ac Meter
Protocol Document

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Acknowledgements

While virtually everyone who has sought meaningful and consistent results has contributed to this evolution of the ac-9 protocol, several scientists provided pioneering efforts, and direct input on this document. They include Scott Pegau, Percy Donaghay, Mike Twardowski, Scott Freeman, and Alan Weidemann.

1. Introduction

The ac-9 was originally developed under Naval Research Laboratory sponsorship. Primary development occurred over a 6-month time span culminating in delivery in September 1993. Since initial delivery, approximately 180 more units have been used in applications ranging from tow-yos to long-term moorings. In 2004 a follow-on hyperspectral absorption and attenuation device, the ac-s, was also introduced. While the manuals for these devices cover basic operation and processing of the raw signals into engineering units, certain protocols for usage and data processing have been developed over the years, largely by the scientific community, to provide the highest possible accuracy in absorption and attenuation data and directly derived products. As a supplement to the ac-9 and ac-s user manuals, this document details these protocols.

Protocols for ac-9 and ac-s use are broken down into three primary sections. We first discuss basic operation and deployment issues. Second, we discuss the ac-9 laboratory and field calibration. Third, we delineate the steps for processing and correction of the data obtained by the instrument. These three sections are prefaced by an overview of the various engineering improvements that have occurred over the past few years. A final section provides a concise summary of the data processing steps as well as a reality check table for determination of data quality.

This protocol is intended as a hands-on guide for data collection and processing of data from the ac-9 and/or ac-s. For more general discussions of meter applications or measurement theory you may wish to consult the references contained in the back of the document.

One should remember that ac-9 and ac-s usage and data processing techniques are subject to continual evolution. This document attempts to summarize the state of the art in commonly applied techniques as they stand today. Even as the document is being written, researchers continue to explore and refine new possibilities in applications, calibration, and processing. Similarly, engineers at WET Labs continue to strive to improve instrument capabilities, reliability and ease of use. We urge researchers to stay in touch through our web site (http://www.wetlabs.com) or by calling us. Likewise, if you have any suggestions or additions to this protocol document please let us know.

2. Background and Evolution

2.1 ac-9

The ac-9 has gone through several major design modifications in the last several years to improve the overall stability and reliability of the instrument. Described below are some of the more significant changes that have been successfully implemented.

2.1.1 Interference Filters

The ac-9 uses nine band-pass filters to spectrally discriminate the light from a tungsten lamp. These nine filters are mounted on a filter wheel located in the transmitter pressure housing.

2.1.2 Absorption Detector

The absorption detectors have gone through numerous modifications in effort to improve long-term reliability, stability, and ease of manufacture.

2.1.3 Internal Optics

Optical mounts for all the lenses and filters were improved to provide better stability and easier meter assembly.

2.1.4 Windows

Pressure window apertures were increased to eliminate possible partial beam occlusions.

2.1.5 Flow Tubes

The flow tubes and sleeves went through several stages of modifications. Most recently inlet and outlet nozzle diameters have been increased to provide improved flushing.

2.1.6 Improved Referencing

The ac-9 employs a reference detector within the transmitter optics. This detector measures the output energy from the source that in turn provides a normalized output from the meter. With the original filters and optics, throughput in the blue region of the spectrum was not sufficient to allow one-to-one referencing. We thus integrated values of all three blue wavelengths and used the single value as a reference for the blue wavelengths. With the increased throughput provided by the new filters, we have returned to a one-to-one referencing scheme throughout the spectrum.

2.1.7 Electronics

In 1995 new electronics were developed for the meter. The new board set allowed more efficient manufacturing and characterization, more flexibility in interfacing, and improved resistance to shock and vibration.

2.1.8 Mechanical

ac-9 design employs a one-piece yoke, or “unistrut” manufactured from one solid piece of metal that effectively ties the ac meter into virtually one rigid optical assembly. This improves long-term stability as well as short-term variability due to mounting stresses.

Older ac-9's that use three independent stainless steel rods can be upgraded to the unistrut design. Please contact the factory for information.

2.2 ac-s

Based on the 9-wavelength absorption and attenuation meter ac-9 (Moore et al, 1992), the ac-s offers almost an order of magnitude increase in spectral resolution of in-situ absorption and beam attenuation coefficients. The ac-s features the same flow-through system as the ac-9, same size, and excellent stability. The ac-s employs a 25-cm pathlength for effective measurement in the cleanest natural waters. The light source employs a linear variable filter imaged with a collimated beam from a tungsten lamp. The absorption side has a reflecting tube and a large area detector, whereas the attenuation side has a non-reflective tube and a collimated detector. The instrument provides an 80+ wavelength output from approximately 400–730 nm with approximately 4 nm steps. Individual filter steps have a FWHM that range between about 10 to 18 nm. Because of the inherent similarities between the ac-s and the ac-9, all procedures described in this document regarding the ac-9 generally pertain to the ac-s as well, except where noted.

3. Operation

3.1 Orientation

Before testing your instrument, familiarize yourself with the ac-9 and the ac-s (Figure 1).

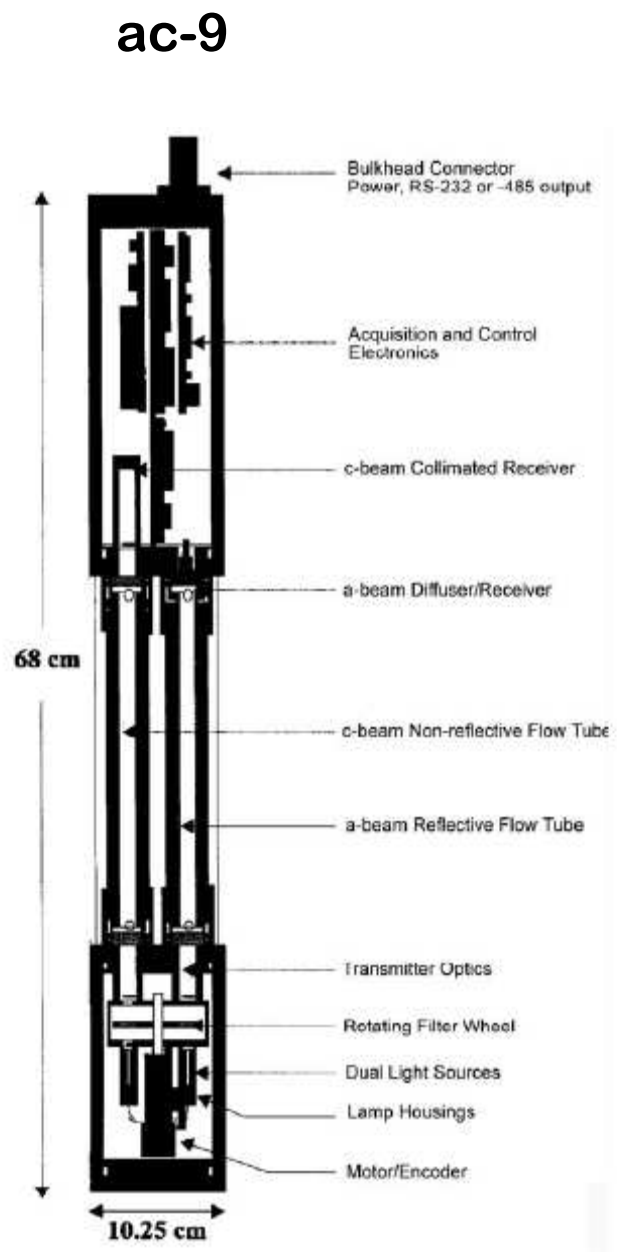


Figure 1. Description of ac-9 components, many of which are shared with the ac-s.

Both instruments consist of two pressure cans separated by a unistrut. The bottom pressure can houses the transmitter optics and filter wheel. The top can contains the receiver optics and the control electronics. Two removable plastic flow assemblies reside within the area separating the two cans. These two assemblies define the flow volumes for the absorbance and transmittance measurements.

Remove the black plastic flow tubes by sliding the flow tube sleeves towards the middle of the flow tube. The flow tube will lift out, exposing the transmitter and detector windows on the lower and upper flanges respectively. Be careful not to scratch the windows. The attenuation tube is different than the absorption tube. Its flow chamber is black plastic and the two sleeves on the tube are identical. This tube installs on the "c" side of the instrument (the side with the identical looking windows). The "c" tube has no "up or down" orientation. The absorption flow assembly is lined with a reflective quartz tube and one of the two sleeves is flat on top (the lip present on all the other sleeves is missing). This tube installs on the "a" side of the instrument that can be identified by the "a" detector that is on the upper flange and is the only window that is clearly different from the other three (has a white diffuser where the other windows are clear). The flow tube sleeve without the lip fits over the absorption window with diffuser, so there IS an "up and down" orientation to the "a" tube.

You may want to mark the flow assemblies and their orientation with tape or marking pen before using the instrument at sea so that there is no confusion when reinstalling the tubes after cleaning your optics. Incorrect installation of the flow tubes will result in incorrect optical measurements and water leaking around the sleeves because of improper o-ring seals (the absorption window with detector has a different o-ring than the rest of the windows).

When re-installing the sleeves of the flow tubes, line up the white nylon set screws with the grooves in the flow tubes. This will ensure that the water flow will not be blocked by the "tabs" on the ends of the flow tubes.

The flow tube for the "c" channel may be considered optional as long as the detector is not exposed to very intense ambient light (e.g., direct sunlight). This allows for the possibility of a free path attenuation measurement when the flow tube is absent. Stray light is normally not a concern with the "c" channel because of the collimating optics in the detector assembly. The flow tube for the "a" channel is always required.

3.2 Testing

Before deploying the ac-9 or ac-s in the field you will want to test the unit to familiarize yourself with the hardware and software, and to verify basic operation. Assuming that you are using the factory-supplied software (WETView) to perform these tests, you will require the following:

1. A clean, solid lab table or workbench;
2. The ac-9 or ac-s with test cable (or sea cable);
3. A power supply (the ac-9 and ac-s require 10–18 VDC);
4. A computer with WETView software installed for data acquisition.

Installing WETView is very simple. You will need a 400 MHz or better PC running the Windows 2000 or higher operating system with at least 10 Mb free hard disk space.

Create a directory or folder to copy the necessary files needed to install WETView onto your machine. Copy the entire contents of the two disks you received with your ac-9 into this directory on your computer. You should have the following files in your directory:

- WETVIEW.001
- WETVIEW.002
- SETUP.EXE
- WETPROCE.EXE
- AC9XXXX.DEV
- AIRXXXXX.CAL

One of the files copied is SETUP.EXE; run this program and follow the online instructions to complete WETView installation.

Connect the factory supplied test cable to COMM port in your computer (or USB port via a serial to USB converter). Connect the power leads to the power supply. The black lead is typically the V+ lead. Before connecting the cable to the instrument, use a multi-meter to check the input power. Connect the ground probe to pin 1 on the pigtail connector (the centrally located pin). Connect the hot probe to pin 4 (the pin directly opposite from pin 1). You should measure somewhere between 10–18 volts across these two pins. No other pins should have any voltage on them. Turn the power supply off. Connect the pigtail to the instrument. Push the connector straight on to avoid damaging the pins. Apply power to the instrument and allow it to warming up for about 30 s.

Run the WETView software by clicking on the icon in WINDOWS. When the interface is displayed, you will need to provide a device file name (DEV file). Click on the <O> button in the center top of the screen or choose “Open Device File” from the File Menu at the top left of the screen. Browse to the folder containing the DEV file. The program will ask you to choose the proper COMM port. Select COMM1 through COMM8 as appropriate. At this point, the software will do some handshaking with the instrument and the “Start Logging” Button (or the F1 key) can be used to start data collection. After 5–10 seconds, tabular data should be displayed on the right side of the screen. A real time graph will begin to develop, using the graph parameters set at the time. Please refer to the manual for the full details of running the WETView software. After a short time, click on the F2 button. Data collection will stop and you will be prompted for a file name to apply to the data if you should want to archive it. Press ESC if you do not want to save the data. To quit the program, choose QUIT from the File menu, not the (non-functioning) close button in the upper right of the program window. At this point you have successfully completed a bench test of the instrument.

3.3 Mounting

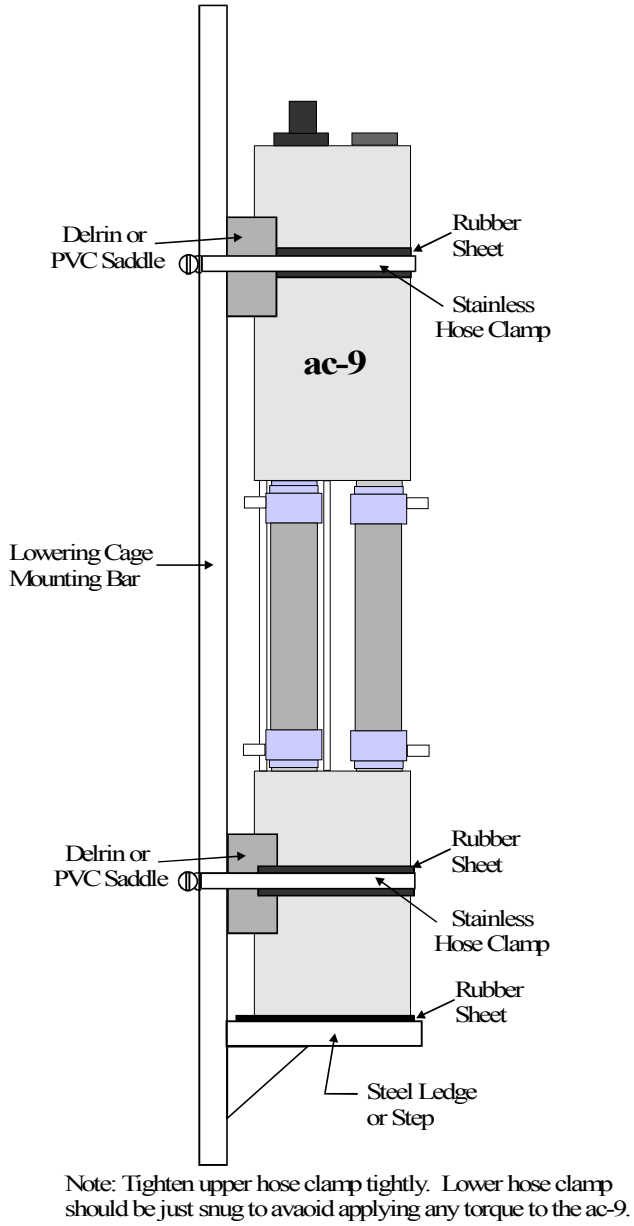


Figure 2. Deployment cage mounting suggestion for ac-9 and ac-s.

The ac-9 and ac-s contains two optical paths that are sensitive to lateral and torsional stresses. To ensure that the unit functions properly, it is important to minimize stresses when mounting the unit to a frame. If possible, the ac device should be mounted vertical. These sensors can be used in other orientations, but for the most accurate results field water calibrations should be carried out when in the preferred deployment orientation to account for drifts associated with small changes in the alignment of the optical paths. In the vertical orientation, it is preferable to rest the bottom of the ac device on the cage framework and attach both the upper and lower housings to the vertical framework of the cage (Figure 2). The housing attachments do not need to be any tighter than required to hold the ac device to the cage as the main support is the

bottom rest. If the ac device is to be mounted horizontally, it is critical to support both housings. If the ac device is mounted horizontally and supported by only one housing, more substantial deformation of the optical path will occur that may cause the unit to provide inaccurate readings.

3.4 Plumbing and Tubing

It is important to ensure good flow through the ac meter flow tubes. The flow rate through the instrument should be kept above 1 liter/min to resolve environmental changes over fine spatial and temporal scales. This can be achieved by maximizing the tubing size and using a pump such as the Sea-Bird Electronics SBE-5 running at a minimum 3000 rpm. The ac meter flow tube sleeve nozzles are ½ in. to improve performance by potentially increasing the flow rate and flushing through the flow assemblies, and to easily mate with the pump.

The detector for the absorption channels is very sensitive to external light, and the attenuation detector can be affected when exposed to intense ambient light, so it best to eliminate the leakage of any external light into the flow cells. This is accomplished by ensuring that all tubing attaching to the flow cell sleeves is completely opaque or covered with opaque black tape. Note that some electrical black tape is not completely opaque and can produce errors in absorption readings at the surface.

Tygon tubing and other varieties may contain plasticizers that could possibly affect the optical measurements if exposed to the sample for a significant amount of time. For short lengths of tubing in typical applications using continuous flow, the type of tubing has not proved to be a concern, as long as it is clean, laboratory grade. When using Tygon tubing, it is best to use a thick-wall tube to prevent kinks in the tubing or collapse of the tubing due to possible pressure differentials when pumping. Other types of tubing are available and include Teflon, Teflon-lined Tygon, and expensive grades of tubing without plasticizers. Many of the types of tubing are rigid and care must be taken to prevent kinks from forming.

The plumbing should be installed in a manner that ensures bubbles cannot be trapped anywhere in the system. A typical plumbing set-up is described. The upper and lower flow tube nozzles are used for the outflows and inflows, respectively. Opaque tubing is attached to the intake nozzles and dropped to the bottom of a deployment cage. The pump for the ac device should be placed above the upper set of nozzles of the flow tubes. A “Y” fitting is used to merge the outflows from the two flow cells into one flow that can be connected to the pump. On the outflow from the pump a bubble degasser is typically installed. This device is an inverted “Y” housing a Teflon insert with a small hole through the center that allows bubbles to escape the system. It is required that the pump pull the water through the tubes rather than push it through. The key consideration is that the plumbing configuration provides a clear path for bubbles to escape the system when the sensor is deployed. If small bubbles are lodged in the flow cells, the optical measurements will have errors. If bubbles become lodged in the pump, the pump will stall and not work.

Separate intake tubes for the “a” and “c” sides of the instrument are recommended over using “Y” or “T” fittings to separate the flow from a single intake tube. This is because evidence from laboratory measurements indicates that a “Y” fitting may partition some particles preferentially into one arm of the “Y” (Twardowski et al. 1999).

In profiling applications where the sensor package may experience abrupt changes in rates of descent and/or ascent, it is recommended that the inlet and outlet pressures of the flow system be balanced. This is achieved by assuring that the entrance point and exit point of the tubing are positioned at the same depth, i.e., a tube is installed that runs from the outflow leaving the pump to the bottom of the cage where the sample intake tube is positioned (taking care not to orient them too close together).

3.5 Attaching Prefilter to Remove the Particulate Fraction

An ac-9 or ac-s can be used to measure absorption by the dissolved fraction of water only. The dissolved material responsible for this absorption is collectively known as colored dissolved organic material (CDOM), "yellow matter," or Gelbstoff. A capsule filter, typically with 0.2 μm pore size, is attached in-line to either the "a" or "c" flow tube (or both) intake, so that particles are removed prior to measurement. It is best to carefully cut the outer capsule of the filter off with a saw (careful not to cut the filter pleats) to expose more filter surface area to the water. Because CDOM is primarily composed of hydrophobic humic material, it is essential that the capsule filter have a hydrophilic membrane. Otherwise, the filter may remove important hydrophobic dissolved material.

Because scattering from the material present in the <0.2 μm fraction from natural waters typically is negligible, attaching the filter to the intake of either the "a" or "c" side should yield the same results. This is actually an excellent test to determine if your meter is operating as expected. When deploying multiple ac devices, occasionally attaching prefilters to all the meters is also an effective means of cross-calibrating the sensors.

To measure both the dissolved and particulate fractions of water independently, a dual ac-9 or ac-s configuration may be assembled where one device has a prefilter (measures the dissolved fraction only) and the other device does not (measures the dissolved + particulate fractions). One ac device may be used to obtain the same set of data if successive casts are made, some with the prefilter and some without. Extra care must be given to purging the system of air when a filter is used, and there are other considerations to take into account, such as smearing of the data because of longer (and variable as the filter captures more and more particles) time lags (the time required for a sample to transit from the intake, through the filter, into the flow tube, and undergo measurement). Using a high-speed pump (e.g., 4000-RPM SBE-5) is recommended to minimize this effect. Even with a high-speed pump, however, time lags are typically greater than 10 seconds (see section 5.3).

3.6 Deployment

The ac-9 and ac-s may be used in a variety of deployment modes. While emphasis and protocol development has focused primarily upon profiling applications, the meter has also been used in moored, lab flow-through, autonomous underwater vehicle, and towed applications. Each of these modes requires some consideration in how best to optimize results from the meter. Below, some of the most important issues are addressed with the primary modes of deployment.

3.6.1 Moorings

Anti-fouling—One of the most problematic aspects of a moored deployment of any optical device is accumulation of biological growth on the optical surfaces. The enclosed

flow path of the ac-9 helps to retard biological fouling of the meter's windows and the reflecting tube. Additional protection against biofouling may be provided by using copper tubing on the inflow and outflow tubing of the flow tubes. The inhibitive effect is provided by the slow dissolution of copper into the water between sampling events. Research has shown that the use of copper tubing on the inflow and outflow tubing on an ac meter can extend the measurement duration up to 60 days on coastal moorings (Manov, et al., 2004).

Warm-up—It is normally best to characterize and use the ac-9 or ac-s after a 5- to 10-minute warm-up from initially powering the meter. Moored deployments, however, typically require sampling within thirty seconds after turning the unit on to conserve power. In order to assure accuracy in the field, multiple samples should be collected with a clean dry system in the lab, using the sample interval that is to be employed in the mooring. For best results, the testing should occur at temperatures close to those to be found in the water. Once multiple files have been collected, measurements in optically clean water (see Calibration, section 4) may be made and compared to baseline zero values expected when applying the device file (.dev) provided by the factory. Any offsets, which may or may not have a temporal dependence while the instrument warms up, can later be applied to field measurements as a correction.

Ground loops—The housing of the ac-9 and ac-s operates at ground potential, effectively tying the instrument common to the seawater. Under normal circumstances this should create no problems. However, depending upon other instrumentation attached to the mooring, inadvertent current leakage paths, and ill-considered power schemes, there lies potential for ground loops. In moored deployments, where packages can potentially be left unattended for months, the ground loops can drain batteries, result in noisy measurements, and damage instruments. While there is no set method for the determination and elimination of ground loops the following steps provide general guidelines:

- Create a systems grounding diagram. Consider the seawater as a ground plane.
- Note all terminations to the seawater.
- Measure voltages across these terminations to determine possible voltage potentials. Also check voltages across the instruments to the cage.
- If possible, immerse the package in salt water, and repeat the previous step
- A 2–3 day test deployment with instruments in the water could provide important information on expected versus realized battery voltage decay.
- Mitigating a suspected ground loop is highly system specific. If you suspect a loop you may wish to consult the factory for advice.

Plumbing—The inability to pre-purge moored deployments in near surface waters makes it vitally important to properly plumb your system. If the tubing and meter orientation do not facilitate rapid flushing of bubbles, air could easily become entrapped within the flow assemblies. Also, in areas where the meter may be sampling large amounts of re-suspended particulates, good flushing is critical to prevent sediment build-up within the meter. If possible, pumping speeds may be set to higher speeds (4000–4500 RPM for the SBE-5) and the incorporation of the larger nozzle diameter lock sleeves is recommended.

Calibration—Field calibrations immediately before and after mooring deployments are essential to allow tracking of any drift due to fouling or possible instrument changes (see section 4). The calibration should be performed as soon as possible after removal of the mooring from the water and after stored data is uploaded. Conducting a field water calibration before cleaning the meter allows drift assessment in the "as-is" condition, which will include drift due to both fouling and instrument changes. A second calibration after the meter has been thoroughly cleaned will allow the user to track instrument specific drift. The effects of fouling may be obtained by taking the difference between these two calibrations. In situations where optically clean water is not available, obtaining an air tracking file after the meter has been cleaned and dried will at least provide an indication of the meter stability through the period of performance.

Power consumption and battery life—To assure that a viable data set is collected during the entire period of deployment one must assure that they provide enough energy capacity (batteries) to effectively operate throughout the duration. The ac-9 or ac-s with pump will consume approximately 1 amp at 12 volts DC. Assuming a nominal on-time of one minute for each sample, the instrument will use about 1/60 of an amp-hour during each cycling. In addition, one must consider the power consumed by the data logger tied to the instrument in both its "on" and "off" states. Batteries typically provide a rated capacity in amp-hours, but this can mean different things for different types of batteries. For instance a twelve volt, D-cell alkaline battery pack is rated around 12–14 amp hours, but due to the near-linear decay rate of the batteries and the fact that this rating implies the amount of energy that the battery might provide until it is at 50 percent voltage, the usable capacity is only about 1/3 of the rated capacity. You must also take into account de-rating of the capacity due to lower water temperatures. Near-zero degree Celsius temperatures could reduce usable lifetimes by 30 percent. In generally, it is wise to provide ample over-capacity in your power system. All things considered, the price of batteries is usually cheap compared to the price of lost data.

3.6.2 Towed Bodies

Mounting—In mounting to a towed unit you must consider both the stability of the device and the flight characteristics of the entire towed unit. While the latter consideration is out of scope for this discussion, the former topic is straightforward. The mounting should firmly secure the meter towards both ends, without applying excessive torque on the unit. Neoprene-lined saddle clamps are recommended for this purpose. The clamps should be securely anchored to the frame. In securing the meter, make sure that adequate clearance is provided for plumbing and wiring. Because of size constraints, the meter usually must be mounted near horizontal. As a result, it is imperative that a field water calibration be carried out with the installed meter in the orientation expected during measurement to ensure the meter is stable in its new orientation (see Section 4).

Plumbing—It is recommended that flow inlets and outlets be oriented so that the hydrostatic pressure is equivalent, thus avoiding variable flow rates associated with variable rates of ascent and descent (if applicable). This is most easily established by locating the inlet and outlet hoses at the same level. Plumbing should be installed to allow the system to completely purge all air when deployed. Because the meter may be mounted horizontally, use bubble degassers and tubing to allow bubbles to escape. If

possible, sending the package down to 10 m or deeper before underway towing will help pressurize air out of the system. If orientation and space constraints do not permit a plumbing configuration that enables air to fully escape, plumb the meter in a manner that will allow air to escape when positioned in another orientation. On initial deployment, use a tag line to allow immersion of the towed body in this orientation, allow full degassing and run an instrument and data check if possible, remove the tag line, and tow.

3.6.3 Ship Underway and General Benchtop Operation

Keeping the meter within its specified internal temperature range—If the internal temperature of the ac-9 or ac-s exceeds about 35 degrees C, the automatic temperature compensation algorithm will start to break down. In general, temperature characterization and compensation of the ac-9 are based upon in situ or underwater operation of the meter. The meter's internal temperature characteristics depend upon the thermal flux between the meter and its environment. Since water and air make substantially different ambient environments, it is recommended that the instrument be immersed in water to assure stable operation. At very least, the transmitter housing (bottom can) should be submerged in water that is being actively exchanged so it does not overheat. If possible, the instrument may also be placed in a cold room and allowed to run for at least 10 to 15 minutes until the internal temperature stabilizes. For best results, carry out a field water calibration after the instrument temperature has stabilized for a given set of ambient conditions.

Eliminating air from the system—Providing a bubble-free water delivery system for the unit can usually be accomplished by simply plumbing the unit so that water flows into the unit from the base and flows out from the upper side of the flow cells (i.e. the water should always flow upward.). Often, however, shipboard seawater supplies have bubbles, which requires a degassing system of some kind. The simplest method of degassing pumped seawater is to send the water to a holding tank and then use gravity to draw the sample for the ac-9 or ac-s from the bottom of the tank. The larger the tank, the more temporal and spatial smearing the optical signal will experience. Once you are convinced that the water is flowing through your unit is bubble-free, check the data stream readouts in WETVIEW to verify. Bubbles in the water flow typically generate substantial spiking, sometimes negative, in both "a" and "c" channels. A lodged bubble in a flow tube may not introduce substantial variance in the signals, but will typically shift baselines. If it appears there is a lodged bubble in a flow tube that is difficult to remove, try stopping the flow, removing the flow tubes, drying the inside of the tubes and the ac-9 or ac-s windows with lint-free lens paper, reassemble and test again.

3.6.4 Profiling

Mounting—When profiling, the meter is usually mounted vertically on a cage. The pump should be located above the ac-9 flow tubes to allow it to pull water up through the flow tubes. The inlet nozzle tubing should be arranged to sample from undisturbed water below the package. (See Section 3.3 for detailed instructions on instrument mounting and Section 3.4 for instructions on plumbing).

Pre-purge—Care must be taken to ensure that all bubbles are purged from the system before beginning to sample. After the meter is appropriately mounted and plumbed (see Sections 3.3 and 3.4), lowering the package to 10+ meters during the initial 5-minute warm-up provides effective purging.

Free-fall Descent—To provide the highest quality data with good vertical resolution when deploying from a ship on a wavy ocean, the deployment package should ideally be a free-fall type system, with the buoyancy set to allow a slow descent rate. By making the package a free-fall type, it becomes de-coupled from the ship's motion, allowing better vertical resolution and preventing hydrostatic surging in the flow system. If a free-fall descent is not feasible, make sure the intake and outflow of the plumbing for the meter are at the same depth to ensure a constant flow rate (see section 3.4).

Time Constants and Spatial Resolution—The actual descent rate you use should depends on system capabilities and the desired vertical resolution. In a free-fall mode, descent rate will be determined by the net buoyancy of the package. A descent rate of ~30 cm/sec will provide ~20 data points in each meter. This is typically considered adequate resolution for sampling the open ocean, but sampling to 500 m would take almost 30 minutes. In considering spatial resolution, the flushing rate and volume of the flow assembly are also factors. Each side of the flow assembly encapsulates a ~30 ml volume. This means that for a 2 liter/min flush rate, the meter will completely exchange volumes about 67 times in 1 minute. For significantly reduced flow rates, the package descent rate may need to be reduced to maintain adequate spatial resolution for a specific application.

Care of Meter Between Casts—Requirements for cleaning the ac-9 and ac-s between casts vary depending upon the interval between casts, water conditions, and signs of obvious fouling from previous casts. Basic guidelines:

- The meter should be cleaned at least once per day. This could occur after the last cast of the day or before the first cast of the day. It can also correspond with a field calibration. (See Section 4.3 for field calibration details.)
- The meter should be cleaned if fouling is suspected.
- The meter should be cleaned if the intervals between casts are sufficiently long to allow drying within the flow assemblies.
- Profiling in very clean waters where signal changes are on the order of 0.01 m^{-1} may require more frequent cleaning.

In addition to cleaning optical surfaces, washing down the exterior of the meter regularly with fresh water reduces possible effects of corrosion.

4. Calibration

4.1 WET Labs Calibration Procedures

The standard ac-9 and ac-s calibration procedures at WET Labs include a series of characterization tests to confirm the instrument's performance is within factory specifications, temperature calibration, pure water calibration, and an air calibration.

4.1.1 Factory Pre-calibration Procedures

The pre-calibration procedures at the factory confirm that the meter is operating within specifications before it goes through calibration. First, a 12-hour burn-in period indicates if there are any immediate problems. The optical throughput of the ac-9 or ac-s is then tested by recording the output of the signal and reference detectors. Minimum and maximum signal levels are determined to assure that the appropriate instrument precision and dynamic range can be obtained for each channel. A mechanical stability test is performed by subjecting the meter to shaking/vibrations in both the horizontal and vertical positions. The meter is also subject to a shock test to make certain that the output of the meter is not altered during normal shipping and handling procedures. A final performance test is performed by collecting data with the meter on the bench. After a sufficient warm-up period, the raw precision of each channel should be approximately 0.001 m^{-1} or less. Precision is determined by taking the standard deviation of a one-minute air data file, measured in inverse meters at approximately 1 Hz.

4.1.2 Factory Temperature Calibration

During the temperature calibration of the ac-9 and ac-s, the instrument's temperature coefficients are determined. The temperature coefficients provide a correction factor for temperature for each channel of the ac-9 and ac-s. The temperature calibration data is also used to identify unusual instrument performance issues causing the output of the meter to change dramatically as a function of temperature.

The WET Labs temperature calibration is performed by placing the meter in a water bath. Initially, the meter's flow tubes are completely dried, filled with argon gas, and sealed off, preventing any moisture from reaching the flow path or the windows. The water bath temperature is cooled from about 35 degrees Celsius down to approximately 5 to 7 degrees Celsius over a 90-minute period. This water temperature range corresponds to an internal instrument temperature range of approximately 10–40 degrees Celsius. Data is recorded during this period. After a complete temperature cycle, the data is examined to determine if there are any unusual features in the absorption and attenuation values as a function of internal instrument temperature. If changes over temperature of the meter vary too greatly (within about 0.01 m^{-1} overall) or if severe non-linearities are detected, the instrument is sent back to the production floor for examination and necessary modifications. This process may include replacement of detectors, lamps, and/or electronics depending on the cause of the problem. If the instrument looks good after the initial temperature cycle, the temperature coefficients are calculated and applied to the device file that is ultimately supplied with the meter.

Acquisition software, including versions of WETView 5.0 and higher, employ a correction algorithm that uses multiple offset values, Δ_{Tn}, obtained by measuring output differences over small temperature increments. Instrument values are collected and averaged every one to two degrees C through the operational temperature range of the instrument. From these values we generate a look-up table of temperature compensation offsets [Δ_{Tn}]. This table is contained in each instrument's device file. Using the table, WETView then applies the algorithm, [$a' = a_{raw} - \Delta_{Tn}$] for given temperatures in the table. For temperatures that fall between table values, the program applies a linear interpolation upon the data for further correction. By using this scheme, we can thus effectively compensate for any non-linear changes due to temperature, in the instruments' output.

For examples and an explanation of device files, refer to Appendix 1.

The internal instrument temperature range, defined for each individual meter, may vary by a few degrees although typically the range extends from about 10 to 40 degrees Celsius. The exact temperature range is specified for each meter on the Calibration Sheet that is supplied for every new calibration. The ac-9 will remain within the factory temperature specifications over the internal instrument temperature range specified. Operation within this range is necessary to obtain results within the specifications of the device. For most accurate results, avoid operating the meter above about 35 degrees C. Typically, temperature characterizations below 10 degrees C are not required, even in the coldest waters, because internal heat generated by the lamp and electronics maintain internal temperatures at or above this level.

For an example and explanation of a Calibration Sheet, refer to Appendix 1.

4.1.3 Factory Water Calibration

The purpose of the WET Labs water calibration is to determine the offset values of absorption and attenuation that result in a zero reading with optically clean water in the sample volume of the flow tubes. This is analogous to a blank used in any spectrophotometer. These water offset values are listed on the Calibration Sheet and included in the device file for each meter's new calibration.

Before conducting a water calibration, the ac-9 and ac-s optics are properly cleaned and the meter is allowed to warm up for at least 15 minutes (see Section 4.2.2 for detailed cleaning instructions).

WET Labs maintains a custom water purification system that includes a commercial de-ionization system and filtration system. After primary de-ionization, the water is processed by a Barnstead purification unit and stored in a 60-liter holding tank that re-circulates through an ultra-violet chamber and additional purification filters. Water for calibration is drawn through a final 0.01-micron ultra-filter at the point of delivery. The circulating holding tank allows the highly reactive de-ionized water to equilibrate with

the ambient conditions and the ultra-violet chamber prevents any biological contamination from entering the reservoir. The system is continuously monitored and water quality is checked using a simple scattering detection test prior to each calibration to maintain consistent and accurate water calibrations.

During the water calibration, water from the pure water system is flushed continuously through both flow tubes of the meter at a rate of approximately 1.5 L/min. Values of absorption and attenuation are collected using WETView and the results are used to create a device file. Thus, with optically clean water in the flow tubes, the ac-9 or ac-s should read zero on all channels when using this device file. In order to confirm that the offsets are accurate, the cleaning process is repeated until the results are repeatable to within +/- 0.003 m^{-1}. Once the final offsets are collected, they are used to create the final water calibration values in the factory device file specific to that meter. The offsets are thereafter automatically applied when running WETView with that device file.

For an example and explanation of a Device File refer to Appendix 1.

The water temperature and the internal instrument temperature are important parameters for the user to consider when processing data, trying to obtain water calibrations in the field, or reproducing pure water calibrations in the laboratory. The water temperature is recorded during the calibration with typical values ranging from less than 5 to 35 degrees Celsius. When processing data it is important to correct for changes in the absorption of pure water that occur as a result of temperature fluctuations (see Section 5, Data Processing). These changes are a physical phenomenon that have nothing to do with the instrument, but require attention to obtain the most accurate results possible. Knowledge of the water temperature during calibration is thus a critical parameter because one needs to know the temperature difference between the water sample and water used for calibration to apply a correction. Internal instrument temperature is also recorded for each water calibration. It is important that this value fall within the temperature range specified in the temperature calibration. Both the water temperature and the internal temperature of the instrument during calibration are recorded on the Calibration Sheet.

4.1.4 Factory Air Calibration

The purpose of the WET Labs air calibration is to determine the offset values of absorption and attenuation that result in zero readings with air in the sample volume of the flow tubes. These air offset values are listed on the Calibration Sheet and included in the air tracking device file for each meter's new calibration.

Before conducting an air calibration, the exposed optics are properly cleaned and completely dried, the flow tubes are filled with argon, and the meter is allowed to warm up for at least 15 minutes (see Section 4.2.2 for detailed cleaning instructions). One of the most critical aspects of obtaining a good air calibration is that the exposed optics and flow assemblies of the meter must remain absolutely dry and that the air in the flow tubes be devoid of humidity.

During the air calibration, the meter's absorption and attenuation values are collected using WETView and the values used to create a device file for air. With these offsets applied, the ac-9 should thus read zero on all channels. To confirm the offsets are accurate, the cleaning process is repeated until the results are repeatable to within +/- 0.003 m-1.

Once the final air offsets are collected they are used to create a final factory device file for air tracking. This file is provided with each new meter distribution and is denoted as AIRXXYYY.CAL, where the XX represents the calibration number and the YYY represents the instrument serial number. This file can subsequently be used in air tracking procedures (see below).

The air CAL file is similar to the DEV file and can be applied in WETView in the same manner. The difference in the two files is that the DEV file provides the clean water offsets so that when measuring clean, fresh water, the instrument's output should be zero for all channels if the instrument has not experienced any drift. The CAL file provides the offsets that provide zero values when the instrument is clean and dry and measuring air values. Refer to Section 4.2 for more details on using your air tracking files. Remember, when obtaining air files, it is important to block light entering the flow assemblies by covering the inlet and outlet nozzles with tape or the black plastic caps provided by the factory.

An important parameter to consider when trying to confirm or reproduce air calibrations is the internal temperature of the instrument during the air calibration. Because the output of the ac-9 is only compensated for temperature over the temperature range specified on the Calibration Sheet, any operation outside of this range may result in offsets in the data. This is most often a concern with air calibrations because the instrument is operating in air, meaning a large portion of the heat generated internally by the ac-9 is not rapidly dissipated to the surrounding environment. The temperature of the instrument during the WET Labs air calibration is recorded on the Calibration Sheet.

4.2 Air Tracking Procedures

4.2.1 When to Use Air Tracking

Air tracking can be used to monitor offsets in the instrument's output due to changes in the optical system caused by shipping or mounting of the instrument to a cage or other deployment package. Air tracking can also be used to monitor instrument drift over extended periods of time. Air tracking involves the collection of data with the ac-9 in air using WETView and the factory air device file. Output collected following the Air Tracking Protocol are considered the Air Tracking Offsets. These offset values are an indication of changes in the optical throughput of the instrument since the factory air calibration and may be used in certain situations to correct data collected using the ac-9 or ac-s.

In practice, it is difficult to carry out air calibrations with the accuracy required for tracking instrument drift offsets. This is because the absolute cleanliness and complete lack of moisture on the optics or in the air may be difficult to achieve, especially in the

field. Furthermore, drifts obtained via air tracking have been shown to be slightly different than drifts obtained via the more accurate water calibration method (see below). One factor thought to influence this dynamic is the subtle change in the reflectivity and transmissivity of the optical windows over time due to continual cleaning and other unavoidable window contact associated with normal usage. Because the reflectivity of the windows is different in air versus water, this could result in air drifts that do not exactly match drifts in clean water.

Air tracking can be effective as a quick check to make sure the meter is functioning correctly, however. Use the air tracking device file, AIRXXYYY.CAL, with the WETView software package. Connect the ac-9 to power and allow it to warm up for at least 15 minutes. Without removing the flow tubes or cleaning the optics, the absorption and attenuation values should be within +/- 0.01 m^{-1} of zero. Use the Air Tracking Protocol listed below to obtain good air readings. Larger offsets may indicate misalignment of the optics during shipping and handling.

Air tracking data is most easily obtained in the laboratory, where the environment is consistently clean and dry. Air calibrations can be performed while in the field, however, it can be difficult to obtain good air calibrations on a ship due to the moist environment. Readings can be significantly offset by small amounts of moisture or dirt in the flow tube sample volume, resulting in considerable tracking inaccuracies.

4.2.2 Air Tracking Protocol

4.2.2.1 Soap wash and rinse—Remove flow tubes and all O-rings from the windows. Remove the collars from the flow tubes. Remove the O-rings on the flow tubes themselves. Use a mild detergent solution to gently wash all of the windows and rinse the flow tubes. Use lint-free wipes or lens paper to wash the windows. Rinse off the meter completely with water to ensure no soap residue is left inside the flow tubes or on the windows.

4.2.2.2 Dry the meter—Place the instrument in a protected area where it can dry out completely. Using a small heater to blow warm air over the meter may help speed up the process. Using dry nitrogen or argon to blow dry the meter and remove water from the small grooves around the windows will also help speed up the process. It is suggested that the instrument be left over night to dry out completely. Reassemble the meter. Carefully replace O-rings and slide the sleeves back on the flow tubes. Replace O-rings around the windows.

4.2.2.3 Solvent Cleaning—Use lint-free wipes or lens paper. Clean the windows with reagent- grade methanol or ethanol. (When using ethanol make sure to use protective gloves. Dilute solutions of at least 50% alcohol can also be prepared.) This process should remove any residual oils or organic material on the windows. Repeat this two to three times. Using a small flashlight or laser pointer to carefully examine the windows is also helpful.

4.2.2.4 The flow tubes should also be cleaned—Place a few drops of methanol on a lint-free wipe and, using a wooden or plastic dowel rod, carefully slide the lint-free wipe through the flow tube. Repeat this procedure with both flow tubes. Examine each flow tube when you are through, to make certain that there are no streaks or small pieces of wipe on the inside of the flow tube.

4.2.2.5 Dry the windows—Since small amounts of moisture can affect the air readings, it is important to ensure that the meter is completely dry. Using nitrogen to blow dry the windows immediately before replacing the flow tubes works very effectively. This will remove any water or methanol trapped in the small grooves around the window.

4.2.2.6 Replace the flow tubes—Carefully slide the flow tubes into place, avoiding direct contact between the window surfaces and the ends of the flow tube. Slide the collars up around the windows and over the O-rings, making certain they are firmly in place and aligned correctly. Use small black caps, or black electrical tape, over each of the nozzles on the flow tubes to provide a dark environment and to keep the meter clean and free of moisture while obtaining data.

4.2.2.7 Allow meter to warm up—If your meter is not yet powered, turn the meter's power on and allow the meter to warm up for at least 15 minutes. When the meter is stable you should be able to collect 10 minutes worth of data and the values should not vary more than 0.005 m^{-1} over the 10-minute time period.

4.2.2.8 Collect data—Use WETView and the air CAL file to record a one to two minute file and save the data. Repeat steps 4.2.2.4 through 4.2.2.6 until you can collect three data files, cleaning after each file, such that the average values for each channel vary by no more than 0.005 m^{-1}.

4.3 Field Water Calibration Procedures

4.3.1 When to use Field Water Calibrations

Maximum accuracy of measurements is obtained by performing water calibrations of the ac-9 and ac-s in the field. Field water calibrations can remove the effects of instrument drift associated with changing optical components and small misalignments of the optical system caused by shipping or mounting of the instrument on a cage or other deployment package. Field calibrations allow the operator to track instrument drift over time and are a highly recommended exercise to help one obtain the most accurate data possible. This is critical in clear ocean waters. Historically, drifts have been recorded as high as 0.01 m^{-1} per month, particularly in the blue channels of new instruments that are used often.

When a reliable source of optically clean water from a high-end water polishing system is available, water calibrations are a relatively straightforward exercise in the field. The concept behind the water calibrations is simple. The idea is to provide the instruments with a source of clean, bubble-free water that can be used as a reference value, or blank. This is the same concept used when the factory offset values are determined.

Clean water can be produced in the lab and transported to the ship in acid and base washed polycarbonate containers, or a portable system can be brought for shipboard use. For shorter cruises, the former option is usually a good one. However, if you are inclined to produce your own clean water, we provide a general description of what is required in this document.

4.3.2 Field Clean Water Production System

4.3.2.1 Pre-Filtration Unit—To increase lifetime of the primary filtration unit it's desirable to provide pre-filtration of the input water. A 1–5 micron commercial cartridge with possible addition of a activated charcoal filter work well for this task.

4.3.2.2 Primary Filtration Unit—The primary filtration unit typically consists of a commercial filtration unit such as the Barnstead E-Pure system or the Milli-Q Q-Pak treatment system. These units incorporate multiple stage filters to remove particulates, free ions, and organics. For the purposes of optically clean water production, organics and particulates form the dominant signals, so be certain that cartridges are used in these systems for organic removal. These systems require an active AC power source, so factor that in when considering use of the system.

4.3.2.3 Water Storage Unit—Rather than directly coupling the clean water output from the production unit to the ac-9 or ac-s outlets, it's advisable to provide an intermediate storage unit. An acid- and base-washed 20-liter polycarbonate carboy works well for this task. The advantages of storing the water are two-fold. It allows the clean water to equilibrate with the ambient temperature and for bubbles to come out of solution or dissolve. This is critical since most water polishing systems that do not have tank reservoirs produce water with microscopic bubbles. Water should sit for at least 4 hours before performing a calibration.

4.2.3.4 Water Delivery System—A field water delivery system is straightforward to set up and operate as shown in Figure 6. A cap with barb fittings is used to allow for the connection of tubing to pressurize the polycarbonate carboy and to allow water flow to the instruments. The carboy is pressurized to no more than 10 psi using a clean air source such as an oil-free air pump or a tank of nitrogen gas. Note that only very slight positive pressure within the system is required and care should be taken to avoid over-pressurizing the system and possibly creating a dangerous situation. The air tube inside the carboy should be short to prevent creating bubbles when pressurizing the carboy. A tube for the water should extend nearly to the bottom of the carboy. The tubing from the carboy is connected to one of the bottom nozzles of the ac-9 or ac-s flow tubes. All tubing must be completely opaque to avoid light leaks. This can be achieved by wrapping black tape around the tubing. A short piece of tubing with a valve is connected to the top nozzle on the flow tube. The valve serves two purposes. It allows the operator to stop the water flow, conserving the calibration water. It also provides required backpressure, which helps to keep gases in solution preventing the formation of micro-bubbles. Typically, the valve is used to restrict flow to a trickle. After the flow of water has been initiated, gently rocking the meter can dislodge any trapped bubbles before the flow is restricted with the valve.

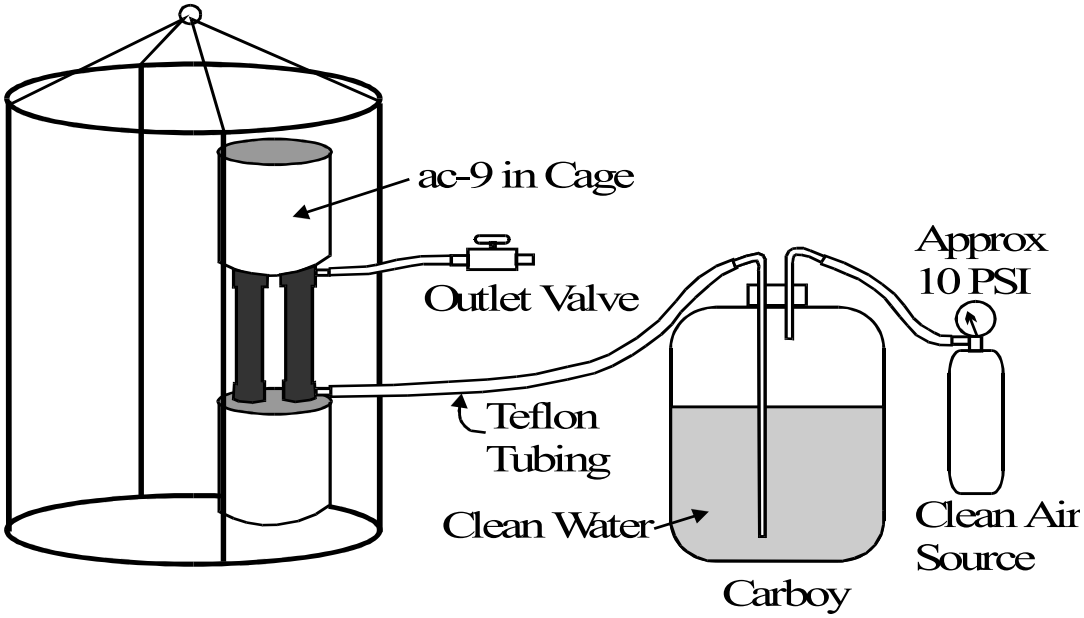


Figure 6. A simple schematic of a field water-calibration delivery system.

Maintaining a viable clean water production system requires some care and common sense. Most filtration packs perform de-ionization of the water. Using a mineral-rich water source may quickly foul the filter cartridge. Storing the unit between uses may require special handling of the filters. Many systems provide a resistivity gauge that indicates the ion purity of the water. This is useful in determining whether your filters are fouled but is not a reliable indicator of optical clarity.

4.3.3 Field Water Calibration Protocol

4.3.3.1 Obtaining a Calibration

1. Make sure that the meter is clean (See Section 4.2.2 for cleaning techniques) and that it has warmed up for at least 5 minutes. Check the internal temperature to ensure that the unit is operating within the temperature range provided on the calibration sheet.

2. Once the water delivery system is connected to either side of the flow assembly, pressurize the carboy to no greater than 10 psi and open the outlet valve to purge air out of the system. Typically you can directly observe the bubbles as they are pushed out of the meter. Rocking the meter back and forth gently aids purging.

3. Once the meter is purged, use the valve to set the flow rate to approximately 100 mL/min. or less. This pressurizes the system while minimizing the amount of water required for a calibration. If bubbles have been effectively purged from the system, restricting flow rates will not change baseline values. In fact, this can be used as one diagnostic to determine if small bubbles are lodged in the flow path.

4. Using WETView or your own data collection software, collect approximately 30 seconds of data into a file. Do not bin your data. This is to ensure that if a small

bubble passes through the system it can be identified and removed from the data stream. Make sure that the output is stable and is not drifting.

5. Repeat steps 1–4 until readings in all channels are repeatable within ~0.005 m^{-1}. With care, repeatability on the order of 0.002 m^{-1} is achievable for most channels, and this level should be a target if the meter is to be deployed in very clear waters. Repeatability is the most important aspect of water calibrations because in many cases (e.g., with a lodged bubble present in the flow cell) anomalous readings may be obtained that nonetheless appear stable.

When the acquisition is completed, turn the water off and place the tubing on the other flow tube. Repeat steps 1–5. Calibration may also be performed on the attenuation and absorption meters simultaneously by installing a "Y" fitting on the intake to split the flow to both flow cells.

During the calibration, the calibration water temperature should be logged to allow water temperature corrections to be performed on the data (see Data Processing section). It is a good practice to always include the date and water temperature in the file name.

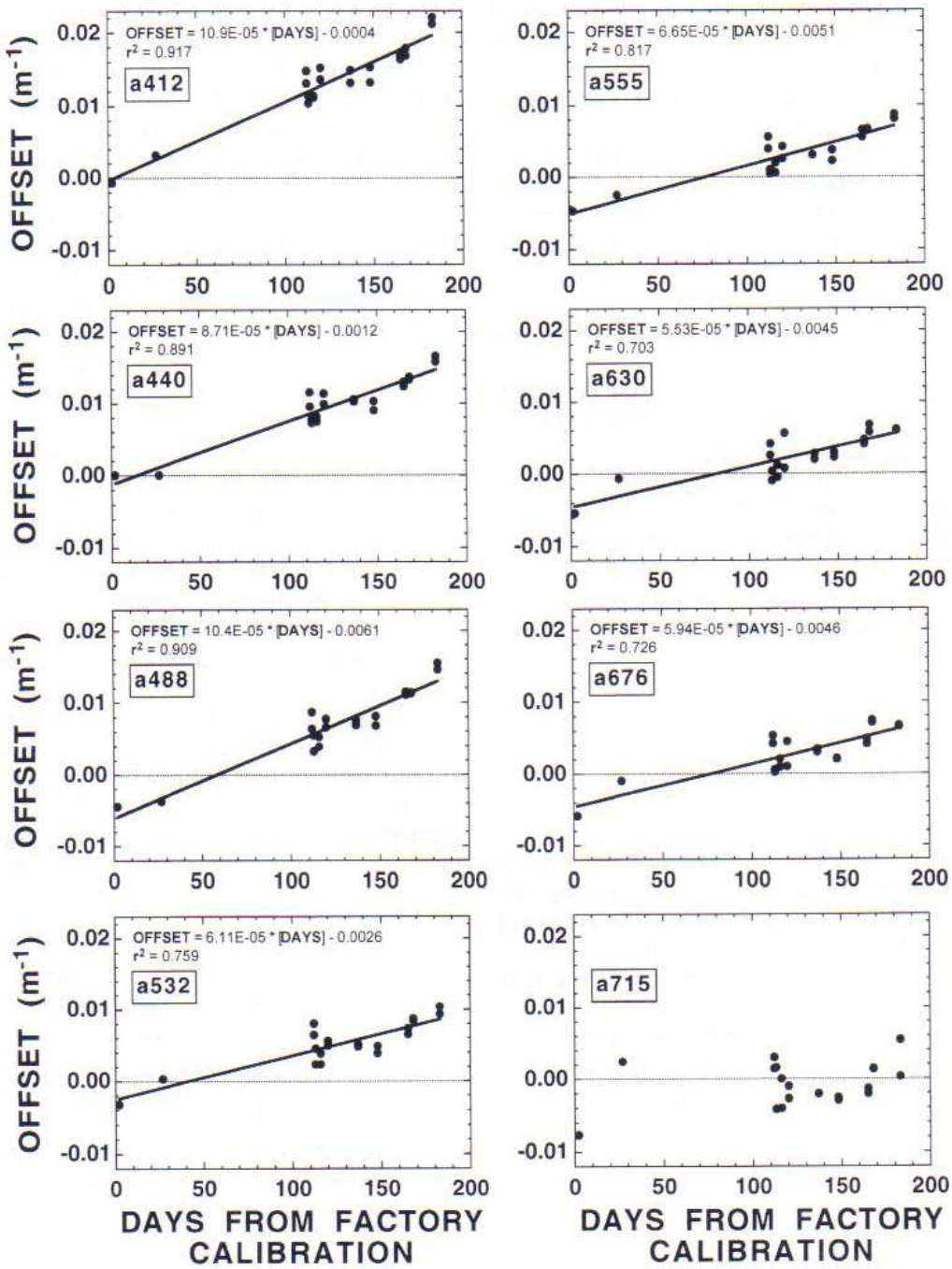
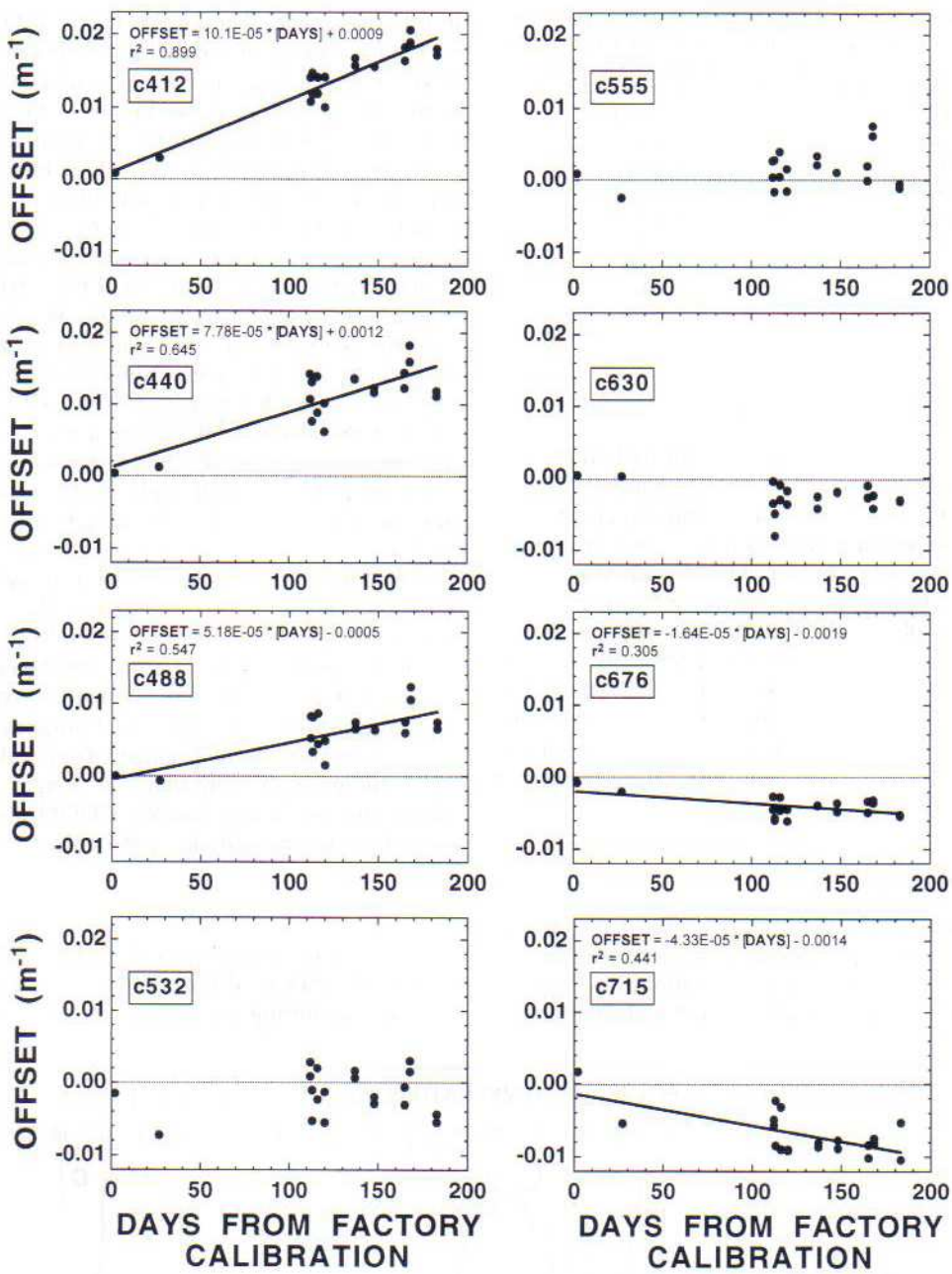


Figure 7A. A sample of the changes in ac-9 "a" side water calibrations recorded in 1997.



7B. A sample of the changes in ac-9 "c" side water calibrations recorded in 1997.

4.3.3.2 Applying Field Calibration Data

To apply the new calibrations, there are two methods that can be used: a new device file can be created, or the calibration offsets can be applied during post-processing. The latter method is strongly recommended, because it is much easier to apply changes and keep track of potential instrumental drift. For instance, if on a long cruise the instrument appears to drift in a predictable manner, a regression can be applied during post-processing to derive drift offsets as a function of time. Using different device files for different time periods can be difficult to keep organized and does not provide for

straightforward drift analyses. Drift analyses versus time help to pinpoint possible inaccurate calibrations that are not consistent with an overall trend (Figs. 7a and 7b). These analyses can also expose calibrations where perhaps the water temperature was inaccurately recorded, usually evidenced by large deviations in the near-IR where temperature has a strong effect on pure water absorption (this is particularly important with the ac-s, where the spectral range is extended to longer wavelengths). We are aware of many instances where periodically inaccurate calibrations were applied to good data, resulting in negative values, oddly shaped spectra, and other peculiarities. If you do choose to make your own device files, use caution—carefully organize the files, only use calibrations you have absolute confidence in, and inter-compare with other calibrations. Large deviations are rare, and should be treated as suspect. It is worth repeating that repeatability in calibrations is essential.

To create a new device file:

1. Average a portion of the data collected during the calibration that does not show evidence of bubbles or any drift.

2. Open the device file that was used when collecting the calibration data in a spreadsheet such as Excel.

3. <u>Subtract</u> the average values from step one from the appropriate water offset value in the device files. The offsets are given in the third column of the device file.

4. Make sure to save the new device file under a new name and as tab delimited text. Save all old device files for reference.

To apply water calibration during post-processing, see section 5.5 below.

5. Data Processing

The ac-9 and ac-s acquire signals representing light losses of a light beam propagating through a fixed path of water. In order to convert these values into meaningful units of absorption and attenuation, and to correct for instrument and environmental factors associated with the measurements, several processing steps are recommended. The following sections within this chapter describe the steps in more detail. The processing steps listed in section 5.1 are listed in approximate order of implementation; not all are carried out by WETView.

5.1 Basic WETVIEW Calculations

WETView is the basic WET Labs software package used to acquire and carry out basic processing of data from the ac-9 and ac-s. WETView automatically carries out these basic data processing steps during acquisition:

• Initial Parsing of Binary Data
• Ratio of Signal to Reference
• -ln (Signal/Reference) / Pathlength
• Application of Internal Temperature Coefficients
• Application of Clean Water Offsets (contained in device file)

WETView reads in the raw binary data from the meter, then parses the data. The parsed data contains digitized signal values for signal and reference levels for each channel. WETView then applies an algorithm that:

1. Computes uncorrected engineering units (in inverse meters) from the signal and reference values.
2. Applies a linear temperature correction (for the meter's internal temperature) using constants supplied in the instrument's device file.
3. Applies clean water offsets supplied from the instrument's device file that provide a value referenced against clean water.

Combining these steps into one formula:

$$c(\lambda) = (c_{off} - 1/x\ [\ln(C_{sig} / C_{ref})]) - \Delta_T$$

and

$$a(\lambda) = (a_{off} - 1/x\ [\ln(A_{sig} / A_{ref})]) - \Delta_T$$

where

$c(\lambda)$, $a(\lambda)$	is the attenuation coefficient and absorption coefficient, respectively in m^{-1}
c_{off}, a_{off}	is the water offset value (provided on the Calibration Sheet) in m^{-1}
C_{sig}, A_{sig}	is the measured amount of light (power) that reaches the receiver detector from the ac-9 or ac-s data stream in raw digital counts
C_{ref}, C_{ref}	is the amount of light (power) measured by the reference detector from the ac-9 or ac-s data stream in raw digital counts
x	is the sample volume pathlength in meters
Δ_T	is the internal temperature compensation correction value in m^{-1} derived from equation below.

The temperature correction is applied using the temperature from the reference line and the channels correction table from the either the Calibration Sheet or the Device File. The approximate correction value is linearly interpolated from the table. First, the correct temperature bin is determined by finding the two bin temperatures, T_0 and T_1, that bracket the current temperature. Then, using the values, Δ_{Tn} and Δ_{Tn+1}, from the table, we obtain

$$\Delta_T = \Delta_{Tn} + \frac{(T - T_0)}{(T_1 - T_0)} * (\Delta_{Tn+1} - \Delta_{Tn})$$

where,

Δ_T = compensation constant

T = current temperature

T_0 = first bin temperature

T_1 = second bin temperature

Δ_{Tn} = first value

Δ_{Tn+1} = second value

This temperature correction is automatically applied by our WETView software. If you are manually processing the raw data stream, this correction must be applied to arrive at the temperature-corrected absorption and attenuation coefficients.

Note

For a detailed discussion of the WETView processing of the binary data stream, consult the ac-9, ac-s, and WETView manuals.

For users writing their own code it is important to fully understand the parsing and these initial processing steps. Examples of code can be found on our web site (http://www.wetlabs.com).

5.2 Merging

Data collected with the ac-9 or ac-s typically must be merged with CTD and other ancillary measurements to be able to investigate relationships between different parameters, plot data versus depth or time, and carry out many of the corrections to ac-9 and ac-s data described below.

5.3 Time Lag Correction

A lag associated with the time it takes for a sample to initially enter the intake and travel through the flow cell typically requires correction to ensure data is synchronized in space and time with other measurements on a sensor package. Typically, all the disparate sensors on a package have unique time records that enable merging in post-processing.

Time lags are a function of overall intake volume and flow rate. Lab experimentation with dyes has demonstrated that this overall intake volume should include the entire volume of the flow cell (~30 mL for the 25 cm path). Flowing sample within the flow cell can be considered relatively well-mixed and not a “plug flow.” Experimentation in the lab and field has demonstrated that with approximately 12 in. of ½-in. diameter tubing on the intakes of the flow cells, time lags are approximately 1.2 s when using a SBE-5 3.5K RPM pump.

When a prefilter is used on the intakes of the flow cells to remove the particulate fraction, time lags increase and become more difficult to assess. There are several options for deriving time lags for this application:

- Install a flow meter in-line with pump. These are available from WET Labs, although for lower flow rates, this flow meter may be too coarse in precision to provide adequate data for a time lag correction.
- Merge CTD and ac-9 or ac-s data as a function of time, and then compare absorption in the near-IR to CTD water temperature. Since pure water absorption is a function of temperature, co-variation will be observed, which will be particularly noticeable at strong gradients in temperature. Absorption in the near-IR will also have some convolved signal from the dissolved and particulate material in the water.
- If there is not a strong temperature gradient in the data, see if a strong salinity gradient exists. Salinity and near-UV absorption measurements co-vary inversely, and this relationship can be used to derive the time lag.
- Collect multiple casts of CTD and ac-9 or ac-s data, each at a different descent rate. Then merge the data as a function of time for each cast, and find the time lag for the ac-9 or ac-s where the different traces overlap as a function of depth. Note that the faster the descent rate, the more smeared the signal will be, so the traces can never be identical. However, breakpoint depths associated with strong gradients in the water column will occur at the same location.

5.4 Water Temperature and Salinity Corrections

Before ac-9 and ac-s data can be corrected for temperature and salinity, the data must be merged with CTD data (section 5.2) and time lags must be corrected (section 5.3).

Since the ac-9 and ac-s measurements are referenced to clean water, the measured absorption and attenuation coefficients, a_m and c_m, represent the absorption and attenuation of all the material in the sample, a_t and c_t, minus water:

$$a_m = a_t - a_w \qquad c_m = c_t - c_w$$

The temperature and salinity corrections discussed here are different than the temperature corrections discussed in the calibration section. These corrections relate to physical changes in the absorption and attenuation coefficients of pure water, a_w and c_w, due to changing dissolved salt content and temperature. Since the water calibration "blank" was carried out with optically clean fresh water, the effects of salt in a seawater sample on the absorption and attenuation of pure water must be removed. Note that the absorption and attenuation from the specific salts in seawater are negligible, i.e., the signal is lower than the precision of measurements; the observed effect relates to the changing absorption and attenuation of pure water due to altered molecular interactions in the presence of dissolved salts. Similarly, a water calibration is carried out at an arbitrary temperature that is likely different than the temperature of the water sample; the effective change in pure water absorption resulting from this difference in temperature should be removed. Note that not all portions of the absorption and attenuation spectra in the visible are affected by temperature and salinity. The temperature and salinity effects are largest in the near infrared and reduce to undetectable in the visible.

Temperature and salinity effects on pure water absorption and attenuation can be removed using a simple algorithm:

$$a_{mts} = a_m - [\ \Psi_t * (t - t_r) + \Psi_{sa} * S]$$
$$c_{mts} = c_m - [\ \Psi_t * (t - t_r) + \Psi_{sc} * S]$$

where t and tr and in-situ and reference temperatures, respectively, and S is salinity. The values for Ψ_T are given in Table 2, and the values for Ψ_{Sa} and Ψ_{Sc} are given in Table 3. Note that changes in temperature affect absorption and attenuation the same (their effect on pure water scattering from temperature is negligible).

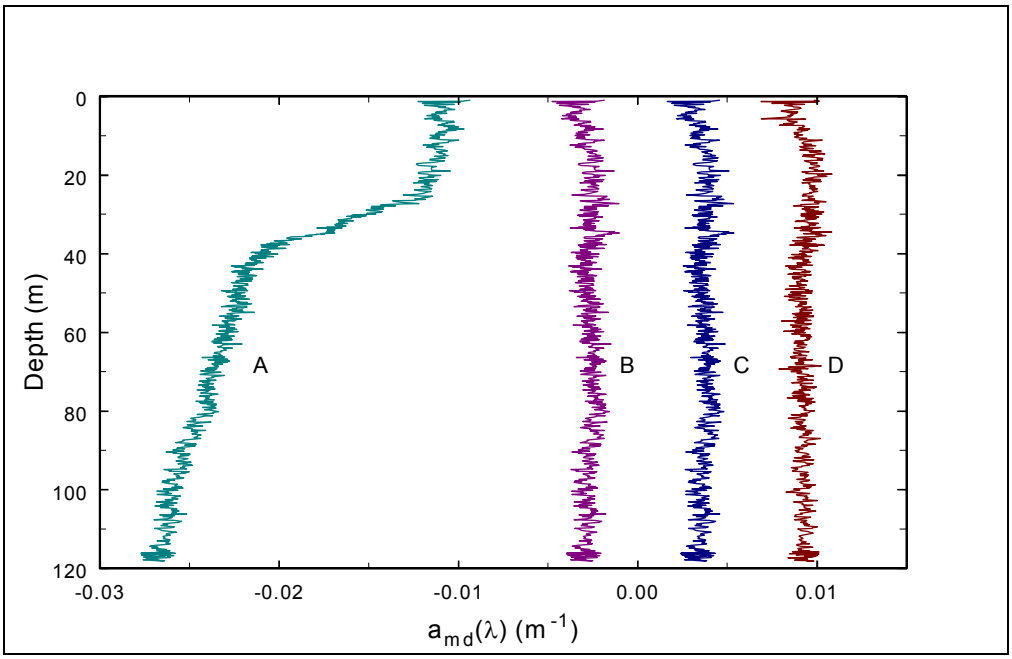


Figure 8. The application of temperature and salinity corrections to a Gelbstoff profile.

In the example provided in Figure 8, line A is the raw a(715). Line B has the temperature correction applied. Line C includes the temperature and salinity corrections. Line D is the absorption coefficient at 650 nm, given to provide a reference profile. Note both temperature and salinity corrections are necessary to provide a profile with positive absorption values in this case. Also note that other corrections such as the instrument drift and reflective tube scattering correction have not been applied.

5.5 Instrument Drift Correction

A field water calibration can be applied in post-processing to correct for instrument drift. The field water calibration directly before or after an in-water measurement will thus serve as the effective blank. This is the recommended procedure to obtain highest quality data. The field water calibration file (collected using WETView and the same factory device file used during acquisition of the in-water data) should be prepared according to the procedures in section 4.3. These values must then be temperature corrected according to the procedure outlined in the previous section. The t_r value should match the t_r used when temperature correcting in-situ data. The value to choose for t_r is completely arbitrary, since this parameter cancels when

temperature-corrected water calibration data is subtracted from temperature-corrected in-situ data (in fact, the corrections can be combined to avoid the use of t_r completely). After the correction, water calibration values can then be subtracted in post-processing from every row of temperature and salinity corrected data from the field.

5.6 Reflective Tube Scattering Correction

Reflecting tube absorption meters (and spectrophotometers in general) do not collect all of the light scattered from the source beam. The uncollected scattered light, also known as the scattering error and nominally comprised of the light scattered from ~41 to 180 degrees when using a quartz tube, causes the instrumentation to overestimate the absorption coefficient. There are several schemes to correct absorption measurements for scattering errors. Note that the data at this point should have already had applied to it the corrections discussed in sections 5.4 and 5.5. The three methods most commonly used include:

1. Subtraction of data at a reference wavelength where the absorption is assumed to be zero.

2. Removal of a fixed proportion of the scattering coefficient, computed by subtracting absorption from attenuation.

3. Use of a reference wavelength to determine the proportion of the scattering coefficient to be subtracted from the signal. Scattering is computed by subtracting absorption from attenuation.

Each of these methods requires different assumptions and ancillary measurements.

The first method to correct for scattering errors is to subtract the absorption measurement at a reference wavelength. It is assumed that at the reference wavelength the absorption by particulate and dissolved materials is negligible, so that the measured absorption signal is caused strictly by the scattering error. It is further assumed that the shape and magnitude of the volume scattering function is independent of wavelength. Commonly, the reference wavelength selected is in the near infrared portion (715 nm on an ac-9) of the spectrum. In very clean water, where absorption at 715 nm may be close enough to zero to generate negative values from normal noise fluctuations (near 0.001 m^{-1}), it is advisable to subtract zero instead of a negative a715 value, as the latter leads to positively biasing absorption at the other wavelengths. Some bin averaging can also be carried out to reduce small noise fluctuations in this case.

The second method assumes that the scattering correction is a fixed proportion, ε, of the scattering coefficient $b(\lambda)$ (note $b(\lambda)$ is obtained from $c(\lambda) - a(\lambda)$).

A value of ~0.14 has been suggested for ε for waters where biological particles dominate scattering. A value of ~0.18 has been suggested for ε when sediments dominate the scattering. These values of ε are empirically derived from field data and the third scattering correction technique as well as being modeled by Kirk (1993). Since the measured absorption has the small error we are trying to correct for here, the estimated scattering coefficient is not equal to the true scattering coefficient, so ε is slightly larger than models would predict. This method

assumes that the shape of the volume scattering function is independent of wavelength and type of material. The magnitude of the scattering correction is, however, allowed to vary with wavelength. Since a reference wavelength is not used there is no requirement that the absorption coefficient equal zero at the reference wavelength.

The third method to correct the scattering error is covered in detail in the ac-9 manual. This technique is a combination of the first two techniques. It is assumed that there exists a reference wavelength at which the absorption coefficient of particulate and dissolved materials is negligible. It is further assumed that the shape of the volume scattering function is independent of wavelength. The correction technique is written as,

$$a_t(\lambda)-a_w(\lambda) = a_{mts}(\lambda) - \frac{a_{mts}(\lambda_{ref})}{[c_{mts}(\lambda_{ref}) - a_{mts}(\lambda_{ref})]} *[c_{mts}(\lambda)-a_{mts}(\lambda)].$$

This technique allows for automatic changes in the scattering correction magnitude with wavelength and changes in types of materials present. It requires the largest number of ancillary measurements (two attenuation values, two absorption values, temperature, salinity, and calibration water temperature and salinity) which makes this technique the most difficult to do correctly. However, if the assumptions are correct, it is the most accurate of the techniques. A consideration in applying this correction scheme is that natural fluctuations in these independent signals can introduce bias errors in the product. For example, the absorption and attenuation measurements are made simultaneously, but in different water samples. At any one instant, a large particle substantially perturbing a signal may be present in one sample volume, but not the other. These errors can be minimized with appropriate binning.

Please note, in coastal waters where the concentration of CDOM dominates the total absorption spectrum (dissolved absorption is an order of magnitude greater than the particulate absorption), care should be taken in applying a scattering correction. In this case, it is best to remove the dissolved fraction from the total absorption spectrum (i.e. compute particulate absorption fraction), and then apply the scattering correction.

5.7 Attenuation Acceptance Angle Correction

Conventional beam transmissometers or attenuation meters measuring attenuation with a near collimated beam and detector are limited by the acceptance angle, defined by the detector optics. The finite acceptance angle of the instrumentation means that the instrument collects a portion of the very near-forward scattered light and thus underestimates the true attenuation coefficient. Since the vast majority of light is scattered in the near-forward, the error is not negligible and may exhibit a small dependency on the volume scattering function of the sample in the near-forward (overall error expected to be anywhere between 5% and 20% underestimation for the ac-9 and ac-s). There is, however, no effective method for correcting attenuation measurements for the errors caused by collection of some scattered light with ancillary measurements of near-forward scattering. It is important to remember that transmissometers with different acceptance angles will provide different measurements because they measure different portions of the scattering function.

The differences appear to be negligible in tests comparing a 1990's Sea Tech transmissometer (acceptance angle ~1 degree) with an ac-9 (~0.93 degrees), but significant differences are expected for meters with acceptance much less or much more than the 0.7 degrees.

5.8 Other Processing Notes

5.8.1 Considering Spatial Variability

Because of the physical separation between the two flow tubes, the attenuation and absorption measurements are instantaneously made in different volumes of water. It is preferable to have the intake tubes for the two measurements as close as possible to minimize signal differences due to spatial variability, but the fact remains that the samples will never be exactly the same. A moving average applied to each data stream will help remove any aliasing from variability over spatial scales on the order of cm's. It may be desirable to bin data before applying the reflective tube scattering correction (section 5.6) if correction scheme #3 is implemented, because this correction uses data from both the "a" and "c" channel.

5.8.2 ac-s Mid-spectrum Discontinuities

A spectral "stair-step" is often observed with the ac-s between approximately 565 nm and 571 nm in the full spectra because the spectrum shorter than 565 nm is acquired at a slightly different time than the spectrum longer than 571 nm. Each of these 2 sub-spectra thus represent different (but overlapping) sample volumes, and natural variability in particle populations normally introduce stair steps where these two sub-spectra meet. The mismatches are consequently completely random and the stair steps are removed with simple averaging. The more averaging that is performed, the smoother the spectra will look. Of course, the more the data are binned, the more natural variability is hidden, so it is up to the user to determine the proper time or depth interval for binning based on the natural variability of the water being studied.

5.8.3 Outliers

Spiking, in general, should be kept and not filtered out as these spikes represent legitimate data, not noise. However, sometimes events occur which lead to obviously erroneous data, such as air intake at the surface, or a profiling package stirring up sediment on the seafloor. In these instances, these sections of data should be removed.

5.9 Directly Derived Products

5.9.1 Computing Total Absorption and Attenuation from Measurements

The ac-9 measurements are referenced ("blanked") to optically clean water, and resulting values thus represent the absorption and attenuation of the sample water minus the calibration water values. If the water is very clean, then it may be assumed that the measured absorption and attenuation represent everything in the water except pure water itself. It is generally accepted that water produced by high-end polishing systems manufactured by Millipore and Barnstead have this level of purity. To derive total absorption and total attenuation, it is therefore necessary to add in the absorption and attenuation, respectively, of pure water. Currently, the most accurate pure water absorption values are considered to be those presented by Pope and Fry (1997). The most

accurate pure water scattering values are considered to be those presented by Buiteveld et al. (1994), which followed the methods of Morel (1974) but used updated physical constants (see discussion in Sullivan et al. 2006). These published values are reproduced in Table 2.

Table 2. Volume absorption and scattering coefficients for pure water, $a_w(\lambda)$ and $b_w(\lambda)$, respectively. Values for $a_w(\lambda)$ are those of Sogandares and Fry (1997) (340 to 390 nm), Pope and Fry (1997) (400 to 700 nm), as derived from Kou *et al*. (1993) (705 to 750 nm). Alternative values of $b_w(\lambda)$ compared here are denoted (B) (Buitveld, et al. 1994) and (M) (Morel 1974). The linear temperature dependence of pure water absorption, $\frac{\partial a_w(\lambda)}{\partial T}$, is due to Pegau and Zaneveld (1993) and Pegau et al. (1997).

Table from Mueller et al., Ocean Optics Protocols for Satellite Ocean Color Sensor Validation, Revision 4, Volume IV, Erratum 1. NASA/TM-2003-211621. See Table 3 for pure water absorption coefficients for the ac-s meter.

λ	a_w	$\frac{\partial a_w(\lambda)}{\partial T}$	b_w	b_w	λ	a_w	$\frac{\partial a_w(\lambda)}{\partial T}$	b_w	b_w	λ	a_w	$\frac{\partial a_w(\lambda)}{\partial T}$	b_w	b_w
nm	m^{-1}	$m^{-1}\,{}^oC$	m^{-1} (B)	m^{-1} (M)	nm	m^{-1}	$m^{-1}\,{}^oC$	m^{-1} (B)	m^{-1} (M)	nm	m^{-1}	$m^{-1}\,{}^oC$	m^{-1} (B)	m^{-1} (M)
340	0.0325	0.0000	0.0104	0.0118	500	0.0204	0.0001	0.0021	0.0022	630	0.2916	0.0002	0.0008	0.0009
350	0.0204	0.0000	0.0092	0.0103	505	0.0256	0.0001	0.0020		635	0.3012	0.0000	0.0008	
360	0.0156	0.0000	0.0082	0.0091	510	0.0325	0.0002	0.0019	0.0020	640	0.3108	-0.0001	0.0008	0.0008
370	0.0114	0.0000	0.0073	0.0081	515	0.0396	0.0002	0.0018		645	0.325	0.0000	0.0007	
380	0.0100	0.0000	0.0065	0.0072	520	0.0409	0.0002	0.0018	0.0019	650	0.340	0.0001	0.0007	0.0007
390	0.0088	0.0000	0.0059	0.0065	525	0.0417	0.0002	0.0017		655	0.371	0.0002	0.0007	
400	0.00663	0.0000	0.0053	0.0058	530	0.0434	0.0001	0.0017	0.0017	660	0.410	0.0002	0.0007	0.0007
405	0.00530	0.0000	0.0050		535	0.0452	0.0001	0.0016		665	0.429	0.0002	0.0006	
410	0.00473	0.0000	0.0048	0.0052	540	0.0474	0.0001	0.0015	0.0016	670	0.439	0.0002	0.0006	0.0007
415	0.00444	0.0000	0.0045		545	0.0511	0.0001	0.0015		675	0.448	0.0001	0.0006	
420	0.00454	0.0000	0.0043	0.0047	550	0.0565	0.0001	0.0014	0.0015	680	0.465	0.0000	0.0006	0.0006
425	0.00478	0.0000	0.0041		555	0.0596	0.0001	0.0014		685	0.486	-0.0001	0.0006	
430	0.00495	0.0000	0.0039	0.0042	560	0.0619	0.0001	0.0013	0.0014	690	0.516	-0.0002	0.0006	0.0006
435	0.00530	0.0000	0.0037		565	0.0642	0.0001	0.0013		695	0.559	-0.0001	0.0005	
440	0.00635	0.0000	0.0036	0.0038	570	0.0695	0.0001	0.0012	0.0013	700	0.624	0.0002	0.0005	0.0005
445	0.00751	0.0000	0.0034		575	0.0772	0.0002	0.0012		705	0.704	0.0007	0.0005	
450	0.00922	0.0000	0.0033	0.0035	580	0.0896	0.0003	0.0011	0.0012	710	0.827	0.0016	0.0005	0.0005
455	0.00962	0.0000	0.0031		585	0.1100	0.0005	0.0011		715	1.007	0.0029	0.0005	
460	0.00979	0.0000	0.0030	0.0031	590	0.1351	0.0006	0.0011	0.0011	720	1.255	0.0045	0.0005	0.0005
465	0.01011	0.0000	0.0028		595	0.1672	0.0008	0.0010		725	1.539	0.0065	0.0004	
470	0.0106	0.0000	0.0027	0.0029	600	0.2224	0.0010	0.0010	0.0011	730	1.983	0.0087	0.0004	0.0005
475	0.0114	0.0000	0.0026		605	0.2577	0.0011	0.0010		735	2.495	0.0108	0.0004	
480	0.0127	0.0000	0.0025	0.0026	610	0.2644	0.0011	0.0009	0.0010	740	2.787	0.0122	0.0004	0.0004
485	0.0136	0.0000	0.0024		615	0.2678	0.0010	0.0009		745	2.836	0.0119	0.0004	
490	0.0150	0.0000	0.0023	0.0024	620	0.2755	0.0008	0.0009	0.0009	750	2.857	0.0106	0.0004	0.0004
495	0.0173	0.0001	0.0022		625	0.2834	0.0005	0.0008						

Table 3. Hyperspectral temperature dependencies (Ψ_T, m^{-1} $^oC^{-1}$) for the absorption of pure water and salinity dependencies ($\hat{\Psi}_s$, m^{-1} S^{-1}) for the attenuation (subscript *c*) and absorption (subscript *a*) of pure water measured with the ac-s. To normalize different channels of the ac-s for averaging, the original wavelength outputs of the ac-s were linear interpolated and output at regular 2 nm wavelength steps (λ, nm). Standard deviations ($\sigma_{\Psi T}$ and $\sigma\hat{\Psi}_s$) for each measured value are also given. These measured Ψ_T and $\hat{\Psi}_s$ values represent ac-s instrument-specific correction factors. Taken directly from Sullivan et al, 2006.

λ (nm)	Ψ_T (m^{-1} $^oC^{-1}$)	$\sigma_{\Psi T}$ (m^{-1} $^oC^{-1}$)	$\hat{\Psi}_{s,c}$ (m^{-1} S^{-1})	$\sigma\hat{\Psi}_{s,c}$ (m^{-1} S^{-1})	$\hat{\Psi}_{s,a}$ (m^{-1} S^{-1})	$\sigma\hat{\Psi}_{s,a}$ (m^{-1} S^{-1})
400	0.0001	0.0002	-0.00001	0.00004	0.00003	0.00003
402	0.0001	0.0001	-0.00002	0.00004	0.00003	0.00003
404	0.0001	0.0001	-0.00002	0.00004	0.00003	0.00003
406	0.0001	0.0001	-0.00002	0.00004	0.00004	0.00003
408	0.0000	0.0001	-0.00002	0.00004	0.00004	0.00003
410	0.0000	0.0001	-0.00002	0.00004	0.00004	0.00003
412	0.0000	0.0001	-0.00002	0.00004	0.00004	0.00003
414	0.0001	0.0001	-0.00002	0.00003	0.00004	0.00003
416	0.0000	0.0001	-0.00002	0.00003	0.00004	0.00003
418	0.0000	0.0001	-0.00003	0.00003	0.00004	0.00003
420	0.0000	0.0001	-0.00003	0.00003	0.00004	0.00003
422	0.0000	0.0001	-0.00003	0.00003	0.00003	0.00003
424	0.0000	0.0001	-0.00003	0.00003	0.00003	0.00003
426	0.0000	0.0001	-0.00003	0.00003	0.00003	0.00003
428	0.0000	0.0001	-0.00003	0.00003	0.00003	0.00003
430	0.0000	0.0001	-0.00003	0.00003	0.00003	0.00003
432	0.0000	0.0001	-0.00003	0.00003	0.00003	0.00003
434	0.0000	0.0001	-0.00003	0.00003	0.00003	0.00003
436	0.0000	0.0000	-0.00003	0.00003	0.00003	0.00003
438	0.0000	0.0000	-0.00004	0.00003	0.00003	0.00003
440	0.0000	0.0000	-0.00004	0.00003	0.00002	0.00002
442	0.0000	0.0000	-0.00004	0.00003	0.00002	0.00002
444	0.0000	0.0001	-0.00004	0.00003	0.00002	0.00002
446	0.0000	0.0001	-0.00004	0.00003	0.00002	0.00002
448	0.0000	0.0001	-0.00004	0.00003	0.00002	0.00002
450	0.0000	0.0000	-0.00004	0.00003	0.00002	0.00002
452	0.0000	0.0000	-0.00004	0.00003	0.00002	0.00002
454	0.0000	0.0000	-0.00004	0.00003	0.00002	0.00002
456	0.0000	0.0000	-0.00004	0.00003	0.00002	0.00002
458	0.0000	0.0000	-0.00004	0.00003	0.00002	0.00002
460	0.0000	0.0000	-0.00004	0.00003	0.00002	0.00002
462	0.0000	0.0000	-0.00004	0.00003	0.00002	0.00002
464	0.0000	0.0000	-0.00004	0.00002	0.00002	0.00002
466	0.0000	0.0000	-0.00004	0.00002	0.00002	0.00002
468	0.0000	0.0000	-0.00004	0.00002	0.00002	0.00002

470	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00002
472	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00002
474	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00002
476	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00002
478	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00002
480	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00002
482	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00002
484	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00002
486	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00002
488	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00002
490	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00002
492	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00002
494	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00002
496	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00002
498	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00002
500	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00002
502	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00002
504	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00002
506	0.0000	0.0001	-0.00004	0.00002	0.00001	0.00002
508	0.0001	0.0001	-0.00004	0.00002	0.00001	0.00001
510	0.0001	0.0001	-0.00004	0.00002	0.00001	0.00001
512	0.0001	0.0001	-0.00004	0.00002	0.00001	0.00001
514	0.0001	0.0001	-0.00004	0.00002	0.00001	0.00001
516	0.0001	0.0001	-0.00004	0.00002	0.00001	0.00001
518	0.0001	0.0001	-0.00004	0.00002	0.00001	0.00001
520	0.0001	0.0001	-0.00004	0.00002	0.00001	0.00001
522	0.0001	0.0001	-0.00004	0.00002	0.00001	0.00001
524	0.0001	0.0001	-0.00004	0.00002	0.00001	0.00001
526	0.0001	0.0001	-0.00004	0.00002	0.00001	0.00001
528	0.0000	0.0001	-0.00004	0.00002	0.00001	0.00001
530	0.0000	0.0001	-0.00004	0.00002	0.00001	0.00001
532	0.0000	0.0001	-0.00004	0.00002	0.00001	0.00001
534	0.0000	0.0001	-0.00004	0.00002	0.00001	0.00001
536	0.0000	0.0001	-0.00004	0.00002	0.00001	0.00001
538	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00001
540	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00001
542	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00001
544	0.0000	0.0001	-0.00004	0.00002	0.00001	0.00001
546	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00001
548	0.0000	0.0000	-0.00004	0.00002	0.00001	0.00001
550	0.0000	0.0000	-0.00004	0.00001	0.00000	0.00001
552	0.0000	0.0000	-0.00004	0.00001	0.00000	0.00001
554	0.0000	0.0000	-0.00004	0.00001	0.00000	0.00001
556	0.0000	0.0000	-0.00004	0.00001	0.00000	0.00001
558	0.0000	0.0000	-0.00004	0.00001	0.00000	0.00001
560	0.0000	0.0000	-0.00004	0.00001	0.00000	0.00001
562	0.0000	0.0000	-0.00004	0.00001	0.00000	0.00001

564	0.0000	0.0000	-0.00004	0.00001	0.00000	0.00001
566	0.0000	0.0000	-0.00004	0.00001	0.00000	0.00001
568	0.0000	0.0000	-0.00004	0.00001	0.00000	0.00001
570	0.0000	0.0001	-0.00004	0.00001	-0.00001	0.00001
572	0.0000	0.0001	-0.00005	0.00001	-0.00001	0.00001
574	0.0001	0.0001	-0.00005	0.00001	-0.00001	0.00001
576	0.0001	0.0001	-0.00005	0.00001	-0.00001	0.00001
578	0.0001	0.0001	-0.00005	0.00001	-0.00001	0.00001
580	0.0002	0.0001	-0.00005	0.00001	-0.00001	0.00001
582	0.0003	0.0001	-0.00005	0.00001	-0.00001	0.00001
584	0.0003	0.0001	-0.00005	0.00001	-0.00001	0.00001
586	0.0004	0.0001	-0.00005	0.00001	-0.00001	0.00001
588	0.0005	0.0001	-0.00005	0.00001	-0.00001	0.00001
590	0.0006	0.0001	-0.00005	0.00001	-0.00001	0.00001
592	0.0006	0.0001	-0.00005	0.00001	-0.00001	0.00001
594	0.0007	0.0001	-0.00005	0.00001	-0.00001	0.00001
596	0.0008	0.0001	-0.00005	0.00001	-0.00001	0.00001
598	0.0009	0.0001	-0.00004	0.00001	-0.00001	0.00001
600	0.0010	0.0001	-0.00003	0.00001	0.00000	0.00001
602	0.0010	0.0001	-0.00003	0.00001	0.00001	0.00001
604	0.0010	0.0001	-0.00002	0.00001	0.00002	0.00001
606	0.0010	0.0001	-0.00001	0.00001	0.00003	0.00001
608	0.0010	0.0001	0.00000	0.00001	0.00003	0.00001
610	0.0009	0.0001	0.00001	0.00001	0.00004	0.00001
612	0.0009	0.0001	0.00001	0.00001	0.00005	0.00001
614	0.0008	0.0001	0.00002	0.00001	0.00005	0.00001
616	0.0007	0.0001	0.00002	0.00001	0.00006	0.00001
618	0.0006	0.0001	0.00002	0.00001	0.00006	0.00001
620	0.0006	0.0001	0.00002	0.00001	0.00006	0.00001
622	0.0005	0.0001	0.00002	0.00001	0.00006	0.00001
624	0.0004	0.0001	0.00002	0.00001	0.00006	0.00001
626	0.0003	0.0001	0.00002	0.00001	0.00006	0.00001
628	0.0003	0.0001	0.00002	0.00001	0.00006	0.00001
630	0.0002	0.0001	0.00002	0.00001	0.00005	0.00001
632	0.0001	0.0001	0.00002	0.00001	0.00005	0.00001
634	0.0001	0.0001	0.00001	0.00001	0.00005	0.00001
636	0.0000	0.0001	0.00001	0.00001	0.00005	0.00001
638	0.0000	0.0001	0.00001	0.00001	0.00004	0.00001
640	0.0000	0.0001	0.00001	0.00001	0.00004	0.00001
642	0.0000	0.0001	0.00000	0.00001	0.00004	0.00001
644	0.0000	0.0001	0.00000	0.00001	0.00004	0.00001
646	0.0000	0.0001	0.00000	0.00001	0.00003	0.00001
648	0.0000	0.0001	-0.00001	0.00001	0.00003	0.00001
650	0.0000	0.0001	-0.00001	0.00001	0.00003	0.00001
652	0.0000	0.0001	-0.00001	0.00001	0.00002	0.00001
654	0.0001	0.0001	-0.00001	0.00001	0.00002	0.00001
656	0.0001	0.0001	-0.00002	0.00001	0.00002	0.00001

658	0.0001	0.0001	-0.00002	0.00001	0.00002	0.00001
660	0.0002	0.0001	-0.00002	0.00001	0.00002	0.00001
662	0.0002	0.0001	-0.00002	0.00001	0.00002	0.00001
664	0.0002	0.0001	-0.00002	0.00001	0.00002	0.00001
666	0.0001	0.0001	-0.00002	0.00001	0.00002	0.00001
668	0.0001	0.0001	-0.00002	0.00001	0.00001	0.00001
670	0.0001	0.0001	-0.00002	0.00001	0.00001	0.00001
672	0.0000	0.0001	-0.00002	0.00001	0.00001	0.00001
674	0.0000	0.0001	-0.00003	0.00001	0.00000	0.00001
676	-0.0001	0.0001	-0.00004	0.00001	0.00000	0.00001
678	-0.0001	0.0001	-0.00005	0.00001	-0.00001	0.00001
680	-0.0001	0.0001	-0.00006	0.00001	-0.00002	0.00001
682	-0.0001	0.0001	-0.00006	0.00001	-0.00003	0.00001
684	-0.0001	0.0001	-0.00008	0.00001	-0.00004	0.00001
686	-0.0001	0.0001	-0.00009	0.00001	-0.00006	0.00001
688	0.0000	0.0001	-0.00010	0.00001	-0.00007	0.00001
690	0.0000	0.0001	-0.00011	0.00001	-0.00008	0.00001
692	0.0001	0.0001	-0.00013	0.00001	-0.00009	0.00001
694	0.0002	0.0001	-0.00014	0.00001	-0.00011	0.00001
696	0.0003	0.0001	-0.00016	0.00001	-0.00012	0.00001
698	0.0005	0.0001	-0.00017	0.00001	-0.00014	0.00001
700	0.0007	0.0002	-0.00018	0.00001	-0.00015	0.00001
702	0.0009	0.0002	-0.00019	0.00001	-0.00016	0.00001
704	0.0013	0.0003	-0.00020	0.00001	-0.00017	0.00001
706	0.0017	0.0003	-0.00021	0.00001	-0.00018	0.00001
708	0.0021	0.0004	-0.00022	0.00001	-0.00019	0.00001
710	0.0026	0.0004	-0.00022	0.00001	-0.00020	0.00001
712	0.0032	0.0004	-0.00023	0.00001	-0.00020	0.00001
714	0.0038	0.0004	-0.00023	0.00001	-0.00020	0.00001
716	0.0045	0.0005	-0.00023	0.00001	-0.00021	0.00001
718	0.0054	0.0005	-0.00024	0.00001	-0.00021	0.00001
720	0.0063	0.0006	-0.00024	0.00001	-0.00021	0.00001
722	0.0073	0.0006	-0.00024	0.00001	-0.00021	0.00001
724	0.0083	0.0007	-0.00024	0.00001	-0.00021	0.00001
726	0.0094	0.0007	-0.00022	0.00001	-0.00020	0.00001
728	0.0104	0.0007	-0.00021	0.00001	-0.00017	0.00001
730	0.0113	0.0006	-0.00017	0.00001	-0.00013	0.00001
732	0.0121	0.0005	-0.00012	0.00001	-0.00008	0.00001
734	0.0128	0.0004	-0.00006	0.00001	-0.00001	0.00001
736	0.0133	0.0003	0.00002	0.00001	0.00007	0.00001
738	0.0136	0.0003	0.00012	0.00001	0.00016	0.00001
740	0.0136	0.0004	0.00022	0.00002	0.00026	0.00001
742	0.0133	0.0005	0.00031	0.00002	0.00037	0.00001
744	0.0129	0.0006	0.00041	0.00002	0.00046	0.00002
746	0.0124	0.0007	0.00049	0.00003	0.00054	0.00002
748	0.0116	0.0008	0.00056	0.00003	0.00061	0.00002
750	0.0107	0.0009	0.00062	0.00003	0.00067	0.00003

5.10 Reality Checks

For one unfamiliar with ac-9 data it can be difficult to determine whether or not acquired and processed data is within the realm of reality. While this is a matter of experience and exposure, the following table outlines some of the boundary conditions and possible causes of problems that may be encountered.

Symptoms	Possible Causes	Solutions
Air readings are very noisy	1) Moisture in flow cells	Disassemble flow cells; allow to dry completely.
	2) Ambient light leakage	Cover stainless nozzles with tape or plastic caps
	3) Internal meter malfunction	Contact company
Air readings show significant offset from air tracking file	1) Meter operating outside of compensated temperature zone	Allow meter to cool. Keep instrument temp within cal range. Immerse transmitter housing into water while * calibrating.
	2) Instrumental drift	Compensate with air cal values or re-calibrate
Water–short term variance of signal exceeds 10% of mean	1) Bubbles/air entrapment	Tilt meter, purge all bubbles from the flow path
	2) Particles or debris caught in flow cell	Clean instrument, check water supply for sediment
a > c uncorrected	1) Bad calibration file	Use correct cal file, re-calibrate instrument
	2) Instrumental drift	Apply air cal corrections, re-calibrate instrument
	3) Bubbles/air entrapment	Tilt meter, purge all bubbles from the flow path
	4) Caught particle	Clean instrument, check water supply for sediment
a or c < -0.005*	1) Instrumental drift	Apply air cal corrections, re-calibrate instrument
	2) Bad calibration file	Use correct cal file, re-calibrate instrument
	3) Bubbles/air entrapment	Tilt meter, purge all bubbles from the flow path
	4) Meter out of specified temperature zone	Allow meter to cool. Keep instrument temp within cal range
	5) Over corrected scattering error	Check scattering error correction calculations

**If a or c are < 0 but > -0.005, the instrument is operating properly and a or c may be set to zero.*

6. References

The following is a partial list of references pertaining to the ac-9 and ac-s and their use.

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Sullivan, J.M., M.S. Twardowski, J.R. V. Zaneveld, C.M. Moore, A.H. Barnard, P.L. Donaghay and B. Rhoades, The hyperspectral temperature and salt dependencies of absorption by water and heavy water in the 400 - 750 nm spectral range. *Applied Optics*, 45:5294-5309.

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Zaneveld, J.R.V., J.C. Kitchen, A. Bricaud, C. Moore. Analysis of in-situ spectral absorption meter data, *Ocean Optics XI*, Proc. Soc. Photo-Optical Instrum. Eng. (SPIE), 1750, 187–200, 1992.

Appendix 1. Device Files

Caution

ac-9 DEVICE files are not interchangeable. They provide critical calibration information to the WETView processing software. Always ensure that you are using the proper device file when running your ac-9 in real time or processing logged data from an M-Pak or MODAPS. Using an out of date device file or one created for another instrument will cause WETView to process the data incorrectly.

The ac-9 device file provides WETView with the instrument specific information it needs to carry out primary processing of the binary data. It is an ASCII file that can be edited with any standard text editor however, the file must be saved as tab delimited or it will not be read in by WETView. It contains the instrument serial number, pressure sensor coefficients if applicable, path length and the filter set installed in the ac-9. Note: the serial number contained in the DEV file allows WETView to compare the number to the one burned in to the instrument's NVRAM. Italicized annotation marked by brackets; [*comment* ...] are provided for amplification. These remarks are not found in a real DEV file.

WETView 7.0 device file format (opened in Excel, truncated to the right):

```
AC9 Absorption and Attenuation Meter
      271                    ; Serial number
        2   ; structure version number
Tcal: 20.9 degrees C,  Ical: 24.1 degrees C
        0              0                ; Depth calibration
    19200                               ; Baud rate
     0.25                               ; Path length (meters)
       25                               ; number of temperature calibration bins
                                                 12.51102    13.44218    14.46009
a650      Blue          8.28258            0.00815     0.00769     0.00719
a676      Green         8.29246            0.01026     0.00944     0.00868
a715      Brown         7.82963            0.01289     0.01196     0.01026
c510      Red           8.23092            0.00439     0.00399     0.00361
c532      Magenta       8.25706            0.00672     0.00626     0.00572
c555      Black         8.28164            0.00616     0.00562     0.00511
a412      LtBlue        7.48107            0.00649     0.00632     0.00599
a440      LtGreen       7.73283             0.0089     0.00852     0.00799
a488      Yellow        7.98605            0.00927     0.00855     0.00784
c650      Blue          8.06361            0.01801     0.01619     0.01425
c676      Green         7.84839            0.00578     0.00518     0.00456
c715      Brown         7.42048            0.01065     0.00982      0.0093
a510      Red            8.0872             0.0113     0.01055     0.00973      ...
a532      Magenta       8.14709            0.00825     0.00743      0.0067
a555      Black         8.23866            0.01315     0.01237     0.01148
c412      LtBlue        7.88452             0.0004     0.00056     0.00088
c440      LtGreen       8.04599            0.00263     0.00266     0.00278
c488      Yellow        8.22175            0.00451     0.00429     0.00416
  0.0035        0.004     0.015   0.02      0.015        0.02        2500
        0                               ; auxilliary capabilities                  ...
```

WETView 5.0 device file format

```
AC9 Absorption and Attenuation Meter
00000121        ; serial number
2                               ; structure version number
Reserved                        ; reserved for future
5.3 0.3                         ; depth calibration
19200                           ; baud rate
0.25                            ; path length (meters)
15                              ; number of temperature bins
5.5233 8.4553 11.4712 …         ; temperature bins
a650 Blue 7.6242 0.1411 0.1028 0.0389 …
a676 Green 7.6819 0.1403 0.1041 0.0393 …
a715 Brown 7.6963 0.1369 0.1034 0.0409 …
c510 Red 6.8377 0.1351 0.1045 0.0427 …
c532 Magenta 6.9157 0.1299 0.1034 0.0423 …
c555 Black 7.0137 0.1203 0.0987 0.0423 …
a412 LtBlue 7.1391 0.1169 0.0980 0.0427 …
a440 LtGreen 7.2244 0.1115 0.0959 0.0436 …
a488 Yellow 7.2360 0.1029 0.0893 0.0411 …
c650 Blue 7.1407 0.1001 0.0901 0.0435 …
c676 Green 6.8605 0.0979 0.0861 0.0429 …
c715 Brown 7.2408 0.0949 0.0851 0.0428 …
a510 Red 7.3416 0.0935 0.0839 0.0417 …
a532 Magenta 7.3578 0.0924 0.0827 0.0431 …
a555 Black 7.3922 0.0911 0.0824 0.0436 …
c412 LtBlue 6.0476 0.0903 0.0815 0.0442 …
c440 LtGreen 6.4225 0.0903 0.0805 0.0431 …
c488 Yellow 6.5098 0.0876 0.0793 0.0405 …
0.0035 0.004   0.015   0.02     …        ; reserved info
0                                        ; auxiliary capabilities
```

Calibration Sheet
The following is an example Calibration Sheet supplied with each meter with each calibration performed.

WET Labs, Inc. Philomath, OR 97370 541-929-5650

CALIBRATION RESULTS AND SCALING FACTORS Cal: 003
Model #: 9502002 Date: 04-24-1996
Serial #: AC90152 Job: 003

DIGITAL CALIBRATION
(Kt)

Chan.	Air Val.	Water Off.	Temp. Co.	Prec.	Hex Water	Hex Air
a650	-0.8950	6.0761	-0.00021	0.0002	4FA5	6437
a676	-0.9613	6.1511	-0.00025	0.0002	6479	8076
a715	-1.4817	5.7630	-0.00041	0.0003	3A13	54CF
c510	0.2612	7.5054	-0.00083	0.0002	7645	6E8D
c532	0.2956	7.4744	-0.00070	0.0003	2A4E	273B
c560	0.2085	7.6300	-0.00063	0.0003	3D67	3A39
a412	-0.7238	4.6620	-0.00171	0.0012	0803	099D
a440	-0.7611	5.0389	0.00023	0.0006	136E	178B
a488	-0.7366	5.1652	-0.00050	0.0003	4356	5145
c650	-0.0458	7.5292	-0.00052	0.0002	7227	737C
c676	-0.1431	7.4983	-0.00048	0.0001	8C57	9193
c715	-0.7146	6.9088	-0.00073	0.0002	4DC1	5D79
a510	-0.7425	5.3572	-0.00024	0.0002	4A96	5A0C
a532	-0.7188	5.5060	-0.00035	0.0005	1B5A	20E2
a560	-0.7363	5.6730	-0.00037	0.0004	273A	2F64
c412	0.4077	6.7811	-0.00104	0.0014	0A26	0923
c440	0.3038	7.2107	-0.00037	0.0005	1B2E	1921
c488	0.2691	7.3607	-0.00141	0.0002	69B2	629E

TCal: 25.2 degrees Celsius

ICal: 30.1 degrees Celsius

Temperature Range: 12.9 to 41.2 degrees Celsius

TCal: Water temperature in flow tubes at time of water calibration.

ICal: Instrument internal temperature at time of water calibration.

Temperature Range: Internal instrument temperature range, over which the temperature coefficients are calculated.

Air Values: Air reading, in inverse meters, once the temperature corrections are applied.

Water Offset: The measured value of pure water, in inverse meters, at TCal with temperature corrections applied.

Temperature Coefficients (Kt): Temperature correction scaling factor.

Precision: The standard deviation in air, measured in inverse meters, at a six scan integration.

Hex Water: Raw water values in hexadecimal.

Hex Air: Raw air values in hexadecimal.

Flow rate of 1.5 liters per minute.

Appendix 2. Sample Matlab Routines

To merge and correct ac9 and/or acs data using Matlab, here are some sample functions:

```
function [mergedata] = merge(data1,data2,first)

% merges 2 data sets: data2 is merged to data1. If data2 has fewer
% rows, it will be padded. If data2 has more rows, the first nearest
% value will be taken. First should be a scalar, either 1 if data1
% is written first, or 2 (or anything besides 1) if data2 is written
% first. Both datasets need time as column 1, or change code as
% appropriate.

[r1 c1] = size(data1);
[r2 c2] = size(data2);
mergedata = zeros(r1,(c1+c2));
timecol = 1;                  % if time column is not 1, change 1 to
                              % the appropriate number
for m = 1:r1;
 temp = abs(data2(:,timecol) - data1(m,timecol));
 [dummy, index_a] = min(temp);
 index = index_a(1);     % takes only the 1st value if
                                  % there are more than 1
 if first == 1;
  mergedata(m,:) = [data1(m,:) data2(index,:)];
 else
  mergedata(m,:) = [data2(index,:),data1(m,:)];
 end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%% end merge %%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
function [corrected_data] = ac9cor(data)
% Corrects ac9 for effects of temperature and salinity, and instrument %
drift. There are several instrument or dataset-dependent variables,
% so read through comments carefully.

Tref = 12.0;  % reference temperature (temperature of calibration or
     % temperature that calibration has been corrected to)

ac9_cal = load('ac90270_051006.cor');  % !instrument specific! see
           % ac90270_051006.cor for
           % example

% Find temperature and salinity coefficients at wavelengths matching
% ac9

ac9_wl = [412 440 488 510 532 555 650 676 715]; %!instrument specific!
ac9_tempcor = [0 0 0 0 0.0001 0.0001 0.0001 0.0001 0.0029]; %
wavelength specific
ac9_salcor_c = [0.00007 -0.00007 -0.00007 -0.00007 -0.00008 -0.00008
-0.00005 -0.00007 -0.00032]; % wavelength specific
ac9_salcor_a = [0.00018  0.00008  0.00008  0.00009  0.00004  0.00008
0.00011 0.00008 -0.00018]; % wavelength specific

% Transform calibration into 2x9 matrix; first row is a, second row c
ac9_Wcal = [ac9_cal(:,2)'; ac9_cal(:,3)'];

% Column assignments must be corrected for each dataset
temp = data(:,3);              % temperature column
sal = data(:,5);               % salinity column
% temp = 12;                   % uncomment if temperature is constant.
% sal = 0;                     % uncomment if salinity is constant.
ac9_a = data(:,191:199);       % ac9 a (in ascending wavelengths)
ac9_c = data(:,182:190);       % ac9 c (in ascending wavelengths)

% Correct data to reference temp., 0 PSU, subtract Pure Water Offset.
for y = 1:9;
 a_cor(:,y) = ac9_a(:,y) - ((temp - Tref) * ac9_tempcor(y))...
  - (sal * ac9_salcor_a(y)) - repmat(ac9_Wcal(1,y),r,1);
 c_cor(:,y) = ac9_c(:,y) - ((temp - Tref) * ac9_tempcor(y))...
  - (sal * ac9_salcor_c(y)) - repmat(ac9_Wcal(2,y),r,1);
end
[corrected_data] = [a_cor c_cor]; % add other column variables here

%%%%%%%%%%%%%%%% end of ac9cor %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
function [corrected_data] = acscor(data)
% Corrects ac9 for effects of temperature and salinity, and instrument %
drift. There are several instrument or dataset-dependent variables,
% so read through comments carefully.

load TS.cor; % % temperature and salinity coefficients file

Tref = 12.0;  % reference temperature (temperature of calibration or
     % temperature that calibration has been corrected to)

acs_cal = load('acs010_051006.cor');  % !instrument specific! see
           % acs010_060506.cor for
           % example
c_wl = acs_cal(:,1)';
a_wl = acs_cal(:,3)';

% Transform calibration file to 2x84 (varies with acs) matrix; first
% row is a, second row is c
acs_Wcal = [acs_cal(:,2)'; acs_cal(:,4)'];

% Find temperature and salinity coefficients at wavelengths matching
% acs
t = zeros(2,length(a_wl);
for k = 1:length(a_wl)
 [near_c, t(1,k)] = find_nearest(c_wl(k),TS(:,1));
 [near_a, t(2,k)] = find_nearest(a_wl(k),TS(:,1));
end
acs_c_tempcor = TS(t(:,1),2);
acs_a_tempcor = TS(t(:,2),2);
acs_c_salcor = TS(t(:,1),3);
acs_a_salcor = TS(t(:,2),4);

% Column assignments must be corrected for each dataset
temp = data(:,3);             % temperature column
sal = data(:,5);              % salinity column
% temp = 12;                  % uncomment if temperature is constant.
% sal = 0;                    % uncomment if salinity is constant.
acs_c = data(:,12:95);        % c (in ascending wavelengths)
acs_a = data(:,96:179);       % a (in ascending wavelengths)

% Correct data to reference temp., 0 PSU, subtract Pure Water Offset.
for z = 1:length(a_wl);
 acs_a_cor(:,z) = acs_a(:,z) - ((temp - Tref) * acs_a_tempcor(z))...
  - (sal * acs_a_salcor(z)) - repmat(acs_Wcal(1,z),r,1);
 acs_c_cor(:,z) = acs_c(:,z) - ((temp - Tref) * acs_c_tempcor(z))...
  - (sal * acs_c_salcor(z)) - repmat(acs_Wcal(2,z),r,1);
end

[corrected_data] = [acs_a_cor acs_c_cor]; % add other column variables
                                          % here

%%%%%%%%%%%%%%%%%%% end of acscor %%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
function [scat_cor_apg]=scatcor_proportional(acs_a,acs_c,a_wl,c_wl,...
 ref_wl,ag_ref_wl)

% Corrects for absorption tube scattering error using proportional
% method (Zaneveld et al. 1994, method 3). Either acs or ac9 data
% can be used. ref_wl is usually 715, and in any case should be scalar.
% ag_ref_wl is the dissolved absorption at the reference wavelength
% (measured with a pre-filter).It should be a column vector with
% the same length as acs_a and acs_c. Using this ensures any small
% absorption in the near IR is not subtracted. Make sure there are no
% negative ag values (use something like the routine below). If this
% measurement doesn't exist, insert 0.

% Find a(ref_wl) for scattering correction

[near, ind_a_ref_wl] = find_nearest(ref_wl,a_wl);

% Ensure apg(ref_wl) is not negative

apg_ref_wl = acs_a(:,ind_a_ref_wl);
i = find(apg_ref_wl < 0);
apg_ref_wl(i) = 0;

% Proportional scattering correction to acs

% First interpolate c values to match a wavelengths.

acs_ci = pchip(c_wl,acs_c,a_wl);

% Find scattering error at ref_wl, ae_ref_wl

ae_ref_wl = apg_ref_wl - ag_ref_wl;

% Calculate apg using proportional method

[scat_cor_apg] = acs_a - repmat(ae_ref_wl,1,length(a_wl)).*...
 ((acs_ci - acs_a)./repmat(acs_ci(:,ind_a_ref_wl)...
 - apg_ref_wl,1,length(a_wl)));

%%%%%%%%%%%%%%%%%%%%%% end of scatcor_proportional %%%%%%%%%%%%
```

```
function [scat_cor_apg] = scatcor_baseline(acs_a,a_wl,...
 ref_wl,ag_ref_wl)

% Correct for absorption tube scattering error using baseline
% subtraction method (Zaneveld et al. 1994, method 1). Either acs
% or ac9 data can be used. ref_wl is usually 715, and in any case
% should be scalar. ag_ref_wl is the dissolved absorption at the
% reference wavelength (measured with a pre-filter).
% It should be a column vector with the same length as acs_a.
% Using this ensures any small absorption in the near IR
% is not subtracted. Make sure there are no negative ag values
% (use something like the routine below). If this
% measurement doesn't exist, insert 0.

% Find a(ref_wl) for scattering correction

[near, ind_a_ref_wl] = find_nearest(ref_wl,a_wl);

% Ensure apg(ref_wl) is not negative

apg_ref_wl = acs_a(:,ind_a_ref_wl);
i = apg_ref_wl > 0;
apg_ref_wl = apg_ref_wl.*i;

% Baseline subtraction scattering correction to acs

ae_ref_wl = apg_ref_wl - ag_ref_wl;

[scat_cor_apg] = acs_a - repmat(ae_ref_wl,1,length(a_wl));

%%%%%%%%%%%%%%%%%%%%%% end of scatcor_baseline %%%%%%%%%%%%%

Functions and Files Called:

function [near_scalar, index] = find_nearest(scalar,list);

% Finds the nearest value in a list to the scalar given
% Returns the nearest scalar, and the index to it in list
% such that list(index) == near_scalar
% List is assumed to be a vector. Otherwise
% list = reshape(list, 1, [])
% Assumes that list is sorted and ascending

temp = abs(list - scalar);
[dummy, index_a] = min(temp);
index = index_a(1); % We do this so if we are between 2 values, or
                    % have multiple equal values, we will pick the
      % first
near_scalar = list(index);

%%%%%%%%%%%%%%% end find_nearest %%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
% ac90270_051006.cor. Columns are:
% 1)wavelength, 2)a, 3)c. Corrected to Tref

412 -0.000218176 0.016409491
440 -0.004009941 0.016910659
488 -0.005599808 0.014238527
510 -0.004981576 0.013179569
532 -0.006491022 0.010678814
555 -0.005667489 0.009649864
650 -0.003820464 0.007364143
676 -0.005399499 0.001028188
715 -0.025098163 -0.015690312

% acs010_060506.cor Columns are:
% 1)a_wavelength, 2)a, 3)c_wavelength, 4)c. Corrected to Tref

400.3 0.025929979  400.7 0.011819232
405.0 0.005596177  405.0 0.018329967
409.3 0.002527702  409.4 0.012268044
413.7 0.006751345  413.9 0.015267127
418.2 0.007430073  418.5 0.014592959
423.0 0.011308724  423.3 0.012401351
...
746.4 -0.077942261 747.2 -0.087311156
749.0 -0.069816250 749.7 -0.080618841
751.1 -0.061957811 752.0 -0.072572021
753.8 -0.052815114 754.6 -0.065209093

% TS.cor Columns are: 1)c wavelength
% 2)temperature coefficient 3)attenuation salinity coefficient
% 4)absorption salinity coefficient.

400.0 0.0001   -0.000012  0.000033
400.1 0.0001   -0.000012  0.000033
400.2 0.0001   -0.000012  0.000033
400.3 0.0001   -0.000012  0.000033
400.4 0.0001   -0.000013  0.000033
400.5 0.0001   -0.000013  0.000033
400.6 0.0001   -0.000013  0.000033
400.7 0.0001   -0.000013  0.000033
400.8 0.0001   -0.000013  0.000033
400.9 0.0001   -0.000013  0.000033
401.0 0.0001   -0.000014  0.000034
...
754.2 0.008881636  0.000748814  0.000794
754.3 0.008837636  0.000751825  0.000797
754.4 0.008793636  0.000754836  0.0008
754.5 0.008749636  0.000757847  0.000803
754.6 0.008705636  0.000760858  0.000806
754.7 0.008661636  0.000763869  0.000809
754.8 0.008617636  0.000766879  0.000812
754.9 0.008573636  0.00076989  0.000815
755.0 0.008529636  0.000772901  0.000818
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Revision History

Revision	Date	Revision Description	Originator
A	01/11/00	Begin revision tracking	H. Van Zee
B	02/10/00	Correct table 3, absorption at 715 nm (DCR 16)	D. Hankins
C	07/11/00	Correct temperature correction equation (DCR 45)	C. deLespinasse
D	12/06/00	Replace anti-fouling graphic (DCR 74)	H. Van Zee
E	01/29/02	Correct references to tables (DCR 191)	H. Van Zee
F	07/08/02	Correct scattering correction equation (DCR 229)	D. Hankins
G	03/26/03	Correct table 2 c value at 510 nm (DCR 289)	D. Hankins
H	09/09/03	Correct table 2 after Mueller erratum (DCR 333)	A. Barnard
I	02/05/04	Correct two scattering correction equations, Section 5.4 (DCR 366)	A. Barnard
J	04/11/05	Update scattering coefficients table 2 (DCR 464)	H. Van Zee, R. Zaneveld
K	02/19/07	Update document (DCR 510)	S. Freeman, M. Twardowski
L	03/05/07	Review and add additional updates (DCR 512)	A. Barnard, R. Zaneveld
M	2/5/08	Update internal temperature equations (DCR 562)	A. Barnard, J. Bell
N	5/21/08	Correct temperature correction equation for data processing (section 5.1) (DCR 595)	A. Barnard, J. Bell
O	10/5/09	Correct Matlab routine; scattering correction Section 5.6 (DCR 682)	S. Freeman, H. Van Zee
P	12/1/09	Update Table 2 to reflect NASA-TM 2003-211621, 4,4, Erratum 1, 2003 from Pope and Fry 1997. DCR 686	A. Barnard