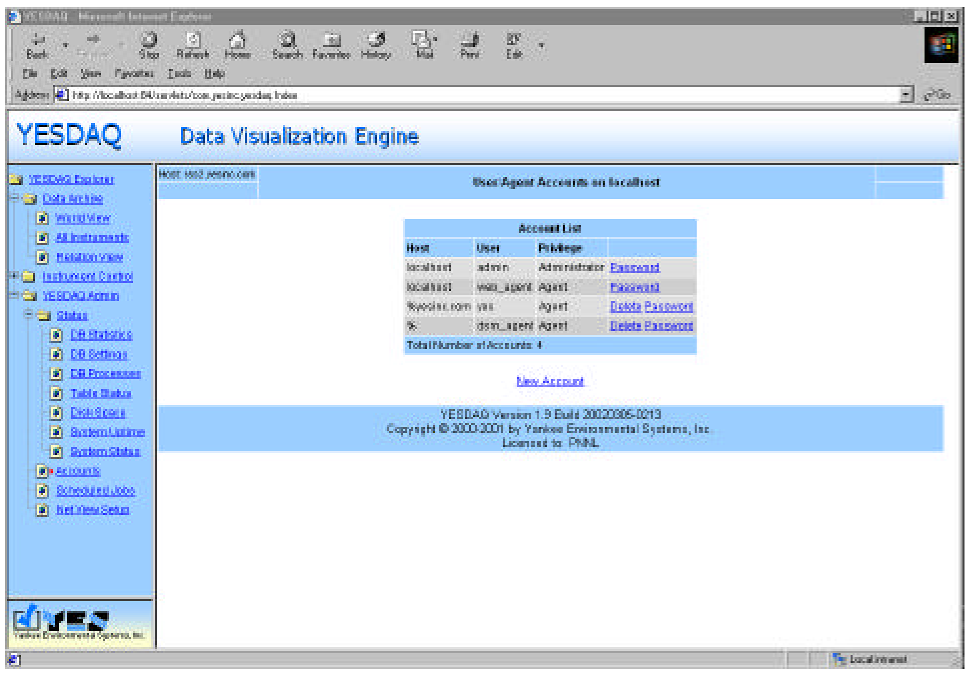


Figure 56. Setting up a YESDAQ User account for read-only ODBC data access.

1 To setup your ODBC application you will first need to create a *User* level account under *YESDAQ Admin.* Click on *Accounts*, then *New Account* as shown below.

2 Next, configure your ODBC application to link to YESDAQ by specifying its unique *hostname*, the ODBC user account name you just created, a password and the TCP/IP port number for ODBC (typically you will want to use the default ODBC port). How you do this depends somewhat on how your specific ODBC application was written. For more information, please refer to the documentation supplied with your third party ODBC application. Always be sure to specify the correct TCP/IP port for your application.

3 You will need to study the table structure of the YESDAQ, specifically the RSS DVE tables to permit your ODBC application to access them.

Database Access via ODBC, JDBC, DBI

In addition to using a web browser with the DVE, you can access YESDAQ data directly via several open connectivity database drivers. Open Database Connectivity (ODBC) and Java Database Connectivity (JDBC) connections support live links to third party MS-Windows applications such as *MS-Excel, Matlab, S-Plus, Crystal Reports*, as well as your own Java applications. By setting up this real time link, you the RSS can automatically drive initial conditions into downstream atmospheric modeling or forecasting tools.

Before database access is possible you must create database user accounts. This is described in the previous section via a web browser, or using *YESDAQ Service Manager* described in the YESDAQ User Guide.

Using Open Data Base Connectivity Drivers

Once database accounts are established, you can establish an ODBC data reference in the control panel of the host that YESDAQ is installed on.

If you want access to the YESDAQ database from a remote MS-Windows host, you must first install the MySQL ODBC drivers on that host. To install the MySQL ODBC driver follow these steps:

1 Insert the YESDAQ CD-ROM into the CD-ROM drive and wait for the Welcome screen.

2 Click on the *Install YESDAQ ODBC Client* link, which installs the MySQL ODBC driver.

Next, to provide access to ODBC for your MS-Windows application you must provide a Data Source Name (DSN) in your ODBC control panel applet. The YESDAQ installation and the YESDAQ ODBC Client installation each create a default DSN (named *"YESDAQ"*) in the ODBC control panel applet for you to use.

Note: Configuring ODBC/JDBC drivers requires that you have a good understanding of how your third party application will interact with YESDAQ database tables. Due to the extremely wide variety of software applications on the market, YES cannot provide free technical support on setting up your application to use ODBC/JDBC connections. If you require application development help, please contact YES technical sales.

ODBC data sources can be defined as *User DSN* or *System DSN*. The User DSN source is accessible to users that are logged into the workstation, while the System DSN is accessible to the background NT services. YESDAQ itself does not use the DSNs defined in the control panel, since it creates one automatically.

The configuration for the YESDAQ MySQL data source is as follows:

- **Windows DSN Name**: The name of the Data Source.

- **MySQL host**: The DNS host name or TCP/IP address of the MySQL database host.
- **MySQL database**: The name of the database, usually "*yesdaq*". Note that the name of the database is *case-sensitive* and is usually lower case.
- **User:** The user account you created earlier.

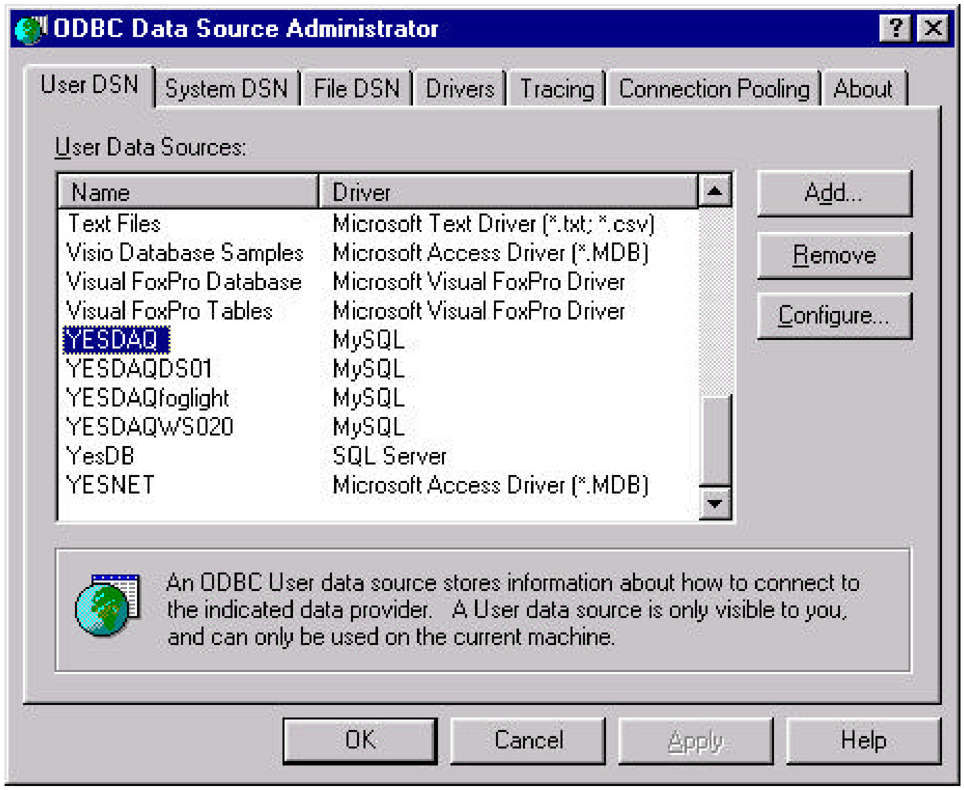


Figure 57. ODBC Data Source Administrator.

- **Password:** The password assigned to the above user account.
- **Port:** The port number assigned to the database server, the default is 3306.

At this point, you should be able to use your application's *data access* interface to access the YESDAQ data via the ODBC connection. Refer to your application's programmer documentation to learn more about using ODBC with your software.

Using ODBC with the Macintosh

While ODBC was developed by Microsoft, it is supported by other platforms such as the Apple Macintosh®. Commercial third party ODBC drivers are available, please visit www.thekompany.com, www.metrotechnologies.com, www.garvan.unsw.edu.au/gerham/macsos/MacODBC/ for the latest information.

JDBC

Similar in concept to ODBC but not necessarily based on Microsoft platforms, JDBC access is provided via the Java programming interface and is intended for advanced Java developers. The JDBC driver is a native driver, which does not require external libraries. Note that YESDAQ itself accesses the MySQL database via JDBC as you browse data.

In the YESDAQ installation directory, under the directory *javalib* is the jar file containing the MySQL JDBC interface. As of this writing the jar file is called *mysql-2.0.8.jar* but will likely be different in later releases. You will need to include this library in your Java application development environment, and then use Java's java.sql package to access data.

The latest up-to-date JDBC drivers are available via www.mysql.com

Perl DBI

In addition to ODBC and JDBC, you can use the Perl language to access YESDAQ data. A popular scripting language, Perl uses the common DBI interface to access databases. It is required in addition to the database driver-specific module.

To get the latest Perl driver, visit the download page on www.mysql.com to find the contributed MySQL Perl API drivers.

Using Other Programming Environments

Several other popular programming environments also support working with MySQL data. These tools include open source Python and Ruby tools as well as Microsoft's .NET initiative. Other environments are likely supported—please visit www.mysql.com for the latest information on using MySQL with other programming environments.

CHAPTER 3

Interpreting the Data

This chapter briefly discusses calibration concepts and procedures and then discusses how to process irradiance data into ozone and, in the case of the Model RSS-1024, aerosol particle size distributions.

Normally, you will ship the RSS to the factory for yearly calibrations, and use the optional PFC-5001 field calibrator absolute calibrate the system in the field. Each RSS system is individually characterized at the factory several ways:

1 CCD pixel-to-wavelength response, using a combination of several different spectral line sources for the Model RSS-1024, or a single mercury lamp for the Model UVRSS-1024

2 Diffuser North/South angular response using a robotic facility

3 Diffuser East/West angular response using the same facility

4 System absolute response, using a 1 kW FEL NIST-traceable irradiance standard, providing power-per-unit-area-per unit wavelength output

Finally, CCD pixel linearity was also verified. Results from these various instrument-unique characterizations are used to create the RSS response files used to apply engineering units to raw CCD data. You can review these configuration files from the **Data Dump Interface** located under the **Instrument** link.

Note: you may see the RSS Icon under the *Device* table heading, indicating that an instrument is on line, otherwise, you are looking at a replicated YESDAQ system

First, select the RSS from the YESDAQ instrument selection page.

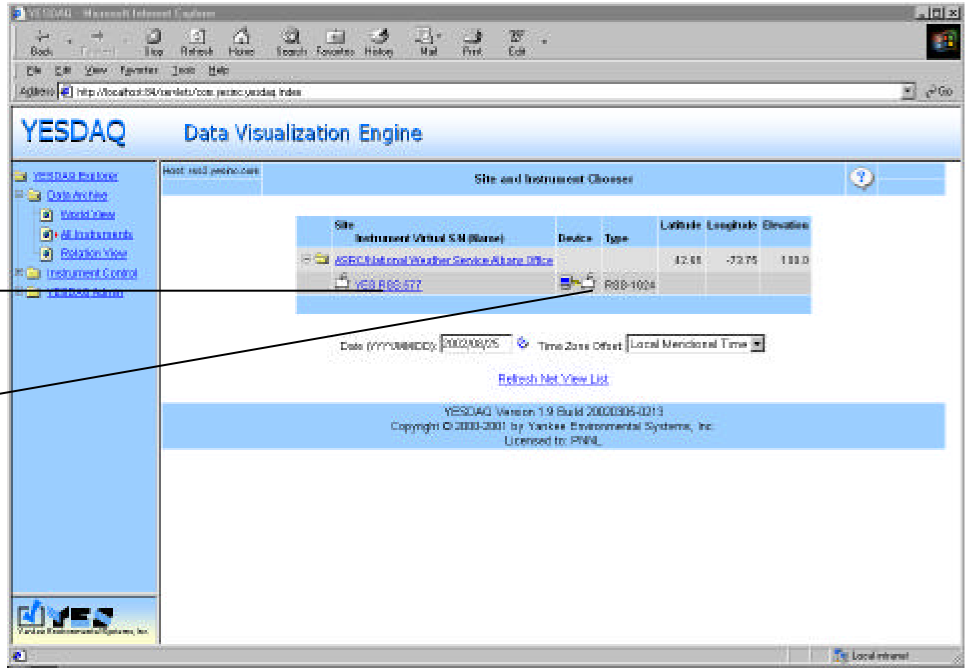


Figure 58. Select the RSS. (Note that a device is present, indicating you are working directly with the RSS system and not a replicated YESDAQ host.)

Instructions at the top of the page instruct how to use URLs to extract data.

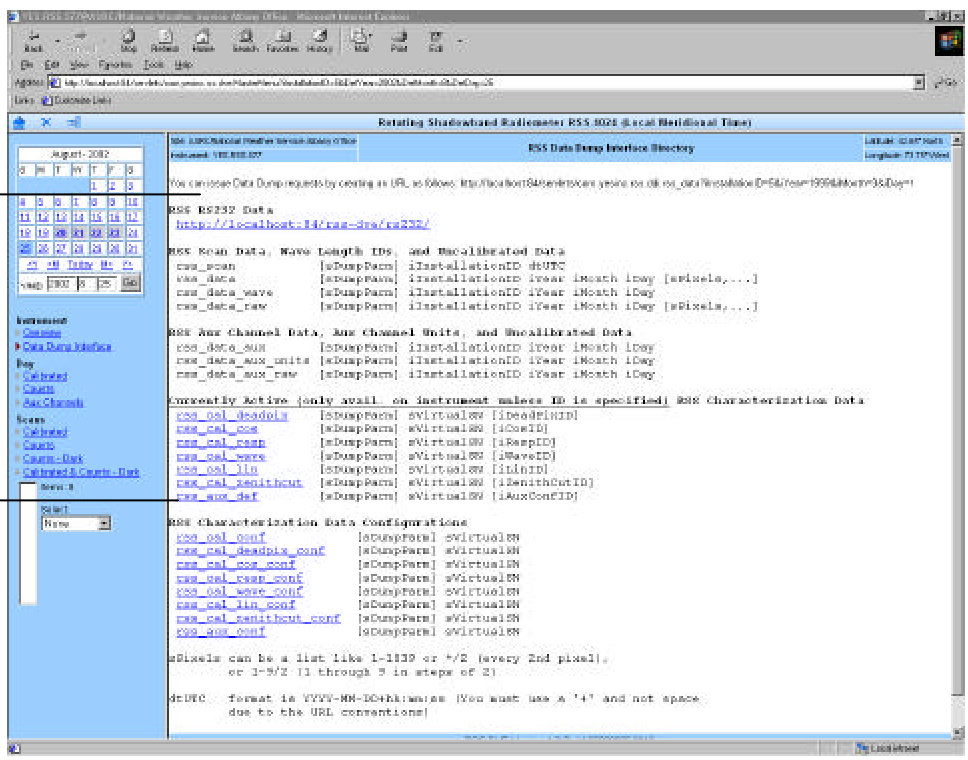


Figure 59. Viewing the RSS Data Dump Interface. Select the **rss_aux_def** file.

Viewing Auxiliary Data Configuration files

On the RSS Data Dump Interface page, you can view a variety of important system configuration information describing how the RSS will interpret acquired data.

One of the more complex characterization data files is the **rss_aux_def** file, which defines how YESDAQ interprets the 20 active *auxiliary channels*. These channels gather important system environmental and power supply data. Channels 8-20 are reserved for future use, and that rather than being a measurand, Channel 32 is provided by the database field that stores the current CCD exposure.

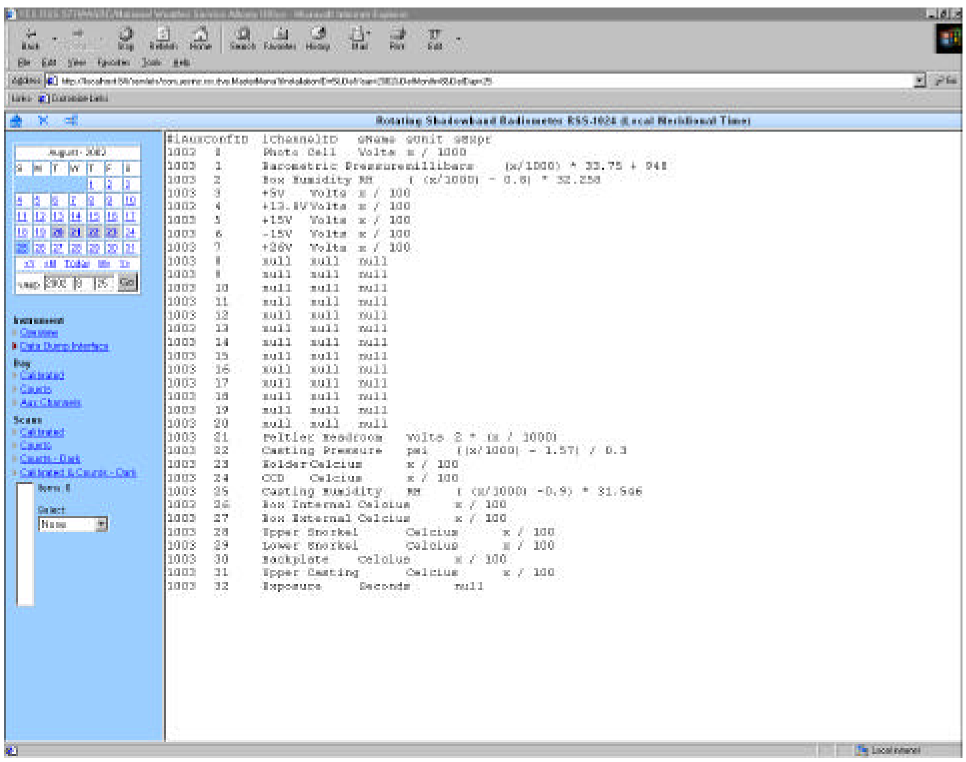
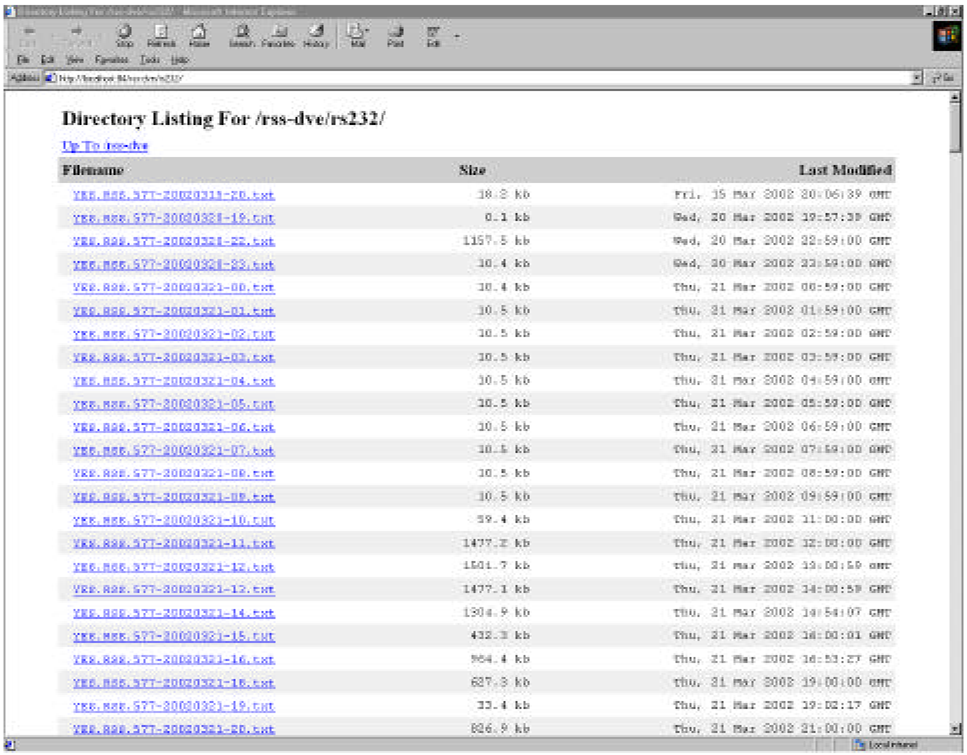


Figure 60. View of the RSS Auxiliary channel configuration, showing how each monitoring channel is mathematically interpreted by YESDAQ.

Retrieving raw data dump files via the DDI

You can retrieve raw data from the RSS by clicking on the top link via the *Data Dump Interface* (DDI) page. You will then see a directory listing such as the one



Directory Listing For /rss-dve/rs232/

Up To /rss-dve

Filename	Size	Last Modified
YES.RSS.577-20020315-20.txt	18.2 kb	Fri, 15 Mar 2002 20:06:39 GMT
YES.RSS.577-20020320-19.txt	0.1 kb	Wed, 20 Mar 2002 19:57:39 GMT
YES.RSS.577-20020320-22.txt	1157.5 kb	Wed, 20 Mar 2002 22:59:00 GMT
YES.RSS.577-20020320-23.txt	10.4 kb	Wed, 20 Mar 2002 23:59:00 GMT
YES.RSS.577-20020321-00.txt	10.4 kb	Thu, 21 Mar 2002 00:59:00 GMT
YES.RSS.577-20020321-01.txt	10.5 kb	Thu, 21 Mar 2002 01:59:00 GMT
YES.RSS.577-20020321-02.txt	10.5 kb	Thu, 21 Mar 2002 02:59:00 GMT
YES.RSS.577-20020321-03.txt	10.5 kb	Thu, 21 Mar 2002 03:59:00 GMT
YES.RSS.577-20020321-04.txt	10.5 kb	Thu, 21 Mar 2002 04:59:00 GMT
YES.RSS.577-20020321-05.txt	10.5 kb	Thu, 21 Mar 2002 05:59:00 GMT
YES.RSS.577-20020321-06.txt	10.5 kb	Thu, 21 Mar 2002 06:59:00 GMT
YES.RSS.577-20020321-07.txt	10.5 kb	Thu, 21 Mar 2002 07:59:00 GMT
YES.RSS.577-20020321-08.txt	10.5 kb	Thu, 21 Mar 2002 08:59:00 GMT
YES.RSS.577-20020321-09.txt	10.5 kb	Thu, 21 Mar 2002 09:59:00 GMT
YES.RSS.577-20020321-10.txt	59.4 kb	Thu, 21 Mar 2002 11:00:00 GMT
YES.RSS.577-20020321-11.txt	1477.2 kb	Thu, 21 Mar 2002 12:00:00 GMT
YES.RSS.577-20020321-12.txt	1501.7 kb	Thu, 21 Mar 2002 13:00:59 GMT
YES.RSS.577-20020321-13.txt	1477.1 kb	Thu, 21 Mar 2002 14:00:59 GMT
YES.RSS.577-20020321-14.txt	1304.9 kb	Thu, 21 Mar 2002 14:54:07 GMT
YES.RSS.577-20020321-15.txt	432.3 kb	Thu, 21 Mar 2002 16:00:01 GMT
YES.RSS.577-20020321-16.txt	964.4 kb	Thu, 21 Mar 2002 16:53:27 GMT
YES.RSS.577-20020321-18.txt	627.3 kb	Thu, 21 Mar 2002 19:00:00 GMT
YES.RSS.577-20020321-19.txt	33.4 kb	Thu, 21 Mar 2002 19:02:17 GMT
YES.RSS.577-20020321-20.txt	826.9 kb	Thu, 21 Mar 2002 21:00:00 GMT

Figure 61. Raw RS-232 data directory listing.

below.

Note: As all data are stored in the YESDAQ database, to conserve disk space raw files are discarded after a week. If you wish to retain these raw data files on another host (for an additional backup purposes), a tool such as *wget* can perform this data transfer for you automatically.

Angular Corrections to the Direct-Normal

The angular response of each RSS is individually characterized at the factory using a large computer controlled robotic turntable. The diffuser used in the RSS has a similar responses at each azimuth angle but with some variation, and is therefore uniquely measured in the four cardinal directions: north, south, east, and west. This periodic laboratory characterization is called a *cosine response* calibration.

A Lambertian surface receives light with a "perfect" cosine response, that is, the light received is directly proportional to the cosine of the angle of incidence. Because no optical detector's receiving surface has a perfect Lambertian response (although the RSS diffuser is among the best), corrections are applied as laboratory characterizations from measured angular responses are known. In the RSS, the Core CPU automatically performs these angular corrections to the direct-normal in real time. Note that it is not possible to angle-correct the diffuse as there is no way to ascertain from which direction in the diffuse that each photon actually arrived from.

The angular response of the RSS is controlled solely by its input diffuser. Compared to normalized cosine responses, an idealized Lambertian response is simply a flat line at 1.0. Figure 62 shows a typical normalized cosine response of an RSS diffuser. To normalize the response, the system divides the measured response relative to 0° incidence by the cosine of the angle of incidence. Generally angular response is normalized against a cosine function and then plotted to enhance its deviation from a perfect, idealized cosine response. Without normalization, the response would look visually much like the cosine function, which might suggest that angular correction is unnecessary. However, notice that the direct solar radiation incident at 60° is 93% of that of a perfect Lambertian receiver. This correction is particularly important when the system uses the total and diffuse solar measurements to accurate calculate the direct solar irradiance, a key feature of the RSS that drives output data products such as optical depth and aerosol particle size distributions.

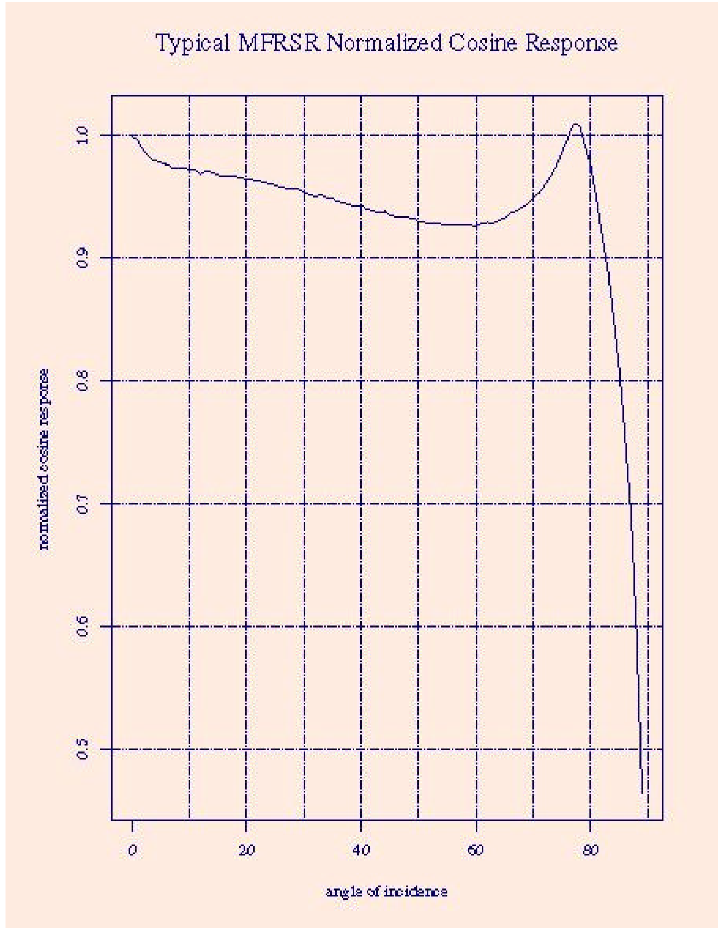


Figure 62. Typical normalized RSS cosine response.

Corrections of the direct-normal are based on azimuth-angle-weighted corrections at a particular solar zenith incidence angle. Calculated direct normal solar radiation is thus corrected throughout the day based on the solar position. The horizontal component of the corrected direct is added to the diffuse to form an improved estimate of the total horizontal irradiance. Since the spatial distribution of diffuse solar radiation is unknown, angular corrections to the diffuse are not performed.

For detailed information on the angular response measurements of the MFRSR and other commonly used pyranometers, see Michalsky, Harrison, and Berkheiser (Solar Energy, Vol. 54, pp. 397-402, 1995).

Introduction to Langley Analysis

After direct-normal spectral irradiance data are angle corrected, Langley analysis can be performed. Solar radiation at wavelengths not within a molecular water or oxygen band is attenuated according to a relatively simple equation:

$$I = I_o \exp(-\tau m),$$

where I is the direct solar at the point of measurement, I_o is the irradiance that would be measured at the top of the atmosphere, t is the total column optical depth from all sources in the zenith direction, and m is the air mass relative to unit air mass in the zenith direction. One commonly used formula for air mass is

$$\text{air mass} = [\sin(el) + 0.50572(6.07995+el)^{-1.6364}]^{-1},$$

where el is the solar elevation in degrees (Kasten and Young, 1989: Applied Optics, Vol. 28, pp. 4735-4738).

Note: A useful program for calculating solar position is available from ftp://hog.asrc.cestm.albany.edu/pub/software/PC/README.asun along with other tools located at http://hog.asrc.cestm.albany.edu/~rsr/bits/software.html. Another useful online solar noon and airmass calculator web page is available from http://hog.asrc.cestm.albany.edu/~rsr/bits/solararcade.html

Taking the natural logarithm of both sides of the equation for irradiance extinction yields

$$\ln(I) = \ln(I_o) - \tau m.$$

Plotting $ln(I)$ versus m on a clear stable day yields a linear plot whose slope is negative and magnitude is the optical depth t. The intercept is $ln(I_o)$.

Figure 63 shows irradiance versus time solar Day plots for wavelengths that do not contain water or oxygen absorption features. The irradiance is in uncalibrated units. Langley analysis only requires a stable and linear detector, whose output is directly proportional to the incident radiation over the entire range of expected irradiance levels. The morning shown is a good candidate for Langley analysis, but the afternoon is not.

The Harrison Objective Algorithm (Harrison, 1994) is applied to RSS data to filter out data with cloud activity that would make accurate optical depth retrieval impossible.

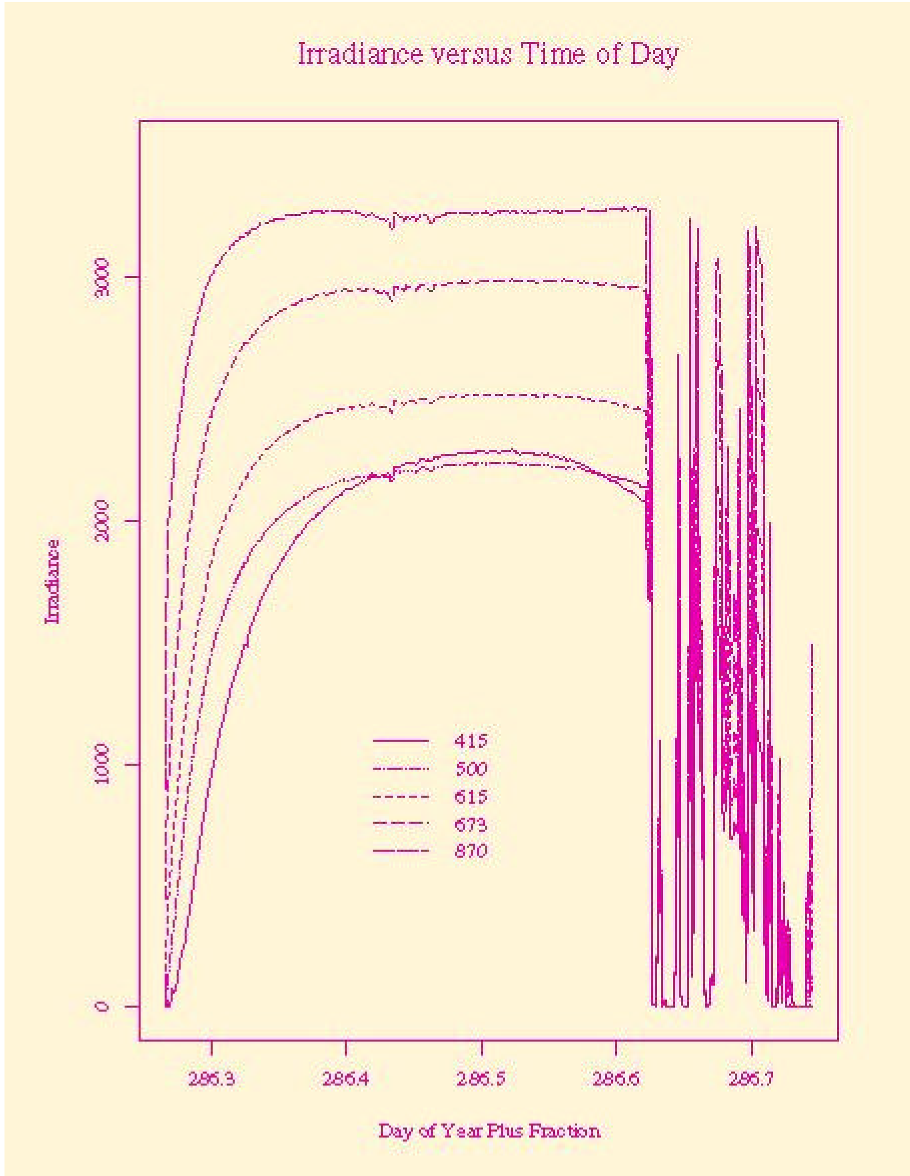


Figure 63. Typical Irradiance versus time of day for several wavelengths.

In Figure 64, the data between 1.8 and 4.8 air masses in the morning of a day at Mauna Loa Observatory have been plotted. A least squares fit to the points produces good linear fits with one slightly discrepant point for both the 415- and 500-nm channels.

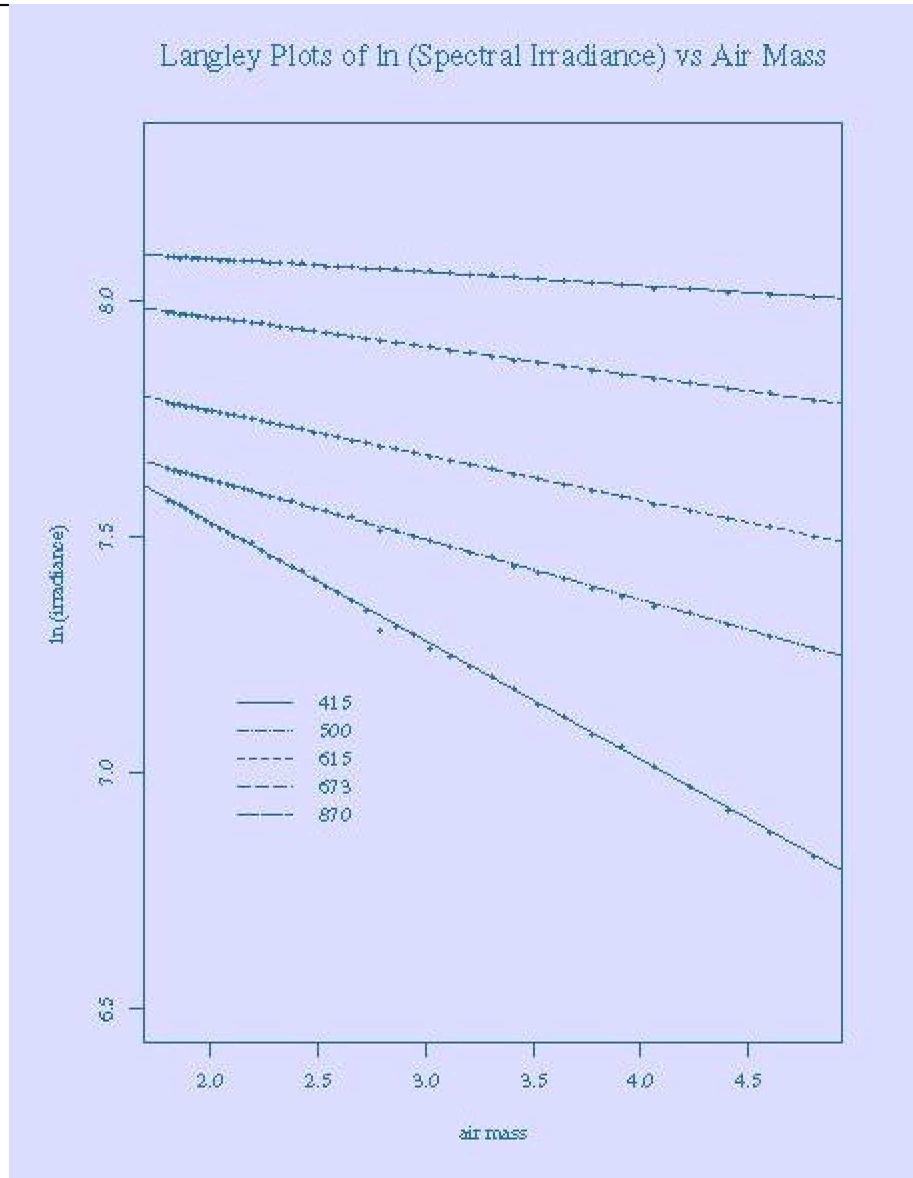


Figure 64. Typical Langley plot of ln(spectral irradiance) versus air mass for several wavelengths.

If the instrument is stable, I_o for any wavelength, corrected for the appropriate solar distance, can be used along with a measured I and calculated m to calculate optical depth at any other time. The challenge is to determine whether the calculated I_o is close to the true value or finding one that is. This is usually done using several clear days and finding some central measure of their values, either a mean or median.

Understanding Langley Processing on the RSS

An important feature of the RSS is its automated cloud filtering algorithm, first introduced on the MFRSR filter-type radiometers. The *Harrison Objective Algorithm* (HOA) is explained in detail in the August 1994 Applied Optics paper: Objective Algorithms for the Retrieval of Optical Depths from Ground-Based Measurements. This paper is provided in Appendix C, and is summarized below.

The HOA reduces user labor and eliminates concern about selective bias of points used for Langley analysis, by performing a regression that applies a series of cloud filters to automate the selection of appropriate data points. Of course, no analysis method can reconstruct good results on a day with overcast or very noisy data, so some user interaction is necessary to pre-select a suitable day.

On the DVE, several graphs are produced for each pixel selected, via **Day** > *Langley Plot* located in the center of the left pane:

- *uncalibrated direct normal data*, used as the input to the HOA, and
- the *AM* and *PM* plots, which shows the results of the automated Langley regression on either the morning or afternoon data

On each Langley plot, data points identified with a small diamond or square box have been rejected by the delta-difference derivative filters that find dips due to cloud passages.

- Points discarded as outliers by the first of two robustified regressions are marked as a diamond symbol
- Points discarded by the second are marked as a square box symbol
- Points that are used to compute the final Langley regression are marked by a simple plus symbol

Optical depth retrieval via Langley regression is complicated by cloud transits and other time-varying interferences. The HOA objectively selects data points from a continuous time series and performs the needed regression. The performance of this algorithm is compared by double blind test with analysis done subjectively. An additional iterative post-processing algorithm improves the accuracy of optical depth inferences made from data with time-averaging periods longer than five minutes. Algorithms such as the HOA are needed to provide intercomparable retrievals of optical depths from widely varying historical data sets, and to support valid intercomparison across networks of different instruments.

The simple-minded notion of using a least-squares regression on all the data only works under perfect sky conditions, (for example, Mauna Loa in Hawaii on a good day.) Elsewhere, cloud transients, even from thin cirrus clouds, will produce dips in the profile that must be removed or else the regression will produce nonsense results. In the past, data screening was done by subjective human editing; a scientist examined the data graphically and determined which points should be used for the regression. Aside from being quite labor intensive this process is subject to criticism that differing analysts may arrive at different results, and that often analysts cannot give useful descriptions of what algorithm they use to decide which points should be kept, and which should be rejected.

The HOA operates on the data with a series of filters to remove erring measurements. The first filter is a delta-difference derivative filter that identifies regions where the slope of dI/d(Airmass) is positive. These cannot be produced by any uniform airmass turbidity process, and are evidence of the recovery of the intensity from a cloud passage. The algorithm then *folds back* to find the point where the cloud passage started. A second derivative filter follows to clean-up points on the boundaries created by the first. The entire region is then eliminated; with these data points identified with a small box as the plotting symbol.

Note: The slope of a Langley plot is a dimensionless quantity known as Tau, the optical depth, while the Y-axis intercept of the line, represented as either V_0 or I_0, the extra-terrestrial voltage or irradiance (respectively) one would theoretically have measured at the top of the atmosphere if the instrument was located there. A Langley *plot* is always the natural log of measured intensity vs. airmass and shows the actual data, while a Langley *report* shows the result after application of the HOA to the measured data. A Langley plot is an excellent diagnostic tool for quality controlling data.

Langley Report Output Column Format

Each line of the Langley report output contains the following columns in order:

- **Spreadsheet Time**: the date in days since 1900, and a fraction that is either 0.25 for an AM or 0.75 for a PM regression. (Note that this obeys the Split Date option of the formatting options dialog; hence this can be two columns. In this case the fraction is always 0.25 or 0.75, as some programs don't like numbers that start with a decimal point)

- **Wavelength**: the actual wavelength processed

- **Points Available**: the number of data points available to the regression

- **Points Used**: the number of points actually used (i.e. not thrown away)

- **Tau**: the total optical depth (τ)

- **Vzero**: the value of V_0 (mV), the extrapolated value at zero airmass

- **Sigma**: the standard deviation (σ) of the residual variance from the data to the regression line of the natural log of intensity

- **AU**: the earth-sun distance in astronomical units (AU), where the mean earth-sun distance over a year is 1 AU

- **Estimated Solar Constant**: (I_0 * distance^2), the value to keep track of for calibrations, because it is the estimate of the solar constant

Adjusting Fraction of Points and Sigma Parameters

In the HOA, two iterations are made of a robustified linear regression. After each iteration, the points that lie more than 1.5 standard deviations from the regression are removed. The HOA will only report data where the number of kept points is greater than five, and greater than 0.3 times the number of points available (**Fraction of Pts Available**). In addition the standard deviation of the residuals of ln(I) around the regression must be less than 0.0060 (**Sigma Limit**). These default criteria have been established by extensive test as useful guides to throwing out erring or suspicious events.

At less-than-perfect sites, using these default HOA values on the Model RSS-1024 tends to throw out so much data that you never get any ozone or particle

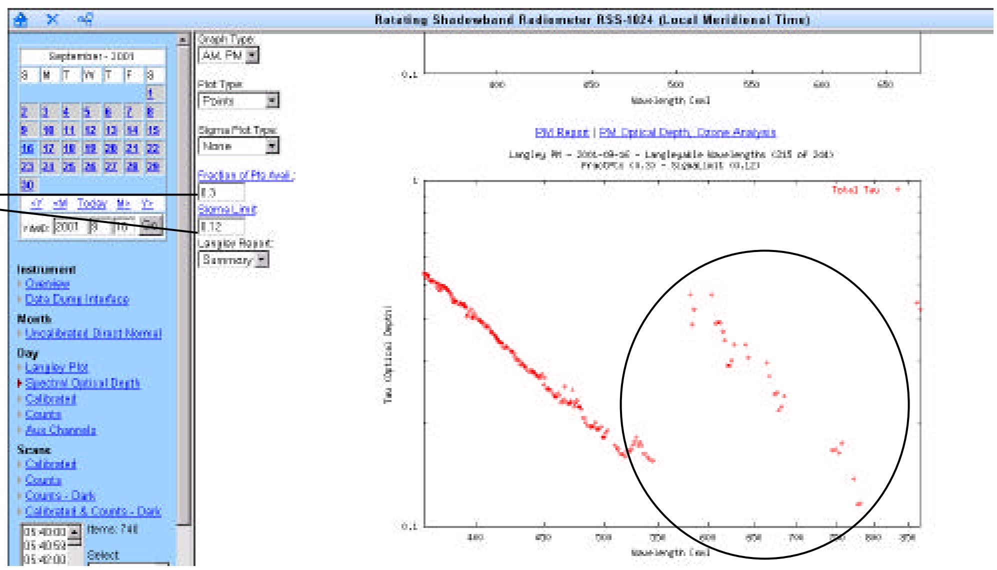


Figure 65. Reducing sigma to only 0.12 lets many pixels though that produce errant Langley results (above 500 nm), but permit better aerosol particle size processing for cleaner CCD pixels/channels (between 360 and 500 nm).

size distributions. The DVE permits you to alter these two key HOA parameters to a limited extent. Below we reduce the default 0.003 Sigma to only 0.12. Observe the wide scatter at right of pixels that are longer than 500 nm.

Finding a clear day to work with

Before you can begin to do further analysis such as ozone (or aerosol particle size distributions on the Model RSS-1024), you will need to find a clear morning or afternoon to process. Use the **Month** -> *Uncalibrated Direct Normal* in the center of the left hand pane to access a month long view of solar data. Find a clear day devoid of significant cloud activity and then use the calendar view to bring up that day.

Next, click on a pixel not contaminated by water vapor, say near 500 nm, and then **Day** > *Langley Plot* to view the optical depth for that day of interest. If you are satisfied that the day has a clear morning or afternoon, either use the quick select pull down menu “every 10 pixels” or manually select pixels and select *Replot.*

Although brought online prior to the 8th, no direct normal data appear in YESDAQ, (it wasn’t yet installed outside so there was no solar signal.)

The 16th and 17th are excellent candidates for Langley Analysis and Aerosol Particle Size Distribution processing.

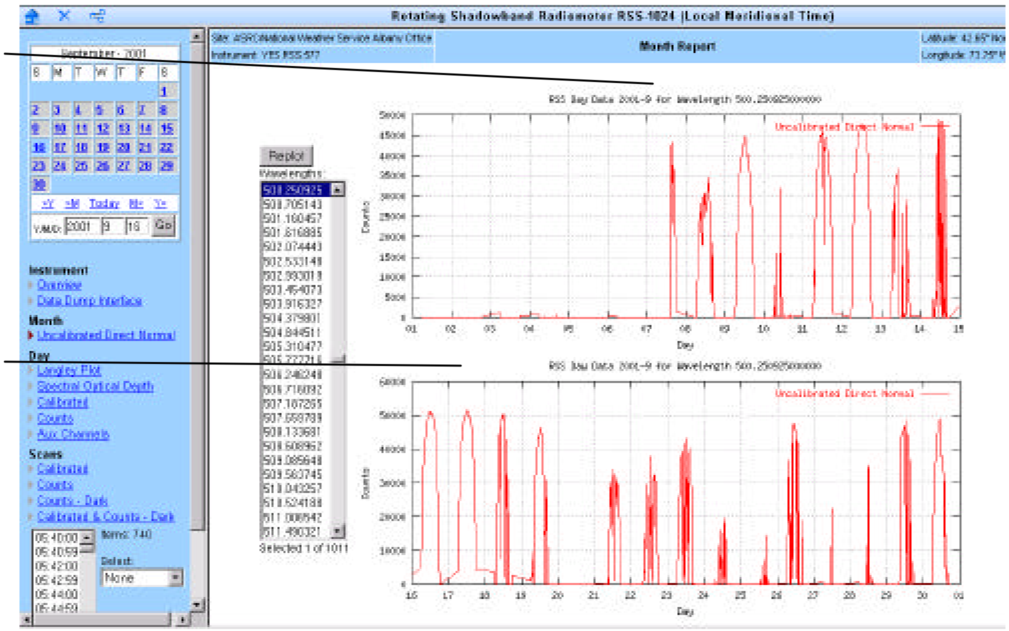


Figure 66. Using the Month > Uncalibrated Direct Normal with 500 nm as a key channel to locate a day of interest with little cloud activity. Next, click on the calendar view for that day to go to it.

Now hold down the *Control Key* (Ctrl) and using the mouse deselect those CCD pixels that produce poorer Langley results (clicking twice toggles their selection.) Once satisfied, press *Replot.* Repeat until you have selected only those pixels that yield good Langley results with little line scatter.

You may decide to alter the default 99% setting for the pixel exclusion threshold. Any pixels/channels with less than this level of atmospheric transmission due to water vapor contamination are excluded from processing. You change this threshold at the top center of the Langley Plot page, then press “Go” to view the new selection range graphically.

Note: If you want to processing *all* CCD pixels/channels (without excluding *any* channels, regardless of transmission), set the threshold to 0% and press “Go”.

The two dimensional false color view in

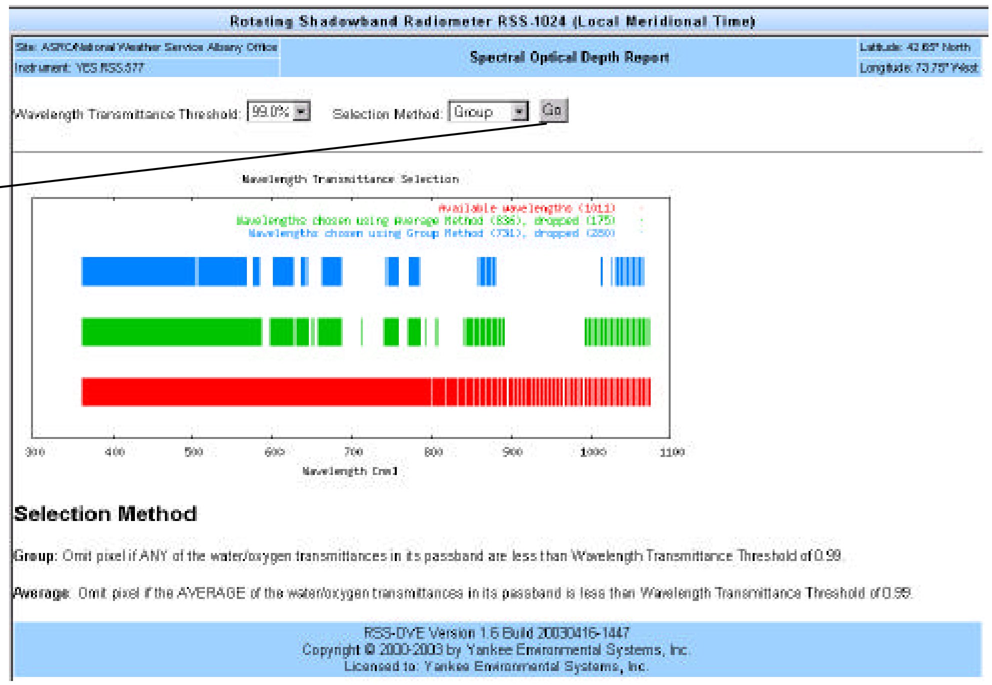


Figure 67. Viewing the default 99% atmospheric transmission threshold Model RSS-1024 channels excluded by Langley processing after pressing “Go.”

Figure 67 shows CCD pixels omitted due to the default 99% threshold.

Calculating Total Column Aerosol Optical Depth and Ozone

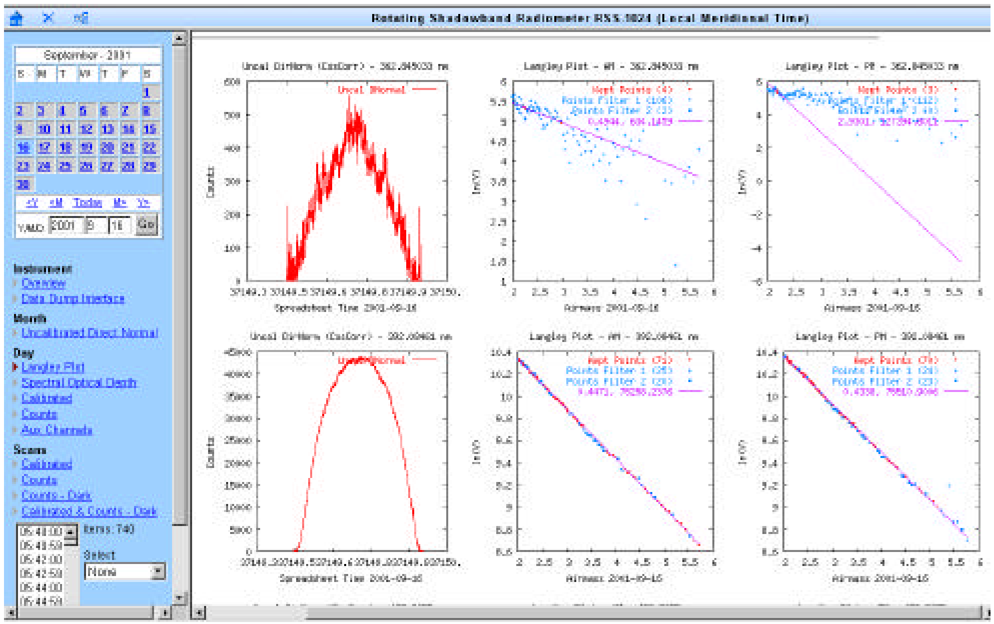


Figure 68. Clear day results from two RSS-1024 channels: spectral irradiance (at left), and AM / PM Langley plots (at center / right). Note 362 nm channel noise and the poor Langley results, and the 392 nm channel's better Langley results.

Once the total column optical depth is determined via Langley analysis with data filtered by the Harrison Objective Algorithm, the various extinction components (Rayleigh scattering, ozone absorption, water vapor absorption, and aerosol extinction), are separated:

$$\tau_{total} = \tau_{rayleigh} + \tau_{ozone} + \tau_{h2o} + \tau_{aerosol}.$$

Channels outside the water vapor absorption (especially near the 940-nm region), are selectable via a user-selectable threshold. The default setting for this selection is 99%.

Next, Rayleigh scattering as a function of wavelength is fairly well understood and is removed using:

$$\tau_{rayleigh} = 0.008569\lambda^{-4}\,(1 + 0.0113\lambda^{-2} + 0.00013\lambda^{-4})\ P/P_o,$$

where the wavelength l is in micrometers, and P is the site pressure relative to sea level pressure P_o (Hansen and Travis, 1974: Space Science Reviews, Vol. 16, pp. 527-610). By avoiding water vapor absorption and removing Rayleigh scattering, we are left with aerosol and ozone absorption for the range from 360 nm to about 900 nm.

The RSS software then extracts ozone via an automated algorithm described in a paper listed in Appendix C.

Alternately, if you have an independent measure of total column ozone over a site, for example (from the NASA TOMS satellite), then ozone optical depth can be calculated for the affected channels by multiplying the total column ozone by the Chappuis or Wulf band ozone absorption coefficients listed in Appendix A. The ozone optical depths can be subtracted from the equation, leaving the aerosol extinction optical depths as a function of wavelength.

It is often interesting to compare results to satellite measurements or against local Dobson measurements. If ozone estimates are not available from TOMS data, Figure 69 shows a plot of the natural log of aerosol plus ozone optical depth as a function of the natural log of the wavelength. The 940-nm optical depth is in the upper right hand corner and is clearly contaminated by water vapor absorption, but two ozone free channels are connected by a straight line. Calculations for typical aerosol size distributions and actual aerosol data indicate that, on a log-log plot, we should expect slight curvature at most and often a nearly straight line. In the ozone channels, the optical depths are too high, and they appear too high in proportion to their absorption coefficients.

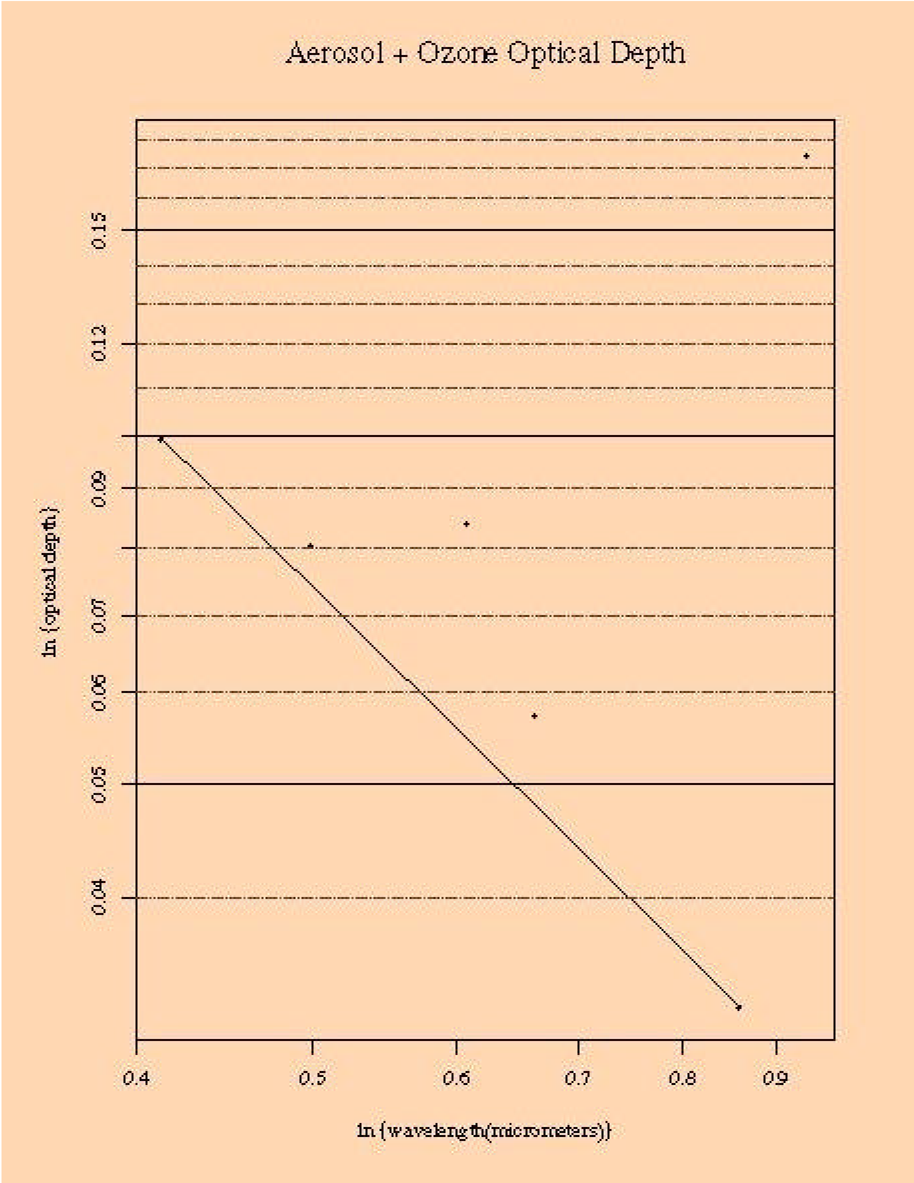


Figure 69. Aerosol and ozone optical depth vs. the natural log of wavelength.

Figure 70 shows a similar plot, except climatological ozone is multiplied by the ozone absorption coefficient at each wavelength and subtracted. The data appears slightly low in these three wavelengths, suggesting that too large an ozone optical depth was subtracted because the climatological ozone exceeded actual ozone for that morning.

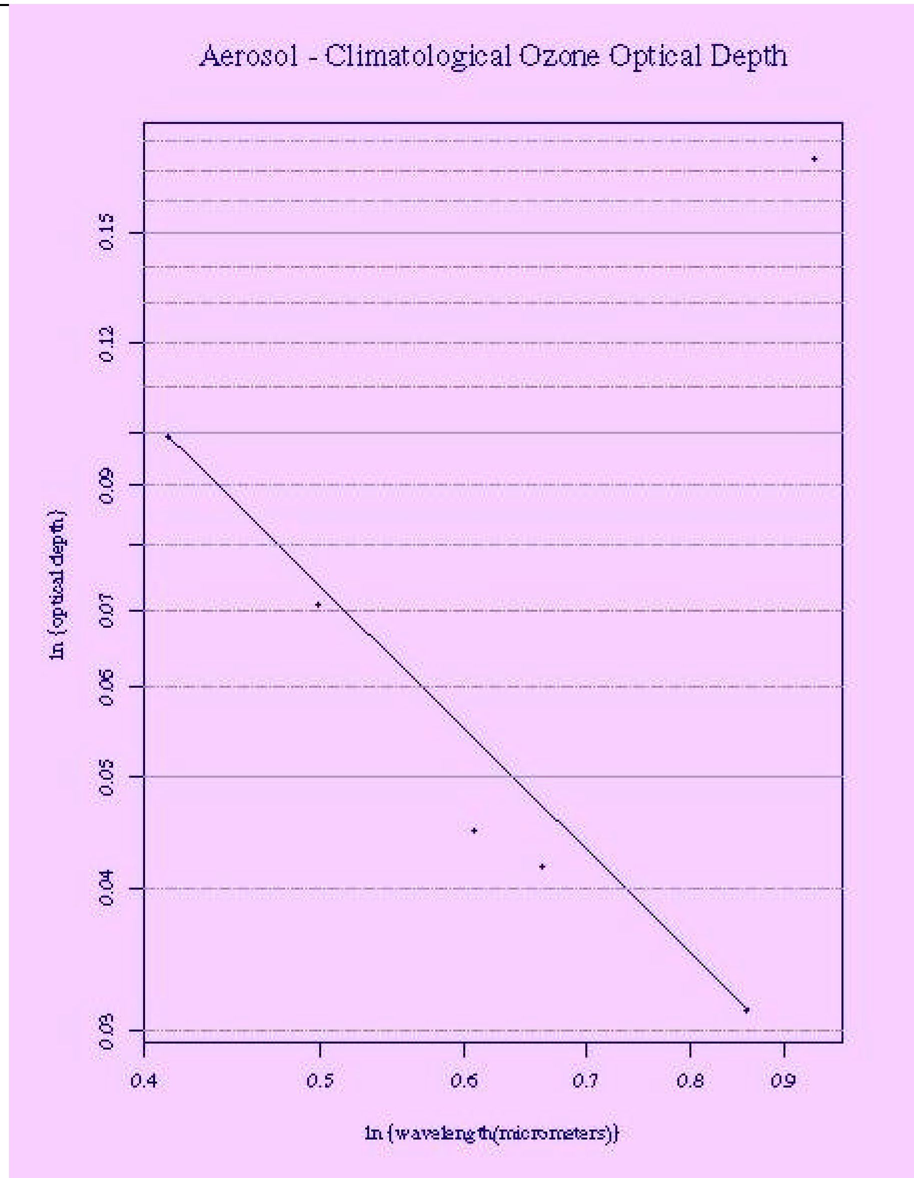


Figure 70. Aerosol - climatological ozone optical depth

The RSS algorithm for estimating ozone is based on the work of King and Byrne (Journal of the Atmospheric Sciences, Vol. 33, pp. 2242-2251, 1976). First, climatological ozone is removed and then a least-squares fit of a quadratic function is performed on the data:

$$\ln(\tau) = a + b \ln(\lambda) + c [\ln(\lambda)]^2$$

Ozone optical depth is then adjusted until the fitting procedure produces a minimum root-mean-square error. The ozone at this point is the estimate of true ozone. Figure 71 shows the result of this procedure after application to the data in Figure 69 and Figure 70.

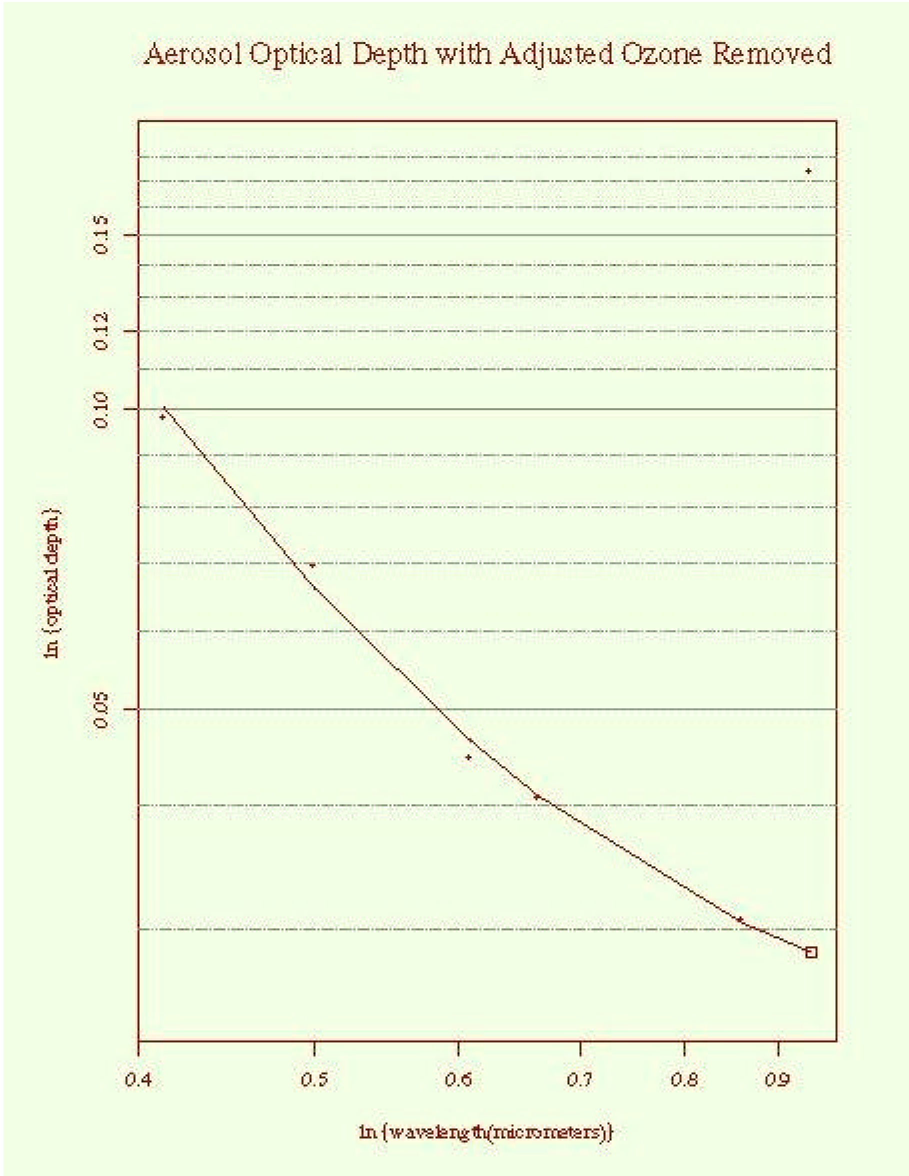


Figure 71. Aerosol optical depth with adjusted ozone removed

Example of time series at several channels

The RSS produces day plots of Spectral Optical depth, shown as log plot of total optical depth vs. time or airmass. To get an idea of how optical depth can change over the seasons and major volcanic activity, below is a long term time series of optical depth as measured by a six channel YES Model MFR-7 Multi Filter Rotating Shadowband instrument, located at the US Department of Energy's Southern Great Plains (SGP) Central Atmospheric Radiation Testbed site in Oklahoma. For RSS results, see the references cited in Appendix B.

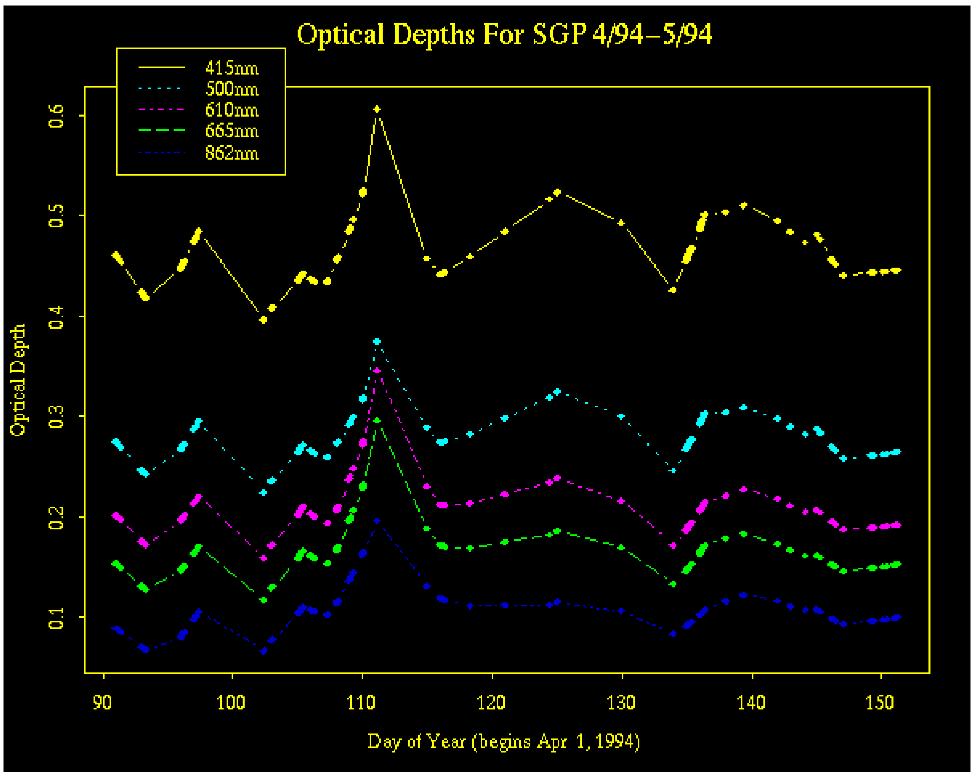


Figure 72. Long term optical depth time series from DOE SGP ARM site.

Modeled Atmospheric Transmission

Because the RSS sits at the surface of the earth, it is important to understand the filtering effects of the atmosphere above it on observable surface irradiances. A popular software tool for modeling expected atmospheric transmission is LOWTRAN. This tool was initially funded by the US Air Force Geophysical Laboratory and has now been extended to higher spectral resolution. Figure 73 is a modeled LOTRAN7 absorption spectra. Note the strong water vapor absorption of photons near 940 nm. A similar simulation was used to generate tables used in the RSS to derive default pixels to exclude from the ozone, aerosol optical depth and aerosol particle size distribution algorithms.

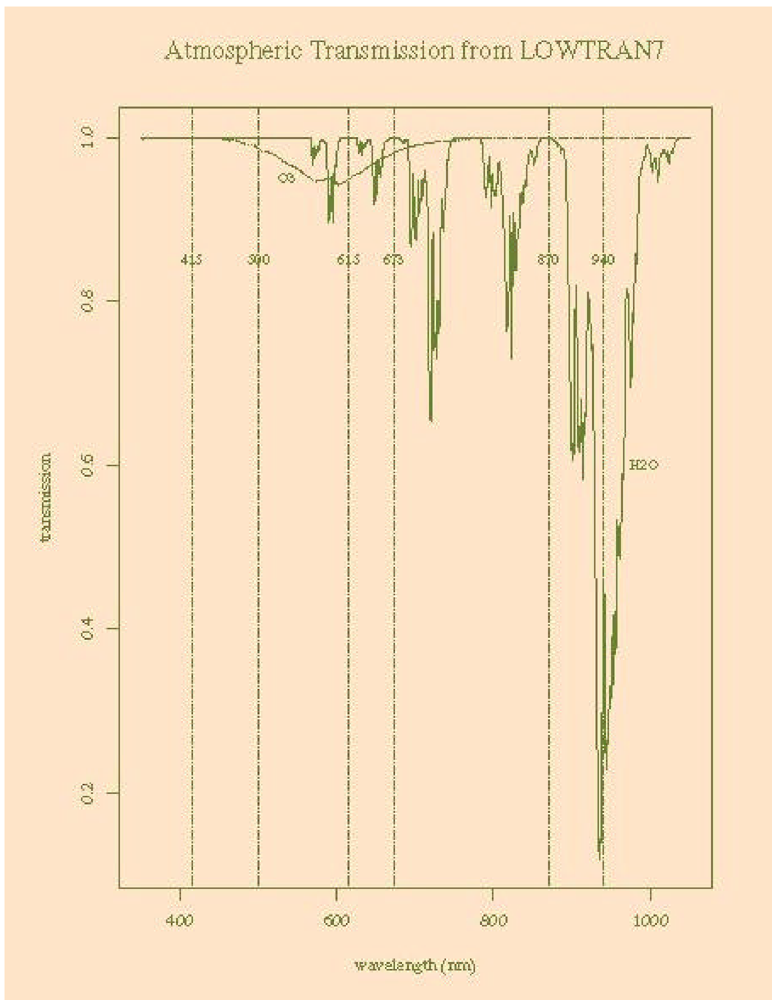


Figure 73. Modeled Atmospheric Transmission

Calculating Total Column Water Vapor

While the Model RSS-1024 does not calculate column water vapor automatically, data near 940 nm can be used to derive it. Reagan, Thome, Herman, and Gall (Proceedings, International Geoscience and Remote Sensing Symposium, '87 Symposium, Ann Arbor, Michigan, IEEE, pp. 63-67, 1987), introduced the modified-Langley technique for deriving water vapor. Bruegge, Conel, Green, Margolis, Holm, and Toon (Journal of Geophysical Research, Vol. 97, pp. 18,759-18,768, 1992) presented a slightly more accessible procedure using this method. Michalsky, Liljegren, and Harrison (Journal of Geophysical Research, in press) contains the actual details of the procedure that follows in outline form here.

The modified Langley equation is:

$$\ln(I) + \tau_{scat}\, m = \ln(I_o) - k(um)^b,$$

where t_{scat} is the aerosol plus Rayleigh scattering optical depth at 940 nm, u is the total column water vapor in the zenith direction, and k and b are constants that depend on the exact slit function profile of the 940-nm filter (in the case of the MFR-7). In the case of the RSS, pixels are on the order of 1 nm wide FWHM and these can be ignored. The transmission t_{water} through the filter is modeled as:

$$t_{water} = \exp(-ku^b).$$

The modeling tool MODTRAN2 was used to calculate transmission through a MFR-7 interference filter for several values of water vapor and a least squares fit of this function to those data provides the constants k and b. The aerosol component of the τ_{scat} is obtained by extrapolating the function in Figure 7 to 940 nm. Plotting the left-hand side of the modified Langley equation versus m^b and fitting with a linear least squares fit allows one to so obtain the slope $-ku^b$ and intercept $ln(I_o)$.

A single fit of the modified Langley equation is not sufficient for a calibration of I_o since water vapor is much less stable than aerosol, so several retrievals of I_o are used to find a median that is used subsequently to calculate u. This is considered more stable since the slope determined from a single Langley regression is subject to the considerable variation because of ever present water vapor changes.

Extracting Ozone from the Model UVRSS-1024

The Model UVRSS-1024 uses a dramatically different algorithm to derive column ozone as compared to the Model RSS-1024.

The Model UVRSS-1024 uses ratios of two or more UV-B wavelengths that are aligned with Dobson line pairs.

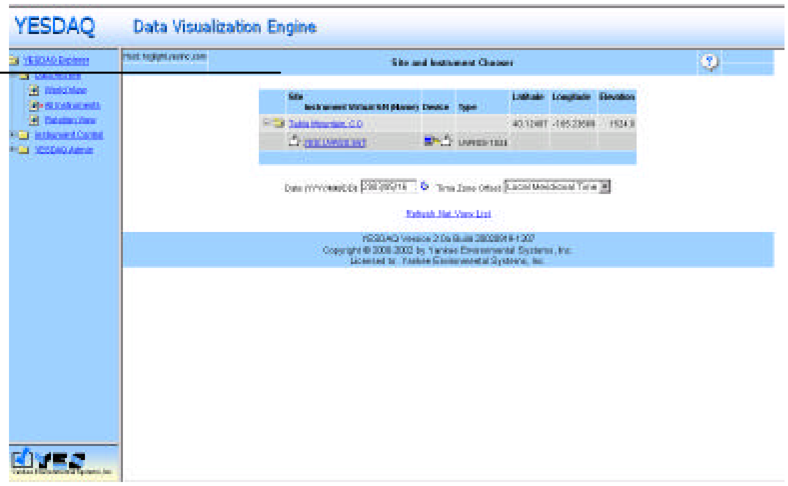


Figure 74. Selecting an UVRSS-1024 instrument to work with.

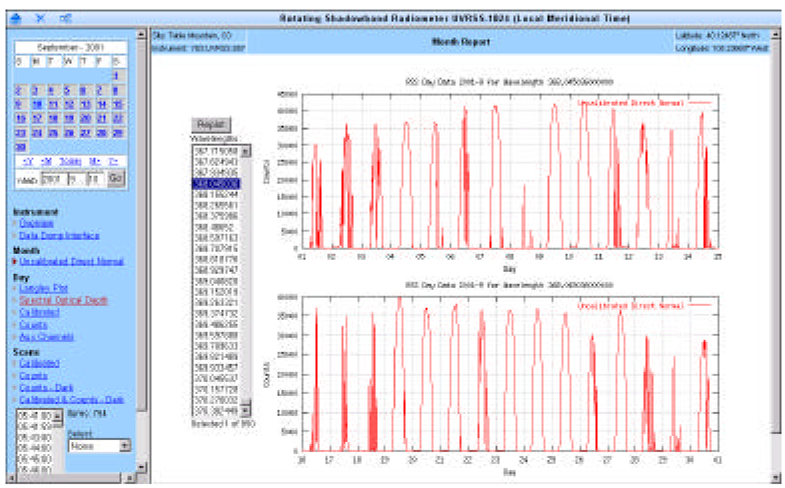


Figure 75. Using the Month Uncalibrated Direct Normal view to find a clear day.

Once you have located a suitably clear day, use the calendar view (at upper left) to go to that day, in this example, we will examine September 10th 2001. At this point you can select one or more individual calibrated scans for the day (in the election box at lower left), or to get a quick view use the window to the right and select “All UVMFR” from the pull down box near the top of the screen. Now select *Replot* to view pixels centered on UVMFR channels over the day.

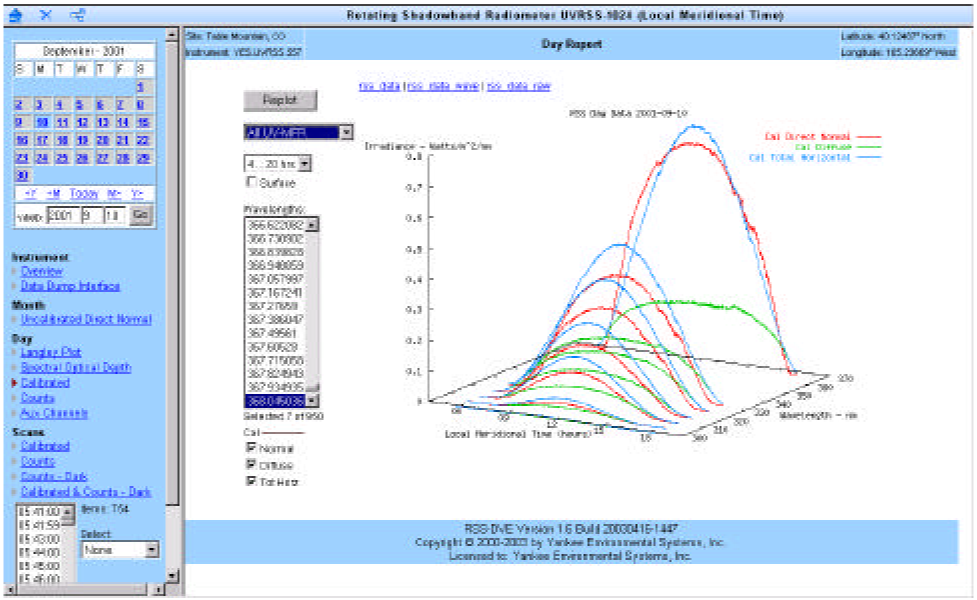


Figure 76. Viewing a day plot of pixels centered on seven UVMFR channels.

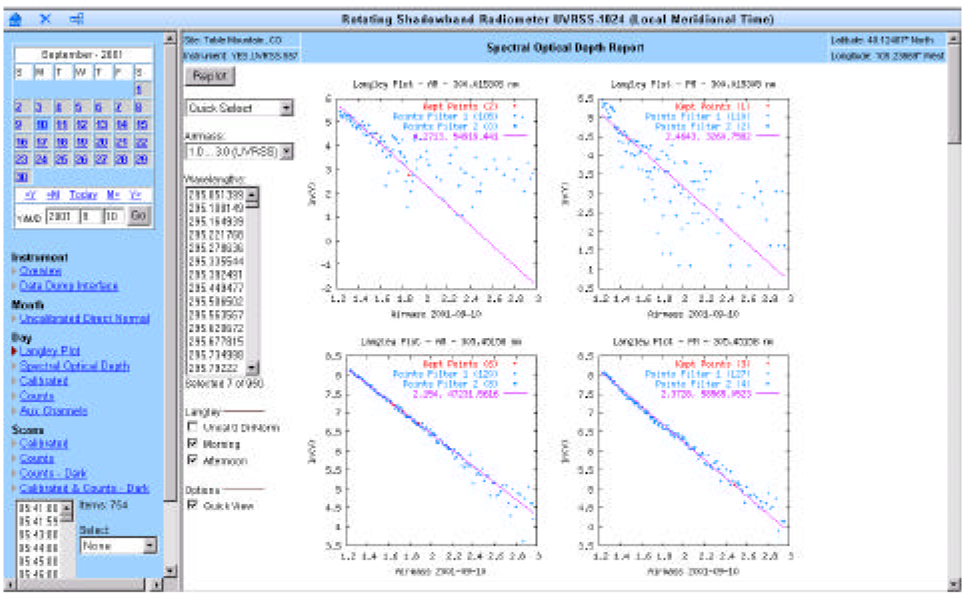


Figure 77. Viewing Langley plots of selected channels. If you selected multiple channels (as shown) you will need to scroll down to view plots of longer wavelengths. Note how shorter wavelengths yield increased point scatter.

Now select *Day, Langley Plot* at left, to view Langley plots of pixels filtered by the Harrison Objective Algorithm (HOA) for the selected wavelengths, as shown in

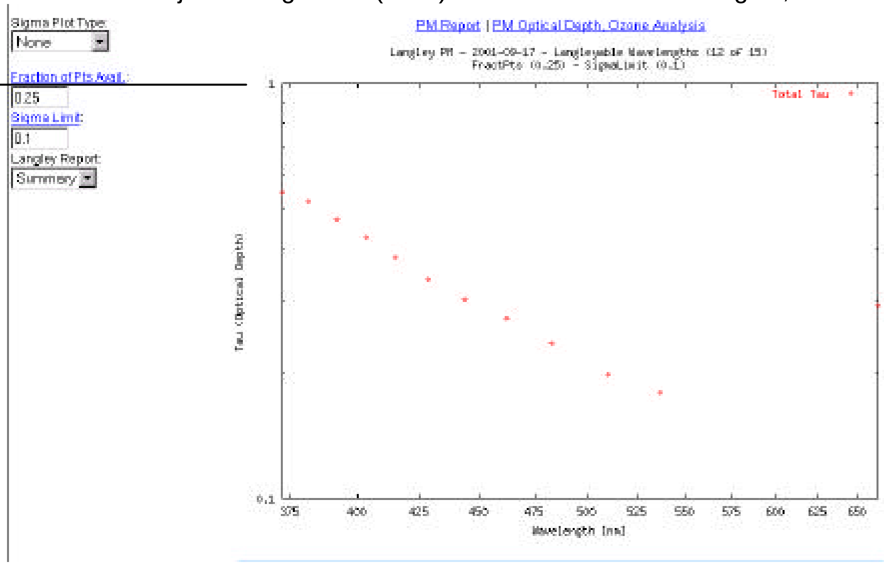


Figure 83.

Next, assuming you observe reasonably good Langley plots with small point scatter, select *Day, Spectral Optical Depth* at left to view a log plot of wavelength vs. total optical depth. Now click on ozone report to see results as shown in Figure 78.

You can view UVRSS ozone results plotted vs. airmass or time. Note that the algorithm proposed by Jim Slusser of the Natural Resource Ecology lab at CSU/Ft. Collins. Note this algorithm uses a V_o for either the morning or afternoon.

The mathematical details of the Model UVRSS-1024 ozone algorithm appear in the example shown in the following section.

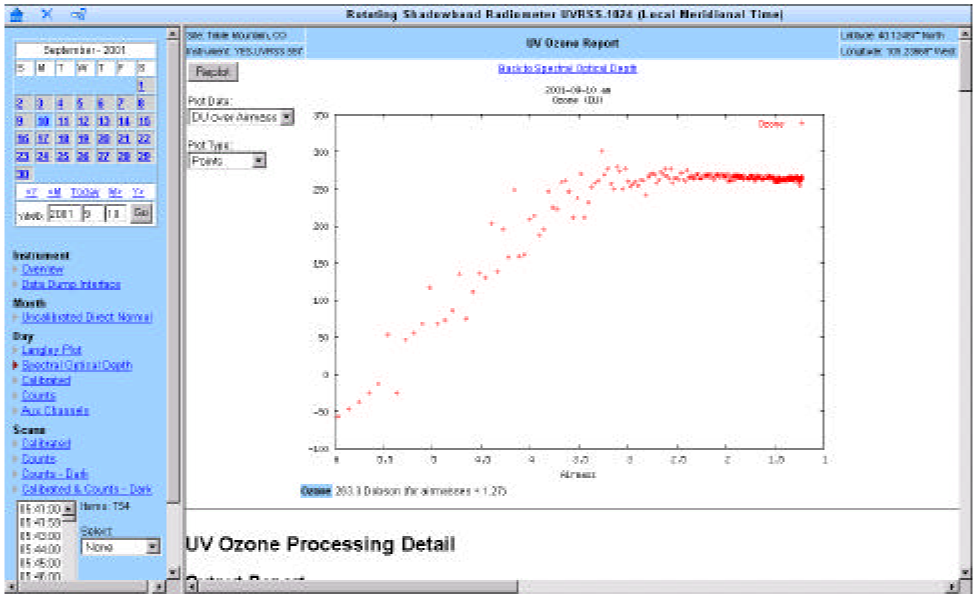


Figure 78. Viewing a UVRSS ozone results plotted vs. airmass, with Dobson units at lower left.

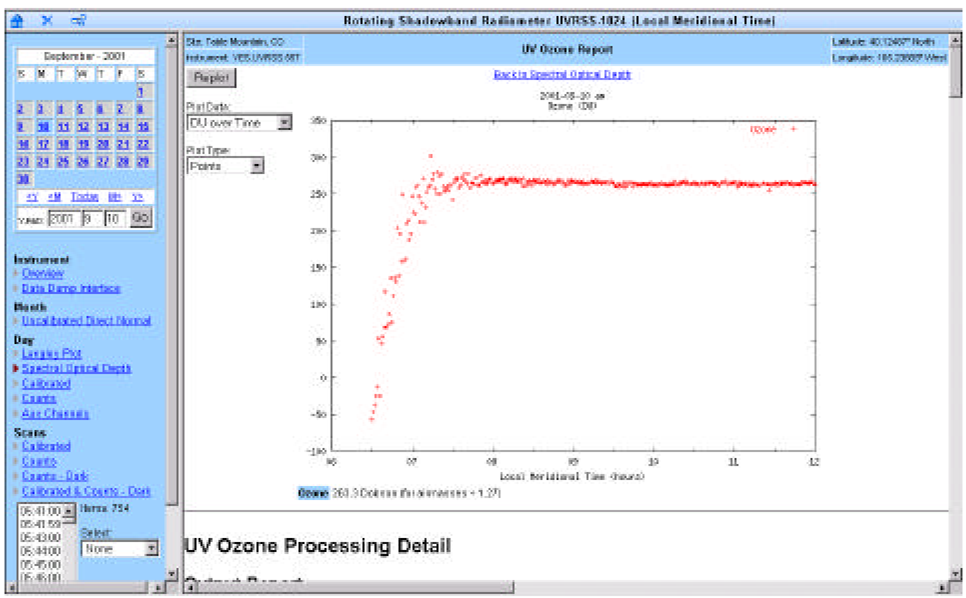


Figure 79. Viewing UVRSS ozone results plotted vs. solar time.

Example of Model UVRSS-1024 Ozone Calculation

$$Vo\_305 := 47286.8385 \qquad V\_305 := 2630.185787741936$$

$$Vo\_311 := 78156.9445 \qquad V\_311 := 11370.810037241377$$

$$Vo\_325 := 99105.7597 \qquad V\_325 := 34291.22578848148$$

$$Vo\_332 := 90607.6083 \qquad V\_332 := 36847.12473088$$

$$N1 := \log\left(\frac{Vo\_305}{Vo\_325}\right) - \log\left(\frac{V\_305}{V\_325}\right) \qquad N1 = 0.79384$$

$$N2 := \log\left(\frac{Vo\_311}{Vo\_332}\right) - \log\left(\frac{V\_311}{V\_332}\right) \qquad N2 = 0.44642$$

$Airmass := 1.318995$ $\quad Pressure := 828.72$ $\quad StdPressure := 1023$ mbar

$elevation := 100$ meters

$$rayleighTau(x) := 0.0088 \cdot \left(x^{-4.15+0.2\cdot x}\right) \cdot e^{-0.118\cdot elevation - 0.00116\cdot elevation^2}$$

$$Rayleigh\_305 := rayleighTau(0.305) \qquad Rayleigh\_305 = 7.77481 \cdot 10^{-11}$$

$$Rayleigh\_311 := rayleighTau(0.311) \qquad Rayleigh\_311 = 7.16945 \cdot 10^{-11}$$

$$Rayleigh\_325 := rayleighTau(0.325) \qquad Rayleigh\_325 = 5.96964 \cdot 10^{-11}$$

$$Rayleigh\_332 := rayleighTau(0.332) \qquad Rayleigh\_332 = 5.46352 \cdot 10^{-11}$$

$$OzAbsCoef\_305 := 4.901815233 \qquad commonLog := \frac{1}{\log(e)}$$

$$OzAbsCoef\_311 := 2.232742586$$

$$OzAbsCoef\_325 := 0.338382172 \qquad commonLog = 2.30259$$

$$OzAbsCoef\_332 := 0.093913674$$

$$OzAbsorp\_Difference := \frac{((OzAbsCoef\_305 - OzAbsCoef\_325) - (OzAbsCoef\_311 - OzAbsCoef\_332))}{commonLog}$$

$$OzAbsorp\_Difference = 1.05299$$

$$Rayleigh\_Difference := \frac{((Rayleigh\_305 - Rayleigh\_325) - (Rayleigh\_311 - Rayleigh\_332))}{commonLog}$$

$$Rayleigh\_Difference = 4.30969 \cdot 10^{-13}$$

$R := 6371.229$ mean earth radius

$h := 20$ height of ozone layer (km) $\quad zenith\_angle := 40.760778$

$$mu := \frac{(R+h)}{\sqrt{(R+h)^2 - (R+elevation)^2 \cdot \sin(zenith\_angle)^2}} \qquad mu = 1.00328$$

$$ozone := \left[\frac{\left[N1 - N2 - \left[Airmass \cdot \left(\frac{Pressure}{StdPressure}\right) \cdot Rayleigh\_Difference\right]\right]}{OzAbsorp\_Difference \cdot mu}\right] \cdot 1000 \qquad ozone = 328.8588$$

Results are in Dobson units. Sample data here were taken at Table Mountain, just north of Boulder Colorado, USA.

Automating a Langley report from the Command Line

Because the RSS is based on TCP/IP standards, a wide variety of interface options is available to you for ingesting data from the YESDAQ system that stores its data. Below we provide an example of a script to produce an automated Langley report from a Unix system command line. This example is used to illustrate the techniques to access RSS data (e.g. replace "*RSS HOST NAME*" with the actual DNS name of your RSS system as installed).

```
#!/bin/sh

OPTS="--silent --cookie g.cookie --cookie-jar g.cookie"

URL_EXEC="http://(RSS HOST
NAME)/servlets/com.yesinc.rss.dve.RssLangleyPlot?"\
"cmd=LangleyReport&iInstallationID=1&"\
"iYear=2001&iMonth=7&iDay=28&"\
"cboAirmass=1&"\
"lstWave=167&lstWave=255&lstWave=346&lstWave=436&lstWave=542
&"\
"lstWave=631&lstWave=1010&"\
"dblAverageWavelengthRange=0.0&"\
"strGraphType=ampm&"\
"strLangleyReportPlotType=linedot&"\
"strSigmaPlotType=none&"\
"dblFractPts=0.25&"\
"dblSigmaLimit=0.12&"\
"strLangleyReport=detail"

curl $OPTS $URL_EXEC --output /dev/null

URL_REPORT="http://(RSS HOST
NAME)/servlets/com.yesinc.rss.dve.RssLangleyPlot?"\
"cmd=DumpLangleyReport&iInstallationID=1&"\
"iYear=2001&iMonth=7&iDay=28&strAmPm=am"

curl $OPTS $URL_REPORT --output /dev/stdout
```

Extracting Ozone AOD and PSD on the Model RSS-1024

The RSS-1024 uses a sophisticated algorithm to derive ozone. Like the Model UVRSS-1024, you must first locate a clear day to work with. Once you have located a nice day that yields a clear Langley plot, proceed with selecting wavelengths/pixels that are suitable for ozone and aerosol particle size distribution processing. Try selecting "All MFR" to start. Initially, may see a "**No data to display**" message such as shown in Figure 80. Try selecting a smaller subset of

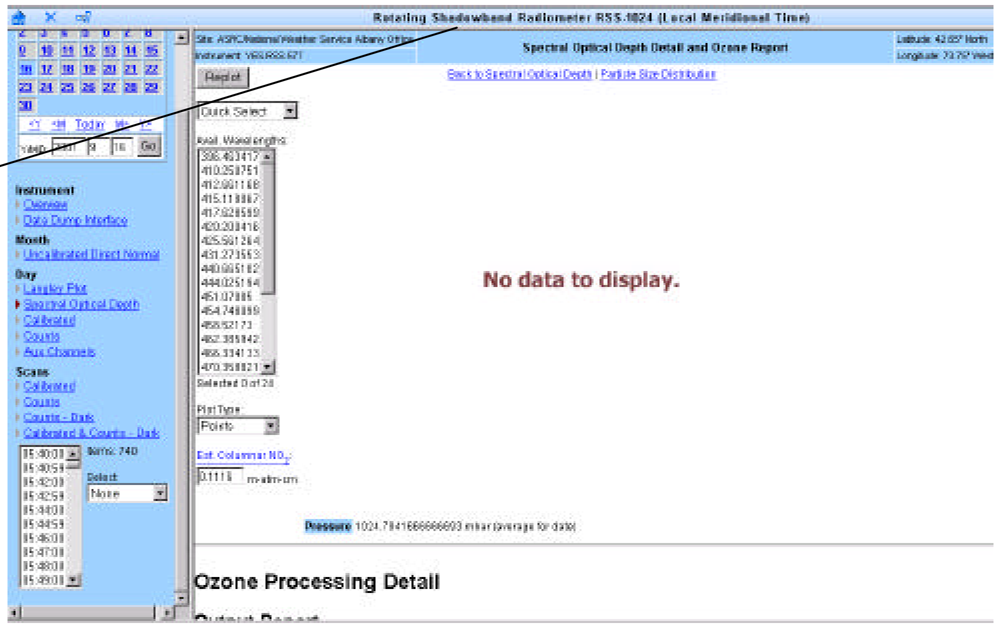


Figure 80. An unsuccessful ozone run (try reselecting pixels and then replot).

pixels and then press *Replot*, or go *Back to Spectral Optical Depth* and reselect pixels from there.

Note: This phase of the analysis is somewhat iterative and may require patience. Generally, the input Spectral Optical Depth plot should be as contiguous as possible with few gaps for the King ozone algorithm to be successful. You will likely need to experiment with choosing several different wavelength/pixel sets to get satisfactory ozone results.

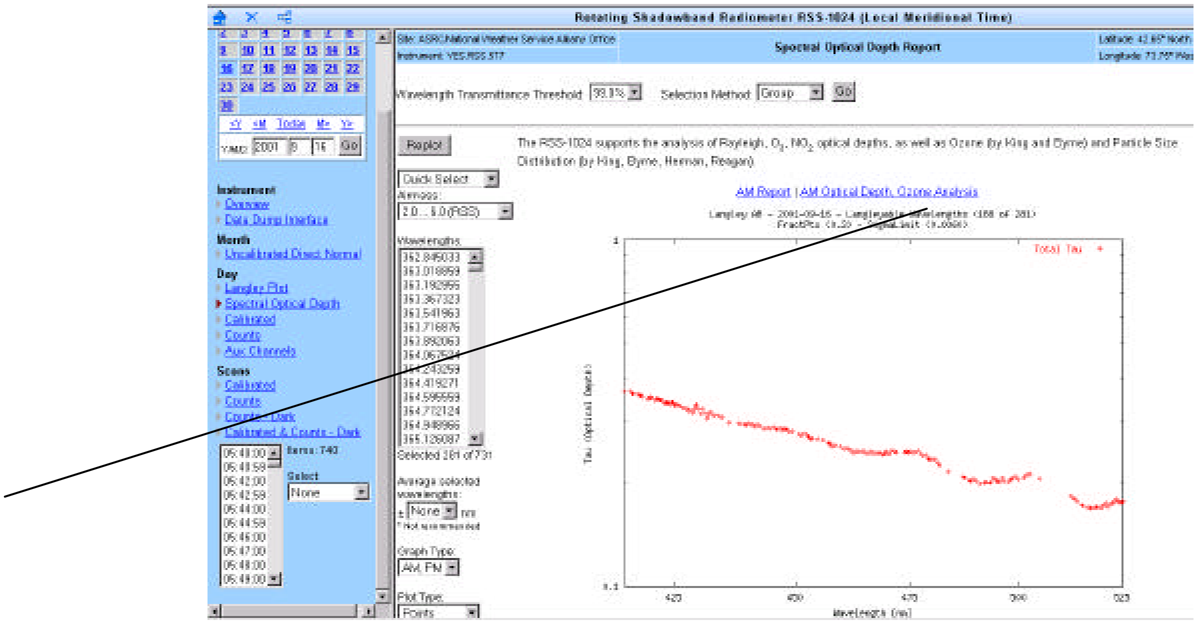


Figure 81. A better candidate for ozone analysis. Next, click on the AM Optical Depth Ozone Analysis at upper right.

You need at least five wavelengths to proceed, but often, the fewer the points, the better the chances to get ozone results. In this example, we were unable to obtain successful ozone results until we finally reduced the default *sigma* and *fraction of point* parameters on the HOA algorithm. Moving the cursor over these selection boxes shows you their limits.

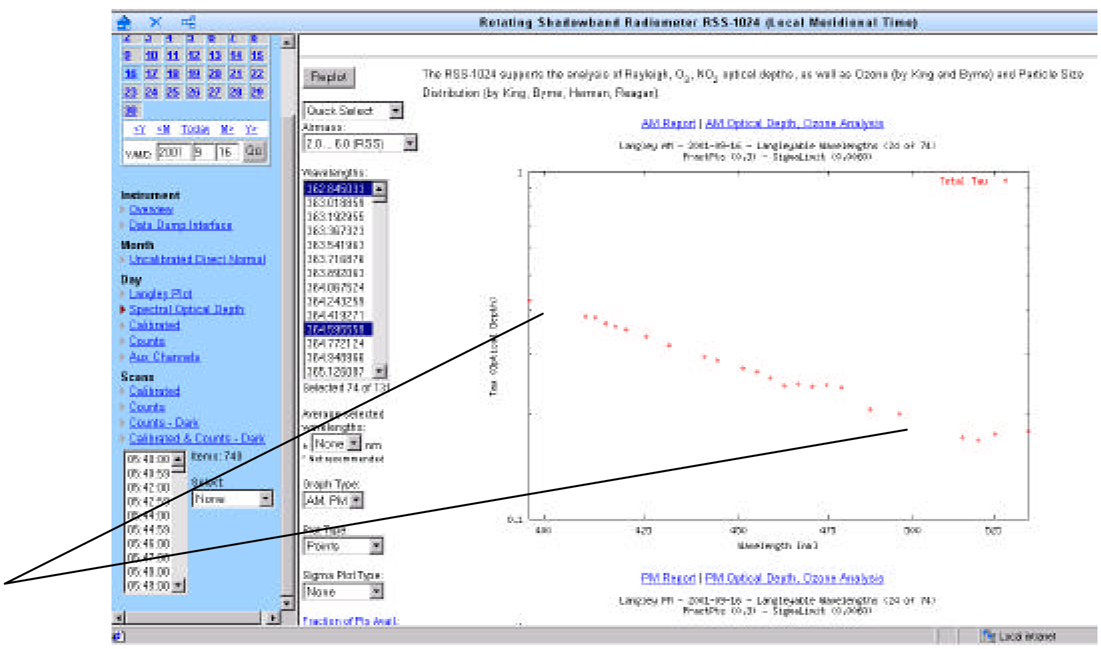


Figure 82. The gap below 415 nm and above 500 are problematic in this plot.

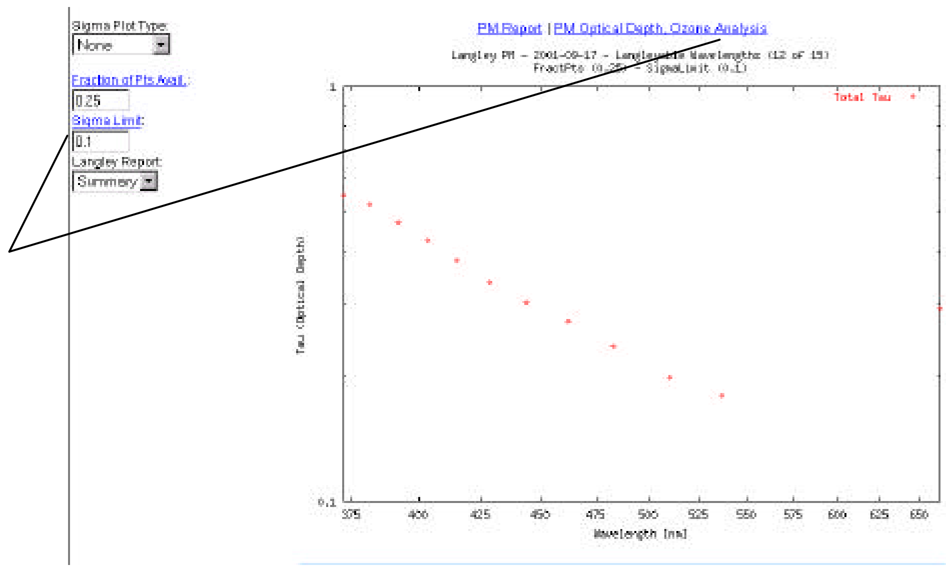


Figure 83. Here we back off on both fraction of points available and sigma. Next, click on PM Optical Depth, Ozone Analysis to see the result.

You will likely need to keep iterating, using different sets of pixels until you get a successful result plot as shown in Figure 84. Use *the Back to Spectral Optical Depth* to move back and retry a different set of wavelengths. A successful plot will show individual optical depth component results for ozone, Rayleigh and NO_2 optical depth components. If you have a clear day both in the morning and afternoon, try experimenting with both AM and PM data to compare results.

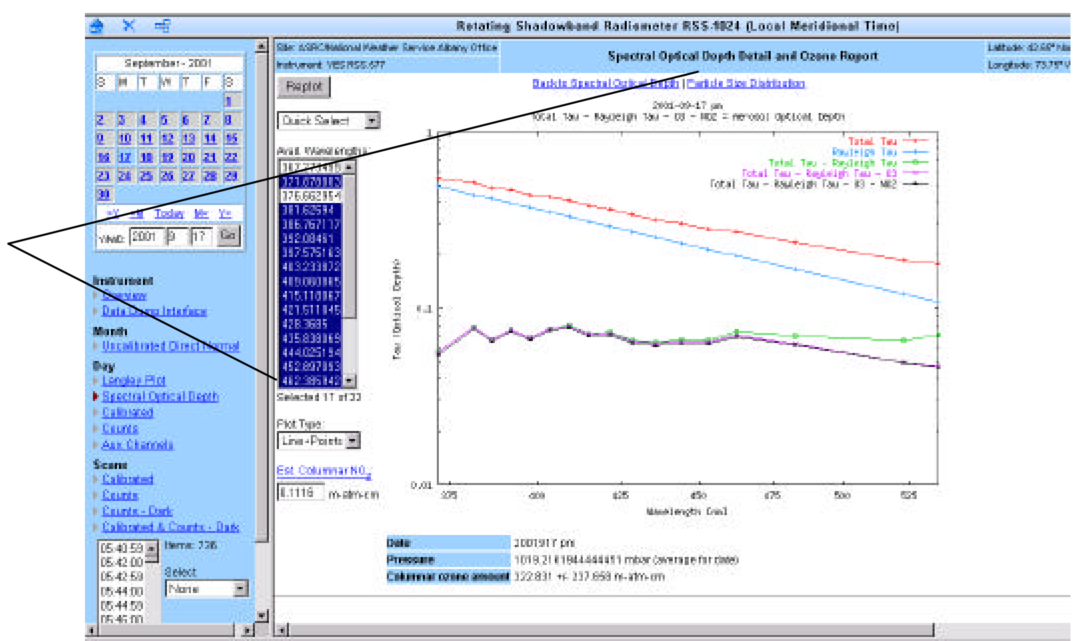


Figure 84. When you see individual plots for Rayleigh, ozone and NO_2 components of optical depth you have been successful in picking a set of wavelengths. Next, reduce the set of pixels be to less than 25 before proceeding to PSD by pressing "Particle Size Distribution" at upper right.

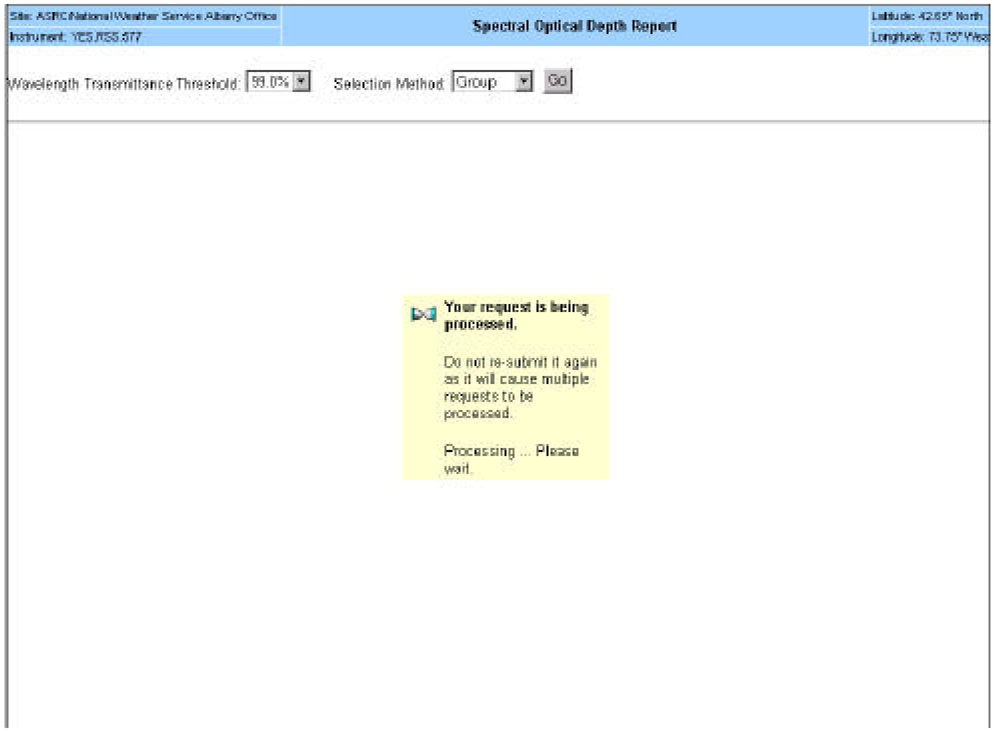


Figure 85. Depending on the data set, you may have to wait a few minutes. If you see this screen for a long time, you may have processed too many pixels for the algorithm to locate a mathematical solution. Try reducing the number of pixels.

Now that you have some preliminary ozone results, select and/or deselect more wavelengths and *Replot* to observe how these changes affect your ozone results.

Important: Aerosol Particle Size Distribution processing, the final step, is *extremely* memory intensive. Due to the mathematics involved, the King algorithm cannot handle more than about two dozen pixels at a time. Before proceeding to particle size distribution processing, be sure that you have not selected more than 25 wavelengths to work with at once.

The King particle size distribution algorithm (see Appendix C), attempts to solve an inversion problem, which may itself be indeterminate. Eventually, if a solution is found, the algorithm may yield results such as those shown in Figure 86. Note there are two graphs, the upper is an estimate of the size distribution and the lower is a recalculated aerosol optical depth based on the distribution.

Note that the ASD processing needs at least five wavelengths to proceed, otherwise you will see an *Inversion Processing Detail* message similar to:

```
Particle Size Distribution for Visible Wavelengths
Version 1.1, 2003-03-20
Copyright (c) 2003 Yankee Environmental Systems, Inc.
ERR> At least 5 wavelengths are needed., Fix input file and try
again.
```

Try choosing a different set of wavelengths and try again, but do not select more than 20 wavelengths. If you see no graph and see the output message "`Too many components of F are nonpositive`" the algorithm failed to find a solution—go back to ozone analysis and reselect a different set of wavelengths and try again.

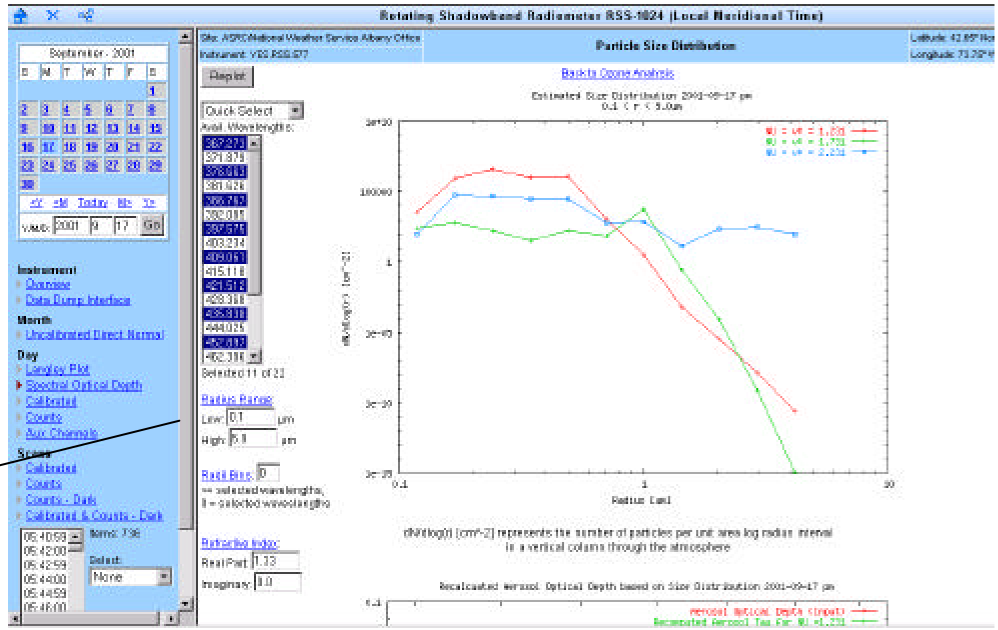


Figure 86. Estimated Aerosol Particle Size Distribution Results. Try experimenting with different Radii ranges and refractive indexes and observe the results.

Note: The mathematics of the King aerosol particle size distribution algorithm are imperfect for some data sets and should be used with care. The Amore, et al Reference in Appendix C discusses these various shortcomings in great detail. We urge you to read the following section to learn more about these algorithms.

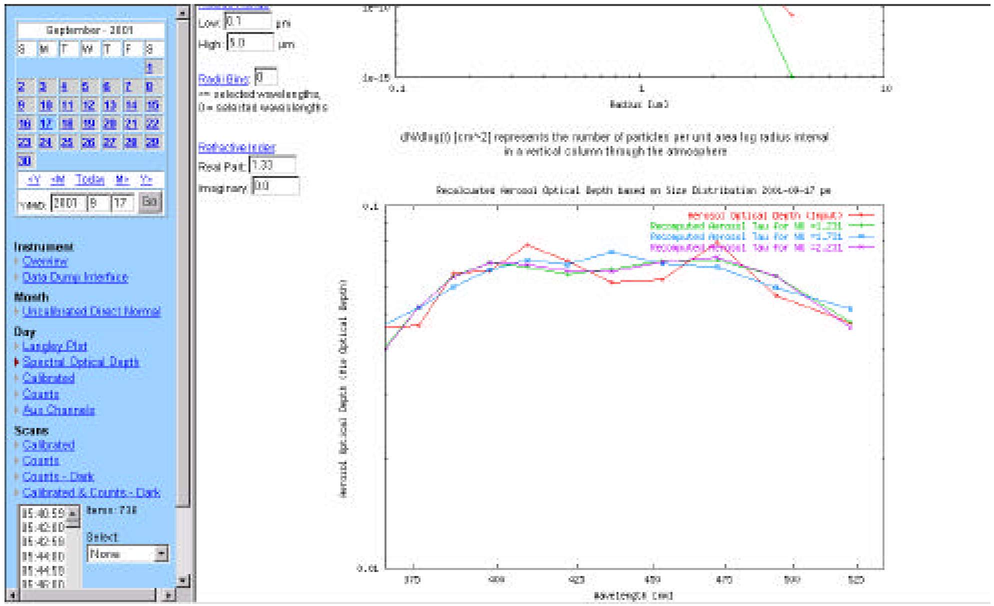


Figure 87. Scroll down to see recalculated Aerosol Optical Depth based on the Particle Size Distribution results. Note that selecting too many wavelengths (or a generally poorly chosen set), will tend to make the algorithm fail.

Inversion of integral equations: Concepts and application to the retrieval of aerosol size distributions

The RSS data processing algorithms that precede ozone and particle size distributions involve relatively simple tasks that are mathematically straightforward. Although each of these steps may be done by different methods, and there may be debate about the relative accuracy of each method, there is nothing inherently unstable or mathematically *pathological* about any of them. To review, what we've discussed and/or implemented so far is:

1. Mapping a set of direct normal irradiances (or a proportional measure of the irradiances, e.g. A/D converter counts from the detector) into a set of (total) optical depths by the Langley method;

2. Separating the optical depths into their various components, representing

(a) Rayleigh scattering by individual molecules of all the atmospheric gases, i.e. by scatterers whose diameters are much smaller than the wavelengths of light;

(b) Mie extinction (including both scattering and absorption) by aerosols, i.e. suspended particles whose diameters are comparable to the wavelengths of light;

(c) Absorption by those atmospheric gases that do absorb in the wavelength range of interest, mainly water vapor (H_2O), ozone (O_3), and oxygen (O_2), and to a lesser extent nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon dioxide (CO_2).

The approach used by the RSS in accomplishing the separation of optical depths follows this path:

1. Calculate Rayleigh optical depths exactly, as they depend only on wavelength and barometric pressure, and subtract them off;

2. Identify and avoid those wavelengths at which H_2O or O_2 absorb significantly;

3. Neglect the tiny amounts of absorption by SO_2 and CO_2;

4. Estimate NO_2 optical depths from typical values for the latitude and season, and subtract them;

5. The remaining optical depths are due to either O_3 or aerosols. Since the wavelength variation of ozone optical depth has a known form, the amount of ozone is estimated as that amount which produces O_3 optical depths which, when subtracted, result in aerosol optical depths with the most probable form of wavelength variation;

6. After subtracting the O_3 optical depths thus found, what remains is our best estimate of aerosol optical depths.

At this point, we seek an estimate of the size distribution of the particles that gave rise to these aerosol optical depths. But first, there needs to be an appreciation for the nature of this problem and why there are such difficulties in solving it. In this section we attempt to discuss a simplified explanation of the mathematical task, why the problem is inherently unstable, and why having more wavelength measurements available does not necessarily improve the retrieval accuracy.

Getting size distribution from optical depths is a classic example of an inversion problem, i.e. solving an integral equation, which can be much more difficult than solving a differential equation. In general, this type of problem can be written:

$$g(y) = \int_{-\infty}^{\infty} K(x,y) f(x) dx$$

and is also known as a Fredholm equation of the first kind. *K(x,y)* is called the kernel function, and the act of integrating a function *f(x)* against this kernel can be thought of as a linear operation which maps the function *f*, defined over the domain of all *x*, to a new function *g*, defined over the domain of all *y*. As a familiar example, if *K(x, y)* were exp(*-j x y*) where *j = Ö -1*

If *K(x, y)* was known, then for any given *f(x)* it's easy to find the *g(y)* that results from this mapping, whether you find it by integrating analytically or numerically. But it's difficult to do the inverse mapping, that is to find *f(x)* when you're given *g(y)*. In fact there may be infinitely many functions *f(x)* that all map to the same function *g(y)*, or at least to a function which is indistinguishable from *g(y)* at the finite number of y-values where you're able to observe it.

You may wonder then why inverse Fourier transforms are relatively easy to compute. That's because while the Fourier transform is indeed a simple example of a Fredholm integral equation, it's also a special case in that the kernel represents an *orthogonal* basis for the function space. Put simply, when you integrate (over infinite limits) the product of two complex exponentials, the integral is always zero except when the frequencies of the two are identical. Sadly this is not the case in most mathematical inversion problems.

Now, to temporarily get less abstract, in the present instance, $f(x)$ represents the size distribution of suspended particles, and the symbol we will use for it is dN_c/dr where r is effective particle radius and N_c is the actual number of particles per unit area in an entire vertical column of the atmosphere. This looks like, and really is, a derivative because the number of particles whose radius is *exactly* some value, is infinitesimal; it only makes sense to talk about there being a finite number (ΔN_c) of particles with radii in some range (Δr). So $dN_c = dr$ is the limit of this count, as $\Delta r \rightarrow 0$. Often instead of dN_c/dr, the quantity found is $dN_c/d(\log r)$, implying that the function represents not the number of particles in equal intervals of radius but rather in equal intervals of logarithm of radius.

The function $g(y)$ in our case is aerosol optical depth as a function of wavelength, and we will use the symbol $t_a(l)$. The kernel $K(x, y)$ is in our case the *extinction cross-section* calculated by the Mie theory of scattering. It represents the probability that any given photon will be removed from the forward-propagating beam when it encounters a spherical particle. A particle's extinction cross-section is the product of its geometrical cross-section pr^2 and its Mie extinction efficiency Q_{ext}, which is a function of particle radius, particle refractive index (n), and wavelength of the photon (l). The formula for $Q_{ext}(r, l, n)$ is extremely complicated, involving spherical Bessel functions, Hankel functions, and Legendre polynomials, but at least it is well-defined, and there have been numerical programs written to calculate it.

Note: The ozone algorithms used by the Model RSS-1024 are based on algorithms originally implemented by programs attributed to John Livingston and Warren Wiscombe of NASA. Particle size distribution inversion routines are based on code originally written by Mike King and Howard Meyer as part of King's research at the University of Arizona. More details on these programs and modifications of them appear later on in this section.

Returning to the general mathematical description of the problem, since an integral is nothing more and nothing less than an infinite sum, the obvious approach to solving an integral equation is to approximate it by a finite sum, i.e. replace the continuous function g(y) by a set of discrete samples $g(y_1); \ldots , g(y_N)$, and instead of finding a continuous solution f(x), find discrete samples of it at $f(x_1); \ldots , f(x_M)$. This of course is just replacing the integral by a Riemann sum that approximates it. The x_i do not necessarily have to be evenly spaced; therefore we'll use the symbol $(\Delta x)_i$ for the width of the bin of x-values that are centered around x_i. (The theory of Gaussian quadrature gives formulas for optimum placement of the x_i for efficient and accurate approximation of an integral, but that issue has become less important with the development of faster computers, and we won't concern ourselves with it at the moment.)

The linear mapping which was represented by the integral then becomes a system of linear equations,

$$\begin{array}{rcl} g(y_1) & = & K(x_1, y_1)f(x_1)(\Delta x)_1 + \cdots + K(x_M, y_1)f(x_M)(\Delta x)_M \\ g(y_2) & = & K(x_1, y_2)f(x_1)(\Delta x)_1 + \cdots + K(x_M, y_2)f(x_M)(\Delta x)_M \\ \vdots & & \vdots \qquad\qquad\qquad\qquad \vdots \\ g(y_N) & = & K(x_1, y_N)f(x_1)(\Delta x)_1 + \cdots + K(x_M, y_N)f(x_M)(\Delta x)_M \end{array}$$

which can be more conveniently written as a matrix equation:

$$g = \mathbf{A}\, f$$

with **A** being the matrix whose $(i\ j)^{th}$ element is $K(x_i;y_j)(Dx)_i$.

Note: In this notation, boldface capital letters represent matrices, boldface lower-case letters represent vectors, an asterisk (*) is matrix transpose, and an exponent of –1 means matrix inverse. Single vertical lines around the symbol for a matrix means the determinant, and double vertical lines around the symbol for an *N*-dimensional vector means its norm, given by

$$\|\mathbf{v}\| = \sqrt{\sum_{j=1}^{N} v_j^2}.$$

Also, for the rest of the section, elements of the **f** and **g** vectors are from this point onward denoted by f_j and g_i rather than by $f(x_j)$ and $g(y_i)$, which still suggest continuous functions rather than discrete components of vectors.

So it would seem that one could then solve the problem by simple linear algebra. Particularly if $M = N$, the matrix is square, and if it is invertible, you could write

$$\mathbf{f} = \mathbf{A}^{-1}\, g \qquad [1]$$

if $N > M$, the system is over-determined, and a solution for vector **f** could be found that minimizes the mean square error in the system, i.e. $\|Af - g\|$, even if an exact solution does not exist. It can be shown that this “least squares” solution is given by the formula

$$\mathbf{f} = (\mathbf{A} * \mathbf{A})^{-1}\, \mathbf{A}^{*} g \qquad [2]$$

This formula can also be used when **A** is square but not invertible.

All of the above formulas would work just fine if the g_i were *exactly* correct to infinite precision. But such a solution is unstable, that is, small perturbances in the g_i can produce enormous variations in the f_j. Roundoff errors, of much smaller magnitude than the uncertainties inherent in the determination of optical depth, can produce size distributions that are orders of magnitude outside the range of physical plausibility.

The reason for this instability is the fact that the matrix representing the mapping is close to being singular. This can be stated in a number of equivalent ways, which may be more descriptive:

1. Its *determinant* is very small.

2. It represents the mapping with respect to a set of basis vectors that are not even close to being orthogonal.

3. At least one row of the matrix can be approximated pretty closely by a linear combination of other rows of the matrix.

4. The kernel *K(x,y)*, when thought of only as a function of *x*, has at least one value of *y* for which it can be approximated pretty closely by a linear combination of the kernel functions associated with other values of *y*.

5. The matrix has some very small *eigenvalues*.

Recall that eigenvalues (often denoted by λ, but here to avoid confusion with wavelength we will use ξ instead) of a matrix (or of a linear transformation) are the "gains" associated with the matrix's eigenvectors (**u**), which are those inputs that just get scaled by the transformation

$$\mathbf{Au} = \xi u$$

The eigenvalues of a matrix's inverse are the reciprocal of the original matrix's eigenvalues. Thus, if **A** has very small eigenvalues, $\mathbf{A}^{-1}$ has very large eigenvalues. Thus in equation 1, the components of the errors in g in the directions associated with small eigenvalues of A, get hugely amplified when multiplied by $\mathbf{A}^{-1}$ leading to gross errors in **f**.

A dramatic numerical example of this phenomenon, and a lucid explanation, are given on pages 116-119 of Twomey's excellent book on inversion problems. The example problem is

$$g(y) = \int_0^1 x e^{-yx} f(x) dx \qquad [3]$$

with $f(x)=1 + 4(x - ½)^2$, a well-behaved smooth function which stays between 1 and 2 over the range $0 < x < 1$. However, discretizing this equation and "solving" it by applying Equation [1] produces a function which fluctuates wildly between positive and negative values with magnitudes in the tens of thousands. Plugging this crazy estimate of *f(x)* back into [3] nevertheless still results in a *g(y)* very close to the correct one.

The physical nature of remote sensing problems usually leads to kernel functions that only vary slowly with *x* and *y* (in our case, with *r* and *l*). For two wavelengths that are close together, the resulting extinction efficiencies as functions of *r* look pretty similar, i.e.,

$$\lambda_1 \approx \lambda_2 \Rightarrow Q_{ext}(r, l_1, n) \approx Q_{ext}(r, l_2, n)$$

Hence the matrix **A** has at least one very small eigenvalue. Adding lots of wavelengths which are close together makes the matrix bigger and the system of equations harder to solve, but doesn't increase the accuracy of the solution if all the eigenvalues which are added are smaller than the noise and uncertainty inherent in the optical depth estimates t_a. The maximum possible number of independent pieces of useful information in an inversion problem depends only on the mathematical character of the kernel and the level of noise and uncertainty in the inputs. One essentially does not gain anything by including more inputs if they just introduce more small eigenvalues.

What this means for the RSS is that even if we have, say, 700 pixel channels that are outside of strong absorption bands, using all of them as inputs to a particle size distribution algorithm doesn't necessarily provide any more information to it than using just 7 or 10 or 15 of them. Nevertheless, the RSS does have one advantage in this area over an instrument with just a few wavelengths. Even if just a few wavelengths are used in an inversion algorithm, they can be chosen in a way that might be closer to optimum. A set of wavelengths can be selected for which the kernel functions are as close as possible to orthogonality, which is to say the eigenvalues are maximized. Also, the routine could perhaps be run using several different sets of wavelengths, and the resulting size distributions compared/averaged/error-corrected.

So far, we have discussed the general problem of finding particle size distribution from aerosol optical depths, attempted to give an appreciation for what is really happening mathematically, and explained why the “obvious" straightforward approach to solving the problem is very unlikely to work. Now we turn our attention to how to deal with these difficulties, and present a standard method that does work (or that works, some of the time).

An approach to finding a “plausible" solution to integral equations of the type seen here is to impose a side constraint, usually a smoothing constraint. In other words, as long as there's *any* uncertainty, even roundoff error, in the optical depths (which of course there always will be), there will be a number (probably an infinite number) of theoretical size distribution functions that would produce that set of optical depths within the range of the uncertainty. Most of these *mathematically* correct solutions, however, are *physically* ridiculous, swinging through wild extreme values and thus having large derivatives. The most physically plausible solution is usually one that is smooth, *i.e*. it varies slowly and thus has relatively small derivatives.

To implement this constraint, one incorporates a smoothing term into the least-squares matrix solution, parameterized by a LaGrange multiplier γ that can be tuned to find the appropriate balance between smoothness and agreement with the input data. Furthermore, the relative uncertainties σ_i of the measurements at each wavelength λ_i can be brought into the problem in the form of weights $w_i = 1/\sigma^2_i$. Since the uncertainties are really standard deviations of the random processes associated with measuring optical depths, a matrix **C** with the σ^2 on the diagonal and zeroes elsewhere is the covariance matrix for the set of measurements, assuming the errors at different wavelengths are uncorrelated with each other.

Thus Equation 2 is modified to the following:

$$\mathbf{f} = (\mathbf{A}^* \mathbf{C}^{-1}\mathbf{A} + \gamma\, \mathbf{H})^{-1}\, \mathbf{A}^*\mathbf{C}^{-1} g \qquad [4]$$

where **H** is a matrix that represents the coefficients of a quadratic expression in **f** (in precise language, a quadratic form $\mathbf{f}^*\, \mathbf{H}\, \mathbf{f}$) which can serve as a measure of smoothness. Most commonly, the quadratic form used is the sum of the squares of the second differences $f_{j-1} - 2f_j + f_{j+1}$, which are the discrete equivalent of equivalent of second derivatives. This leads to the following smoothing matrix:

$$\mathbf{H} = \begin{bmatrix} 1 & -2 & 1 & 0 & 0 & . & . & . & 0 \\ -2 & 5 & -4 & 1 & 0 & 0 & . & . & \\ 1 & -4 & 6 & -4 & 1 & 0 & 0 & . & \\ 0 & 1 & -4 & 6 & -4 & 1 & 0 & . & \\ 0 & 0 & 1 & -4 & 6 & -4 & 1 & . & \\ . & . & . & \ddots & \ddots & \ddots & \ddots & \ddots & \\ . & & & 0 & 1 & -4 & 6 & -4 & 1 \\ . & & & & 0 & 1 & -4 & 5 & -2 \\ 0 & & & & & 0 & 1 & -2 & 1 \end{bmatrix}. \qquad (5)$$

The inversion technique developed by Mike King, Dale Byrne, Ben Herman, and John Reagan is a variation on this approach which has been widely used on data from sun photometers since the 1970's. The smoothing constraint shown above minimizes second derivatives on a linear scale, but particle size distribution is a quantity that varies over many orders of magnitude and is more usefully displayed on a log-log scale. To make the smoothing constraint more appropriate, the size distribution is written as the product of a rapidly varying function *h(r)* and a more slowly varying function *f(r)*:

$$\frac{dN_c}{dr} = h(r)f(r).$$

Now *h(r)* can be set to some plausible shape for aerosol size distributions as an initial guess, and incorporated into the kernel of the integral equation. The shape usually used for this initial guess is that of a Junge distribution:

$$h(r) = r^{-(\nu^* + 1)}$$

with ν* set to a value around 3. The $(i, j)^{th}$ element of **A** is then given by

$$A_{i,j} = \int_{r_j}^{r_{j+1}} \pi r^2 Q_{\text{ext}}(r, \lambda, n) h(r) dr \qquad (6)$$

and this integral is itself evaluated numerically by dividing it into subintervals.

A first estimate of *f(r)* can be calculated by Equation 4, using the smoothing matrix given in Equation 5. This produces values of *f(r)* at the center radii of the coarse intervals. The LaGrange multiplier γ is varied through a range relative to the $(1,1)^{th}$ element of $\mathbf{A} * \mathbf{C}^{-1} \mathbf{A}$ until the smallest value is found that makes all the f_i positive. If this never happens, γ is set to the maximum value in the allowable range, and the negative values of f_i are replaced with positive values interpolated or extrapolated from the others.

With γ set properly, the resulting f_j , defined at the center wavelengths of the coarse intervals, are then interpolated/extrapolated to the center wavelengths of all the subintervals that were used in evaluating Equation 6. These values are multiplied by *h(r)* to give an updated estimate of *h(r)*. The whole process is repeated to give a second estimate of *f(r)*, which can again be incorporated into *h(r)*, and so forth. Iteration continues until *f(r)h(r)* converges to a stable function, which is taken to be the best estimate of particle size distribution that the algorithm could find (given that particular initialization of *h(r)*). As a final outermost level of iteration, the entire routine is performed for three different initial estimates of ν^*, namely the one that is read or inferred from the input data file, and those that are $\pm$0:5 from it.

The inputs to the code include the wavelengths, aerosol optical depths, uncertainties, range of particle radii to consider, number of radius bins, particle refractive index (real and imaginary parts), and flags to direct it how to assign weights to the wavelengths and whether to calculate ν^* from the optical depths or calculate optical depths from ν^*.

Limitations of Particle Size Distribution Algorithms

The RSS implements but one (albeit popular) particle size distribution algorithm, however, there are many other proposed methods to try to invert spectral irradiance data to obtain aerosol particle size distributions. No algorithm is perfect, and there are times when the King algorithm is unstable. A completely reliable generalized aerosol particle size distribution algorithm has yet to be developed, and in this section we discuss why this is the case.

Amato *et al* point out several issues with the King algorithm and proposes a new method. The whole point of these proposed algorithms is to replace an inversion problem of trying to obtain an arbitrary (but smoothed) size distribution, with a problem that amounts to finding the best coefficients for a specified set of log-normal size-distribution equations (i.e. a chosen aerosol parameterization.)

The obvious limitation of this method is that if in fact an aerosol is present *which is not well fitted by the parameterization*, then the results will be nonsense. Amato proposes a straightforward standard LS methodology, and ignores maximum-entropy technique exposition, as they concede that in this case it isn't superior to a regularized LS solution with non-negativity constraint as the fundamental retrieval algorithm.

The King, and Nakajima and King algorithms are also fundamentally LS, but are inappropriately regularized. In addition, these algorithms are basically heavily smoothed "Tikhonov Regularizations" in the modern nomenclature ("Tikhonov Regularization" was commonly referred to as "Twomey's method" in the western geophysical literature, but Tikhonov got there well before Twomey). The problem is that the kernel for that inversion is so bad that even the heavy smoothing isn't enough. The frequent aphysical consequences of the King and N&K algorithms are:

- Tri-modal mass distributions with a mass peak that isn't there, and
- Grossly aphysical large-particle concentrations (at relatively impossible "boulder" sizes like a 10 micron radius)

A very hard test for these inversions to pass is to get the integrated aerosol mass anything like really right, for tougher cases. The converse of this is if there was a routine, remotely-sensed way to observe a column mass constraint it would really help the inversions. (While there isn't, the analogy is the liquid-water constraint from microwave radiometer yielding cloud-droplet Re directly from an optical Cloud Tau)

The book *Numerical Recipes in C* has a good backgrounder on Singular Value Decomposition. The excellent book *Rank Deficient and Discrete Ill-Posed Problems* (P.C. Hansen, ISBN 0-89871-403-6) takes away a lot of the mystique of many of these mathematical inversion methods. However, caveat emptor, as most of these methods are known to fail quite often.

CHAPTER 4
Maintenance and Service

The RSS system was designed to provide years of trouble free unattended operation in the field, and utilizes a combination of remote monitoring, internal environmental monitoring sensors, and robust mechanical design. They were also field-tested for several years. However, like any complex system, maintenance is required to keep the instrument in good working order. These procedures include:

- Cleaning the diffuser about once a week
- Checking band alignment once a month

  You can see band alignment problems in the data; see the discussion below for more information.
- Checking the instrument level once a month
- Checking system time once a month (assuming a NTN time server via the Internet is configured, much more often if standalone)

  Clock drifts can affect the position of the shadowband during blocked measurements and result in incorrect readings.
- Checking AC or fiber Ethernet cables for animal or wind wear annually
- Recalibrating the instrument as often as you can, but at least annually
- Checking UPS battery annually
- Checking internal and external cooling fans and if necessary replacing them
- Replacing the Pentium cooling fan in the Core CPU annually
- Checking the spectrograph casting pressure, recharging after 4-5 years
- Replacing the RAID-1 drives every 4-5 years

These tasks are described below. This chapter also provides troubleshooting and service information for the system.

Weekly Maintenance

To ensure that your measurements are accurate, you ideally should clean the instrument diffuser weekly. The cleaning frequency may vary with the season or location, depending for example on pollen cycles. In the spring months when pollen is heaviest, more frequent cleanings might be required for best results. If the site is near the ocean where large birds are common, you might also need to check the instrument more often.

WARNING: It is critical not to leave your RSS instrument powered off outside for any length of time. Aside from water penetrating the system, birds have been known to try to eat the white diffuser button when the shadowband is not moving.

Clean the diffuser

A cleaning solution can be prepared using distilled H_20 and up to 50% *pure* ethanol under cold conditions. Do *not* use methanol, which attacks aluminum, or *denatured* ethanol whose usual denaturant is methanol. Optionally add one drop of Ivory dish washing soap per liter. This is a source of sodium lauryl sulfate and can help in greasy or sooty environments.

To clean the diffuser:

1 Use a lab squirt bottle to hydraulically flush the diffuser and area inside the blocking ring. Let this drain away on its own. Be sure to squirt the jet at an angle to wash deposits from the surface. Do not hold the nozzle of the bottle close to the surface at a normal orientation. The center of the face of the diffuser is a relatively thin plastic membrane and must not be dimpled.

2 Check that the fluid drains away from the blocking ring.

If the diffuser is visually soiled after normal cleaning, then more aggressive steps must be taken with care as described below. In general, however, contamination that resists cleaning with the wash bottle method is probably caused by a factor other than atmospheric deposition. Try to eliminate the source.

For more rigorous cleaning, purchase standard laboratory or computer grade cotton swabs. Be sure that they do *not* contain a skin lubricant. Prepare the swabs as follows:

1 Soak the swab end for at least one hour in a Normal Sodium Hydroxide solution in distilled water.

2 Remove from the solution and rinse with distilled water.

3 Soak the swab in excess distilled water overnight to eliminate sodium hydroxide residue, which will attack aluminum. Then dry and package the swab.

The treatment with NaOH improves the wicking ability of the cotton, and removes residual oils. (You can test this method on a piece of cotton shoe lace; you will see a dramatic improvement in its ability to wick up water.)

4 The treated swabs can be used *delicately* with excess cleaning solution for stubborn soil. As mentioned earlier, take care not to damage the diffuser membrane.

If the above procedure does not sufficiently clean the diffuser, it should be returned to YES for service. More aggressive cleaning procedures will generally require disassembly and subsequent full recalibration.

Ice on the diffuser

Do not attempt to mechanically remove ice because the optical diffuser surface can be damaged easily. If the instrument's heater and a generous squirt of the EtOH solution doesn't remove it, let the system run a while. The instrument's heater will eventually take care of it. It is better to loose a little data than damage the instrument.

Check band alignment

Normally, the band needs no adjustment once it is set up properly. However, if the instrument has suffered an animal attack or severe ice storm, the band might be slightly bent. By looking at plots of the retrieved data you might remotely diagnose a band alignment problem. For example, if on a partly sunny day, you have diffuse data only (i.e., no direct data and the total reading is equal to the diffuse), then the band is not properly blocking the direct beam.

Be aware that incorrect data does not necessarily mean that the shadowband is bent. The most common cause of alignment errors is failure to maintain UTC time. If you have verified that these parameters are set properly and checked your time server Time Synchronization Status, then you should check the band alignment. The band should rest in the side position when stopped. Use the procedure on page 2-28 to re-align the band.

Monthly Maintenance

Monthly, check the system diffuser with a high precision bubble level to verify that the mounting platform or instrument has not shifted from the horizontal position. A small machinist's level works well for this purpose (do not simply check the white enclosure top). However, be careful to use the black shade rim immediately surrounding the diffuser as the reference point. Do not physically contact the diffuser with the level. Any errors in leveling of the diffuser will seriously impair the quality of measurements made in the visible region.

Check diffuser level

From the main YESDAQ window, under **YESDAQ Admin**, **Status**, **System Status** you can view disk usage statistics and the Core CPU voltages. (Note that ALARMS can safely be ignored as they refer to peripherals not connected).

Checking time and disk if not on Internet

If you are using a TCP/IP network to connect to the system you configured the NTP time server to retrieve time properly via a network time server you can skip this step. If you do not have the RSS on the Internet and therefore cannot rely on Internet time servers synchronization, you will need to connect a laptop to the console port to check the system time as described in Chapter 2. During this check, also view the RAID-1 disk drive array status and look for failures,

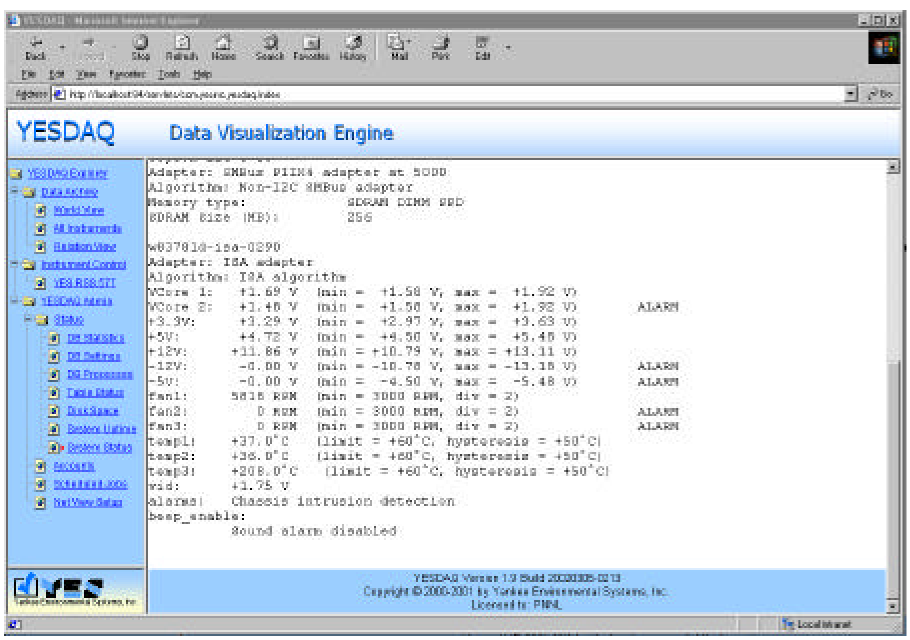


Figure 88. Core CPU statistics. It is safe to ignore the voltage and fan 2&3 alarms. Look for fan 1 which may need replacement.

especially if the drives are more than 4 years old.

Check fans

Check the outside fan for blockage and from the main YESDAQ window, under **YESDAQ Admin**, **Status**, **System Status** you can view the Core CPU fan status. Note that only the first fan is connected to this monitor.

Check cables

Check the insulation on cables. System operation as well as your data can be affected by water leaking into a broken cable. Cable failures are often started by UV degradation jacket failure or caused by rodents chewing on wires.

Annual Maintenance

While monthly maintenance does nor require opening the enclosure, annual maintenance generally involves removing the enclosure door for a look inside. Be sure to remove and replace the enclosure door carefully, such that the water seal is not compromised.

Check UPS Battery and swap fans

Replace the internal UPS battery every 4-5 years. It is a 12 V sealed "gel cell" type. Also check the small Pentium CPU cooling fan yearly, *whether it appears to be working or not*. Swap the other larger internal and external DC enclosure fans every two to three years *whether they appear to be working or not*. The external fan is a special waterproof type. You can order a RSS fan kit from YES.

Check Disk Drive Health

The Core CPU Module stores data on two IDE hard drives setup as RAID-1. Because hard drives do not last forever, you need to swap them about every four to five years. If one drive fails, its RAID-1 partner mirrors the data and will carry on until the drive is replaced. If a Core CPU fails, swap the entire a

Check/Recharge Pressure

The CCD spectrograph itself is contained in an O-ring sealed, dry nitrogen purged casting. If even a slight amount of moisture is allowed to enter the casting, the dew point temperature inside the system can exceed the temperature of the cooled and exposed CCD surface, permitting corrosion to set in, altering the calibration and destroying the device. At the factory, each RSS is carefully evacuated and purged with nitrogen gas, and left at a slight positive pressure of approximately 5 PSI. The internal RCB subsystem monitors this casting pressure and uses a failsafe circuit that turns off the CCD thermoelectric coolers.

WARNING: Both spectrograph pressure vessel pressure and relative humidity are permanently logged to detect tampering that would effectively void your RSS warranty. In order to avoid destroying your CCD and voiding your warranty, ***NEVER OPEN THE SPECTROMETER CASTING!*** Special fixtures and leak detection apparatus are required to properly dry purge and reseal the system. Under no circumstances should this vessel be opened except by the factory.

Recharging the RSS Casting

While your RSS was engineered to provide years of service, over time, all pressure vessels will leak. You need to monitor the casting pressure periodically via the web interface. As of this writing, the casting should hold from one to five PSI over atmospheric for several years.

After the pressure differential falls to about one PSI over ambient pressure, you will want to inject a small amount of dry nitrogen from a tank of gas. You do this using a low pressure regulator and a medical grade nitrogen gas bottle, via the two valves located on the CCD backplate of the instrument casting. Be sure to power off the system during the recharge procedure and do it on a very dry day.

WARNING: The following is an involved procedure and should only be performed under factory supervision. When increasing the pressure, do not increase the casting pressure more than about 8 PSI over ambient!

You MUST use a *low pressure* nitrogen regulator. Many nitrogen regulators are not of the low pressure variety and do not permit you to inject the small pressure level required. Never let the casting vent to the atmosphere, as water vapor will enter. Be sure you are always looking at gauge pressure, that is, the *difference between atmospheric and the internal casting pressure*. If you are unsure, consult the factory.

To pump and purge the RSS casting:

1) Preheat the casting. With the RSS casting attached to the vacuum pump as well as the source of dry air or dry nitrogen, use an AC Variac set to provide about 55 Vac into the heater pads that heat the lower main casting (but not the snorkel), attached to the orange and yellow pairs of wires. With the casting sitting in a room temperature environment and uninsulated, 55 VAC will get the casting up to about 70-75°C after about four hours. It is extremely important that the RSS backplate not exceed 80°C, because it will degrade or destroy the Peltier thermoelectric cooler under the CCD. You can monitor the temperature of the cooler using an ohmmeter attached to one of the thermistors attached to the CCD/peltier backplate, available via pins 12-13 on the DB15 that feeds the peltier/prism heater circuitry. If the resistance doesn't drop to anything less than 1.5K, this is satisfactory. Adjust the Variac to get the thermistor to read about 1.6-1.7K, which translates to about 52 to 55Vac on the heaters. Just one or two extra volts can easily make it too hot so use care.

2) Monitor the humidity sensor to determine how the casting preheat process is going. Apply +5 volts to pin 14 of the utility DB-15. Attach the ground return from the +5 volt source to either pin 10 or 11 of the other DB15 that supplies the connection to the CCD. (Pins 10-11 are connected to the CCD substrate which is operated at analog ground). With a voltmeter attached to analog ground and pin 9 of the DB-15 utility connector, you should then get a reading of about 1.5-2.2

volts or so from the humidity sensor when it is surrounded by room air. Be sure to get this measurement in place before you begin the pump and purge process so that you can monitor the change in RH during the first moments of the process, which are important because it can tell you if the RH sensor is working properly and is to be trusted.

3) Turn on the vacuum pump and monitor the RH sensor - the voltage should drop rapidly during the first pump cycle down to about 1.1 volts. Then backfill/repressurize the casting with low pressure dry air/nitrogen and watch the RH sensor. It should drop a little more. Perform 5-8 cycles, initially quite rapidly, making a note of what the sensor is reading. After this series of pump and purge cycles, the RH sensor should be close to or below 1 volt, at which point you can use dry air if you wish to save nitrogen. It is also good to test bleed a little of nitrogen or dry air through the vacuum purging process for a day or so. Pump down for at least 48 hours. At the end of this phase, the RH sensor should read around 0.98-0.99 volts when the RSS is really baked out and dry, which should happen after 48 hours.

4) If the sensor doesn't get below 1.1 volts after this point, the RH sensor may have been damaged by solvents, epoxy spillage or handling, at which point you may not be able to tell how dry it really is inside the casting and will need to return the RSS to the factory. However, that some RH sensors over time tend to revive a little and eventually get down to less than a volt if the RSS is baked and purged for a longer time, (five days or so.) If the RH sensor is working properly, if your air or nitrogen is dry enough and the vacuum pump aggressive enough, you should be able to get less than 1 volt within two days.

5) At the end of the pump and purge process, reinstall the dessicant. Turn off the vacuum pump, pressurize the casting slightly (just a little bit of positive (one PSI) and then quickly remove the blank cover plate and install the plate with the desiccant canister on it. Then do a few more rounds of pump and purge to dry out the now desiccated RSS and you should be done.

6) The desiccant in the canister is Multisorb's molecular sieve, and should be wrapped up in small Tyvec™ packs, not in plastic capsules (the plastic in those capsules contains diethyl phthalate.) Molecular sieve cannot be re-dried out very effectively except at extremely high temperatures(300-400C), and once it has acquired a little room moisture, it is pretty much useless. And so great care has to be taken to preserve it in a very dry space once it is removed from the casting - a vacuum canister or one filled with very dry air is mandatory. The Tyvec enclosed molecular sieve will take on moisture very rapidly. If it has sat in the open air for more than 10 minutes, it must be replaced. It is the only desiccant that works effectively at extremely low RHs. When installed, you should be able to see the RH inside the casting drop even further if you continue to monitor it.

7) When you are pressurizing the casting, you can monitor the vacuum/pressure inside by attaching a millivoltmeter to pins 10 & 11 of the utility DB-15. At a 30 inch vacuum, you should get a reading of approximately -27 millivolts. As you pressurize the casting it will change to a positive voltage. At room pressure it will be approx. 24-27 millivolts. 5 PSI is around 40-45 millivolts. The -27 millivolt reading at maximum vacuum might range as far as -15 millivolts, but the millivolt

readings will change polarity at some point during the reduction of the vacuum. Regardless, 0 PSI is around 27 millivolts and 5 PSI is around 40 millivolts.

Calibrating the RSS

It has been said that with radiometric field instrumentation, "calibration ***is*** *operation."* You should perform these calibrations as frequently as possible but no less frequently than yearly.

Your system was characterized by the factory three ways:

- **Angular Response** (cosine test) two seperate north/south and east/west, via a rotary computer-controlled dual axis optical table 3 meters in diameter
- **Spectral Response** (wavelength scan) via a set of gas discharge lamps (for example, Hg-Cd)
- **Absolute Response** (spectral irradiance) via a NIST-traceable FEL lamp and precision current source

YES recommends a full instrument re-characterization annually. If possible, absolute and spectral calibrations should also be performed once a month in the field if possible.

When it is time to recalibrate your instrument, you have a choice: ship the system back to the factory, or use a PFC-5001 optical sources to perform absolute or spectral characterization. Due to the complexity of making angular (cosine) characterizations and the expensive tooling required we do not support in-the-field customer cosine characterizations.

Absolute Calibration using the Model PFC-5001

Like most radiometric instruments, the shadowband instrument should be periodically recalibrated using a NIST/NPL/PTB-traceable irradiance source as shown in Figure 36. The ideal frequency of these recalibrations is a function of how long the instrument has been exposed in the field, your budget, and how important the precision and reliability of the measurement is to you. We recommend recalibrating the RSS *at least* once a year, or monthly if possible.

Each RSS instrument undergoes three types of calibrations: angular, spectral and absolute. These calibrations are performed at YES in dedicated, NIST-traceable optical calibration facilities. Because extensive equipment and expertise is required to calibrate the instrument (especially with regard to angular characterization), we recommend that you return the instrument head to YES for recalibration. However, you can check the absolute response of the RSS via a NIST-traceable optical field source, such as the YES Model PFC-5001 Portable Field Calibrator.

Absolute calibration

Performing Absolute Calibrations via a Portable Optical Calibrator:

1 Connect to the system via the web and log into YESDAQ as *admin* and check to that the YESDAQ parameters that control the Portable Field Calibrator (PFC) are correct. Refer to the PFC manual for details.

2 Plug in and power up the PFC.

3 Verify that there are no errors and the system is collecting data normally.

4 With the instrument operating, plug the PFC control cable's round connector into the bottom of the system enclosure. This will force *calibration mode*.

5 Once the shadowband has parked itself, physically place the PFC over the canister/diffuser assembly. You may want to have another person assist you in order to avoid damaging the RSS' relatively fragile optical diffuser.

Thermal zones

6 Carefully mechanically align the PFC to the instrument diffuser and verify level and spacing. You may wish to refer to the PFC manual.

7 If you are using a FEL lamp, via the web interface, enter manual mode and take a few scans. Store these as described in Using the system as a CCD spectrograph on page 2-17. If you are using the PFC, the system operates autonomously, the entire sequence will take a few minutes while the PFC lamp warms up and then cools down.

8 Remove the PFC from atop the instrument and check that the system is still level.

9 Remove the control cable and via the web interface and visual feedback observe the system shadowband restart itself and resume normal operation.

10 Turn off the PFC and store it in its case. *Do not leave the PFC outside!*

Performing Wavelength Calibrations with Gas Emission Lamps:

1 Plug in and power up the gas discharge lamp and be sure it ignites. Do NOT look directly into the lamp!

2 Connect to the system via the web and log into YESDAQ as admin.

3 Verify that there are no errors and the system is collecting data normally.

4 Hit the stop button to halt data acquisition, and go to the manual scan mode.

5 Once the shadowband has parked itself, physically place the line source gas emission lamp over the shadowband assembly. Note you will need to build or buy an appropriate alignment fixture to ensure the lamp is properly positioned. You may want to have another person assist you in order to avoid damaging the RSS' relatively fragile optical diffuser.

6 Via the web interface, enter manual mode and take a few scans. Store these as described in Using the system as a CCD spectrograph on page 2-17.

7 Take a quick snapshot and verify the spectra look reasonable for the line source lamp. Note that older bulbs tend to drop lines and are unsuitable for use. This is a critical quality control step and you should take your time.

8 Observe the web interface and verify that the system is taking spectral measurements; the entire sequence will take a few minutes. Repeat for several scans until you are satisfied with the displayed spectra.

9 Remove the line source gas discharge lamp and store it.

10 Repeat steps 5-12 with additional gas discharge lamps as required.

11 Finally check that the system is still level.

12 Via the web interface and visual feedback observe the RSS shadowband restart itself and resume normal operation.

Note: Depending on the spectral range of the instrument, different gas discharge lamps are appropriate. For the Model UVRSS-1024, Mercury-Cadmium lamps are used ; for the Model RSS-1024, Mercury, Cesium and Rubidium lamps are used. These lamps, their necessary fixtures, socket/housings, and high voltage power supplies are available options from YES, or you can buy them from optical supply vendors such as Thermo-Oriel Corp. (see www.oriel.com)

Changing Fuses

In addition to the two main AC circuit breakers, there are several other protective fuses in the system.

WARNING : Always remove power and wait for the UPS to shutdown before working on fuses!

A main DC supply fuse is located on the right side of the *Power Supply Module* (PSM). The PSM and its internal UPS subsystem is physically located behind insulation in the upper left hand corner of the enclosure. Because it is covered in thermal insulation, you must gain access by slicing the foil that holds the insulation cover in place. The Core CPU must be removed first to permit physical access, via its four captive retaining screws that hold it to the rear chassis. Once the insulation is removed, the main DC fuse is then accessible.

Note: The PSM insulation helps to keep the heat from the power supply out of the inside of the box and needs to be replaced after servicing. This vertical piece of insulation that needs to be removed faces the top of the instrument casting. Make note of the position of this insulation so you can reapply it on reassembly.

There are a total of three internal fuses in the PSM itself:

- A 6.3 Amp protects the main 14.5 Volt switching supply, and should not need replacement as it is protected by a separate 5 Amp circuit breaker
- A 10 Amp, type 2AG fuse, protects the 12 Volt input to the two 12-to-5 volt DC-to-DC inverters, and should never need replacement since both the inverters and the 14.5 volt switching supply are short-circuit protected
- A 5 amp fuse protects the 12 Volt supply lines feeding the RCCB and everything else including the shadowband stepper motor to the system hard drives. For example, this fuse will blow if the 12 Volt supply is accidentally shorted to ground.
- Individual PID zone fuses located in each black electronic control solid state relay module. These zone fuses are located on the RCB, just beneath the shiny metal tabs, which rotate to expose them, next to the zone activity LEDs. (Note that the LEDs are independent of the fuse, indicating control signals, not output)

If you have a malfunctioning thermal zone on the spectrograph pressure vessel casting, check these PID fuses. If these fuses blow repeatedly, suspect a short in the casting wiring harness.

Troubleshooting Hardware Problems

This section assumes you have successfully installed the RSS and later encountered operational problems. The rugged design of the instrument helps to minimize most hardware problems. Problems that you may encounter typically fall into the two categories of initial installation and setup/alignment issues or hardware component failures. A good question to ask yourself is: did the problem just start or has it always been there?

If you notice inconsistencies in your shadowband data, most likely the band is not shading the diffuser correctly. You should check all installation parameters carefully.

TCP/IP Networking and Communications Problems

This section helps you troubleshoot problems related to RSS operation, which are the most common problem after AC power loss. For help on troubleshooting network problems involving LAN communications specific to your network, see your local network administrator. For trouble shooting network connectivity, a LAN cable tester and a known working RJ-45 10/100-BaseT network device can be valuable aids for debugging cable problems.

If you lose TCP/IP access to a remote system, it is possible that the problem is somewhere on the network between your workstation and the RSS. Try the following steps before concluding that the problem is with the RSS system itself.

1 First, try the ping command to see if the system responds, the RSS will respond to a ping if all routers between them are configured properly.

2 If the RSS does not respond, but otherwise seems to be powered on (that is, the fans are on and the two AC switch lamps are on), try using the ping command from a PC or Unix system prompt to another TCP/IP device on the local subnet where the RSS is installed to check the network is up. See if you see LAN activity LED on the Core CPU flicker during this test.

3 Next, substitute another known working TCP/IP device on the end of the 10/100Base T Ethernet cable running to the RSS and see if you can pin it.

4 Finally, try cycling the power by turning off AC for at least 10 minutes (to force the UPS to fully shut the system down), before restoring power.

Band has Stopped Moving

If the system seems to be alive but the shadowband either has stopped moving, or is moving erratically, stop the system via the web interface. First, check the error log. Next, check that the band is still mechanically tight on the motor shaft. If it is, next disconnect and inspect the external motor cable for signs of corrosion (look for a fine, greenish dust on the gold pins on the motor or cable side).

Next, using a Digital Volt Meter set to *ohms*, test the continuity of each wire in the motor cable end-to-end. This cable runs to the RCCB board inside the enclosure. If this cable checks out and you suspect the system was hit by lightning, you might need to replace the stepper motor driver IC located on the RCCB board. Otherwise, replace entire the motor assembly with a known working assembly (these can be ordered from YES as spares, and note the assembly is identical to that used in the YES Model UVMFR-7 instruments.)

Band is Not Shading the Diffuser Properly

Several factors can affect the position of the band during blocked measurements. If one or more of them is set incorrectly, your band will not shade the direct beam properly. By comparing plots of shadowband data with empirical data (notes of sky conditions for the day, for example), you can detect band-shading problems. For example, if no direct data was collected on a day that you observed clear sunny skies, then the band position should be checked.

- **System location.** Via the web, verify the latitude and longitude are correct.
- **System time.** Via the console port, ensure that the system setup screens are properly configured for an appropriate NTN network timeserver or atomic time standard. The RSS must be able to see the timeserver's IP address via the LAN connection. It is common for system administrators to block router firewall TCP/IP ports corresponding to network time services—contact your local system administrator or ISP for help as this is an organization-specific policy. Try to ping the time server from a terminal session on your LAN.
- **Instrument leveling and alignment to geographical north/south.** See Chapter 2, Installation, for detailed information on setting up the instrument. The instrument should be within 1° of vertical and, at solar noon, the motor bracket should not cast a shadow to either side of the shadowband motor.
- **Shape of the band.** Check the band is not bent. See page 2-28 for more information on checking the band.
- **Latitude adjustment.** There are three possible motor mounting positions and the motor was setup for your site location prior to delivery, so you should not need to adjust this setting. You might, however, need to relocate the motor to one of the other holes if you move the instrument out of the range supported by the current hole. The latitude of the motor should be set to the angle lower than but closest to the site latitude and for; the three holes are at 15°, 30° and 45°. For example, at a site of 48°N, the motor should be in the to 45° hole; for sites closer to the equator than 15° mount the motor in the 15° position. At sites above 45°, a slightly longer shadowband will be required to block the sun during the summer solstice.
- **Band offset**. The round canister prevents the shadowband to rest at the nadir position, directly below the diffuser position. Instead, the band is arbitrarily offset from the nadir, effectively changing the home position of the band. The exact offset was set by the factory but over time the band may require service and this offset must be determined again based on the new shaft position. In order that the system firmware can determine the correct number

of steps required to make a blocked measurement, the firmware must be instructed the physical offset of the band on the motor shaft. This offset is specified in the system initialization screens on the web interface and is typically -125. Otherwise, the system assumes the home position is at the nadir (vertically directly below the diffuser) and ignores the offset when moving the band, usually causing the band to hit the canister.

You specify the offset in the RSS setup page. The offset is based on the distance the band is set from the canister. If it becomes mechanically loose, the offset setting will no longer work. If the band ever strikes the canister during a measurement cycle, it will cause a band motion error, and the system will stop.

Because the canister is "in the way" of the nadir position, the home position of the band is offset rather than directly below it. Although the band is properly adjusted during manufacture, it may become loose over time. If the band strikes the canister during a measurement cycle, it will likely cause a system error and halt the band and system data collection. If this occurs, the band must be manually loosened, adjusted and then re-tightened, and a new offset specified.

> **Note:** The offset factor that you specify does *not* affect the physical distance that the band is located from the canister. The only way to prevent the band from striking the canister is to manually change the home position of the band. Once you adjust the band, the offset factor tells the firmware the number of steps the band is offset. The offset is factored into calculations that move the band from the home position to the appropriate position for a blocked measurement. If you do not specify an offset factor, it assumes the home position is at the nadir, regardless of its actual position.

Thermal Control is Out of Range

It is important to check that the RSS maintains its temperature to a high degree of stability, and you can monitor these via auxiliary channels. The RSS tries to hold the system above ambient temperature swings, but in extreme environmental cases, the input fore optic and backplate can lose thermal control for brief periods of times of extreme weather. This can occur for example, when a cold downpour of rain hits the system after it has been sitting in the hot sun for some time. In addition, it is normal for the enclosure air temperature to track the external air temperature and as the fans cycle on and off. However, if you observe the lower casting zones, backplate or the CCD coolers are not controlling to a high degree of stability you may have a problem.

Check the status of the LEDs on the opto-isolated heater drivers on the TCB. They should be off or dim/flickering once warmed up. (Note that the Model RSS-1024 does not use the upper snorkel heater zone required by the Model UVRSS-1024 so some LEDs are normally off or not isntalled.)

> **WARNING**: Although rare, if a fuse on one of the opto-isolated heater output drivers blows, the LED will turn on continuously, indicating that zone is calling for heat, but none is being delivered. These fuses are located under the shiny metal retainers that are swung to the side to access. Before attempting to remove a fuse, shut down the system and remove the suspected fuse. Check the fuse by using a DVM to check continuity. If a LED is out you might suspect that the fuse is blown.

If the fuse appears OK, contact YES technical support for further help.

Hard disk RAID array problems

There are two redundant disk drives in the system that store data. On the Web interface, drive "had" is the primary or first IDE channel (marked IDE0 on the core CPU motherboard) and device "hdc" is the second IDE channel (marked

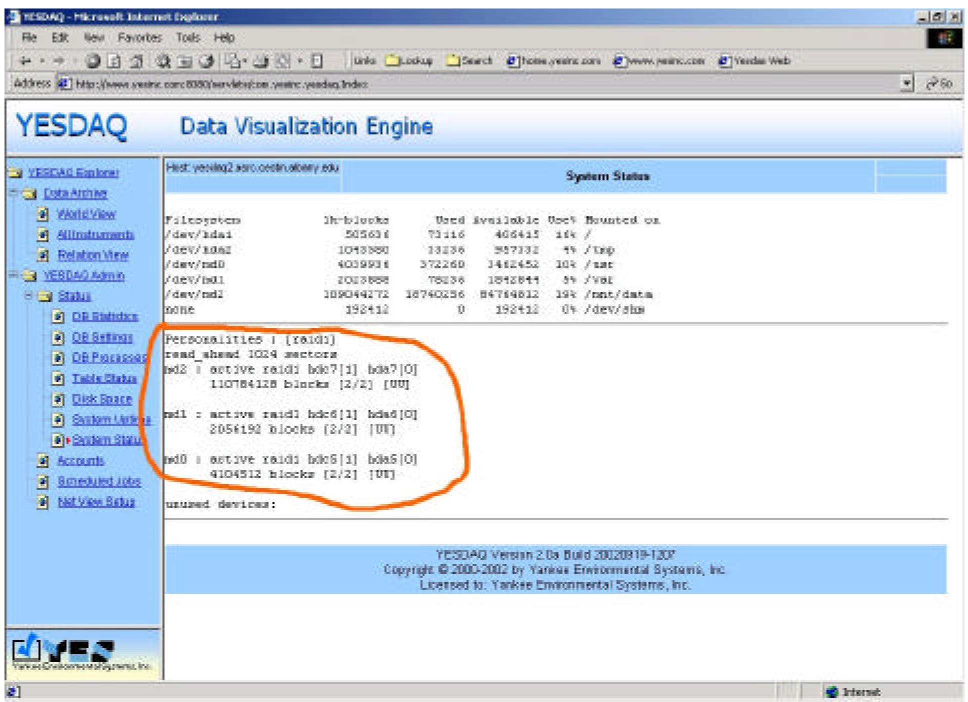
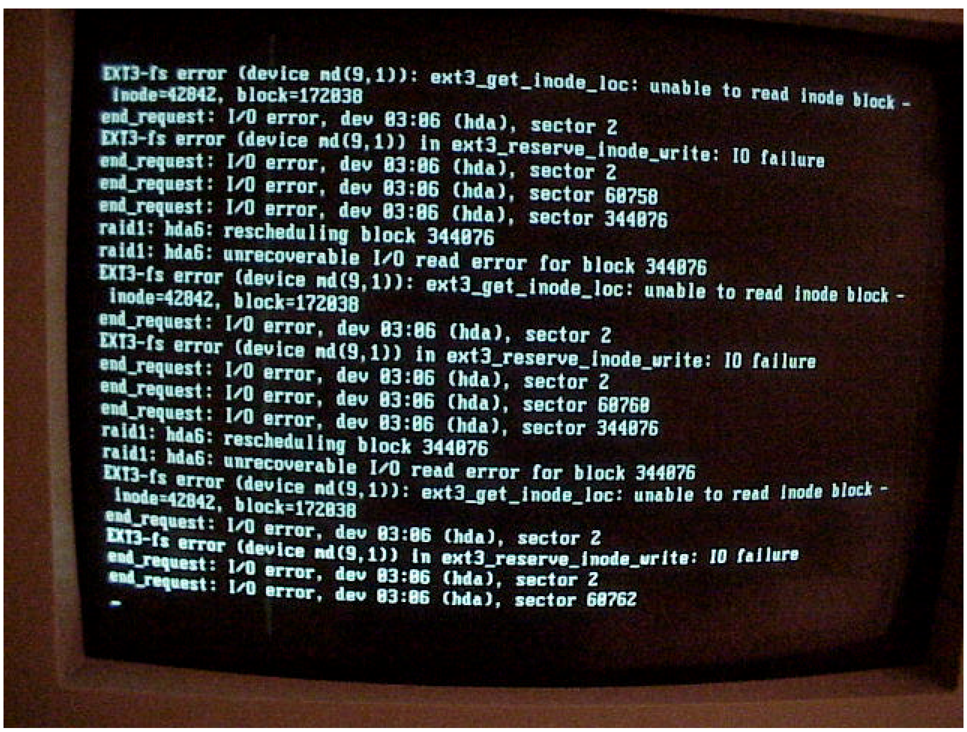


Figure 89. DVE Status view showing device HDA.

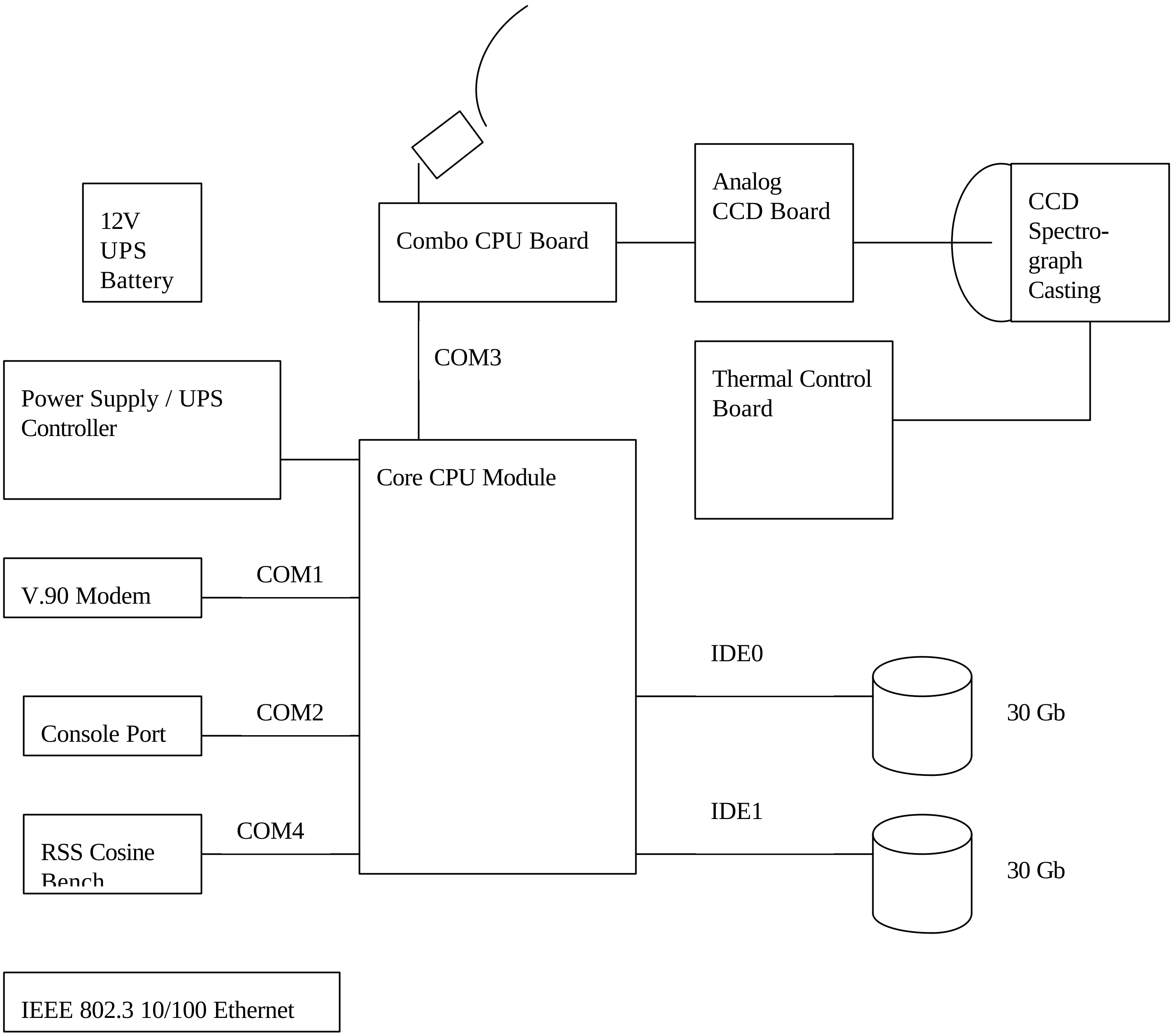
IDE1).

Figure 90. VGA monitor connected directly to the DB-15 VGA port on to the core CPU showing messages seen with hard disk failure.

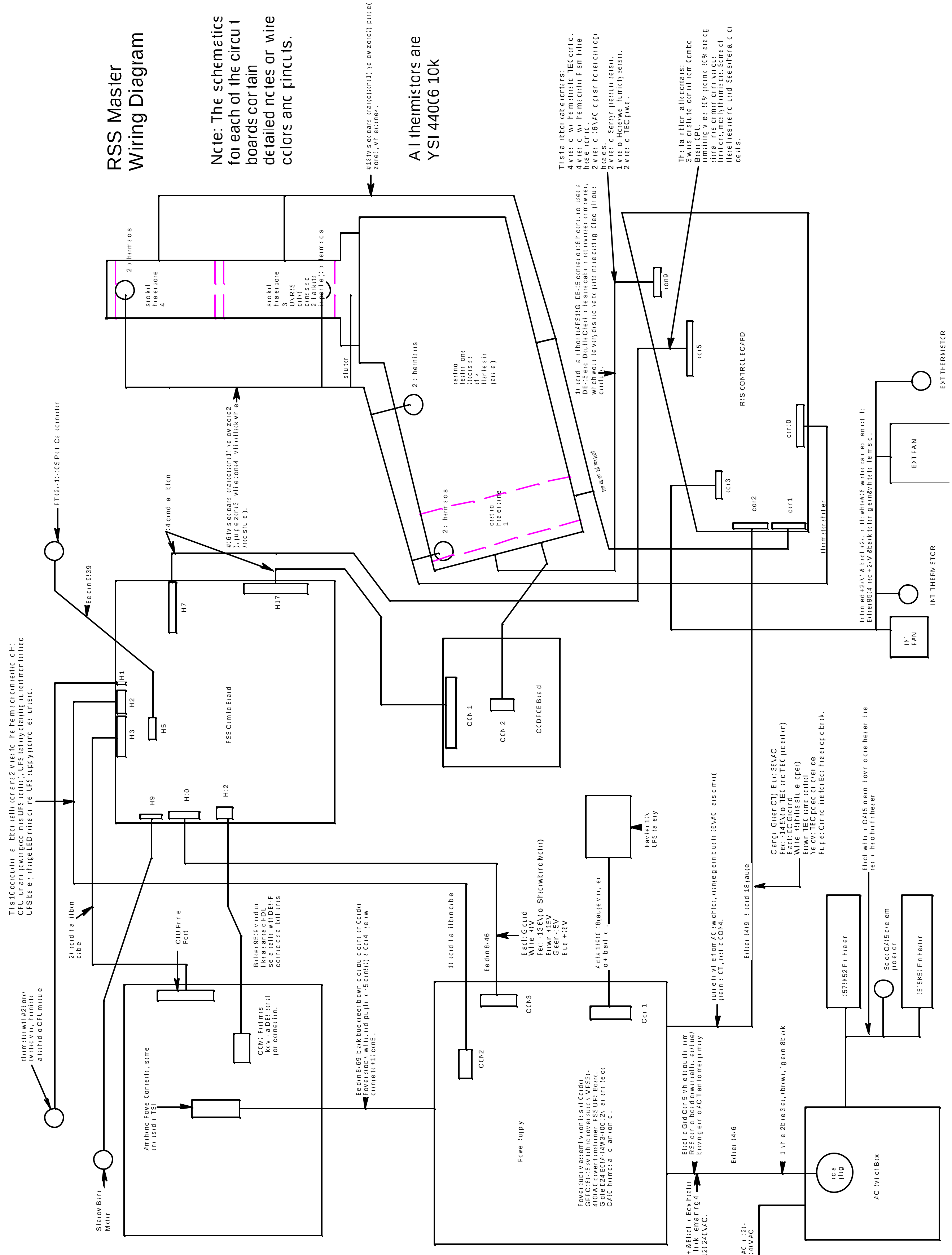


Look at the messages on the console screen or in the message logs. A failed drive is indicated by messages such as **I/O Error, and Sector Error.** If **hda** is failing, go to step 6. If **hdc** is failing, go to step 5. If hdc is failing, you can simply shut down, remove the bad drive and replace it with **an equivalent or larger** size drive. Now reboot, and hdc will automatically mirror from hda. Wait for this to complete before putting the system back into service.

If hda is failing: shutdown, remove hda (first IDE channel). Remove hdc (the drive on the second IDE channel), and put it on the first IDE channel (the former place of hda). Do not put anything on the second IDE channel, unless you have a replacement drive ready **(equivalent or larger size).** Then boot up with the rescue disk provided to you with the system (should be taped inside the enclosure).Once the system is up, (booted off the floppy), reboot it by pressing ctrl-alt-del and remove that floppy disk. It should now reboot properly without a floppy, since on this shutdown the boot sector (lilo) got written. You now have no second drive. Buy one and follow the procedure for what happens when hdc fails in step 5. When the new drive is placed in hdc, the data from hda (previously hdc) will be mirrored over.


12V
UPS
Battery
Combo CPU Board
Analog
CCD Board
CCD
Spectro-
graph
Casting
COM3
Power Supply / UPS
Controller
Thermal Control
Board
Core CPU Module
V.90 Modem
COM1
IDE0
Console Port
COM2
30 Gb
IDE1
RSS Cosine
Bench
COM4
30 Gb
IEEE 802.3 10/100 Ethernet

Master Wiring Diagram



Documentation Feedback

While we have tried to provide the highest level of technical accuracy in this document, our documentation team welcomes any comments you may have, both positive and negative. Please do not hesitate to contact us via any of the methods listed in the section *In this Manual*, located just after the table of contents.

Also, be sure to check our corporate web site for the latest technical information on the RSS and YESDAQ—look in the *support* section, under the RSS and YESDAQ data sheets and in the *frequently asked questions* link. In addition to providing the latest development news, the YES web site www.yesinc.com offers downloadable software updates to licensed customers, and tutorials on topics too changeable or complex to be covered in a printed manual (such as videos demonstrating complicated service procedures). You can also submit feedback and questions directly to the YES engineering team via email links.

APPENDIX A

Ozone Absorption Coefficients and SSA

The ozone absorption coefficients listed in the table that follows are based on E.P. Shettle & S. Anderson (1995), "New visible and near IR ozone absorption cross-sections for MODTRAN", Page 335-345 in the "Proceedings of the 17th Annual Review Conference on Atmospheric Transmission Models, 8-9 June 1994, Edited by G.P. Anderson, R.H. Picard, & J.H. Chetwynd PL-TR-95-2060, Phillips Laboratory, Hanscom AFB, MA, 24 May 1995.

The complete ozone cross section routine, which includes temperature dependence and interpolation to arbitrary wavelengths, is available from Eric Shettle at the Naval Research Laboratory (**shettle@poamb.nrl.navy.mil**). Note that temperature dependence becomes significant only away from the peak of the ozone absorption, where ozone attenuation is only a couple of percent or less.

For more information on using the coefficients to calculate ozone optical depth, see page 3-18.

Ozone Absorption Cross-Sections (10^{-24} cm^2/molecule) at Room Temperature

WAVELENGTH (NM)	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
400	.000	.000	.000	.000	.000	.000	.000	3.100	7.100	9.900
410	12.000	13.300	12.400	10.800	11.200	14.000	17.500	20.200	21.700	22.000
420	21.900	22.900	26.300	32.200	40.100	48.100	53.300	53.700	51.000	48.700
430	48.200	51.100	58.900	66.300	68.700	68.400	68.800	72.000	80.600	94.200
440	112.00	129.00	141.00	151.00	153.00	148.00	140.00	135.00	137.00	148.00
450	162.00	171.99	176.96	176.09	176.03	182.28	198.38	225.65	259.52	294.44
460	329.76	357.24	370.84	370.21	353.46	332.99	321.90	331.93	350.67	367.43
470	386.42	395.21	401.45	401.24	412.04	439.05	483.80	534.56	594.69	655.54
480	723.08	772.08	808.57	820.76	803.86	776.56	755.50	741.39	744.46	767.75
490	801.9	824.0	839.5	847.8	865.0	882.0	917.4	966.6	1028.1	1105.4
500	1197.8	1294.2	1390.4	1479.0	1547.5	1596.4	1613.6	1607.8	1589.5	1558.8
510	1536.1	1522.9	1540.0	1567.7	1602.6	1636.2	1669.1	1702.4	1732.2	1763.4
520	1800.4	1854.9	1912.3	1985.1	2071.3	2166.6	2260.4	2363.3	2459.1	2552.9
530	2635.1	2706.1	2761.6	2797.5	2816.6	2821.2	2814.8	2813.4	2825.9	2852.6
540	2889.4	2935.2	2992.4	3051.5	3102.9	3153.3	3188.7	3226.7	3262.0	3286.1

WAVELENGTH (NM)	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
550	3316.2	3348.1	3383.6	3422.1	3467.9	3519.0	3581.9	3651.8	3729.6	3821.8
560	3914.1	4009.9	4102.7	4191.9	4267.9	4335.8	4400.1	4451.3	4506.2	4562.1
570	4616.4	4665.8	4708.8	4734.4	4747.9	4744.7	4724.9	4693.5	4655.6	4614.2
580	4571.3	4527.4	4488.4	4451.0	4423.5	4401.4	4385.3	4382.2	4381.9	4390.1
590	4409.5	4447.4	4494.5	4557.6	4637.3	4720.0	4810.0	4897.5	4979.3	5049.5
600	5103.6	5136.6	5153.7	5148.3	5123.9	5082.8	5026.6	4956.8	4880.6	4795.8
610	4709.0	4621.0	4535.0	4455.8	4375.9	4303.0	4233.8	4167.4	4108.1	4048.6
620	3997.7	3950.2	3898.5	3853.7	3808.4	3761.6	3709.1	3661.2	3609.1	3554.8
630	3503.1	3452.4	3402.3	3349.4	3295.6	3239.7	3184.3	3126.3	3068.3	3010.5
640	2950.2	2893.9	2841.3	2789.2	2740.6	2692.2	2648.1	2601.3	2557.8	2519.3
650	2477.4	2439.4	2399.6	2359.4	2318.1	2278.9	2238.6	2197.6	2157.4	2120.1
660	2083.4	2047.5	2011.1	1973.7	1937.1	1896.7	1855.3	1813.5	1772.3	1732.8
670	1693.6	1655.9	1617.2	1580.8	1545.7	1514.4	1481.9	1448.7	1418.1	1391.0
680	1366.3	1343.6	1322.5	1304.1	1283.4	1262.2	1237.0	1212.2	1180.7	1149.3
690	1119.5	1089.9	1060.3	1036.3	1009.3	981.7	955.6	928.5	904.9	883.1
700	861.76	841.55	826.76	809.54	793.93	780.62	767.97	756.17	745.52	734.49
710	724.72	716.32	708.82	702.84	700.02	692.97	684.60	670.77	654.27	634.31

WAVELENGTH (NM)	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
720	613.41	592.76	574.13	559.51	543.96	531.66	517.16	507.18	493.50	479.53
730	466.78	457.05	449.25	441.82	437.25	433.54	430.88	428.15	424.56	424.10
740	423.88	426.80	431.22	434.22	439.67	442.99	446.83	446.06	441.68	432.63
750	416.78	397.19	379.05	359.45	340.63	325.35	310.77	299.44	289.89	282.59
760	276.17	270.86	266.40	260.69	258.61	255.20	252.23	249.18	250.32	251.31
770	251.48	256.96	262.55	269.63	279.50	292.45	302.66	309.17	314.14	315.50
780	311.92	303.45	293.46	279.12	264.20	247.82	235.85	226.56	216.87	206.78
790	199.90	191.90	183.30	176.37	169.58	163.20	159.71	157.10	155.27	152.20
800	148.88	147.65	147.23	146.86	147.33	149.75	152.46	156.87	163.77	171.33
810	179.48	186.58	193.74	200.94	207.19	211.42	213.52	212.68	208.92	202.80
820	194.61	183.91	171.66	159.11	147.07	135.92	125.22	115.42	107.06	100.06
830	93.958	88.546	84.627	81.429	78.482	76.794	76.048	75.140	74.459	74.264
840	74.58	75.62	77.12	78.74	81.20	85.23	90.08	95.62	102.43	110.55
850	119.62	129.00	136.82	141.17	141.51	138.79	134.68	129.77	124.28	117.63
860	109.06	100.16	92.02	84.38	77.20	70.25	64.19	59.40	55.33	52.03
870	49.584	47.445	44.752	42.391	40.749	39.597	38.985	38.523	38.468	38.788
880	39.277	39.914	41.022	42.457	44.007	45.868	47.687	48.869	49.738	50.379
890	50.351	49.847	49.810	50.996	53.128	55.968	59.000	61.170	61.975	61.429

WAVELENGTH (NM)	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
900	59.584	56.846	53.845	50.679	47.593	44.097	39.991	36.704	34.152	31.681
910	29.225	26.833	24.876	23.290	21.425	20.142	19.446	18.616	17.947	17.370
920	16.821	16.572	16.503	16.333	16.255	16.372	16.464	16.418	16.283	16.451
930	16.506	16.689	16.620	16.224	16.310	17.032	18.342	20.250	22.842	25.640
940	28.997	32.766	36.226	39.129	40.494	40.187	38.485	34.927	31.353	27.402
950	24.345	21.292	19.378	16.831	15.120	15.115	14.358	13.677	12.710	11.613
960	10.656	9.900	9.293	8.866	8.599	8.295	7.920	7.137	6.496	6.058
970	5.446	5.003	4.651	4.341	4.207	3.977	3.942	3.827	3.777	3.701
980	3.676	3.841	4.032	4.367	4.989	5.915	7.191	8.732	10.413	12.460
990	18.024	30.485	27.133	21.950	21.949	21.024	17.237	13.447	11.339	9.501
1000	7.456	7.291	5.993	5.603	5.164	4.140	4.452	3.733	3.303	3.501
1010	2.965	2.673	2.804	2.559	2.322	2.200	2.250	2.078	1.892	1.889
1020	1.808	1.631	1.532	1.452	1.463	1.406	1.329	1.351	1.402	1.384
1030	1.420	1.410	1.463	1.525	1.564	1.662	1.764	1.876	1.944	2.073
1040	2.282	2.512	2.745	3.104	3.730	5.270	7.263	5.683	5.129	5.166
1050	4.980	4.406	3.500	3.188	2.659	2.647	2.225	2.262	1.937	1.926
1060	1.834	1.705	1.849	1.852	1.987	2.347	2.290	1.889	1.746	1.879

WAVELENGTH (NM)	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
1070	1.671	1.422	1.280	1.116	1.073	1.104	.939	1.014	.885	.840
1080	.762	.697	.709	.723	.685	.662	.786	.727	.712	.628

Retrieving Single Scattering Albedo

Propagation of electromagnetic radiation in the atmosphere (light) is affected by a variety of mechanisms involving scattering, absorption, re-emission and reflection. Quantifying scattering is challenging as it involves a number of mechanisms that are geo-spatially and wavelength dependent. *Rayleigh* scattering is due to small particles, i.e. air molecules. It affects light on the blue end of the spectrum strongest, and is the reason the sky appears blue. *Mie* scattering is created by larger particles, mainly water vapor, and is responsible for the white appearance of clouds. Finally, tiny suspended aerosols produced by oceans dust from deserts and point source pollution.

Accurate knowledge of scattering is critical to a number of real time and modeling applications involving atmospheric transmission and climate forcing. Essentially, the direction an observer is looking relative to the sun's current position governs the scattering of light between the object and the observer. Forward and back scattering of sunlight into the observer's field of view greatly impacts image contrast.

Aerosol *single scattering albedo* (ω) is the ratio of aerosol scattering coefficient to total aerosol extinction coefficient at UV-A wavelengths of 320-400 nm. It is an important aerosol radiative parameter in determining surface irradiance. It assumes each photon is scattered exactly once by a single particle (e.g. a spherical aerosol). In practice, multiple scattering is occurring. However, SSA is a useful conceptual value that drives the downstream visibility models. SSA is vitally important to a number of visibility and remote sensing satellite data validation problems.

Note: Single scattering albedo (SSA or ω), a metric that describes scattering, is a theoretical construct that is a critical input to atmospheric correction models. In theory if one could make a purely single scattering atmosphere, there would be no information about single scattering albedo at all. In other words, if all photons coming towards you were scattering just once, there would be no information about SSA. The only reason there is some information in practice is that some photons are multiple-scattered. The dominant scattering mechanism at short wavelengths is Rayleigh scattering (and is why the sky appears blue). The beauty of this is that we know the Rayleigh scattering function exactly. SSA retrieval therefore depends on the fact you always observe multiple scattering photons.

Measuring SSA involves a joint retrieval. To derive SSA, one first must make well calibrated down-welling spectral direct and diffuse irradiance measurements at the earth's surface during the launch or satellite overpass. Surface irradiances must be accurately known and they must be split in their direct and diffuse components across the entire spectral passband of interest—the RSS-1024 provides this ratio over typical visible/NIR spectral ranges of interest. Using a suitable bi-directional reflectance model, you can model the outgoing surface irradiances and ultimately the expected visibility from observation cameras.

The measurement of phase functions are sensitive to multiple scattering photons, requiring a relatively cloud free sky. Conditions in tropical and subtropical domains exacerbate this requirement. At short wavelengths, where scattering is highest, multiple scattering is so high that one can infer something about SSA via the RSS-1024's direct-to-diffuse ratio from 360 to 400 nm. A SPUV-10 is required to get the scattering function as you cannot derive phase functions from an RSS-1024 alone. In *very clear* sky conditions can you get partial phase functions from a SPUV-10. Co-located SPUV-

10 almucantar scans (a circular scan of the sky taken at the current solar zenith angle) provide another data pathway. However these scans are temporally slow and so the two instruments used together are ideal. The use of TSI-880 sky imager to screen SPUV-10 almucantar scans is also critical as all it takes is a few white puffy clouds and the almucantar-based algorithm fails. The number of days when there are no clouds in the sky can be few.

Note that at longer wavelengths one cannot readily get SSA, as Rayleigh scattering goes down as $1/\lambda^4$ so you'll see only1/ 16^{th} the Rayleigh scattering at 1000 nm vs. 500 nm. This implies there is very little info about SSA at longer wavelengths—there is simply no information there.

General Procedure

There are several paths to get the single scattering albedo (SSA) but the general idea is to use DISORT as a forward model, and vary the forward scatter parameter iteratively until you close in on the same direct-diffuse ratio of the spectral irradiance as measured by the RSS-1024. A general procedure follows, which uses a pair of TSP-700 pyranometers, an RSS-1024 and a TSI-880:

1. Use a co-located TSI-880 total sky imager to filter out all cases of clouds in the data. Note that a sun photometer alone can't provide this screening.
2. Take the log extinction (OD) as a function of wavelength. Roughly 90% of the instrument challenge involves this step and the RSS does this automatically.
3. Retrieve ozone and AOD as a function of wavelength that is independent of total optical depth doing this correctly is non trivial, but the RSS does this step. Ideally, a co-located UVRSS can get an ozone value independently, but the RSS values within the ozone-affected chappuis bands are typically suitable.
4. Get Aerosol Size Distribution (ASD): For SSA, you don't need the aerosol scattering phase functions exactly, and you only need it over the wavelength range you are working (i.e. you don't need to extrapolate them). An aerosol model retrieval or an Angstrom fit in wavelength (inferring there is a power law distribution is size), works. King's algorithm for size distribution is imperfect but typically works well, and again the RSS provides this.
5. You next will need to measure surface albedo reasonably accurately, via two pyranometers one aimed up and the second down (Model TSP-700). Making this albedo measurement over the ocean is easier than land, but you will want to work at wavelengths shorter than 650 nm, due to the chlorophyll edge in the oceans. Getting the surface albedo correct strongly biases you to working at sites where the surface albedo is homogeneous over a domain of at least 10 km in radius - a drilling platform out in the middle of the ocean is ideal.
6. Once you know the ASD, Mie theory code predicts scattering answers in terms of infinite series of Bessel-Legendre functions. We numerically evaluate a solution for this series of functions, producing scattering phase functions. The Model SPUV-10 provides this phase function.
7. These scattering phase functions go into TUV or DISORT (discrete ordinates model) or any radiation transfer aerosol scattering model that predicts scattered light at the ground. We're trying to model the *diffuse* light at the surface—so

any model that will predict the diffuse irradiance also produces a diffuse horizontal irradiance (with the exception you don't know the correct SSA for DISORT.)

8. The modeled diffuse irradiance is either up or down-welling, and we iterate a chosen value of SSA until you get the DISORT modeled direct-to-diffuse ratios to agree with the RSS measurement. In practice, the SSA never exceeds one, and is not less than 0.85 under ordinary climatological circumstances (at non-polluted sites e.g. not downtown of metropolitan cities). 0.85 is actually fairly low, normally SSA will not be less than 0.92. Iterations between 0.9 to 1.0 work well.

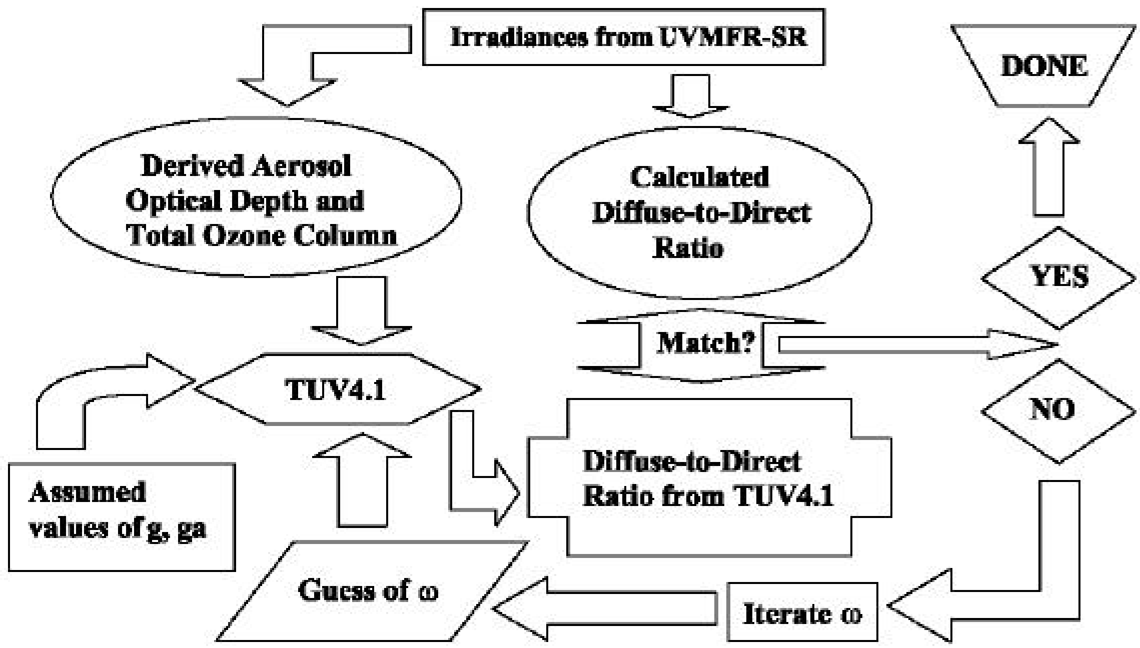


Figure 91. Diagram outlining the inversion process of single scattering albedo retrieval.

Limitations of the method

Retrieving SSA to two digits of significance is currently about the state of the art, as so many assumptions and steps are involved. The RSS' virtually instantaneous measurements of the global/total, diffuse and direct normal spectral irradiances and the Harrison Objective Algorithm then screens direct normal spectral irradiance into a *spectral optical depth* plot. Pixels within absorption features (as modeled by a HITRAN simulation) are removed for further consideration. All pixels are further processed by the King algorithm to extract ozone, Rayleigh and NO_2 optical depth components, to yield aerosol optical depth (AOD). Finally, the spectral AOD is then inverted via the King method to provide aerosol particle size distributions, and ultimately a revised estimate of the AOD based on the particle size distribution (PSD) is calculated. Note that the care and selection of points to feed the ASD algorithm can be important.

Total sky imager data from a co-located Model TSI-880 can screen clouds that are present for the phase function quality control. NASA's Aeronet algorithms have tried to look at each side of an almucantar scan, looking for asymmetries, assuming these asymmetries are clouds. It then tried to “patch over” clouds via interpolation with mixed results. The instantaneous scanning time of the SPUV-10 and the statistics of mixed cloud cover improve this method over older spinning filter wheel sun photometers.

Sensitivity of King PSD algorithm to number of pixels used for ASD

The care and selection of pixels to use as input to the King algorithm has an impact on results. Below is an example of aerosol size distribution retrievals using every third pixels (on left) and every other pixel (at right). Note, however, that below these graphs the corrected AOD is quite similar. Rather than changing the spectral sampling rate, removing an array end point has a much stronger effect.

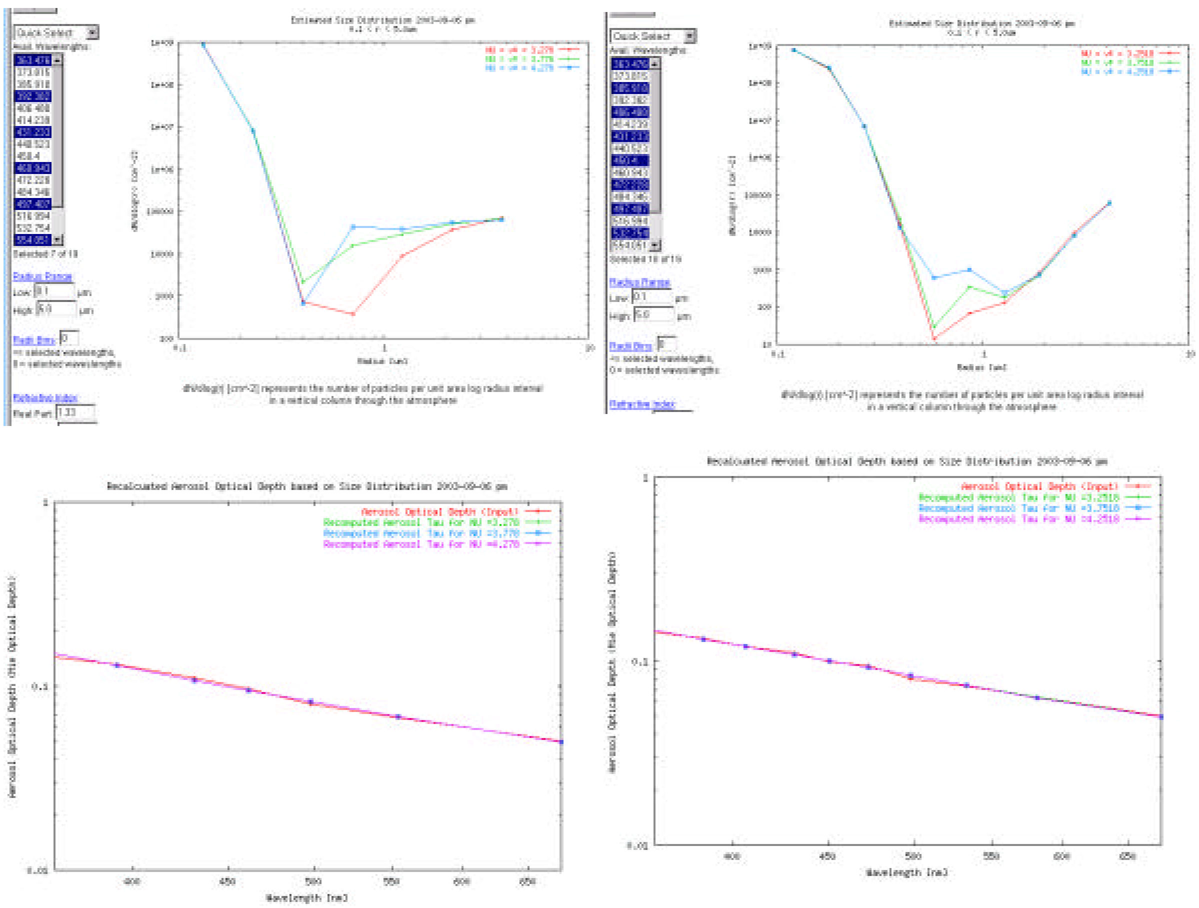


Figure 92. Example showing sensitivity of King ASD algorithm to the number of pixels selected (every third pixel at left, and every other pixel at right). Note how the recalculated AOD (below) changes little. The RSS allows the user to pick and choose the exact number of pixels used as input.

Practical Limitations of the King ASD Algorithm

One cannot always be guaranteed a *unique* solution to the particle size distribution inversion problem. The King algorithm is the only commercially available PSD algorithm and runs on the RSS. Although the King algorithm works well, under cloudy conditions the method is imperfect and has known pathologies. Without the rigorous screening provided by the Harrison Objective Algorithm, in rare cases it can produce tri-modal particle size distributions (that are clearly aphysical), or can over-predict large particles (producing a total column mass that is impossibly large). One could theoretically constrain the algorithm so it is less unstable, and a recent paper (by Amato et al), describes a parametric form of log normal distributions in $r^3n\ d(r^3)$ or volume dn/dv, where *n* is the number of particles. This added constraint tries to guarantee that you don’t get aphysical, explosive, impossibly large mass consequences in the PSD retrievals.

APPENDIX B
References

The RSS has evolved from an earlier class of instrument over the past decade and is at the center of a large variety of research efforts. Spectral irradiance data from an RSS can be used for a wide variety of purposes ranging from satellite calibrations to climate and renewable energy research. Many applications involve specialized retrievals from the direct-normal spectral data and the ODBC functionality in YESDAQ permits links to nearly any data system.

One of the most exciting applications of RSS data has to do with extracting column ozone and aerosol particle size distributions (ASD). The entire topic of optimum retrievals of ASD is an area of intense scientific research and debate. The RSS includes an implementation of the King (et al) ozone and ASD algorithm, and we have enclosed the papers describing these methods below. For purposes of completeness, we recognize the King method has its weaknesses and have included a paper by Amato that discusses these limitations. While this paper claims a better-generalized solution of ASD inversions, it does so only with synthetic data.

Another paper discusses the extraction of ozone from UV data, and a fourth covers the extraction of instrument stability by tracking Langley plot-derived V_o's over extended periods of time.

Below is a partial summary of published work on the instrument. If you are interested in learning more about the algorithms and history of development please consult these published documents. We hope you find these papers interesting and encourage your feedback and research participation.

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APPENDIX C

Comparison of RSS data to Legacy Sun Photometers

The RSS represents a new approach to deriving real time, simultaneous acquisition of direct/diffuse/total spectral irradiance. It provides on board algorithms for producing column ozone, total and aerosol optical depth, as well as aerosol particle size distributions. Unlike legacy sun photometers and mechanically scanning spectroradiometers, the system makes direct normal, diffuse and total/global spectral measurements essentially instantaneously via a scientific-grade cooled CCD. For these reasons and because it makes measurements via a radiometric stable detector, comparing data to older instruments is a non-trivial task. In this section we explore this problem.

Attempting to infer from sky radiance distributions is challenging. Basic Mie theory is covered well in Craig Bohren and Donald R. Huffman's *Absorption and Scattering of Light by Small Particles* 1983 Wiley. A slightly older text is *Light Scattering by Small Particles* by H.C. van de Hulst. One would ideally like to have measurements over a wider spectral range than is practical to make via available technology. We define *phase function* as scattering a function of direction as measured directly by sun photometer.

Caveats

Before we look at some actual solar data and compare retrieval products, there are several key physical differences between classical collimated/limited field-of-view interference filter sun photometers vs. the rotating shadowband method. These differences need to be considered, including:

Temporal averaging: the RSS makes a nearly instantaneous measurement of the diffuse sky irradiance, whereas the sun photometer can take up to six minutes to make a sky radiance measurement. Over six minutes the cloud / sky state and sun angle can change dramatically. Only in perfectly clear days will the instruments agree.

Radiometric Stability: The pass band throughput of interference filter-based radiometers tends to drift over time and solar exposure. Filter radiometers that are sealed and internally thermally controlled (such as the SPUV-10 and MFR-7) exhibit much more stability over time. Low cost sun photometers using interference filters that are not water vapor tight and/or thermally controlled tend to drift over time and temperature. The root cause of this drift is the hygroscopic glues used to laminate the different glass layers. Interference coatings are deposited on many layers of glass that are then used to build up the optical cavities. These stacks of glass layers form the interference filters and delaminate over time under exposure to intense light, heat swings and water vapor. You must keep water vapor molecules away form the filters, and only heat and O-rings can do this.

Pointing accuracy: The RSS has a single axis of rotation and re-aligns its shadowband before every measurement, and long term pointing accuracy is therefore not an issue. Conversely, legacy sun photometers rely on automatic or semi-automatic trackers and often suffer from pointing errors after several days or weeks due to cable or mechanical drag. These subtle pointing errors can be difficult to detect in the data. And while lower cost, handheld sun photometers are often misaligned in the short term, making their data suspect.

Sky radiance vs. irradiance: Technically, the RSS and other instruments measure *spectral irradiance*. The CIMEL measures sky radiance, but it takes many minutes to do so and sky conditions typically change during this scan. Anything you can physically measure is a measure of radiance over a finite solid angle, albeit a small one. The CIMEL makes multiple almucantar scans and each can produce an aerosol size distribution, while the RSS provides one for the morning and potentially a second for the afternoon.

Data retrieval reliability: Stand-alone instruments such as the CIMEL rely on GOES/METEOSAT satellite data communications and often lose data at the link level. A look at NASA Aeronet data reliability index shows this problem graphically.

Data screening and real time availability: The RSS uses TCP/IP and the Internet to present data in real time to your web browser. However, the NASA Aeronet program using CIMELs has an official policy to selectively screen some of its data products manually prior to presentation. Further, Aeronet only takes conditions from CIMEL almucantar scan measurements, which take many minutes and are done rarely. Compare this to the 30 or 60 second real time data rate an RSS produces. If one is trying to coordinate surface spectral irradiance data with satellite overpasses, access to real time RSS data is very useful.

The problems with tracking sun photometer/filter radiometers are actually five-fold:

1. The long term stability and throughput of interference filters is suspect, requiring frequent absolute and spectral calibrations.

2. They take a long time to physically scan the diffuse sky using a tracker. And unlike the SPUV-10 that makes an instant measurement, spinning filter wheels in the CIMEL further slow down these diffuse sky scans.

3. They provide just a small set of fixed spectral channels, that must be carefully interpolated in order to be used with hyperspectral satellite data.

4. They suffer from pointing accuracy, as the tracker inevitably gets mechanically misaligned off the solar disc.

5. Some off axis light is always scattered into the collimator and thus into the detector. At the edge of the collimator’s input aperture, diffraction effects scatter light. The detector sees these additive photons and the algorithms incorrectly believe the photons came from within the field-of-view of the collimator when it did not. The most important component is the forward scattering but most sun photometers such as the CIMEL have trouble due to off axis light getting into collimator.

This last problem is readily observed if one conducts a simple experiment with a sun photometer: On a perfectly clear day, let the instrument make an almucantar scan. Immediately take a second almucantar scan, but this time use your hand or a shading disk to carefully shade only the collimator’s input from the sun’s direct normal beam. The data from the two scans will be significantly different, showing that there is significant off axis light from the powerful direct beam that enters the collimator.

Comparing the RSS to Solar Tracking, Filter-Based Sun Photometers

Multiple optical parameters are required for satellite validation. There is unfortunately no commercially available field instrument that that solves all measurement problems well. The table below summarizes which class of instrument is better at various parameter retrievals.

Parameter retrieved	**Optimal Instrument**	**Reason**
Spectral irradiance	RSS-1024	CCD provides whole spectrum, there are no filters to degrade, produces instantaneous spectra with no temporal smearing, PFC-5001 field calibrator provides radiometric traceability
Aerosol Optical Depth	RSS-1024	CCD, instant
Particle Size Distributions	Both	RSS includes software, the CIMEL doesn't. CIMEL has more sensitivity to large particles, which might be a problem. Whether the sensitivity and inversion is real, remains an open question.
Phase function	CIMEL-318	Provides a direct measurement of phase function, albeit only under *perfectly clear* sky conditions. RSS *cannot* measure phase function
Column Ozone	RSS-1024	King method included. CIMEL provides no useful ozone information
Column Water Vapor	RSS-1024	RSS (Current CIMEL processing, lack of filter functions, no temperature control etc. mean CIMEL retrievals are highly suspect)
Sky radiance	Both	CIMEL makes a direct sky *radiance* measurement of diffuse over 6 minutes; the RSS measures the diffuse spectral irradiance but does so *instantly*
Direct/diffuse ratio and total irradiance	RSS-1024	RSS measures both direct and diffuse instantly, CIMEL *cannot* measure the total downwelling irradiance.

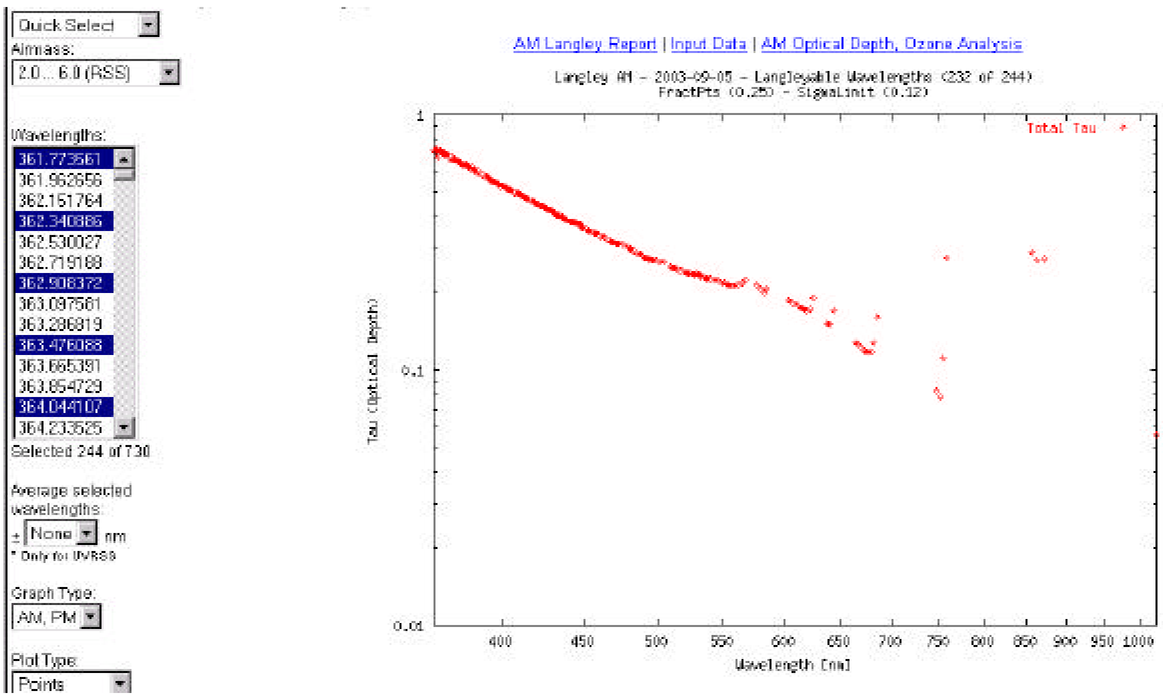
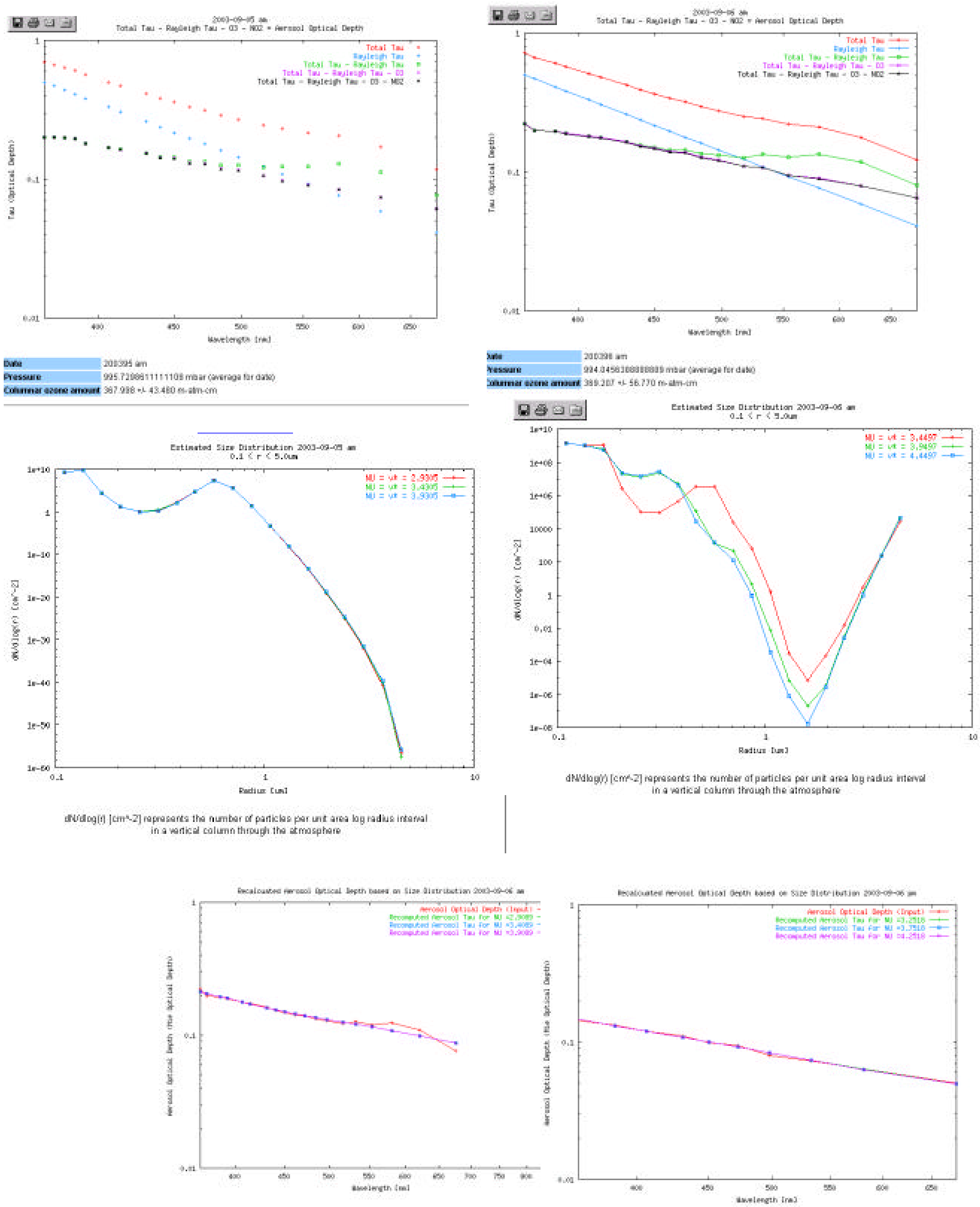


Figure 93. Typical RSS spectral optical depth plot, taken after application of the Harrison Objective Algorithm but prior to ozone analysis. 244 pixels/channels meet the criteria for processing, out of 730 that are not in regions of absorption > 1%. Note this plot reprlesents 244 Langley plots.

A look at two clear days with an RSS-1024



instrumentation is a recent trend. Development on the RSS concept started

Figure 94. Sept 6, 2003 Ozone/Rayleigh/AOD (left side) and Sept 5, 2003 (right side). Optical depths at top, Aerosol Size Distributions are in center and recalculated AOD for Sept 6 are at bottom.)

in the early 1990s at the State University of New York at Albany's Atmospheric Sciences Research Center, and was aimed at making fundamental accuracy and reliability improvements in the automated retrieval so spectral irradiance over conventional sun photometers.

In 1994, Yankee Environmental Systems received a US Department of Energy (DOE) contract to develop a commercialized version to support ongoing remote sensing programs. The US DOE operates in conjunction with the US Department of Defense (DOD) and NASA, a number of satellites used for planetary and military surveillance. Initially, the RSS was developed to support planetary science research, for example, the development and verification of so-called of global circulation models. The initial customer was the DOE's Atmospheric Radiation Measurement Program. However, remote sensing hyperspectral satellite imagery must be validated via calibrated ground instrumentation before atmospheric corrections can be applied to derive intelligence from the data.

Instruments such as the SPUV-10 and MFR-7 employ silicon diode detectors and thus suffer from conventional *kt/q* noise. Diode detectors actually convert a quanta of photons into a single electron, which must then be either analog integrated (which adds noise) or instantaneously digitized. Diode arrays are simply a row of individual silicon detectors mechanically arranged and spatially packaged into a single line. The first RSS used a diode array as a detector but as commercially available slow-scan charge coupled device (CCD) detectors were introduced, the RSS was redesigned to use this much more sensitive spectral detection technology.

In contrast to linear diode arrays, CCD's are typically 2-dimensional arrays of pixels and accumulate charge produced by arriving photons in a capacitive pixel well. These "charge buckets" can be periodically readout and essentially provide optical integration (as opposed to much noisier electronic integration.) CCD's in this respect act more like photographic film. They build up charge during an exposure just prior to readout via an A/D converter. And because they are two dimensional (the CCD device in the RSS is 256 x 1024 pixels) they can be *column binned* which greatly enhances performance. Furthermore, scientific grade *slow scan* CCD's differ from conventional CMOS video devices as they offer improved low noise performance if thermoelectrically cooled and stabilized.

Note: The cooled CCD part used as the RSS detector is very similar to the CCD device used in the Hubble Space Telescope's deep field imager. After months of long, continuous exposure to the same area, Hubble's deep field imager observed *hundreds of galaxies* in areas previously thought to contain no observable stars. This discovery has radically changed our understanding of the total mass of the universe and uprooted previous assumptions about the behavior of gravitational forces and dark matter.

YES tested a the RSS in a 1997 field experiment held in Boulder, Colorado and shipped the first commercial system in 2000. As of this writing in 2003 over fifty cumulative years of field tests has taken place at YES, ASRC and at several government sites. From 2000-2001 at an extended test under the watch of USDA, NIST and NOAA, the RSS demonstrated a 99.9% data availability for production units. The single axis of freedom of the shadowband (vs. a dual axis tracker that can be misaligned) and the internal CPU and UPS is critical to attaining this reliable operation. Retrievals from remote locations require this reliability as communications links can fail.

The UV version of the RSS (the model UVRSS-1024 that covers 292-370 nm) has a smaller market niche in ozone measurement and specialized research applications. Compared to the visible/NIR model RSS-1024 has few applications outside UV research. One specialized application area currently evolving is open path monitoring of outdoor areas to detect the presence of hazardous gasses. When used with a discharge lamp as a source, the absorption spectral measurements the UVRSS provides can detect gasses such as ammonia (NH_3). This data is useful for real time monitoring of effluent from high-density bovine operations, for example from livestock feed yards.