LISST-AOBS

Super-Turbidity Sensor

Version 2

User's Manual

Version 2.2

November, 2021

Describes LISST-AOBS Version 2, serial numbers 6246 and higher.
For earlier Version 1 LISST-AOBS models, see manual version 1

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FOR TECHNICAL ASSISTANCE please contact your local Distributor, or Sequoia if the instrument was purchased directly from Sequoia. Please be sure to include the instrument serial number with any correspondence.

A list of local Sequoia distributors can be found at our website
http://www.sequoiasci.com/about/contact/distributors

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INTRODUCTION

LISST-AOBS system parts

The LISST-AOBS is a system with three main parts:

1. LISST-ABS acoustic backscattering sensor
2. Turner Designs Turbidity Plus™ optical backscattering sensor
3. A Y-cable/adapter connecting the two sensors.

The combination of acoustic and optical sensors provides measurements of total sediment concentration that are much less affected by particle size than standard turbidity measurements (see *How Super-Turbidity Measurement Works* on page 21).

For complete technical details of the Turbidity Plus™, see the User's Manual at https://www.turnerdesigns.com/turbidity-plus-submersible-sensor.

Data outputs

The LISST-AOBS has three outputs:

1. ABS standardized concentration in mg/liter, as calibrated with 75-90 µm microspheres.
2. Turbidity Plus output in Volts (*not* calibrated in terms of concentration or NTU).
3. AOBS concentration (Super-Turbidity) in mg/liter, a combination of the ABS and OBS measurements as described in *Pairing ABS with turbidity* on page 22.

Data interface and logging options

LISST-AOBS has two digital interfaces: RS-232 and SDI-12. Both interfaces are available for communication at any time, although normally you will communicate using only one interface at a time. NOTE: the RS-232 interface will not respond when an SDI-12 command is in progress.

Any logger that supports SDI-12 version 1.3 or higher can use the SDI-12 interface. Sequoia has teamed with NexSens Technology to integrate the LISST-AOBS with the NexSens X2 logger family, using SDI-12. The X2 can automatically detect a LISST-AOBS and deliver its data, with data from other connected sensors, through Wi-Fi, cellular, radio, or satellite channels. See more in *Operation with the NexSens X2 logger* on page 4.

If operating with a logger other than the X2 family, see *SDI-12 Operation* on page 7. For details of the RS-232 interface, see *RS-232 Operation*, starting on page 9.

Anti-fouling wiper

Optical backscattering measurements are much more sensitive to biofouling than acoustic measurements. To prevent fouling, the Turbidity Plus includes an integrated anti-fouling wiper. Operation of the wiper takes about 10 seconds, and is activated in the following ways:

1. Upon power-up,*
2. By certain SDI-12 commands,
3. By the RS-232 WI or WIPE command
4. If operating in the free-running RS-232 mode (after automatic start or GO command), every 10* minutes.

*These are the default factory settings, but can be changed via RS-232 with the OBSSET command (see *Set automatic wiping* on page 11)

Sampling modes and start-up sequence

The LISST-AOBS RS-232 interface can operate in either polled or free-running mode.

The default mode is free-running. Upon power-up, after running the Turbidity Plus wiper if applicable, the LISST-AOBS will start sending one data sample per second via RS-232, and continue indefinitely. The host data system is not required to send any commands in this mode.

The free-running mode can be stopped at any time by sending 3 control-C or carriage-return characters via RS-232, or by sending any SDI-12 command.

When not in free-running mode, the LISST-AOBS can receive other RS-232 commands, as described in the *RS-232 Operation* section, including commands for collecting and sending individual samples.

The SDI-12 interface is always polled: the logger or other data system must request a sample, then request the data from that sample.

Wiring

For SDI-12 operation, as with any SDI-12 device, only three connections are required: power (nominally 12 V), ground, and SDI-12 data. However, for compatibility with existing LISST-ABS cabling, the LISST-AOBS uses the same 8-pin connector as a standard LISST-ABS. For details, see *Connection Details* on page 24. The user must determine how to connect

the LISST-AOBS to the SDI-12 logger. Sequoia Scientific can provide cable pigtails for this purpose.

RS-232 operation requires four connections: power, ground, transmit, and receive. Typically these connections will be made to a computer COM port, or a USB adapter, or to a data logger. The user must determine to exact wiring depending on the mating device.

General Use and Care

- Do not use abrasives or harsh solvents for cleaning. These could damage the plastic exterior.
- Use special caution with the light-colored transducer disk on the face of the LISST-ABS. Damage to the transducer can severely affect accuracy.
- Be sure water flows freely through the area directly in front of the LISST-AOBS, and within 10 cm of the ABS face. Any solid object within 10 cm can interfere with the measurements.

OPERATION WITH THE NEXSENS X2 LOGGER

About the X2 and X2-SDL

The NexSens X2 is a data logger that directly supports the LISST-AOBS, using the SDI-12 protocol, as well as many other SDI-12 sensors. The standard X2 is in a compact weatherproof (but not submersible) housing. The X2-SDL is functionally identical, but is submersible to a maximum depth of 60 meters.

Sequoia Scientific and NexSens offer complete packages that include an X2 or X2-SDL, and all necessary cabling.

For detailed information, see the X2 Document and Resource Library at https://www.nexsens.com/knowledge-base-v2/data-loggers/x2, and the X2-SDL resources at https://www.nexsens.com/knowledge-base-v2/data-loggers/x2-sdl.

Logging process

X2 loggers are optimized for long-term monitoring applications, in which they wake periodically, collect a sample, then return to low-power sleep mode until the next sample. The factory-default sample period is 10 minutes, but can be changed through the X2's Wi-Fi interface, or through the CONNECT software.

Data storage & transmission

The logging of LISST-AOBS data on an X2 is controlled by a script provided with the X2. The standard script

1. powers the LISST-AOBS 10 seconds before the scheduled sample time, running the anti-fouling wiper on the turbidity sensor, then
2. collects a 30-second average of LISST-AOBS data, and
3. logs the averaged values.

X2 loggers store data in their onboard memory, but also support automatic uploading through a Wi-Fi, cellular, radio, or satellite connection (depending on hardware configuration). Data then appear in near-real-time on the WQDataLive website. Raw data can also be offloaded directly to a computer through a USB port.

WQDataLIVE

WQData LIVE is a web-based platform for collecting and displaying data from Nexsens loggers. Users of X2 loggers can set up projects on this platform, free of charge. A project can have one or more X2 loggers associated with it, and those loggers can automatically deliver their data to the site through a WiFi, cellular, radio, or satellite connection

(depending on their hardware). The site aggregates the data and offers customizable graphical and tabular displays of data. See https://v2.wqdatalive.com.

CONNECT software

CONNECT is a Windows application for communicating directly to the X2 logger. It is not required for routine logging, but is often helpful for setup. It also allows copying data directly from the memory of the X2. Full information about CONNECT is available at https://www.nexsens.com/knowledge-base-v2/software/connect/user-guide. The software can be downloaded from https://www.nexsens.com/support/downloads.

Using CONNECT requires an adapter cable, Nexsens part number UW6-USB-485P, which is supplied with most X2 systems sold by Sequoia. This cable connects to any USB port on your computer or laptop, and to the waterproof connection in the center of the X2 logger's cap.

SDI-12 addressing

By default, the LISST-AOBS occupies SDI-12 address 0. If you connect other SDI-12 devices to the logger, you must ensure that they have unique addresses. The LISST-AOBS address can be changed, but the X2 logger detection script requires it to be within the range 0 to 9.

Initial setup

Please follow the latest Quick Start Guide from NexSens, available at https://www.nexsens.com/knowledge-base-v2.

If you purchased the complete X2-LISST-AOBS system as a package, the X2 logger will already be set up to with knowledge of the LISST-AOBS that is connected.

If you add sensors or otherwise change the configuration of the system, you must run the X2's process for detecting which sensors are connected. This can be initiated either with the CONNECT software, or through the X2's WiFi web interface. For instructions on running sensor detection from CONNECT, see https://www.nexsens.com/knowledge-base-v2/software/connect/user-guide/run-sensor-detection.

Parameter labels on WQDataLIVE

In a WQData LIVE project, the 3 parameters from the LISST-AOBS are, by default, labeled as follows:

1. "Suspended Particle" in mg/L—the direct output of the LISST-ABS.
2. Voltage—the direct output of the Turbidity Plus sensor

3. “Suspended Particle” in mg/L—the AOBS composite concentration, as described in *How Super-Turbidity Measurement Works* starting on page 21.

For clarity, we recommend that after setting up a project on WQDataLIVE, you change the parameter names from their defaults. To do this:

1. On your WQDataLIVE project’s dashboard, pull down the Admin menu and select Settings.
2. On the Settings page, find the Parameter Settings section.
3. Under Parameter Settings, click on the name of the logger location, then on the name of the logger.
4. Now you should see a list of all the parameters measured by the logger, including the LISST-AOBS parameters. You can edit the names as you see fit. We recommend “ABS Concentration”, “Turbidity” and “Total Concentration”.

SDI-12 OPERATION DETAILS

Overview

The LISST-AOBS supports numerous SDI-12 commands for flexible control over the timing of samples, and over the anti-fouling wiper on the Turbidity Plus. All these commands are accessible to any logger that supports version 1.3 or higher of the SDI-12 protocol. For complete details of the LISST-AOBS commands, see *SDI-12 Command Reference* starting on page 8.

Addressing

When shipped from Sequoia Scientific, the LISST-ABS is normally set to address 0 (zero). You can change the addresses according to your own requirements, using standard SDI-12 methods. In this document, we use *a* to represent the LISST-ABS address.

Sampling and averaging

The ABS and turbidity sensors in the LISST-AOBS can be sampled every 2 to 3 seconds, using the SDI-12 *M* command. However, we recommend collecting 30-second averages in most cases, to smooth the natural variability created by turbulent motion of particles. Longer averaging intervals are also available by selecting the appropriate commands. The concurrent C commands allow the logger to communicate with other SDI-12 devices while the LISST-AOBS collects and averages its readings.

Control of the anti-fouling wiper

By default, the wiper on the Turbidity Plus runs once when power is initially applied to the LISST-AOBS. If your logger is programmed to turn off power to the LISST-AOBS between samples, the wiper will run upon power-up before each sample, without an explicit command from the logger. However, you can also turn off the automatic wiping and control the wiper with commands via RS-232 or SDI-12. See *Set automatic wiping* on page 11.

SDI-12 COMMAND REFERENCE

The following commands comply with the SDI-12 standard version 1.3. The address of the LISST-AOBS is represented by *a*.

Command Function	SDI-12 Command	Action
Address query	?!	Request address (requires that only one device is connected to the SDI-12 bus)
Acknowledge active	*a***!**	Request response from sensor at address *a*
Change address	*a***A***x***!**	Change address of sensor at address *a* to *x*
Send identification	*a*I!	Send ID string including SI address, SDI version, Manufacturers ID and sensor model
Start measurement	*a*M! *a*M1! *a*M2! *a*M3! *a*M4!	Sample once Average for 30 seconds Average for 60 seconds Average for 120 seconds Average for 300 seconds
Run wiper, then start measurement	*a*M5! *a*M6! *a*M7! *a*M8! *a*M9!	Run the wiper, then average for 30 seconds Run the wiper, then average for 60 seconds Run the wiper, then average for 120 seconds Run the wiper, then average for 300 seconds Run the wiper only; no sampling
Start concurrent measurement	*a*C! *a*C1! *a*C2! *a*C3! *a*C4!	Sample once Average for 30 seconds Average for 60 seconds Average for 120 seconds Average for 300 seconds
Run wiper, then start concurrent measurement	*a*C5! *a*C6! *a*C7! *a*C8! *a*C9!	Run the wiper, then average for 30 seconds Run the wiper, then average for 60 seconds Run the wiper, then average for 120 seconds Run the wiper, then average for 300 seconds Run the wiper only; no sampling
Send data	*a*D0!	Requests output data from the preceding M or C command. The data reply contains three values: ABS in mg/l, Turbidity in V, and AOBS in mg/l.

RS-232 OPERATION

Overview

The LISST-AOBS can communicate through RS-232, or through USB with an appropriate adapter (see *USB-powered operation* below).

With factory-default settings, upon power-up the LISST-AOBS will automatically run the anti-fouling wiper for 10 seconds, then send data, once per second, via RS-232.

NOTE: the LISST-AOBS will not respond to RS-232 commands when an SDI-12 command is in progress.

USB-powered operation

The 2-meter adapter cable from Sequoia, part number SEQ-AC-ABS-CBL02, provides both power and communication through a USB port. However, the Turbidity Plus sensor draws a brief surge of current when it is first powered, **which can trigger a shutdown of the USB power**. To prevent this:
1. disconnect the Turbidity Plus from the Y-cable,
2. connect the cable to the USB port (which will power the LISST-ABS),
3. connect the Turbidity Plus to the Y-cable.

Port parameters

The RS-232 port parameters are 9600 baud, 8-bit data, no parity, one stop bit, no flow control.

Command prompt

When the LISST-AOBS is ready to accept commands, it will display the `LISST-AOBS>` prompt.

COMMAND LIST (see the detailed Command Reference on following pages) Commands are not case-sensitive	
DS *or* **status**	Display the identity and status of the LISST-AOBS.
GO	Starts free-running mode.
GS *or* **GetSample**	Makes a measurement and sends it via RS-232.
HS *or* **HoldSample**	Instrument makes a measurement and stores it in temporary memory. The results are NOT sent to the RS-232 output.
SL *or* **SendLast**	Transmits the last sample collected by the issuing of a GS or HS command that was stored in temporary memory.
WI *or* **Wipe**	Run the anti-fouling wiper on the Turbidity Plus sensor.
HE *or* **Help**	Displays a brief list of commands.
OBSSET OBSI	Controls automatic wiping.

RS-232 COMMAND REFERENCE

Display Status	
Syntax:	**DS** *or* **status**
Description:	Display the identity and status of the LISST-AOBS. NOTE: future firmware versions may include more information in the response.

Example:	`LISST-AOBS>DS`
	`Serial number: 6260`
	`SDI-12 address: 0`
	`Version 2.10 Apr 13 2021 22:59:53`
	`Input voltage is 12.46`
	`LISST-AOBS>`

Get and Transmit Sample	
Syntax:	**GS** *or* **getsample**
Description:	Instrument makes a measurement (for approximately 1 second) and returns the ABS, OBS and AOBS values.

Example:	`LISST-AOBS>GS`
	`+4.66e+01,+1.004,+8.78e+02`
	`LISST-AOBS>`

Start free-running data	
Syntax:	**GO** *or* **GO** ***period***
Description:	Starts free-running mode. If a numeric *period* value is included, that will set the time between samples, in seconds. If no *period* is included, the period is 1 second. Data will continue indefinitely, until stopped by 3 ctrl-C or carriage-return characters are received, or an SDI-12 command is received.

Examples:	`LISST-AOBS>GO`
	`+4.66e+01,+1.004,+8.78e+02`
	`+4.66e+01,+1.004,+8.78e+02`
	`+4.66e+01,+1.004,+8.78e+02`
	…
	
	`LISST-AOBS>GO 3`
	`+4.66e+01,+1.004,+8.78e+02` *[3-second pause]*
	`+4.66e+01,+1.004,+8.78e+02` *[3-second pause]*
	`+4.66e+01,+1.004,+8.78e+02` *[3-second pause]*
	…

Help (list commands)	
Syntax:	**HE** *or* **help**
Description:	Displays a list of commands available with brief descriptions

```
**** LISST-ABS help menu ****
DS or Status      Display status.
GS or GetSample   Take a sample and return the result.
HE or Help        This menu.
HS or HoldSample  Take a sample and hold the value (nothing returned).
GO or GO x        Start sampling once per second or every x seconds.
                  Send <cr> or ^C three times to stop.
SL or SendLast    Display the previous sample taken by GS or HS.
WI or Wipe        Run the OBS wiper.

Commands are not case sensitive.
LISST-AOBS>
```

Get and Hold a Sample (do not transmit it)	
Syntax:	**HS** *or* **holdsample**
Description:	Instrument makes a measurement (for approximately 1 second) and stores it in memory. The results are NOT sent to the RS-232 output. Use the SL command to get the result.
Example:	`LISST-AOBS>HS` `LISST-AOBS>`

Set automatic wiping	
Syntax:	**OBSSET OBSI *interval***
Description:	Controls whether the wiper will automatically run at power-up, and also how often it will run during free-running sampling (started by the GO command). • If *interval* is not included, the command simply indicates the present value of *interval*. The factory default is 10 minutes. • If *interval* is non-zero, the wiper will run automatically at power-up, and during free-running sampling it will run every *interval* minutes. The maximum *interval* is 255 minutes. • If *interval* is zero, the wiper will run **only** when explicitly commanded with the WI command or an SDI-12 command.

Example:	`LISST-AOBS>OBSSET OBSI`
	`OBS wipe interval (obsi)= 10 min` [*the factory default*]
	`LISST-AOBS>OBSSET OBSI 60`
	`OBS wipe interval (obsi)= 60 min`
	`LISST-AOBS>OBSSET OBSI 0`
	`OBS wipe interval (obsi)= 0 min` [*automatic wiping is off*]

Transmit last sample	
Syntax:	**SL** *or* **sendlast**
Description:	Transmits the last sample collected by the issuing of a GetSample or HoldSample command. This can be called multiple times and will return the same result each time until a new sample is collected.

Example:	`LISST-AOBS>SL`
	`+4.66e+01,+1.004,+8.78e+02`
	`LISST-AOBS>`

Run anti-fouling wiper	
Syntax:	**WI** *or* **wipe**
Description:	Runs the wiper on the Turbidity Plus. The command prompt returns immediately, but if you send another command while the wipe is in progress, the second command will be delayed until the wipe is completed. If it is another WI command, the reply indicates the remaining time.

Example:	`LISST-AOBS>WI`
	`Wiping for 10 seconds.`
	`LISST-AOBS>WI`
	`Wipe in progress, 4 s remaining.`

LISST-ABS WINDOWS SOFTWARE

The LISST-AOBS is shipped with a Windows application for basic data viewing and logging. The software is called 'LISST-ABS', but works with both LISST-ABS and LISST-AOBS sensors.

Wiring Requirements

Using this software requires a USB or RS-232 connection to a computer. You must provide the necessary connections, or purchase an optional cable from Sequoia. See *RS-232 Operation* on page 9 and *Connection Details* on page 24.

Installing Software

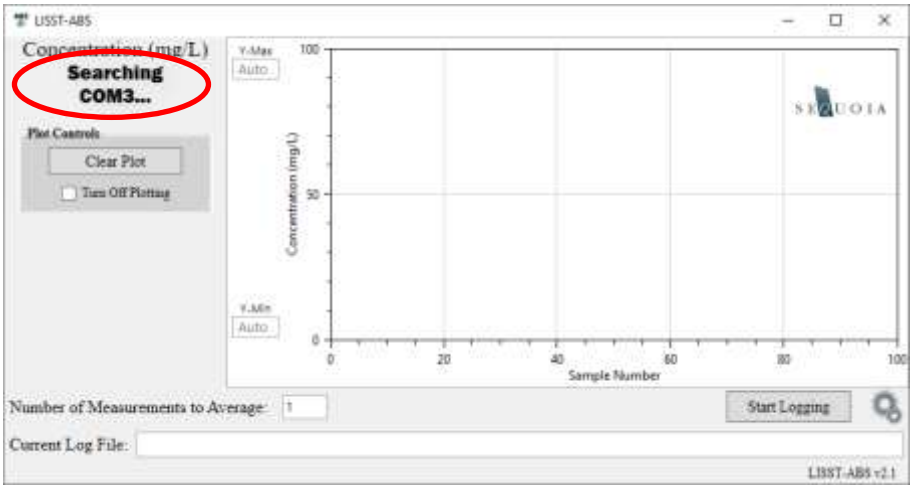
The installer and related software files are located on the USB card included with the instrument. Open the installer by double clicking on 'LISST-ABS_installer.exe.' Follow the onscreen instructions to complete the instillation on your computer.

USB Drivers

Before launching the LISST-ABS software, plug the USB cable into your computer. If the computer has an internet connection it should automatically install the correct drivers for the USB to serial converter. A notification will appear on the screen if the drivers are being installed automatically. If the drivers are not installed, go back to the USB card, and run 'CDM USB Driver.exe.' Follow the on-screen instructions to install the drivers.

Connecting to an Instrument

When the LISST-ABS software is launched, it will begin searching for the instrument on the ports of your computer.



Ensure the instrument is connected to the computer via the USB cable. **The cables must be connected to the sensors in a specific sequence for the LISST-AOBS to function properly; see *USB-powered operation* on page 9.**

Within a few seconds the software will find the instrument and begin displaying concentration values. The software will automatically start plotting the concentration as function of sample number. The instrument serial number will also be displayed at the top left of the screen.

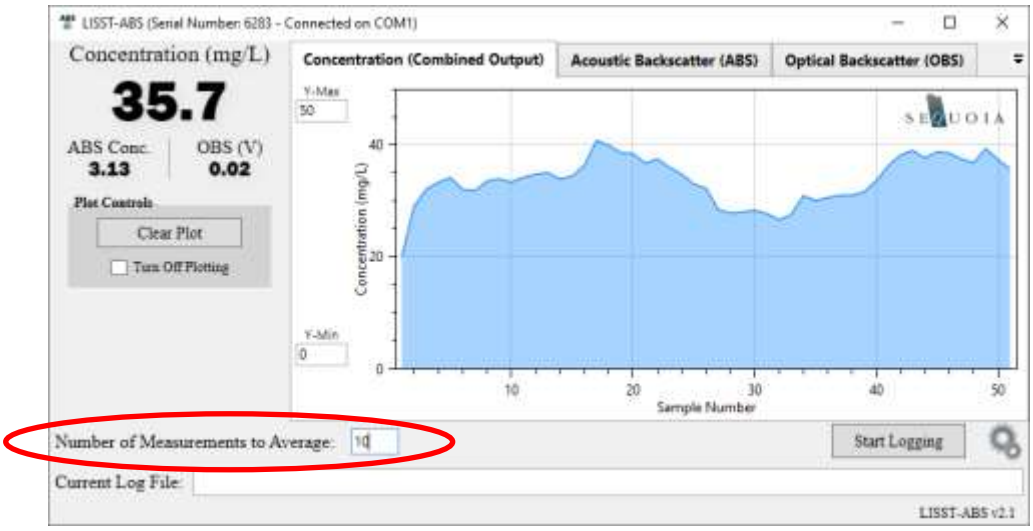
Should you have more than one AOBS instrument plugged into your computer, the software will interface with the first instrument it finds while searching your computer's ports. To change to a different port, see *Settings/Tools* on page 18. You may also open several instances of the LISST-ABS program to view data from multiple instruments.

Software Configuration Options

There are several options in the software for customizing the data display.

Running Average

Just below the concentration plot, you can adjust the number of measurements to average per data point. This is calculated as a running average. For example, if you set the measurement average to 10, each point on the plot will be an average of the 10 previous measurements. If you do not want any averaging of the data, set the measurement average to 1.

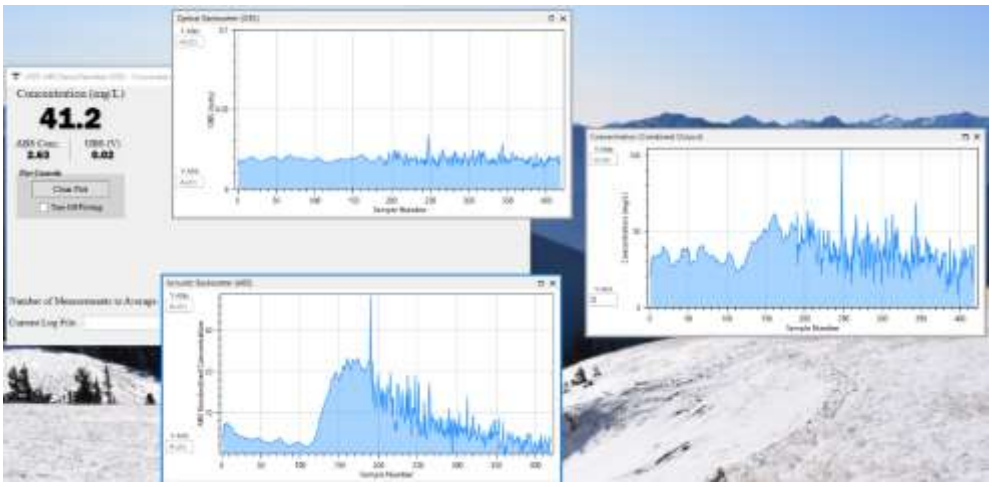


Y-Axis Scale

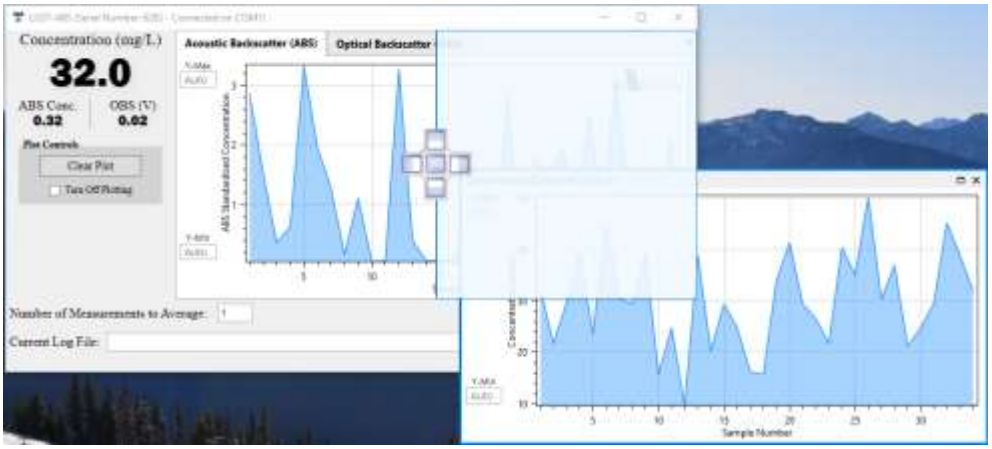
Scaling of the y-axis is handled automatically by default. However, if you wish to lock the y-axis limits at a specific value, enter a number in the text box below 'Y-Min' or 'Y-Max'. You can switch back to auto scaling by deleting the values in the text boxes.

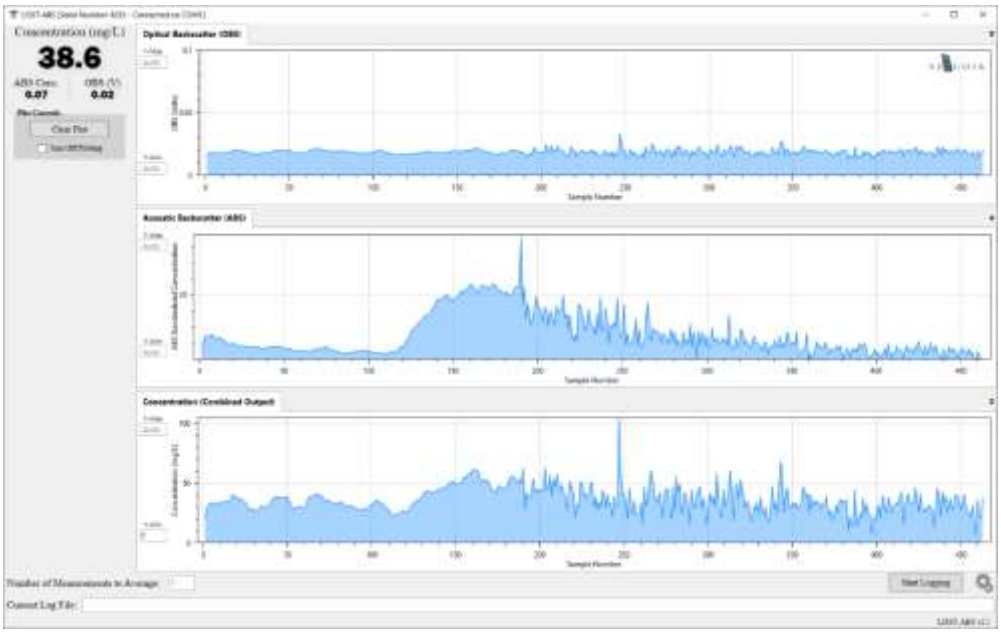
Plot Layout

Each tab of the software shows a time series of the different AOBS measurements (Concentration, ABS Standardized Concentration, and Optical Backscatter). By clicking and dragging each tab, the layout of plots can be changed. For example, they can be undocked and free floating:



Or they can be docked in any orientation by dragging and hovering over the main window:





Clearing or Stopping Data Plotting

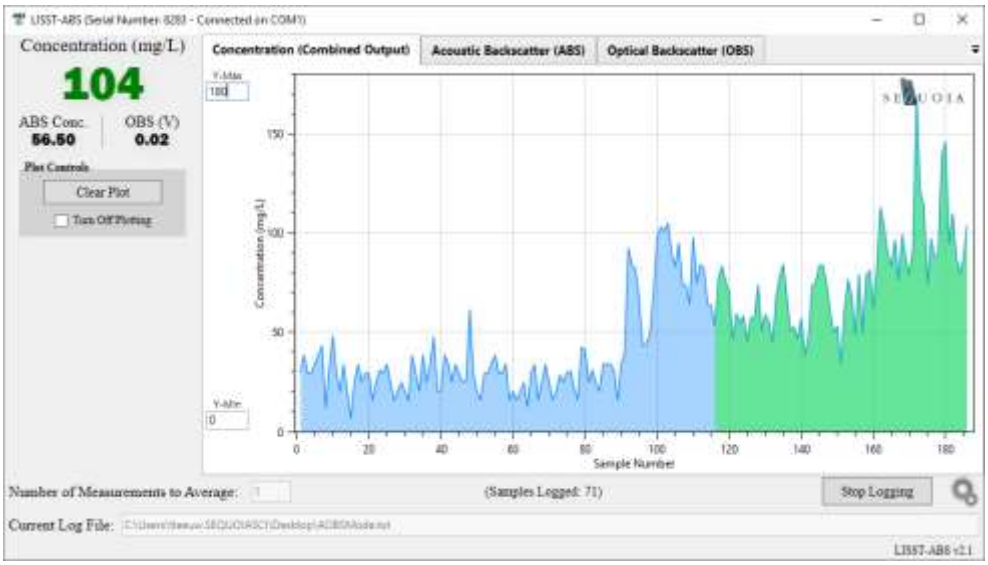
Data currently shown in the plots can be cleared by pressing the 'Clear Plot' button. This will only clear the display and will have no effect on data logging. If the software is left to run for a long period of time, the plots will show a maximum of 900 data points (15 minutes of data). After 900 points, the x-axis will scroll, showing only the most recent 900 points.

Plotting of data can be disabled by checking the 'Turn Off Plotting' checkbox. This is recommended if you will be leaving the AOBS unattended to log data for long periods of time. In these cases, there is no need to tie up computer resources generating a plot that will not be viewed. To resume plotting data, uncheck the box.

Logging Data

Logging is initiated by pressing the 'Start Logging' button. A browser will open that allows you to specify a location and name for the log file. Once that is complete, the location of the log file will be displayed at the bottom of the screen (note: the location displayed at the bottom of the screen can also be edited directly, which is convenient for incrementing file names).

After selecting a file, data logging begins immediately. The number of logged measurements is shown just below the concentration plot. Data that has been logged to a file will appear green in the time series plot:



The log file header contains instrument specific information, the computers current time zone, and the measurement average selected in the software. The header is followed by five columns of data: date, time, ABS standardized concentration, optical backscatter (volts), and total concentration (mg/L).

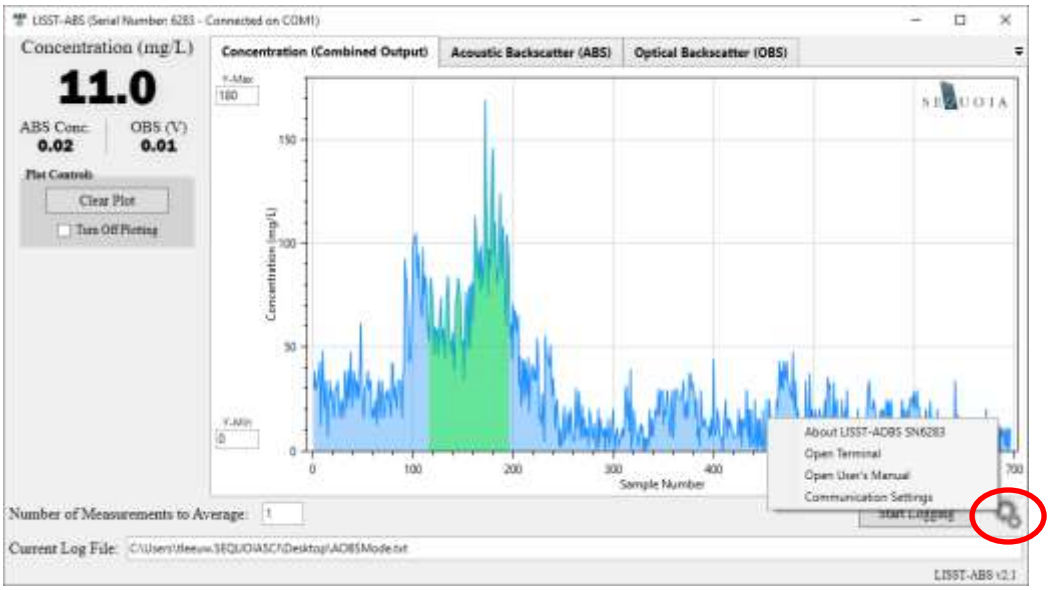
AOBSMode.txt - Notepad

File Edit Format View Help

```
ABS SN = 6283
OBS SN = 1
OBS Wiper Interval = 10
Pairing Factor = 4.587
OBS Voltage Offset = 6.6
ABS Firmware Version = 2.1
Measurment Average = 1
Time = UTC-08:00:00
2021/10/27 09:54:00 19.00 0.02 52.90
2021/10/27 09:54:01 38.70 0.02 77.30
2021/10/27 09:54:02 35.80 0.02 83.50
2021/10/27 09:54:03 32.40 0.02 75.50
```

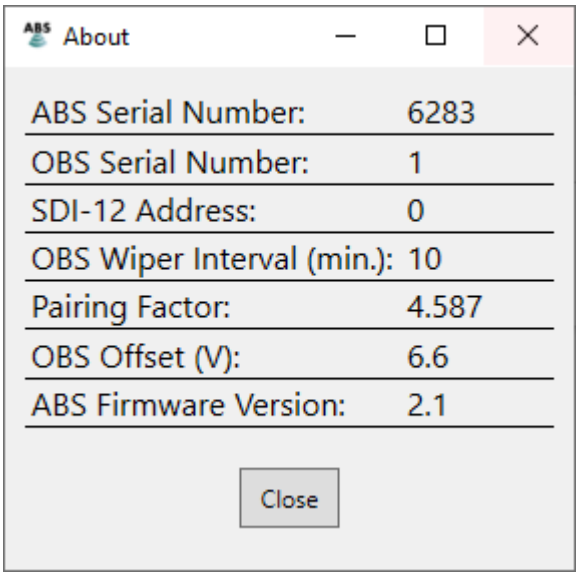
Settings/Tools

Program settings and tools are accessed by clicking the gear icon in the lower right corner. This provides access to instrument information, terminal window, user's manual, and communication settings.



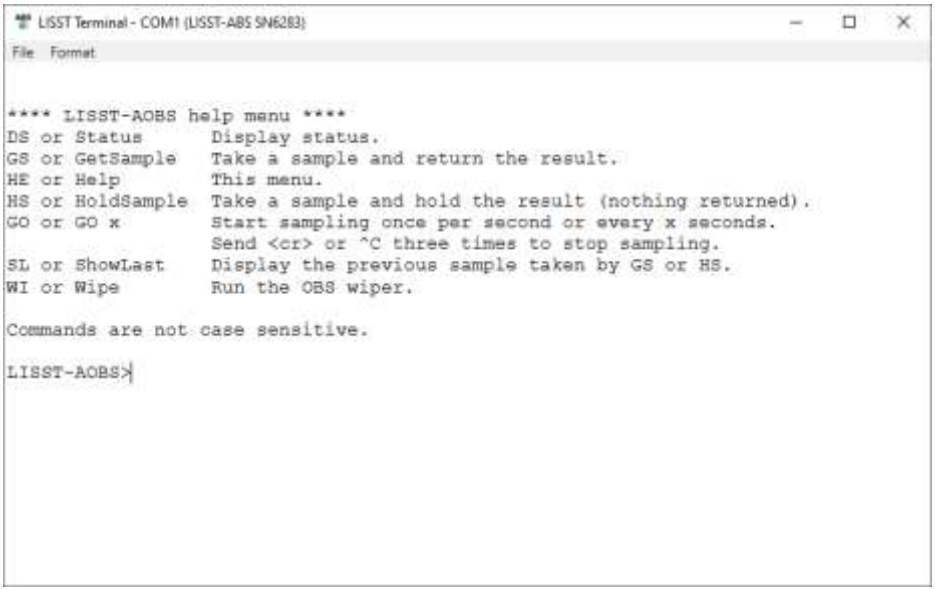
About LISST-AOBS

The ‘About LISST-AOBS’ option will display instrument specific information, which is useful for viewing instrument settings or for troubleshooting purposes.



Terminal

The terminal window allows you to communicate directly with the instrument. This can be useful for retrieving information about your sensor or exploring the instruments serial communication features. Text from this window can be saved to file by selecting ‘Save Buffer’ from the ‘File’ menu. Text from the terminal window can be logged continuously to a text file by selecting ‘Log Buffer’ from the ‘File’ menu.

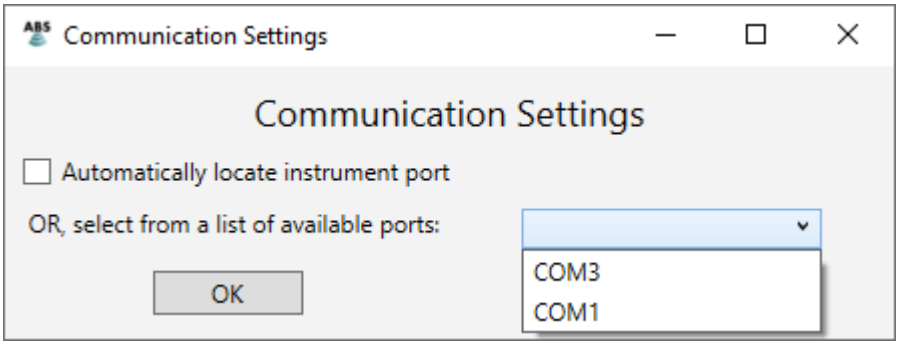


User’s Manual

Opens a PDF of the LISST-AOBS user’s manaul.

Communication Settings

Communication settings allows you to disable the automatic port searching feature. If you know what port your LISST-ABS is connected to, you can specify the port in this window. This can be useful if you are on a computer with many ports, or have multiple LISST-ABS's connected to one computer.



HOW SUPER-TURBIDITY MEASUREMENT WORKS

The LISST-AOBS combines two measurement techniques: acoustic (ultrasonic) and optical, to measure suspended sediment concentration. The two techniques have different strengths, and combining them provides data superior to either one alone.

Acoustic

The acoustic measurement is provided by the LISST-ABS, which measures backscattering with 8 MHz ultrasonic pulses. The LISST-ABS works best for particles with diameters from 30 to 400 µm. For more details, see *Appendix: How the LISST-ABS works*, and the LISST-ABS User's Manual.

Optical

The optical measurement is provided by a Turner Designs Turbidity Plus™ sensor with integrated anti-fouling wiper. The Turbidity Plus's sensitivity to particles, like that of any turbidity sensor, is inversely related to the size of the individual particles. That makes turbidity a poor proxy for total particle mass, because turbidity from small particles can be the same as for a much larger mass of large particles.

Figure 1 shows the contrast between the ABS (blue curve) and turbidity (red) sensor responses versus particle size. For particles larger than about 30 µm, the ABS response is relatively flat, while the response of the turbidity (OBS) sensor is strongest for smaller sizes.

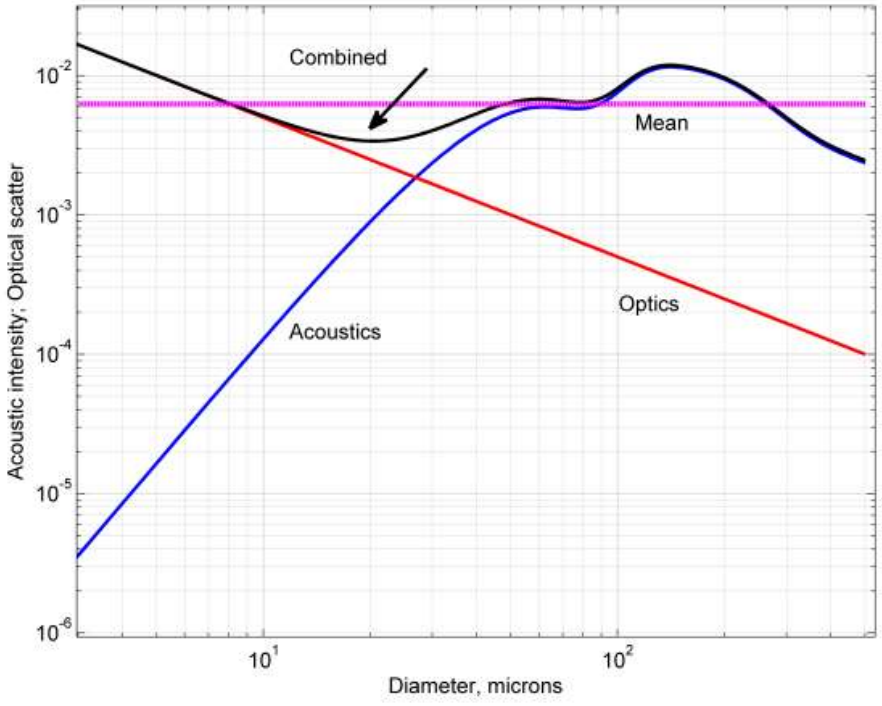


Figure 1: ABS and OBS response versus particle size

Pairing ABS with turbidity

By combining the complementary characteristics of the optical and acoustic measurements, the LISST-AOBS provides better tracking of total sediment concentration than either measurement alone. We can define a combined concentration measurement, C_{AOBS}, as follows:

$$C_{AOBS} = C_{ABS} + P * (V_{OBS} - V_0)$$

where
C_{ABS} is the concentration reported by the LISST-ABS, in mg/l
V_{OBS} is the voltage from the turbidity sensor
V_o is the voltage from the turbidity sensor in clean water
P is the pairing factor in mg/l/V

Intuitively, we can see from Figure 1 that adding the two sensor responses will produce a curve that is "flatter" than either curve alone, but it is not obvious what value of P is optimum. From a combination of theory and experiment, we find that the optimum pairing factor is

$$P = C_{ABS}/V_{OBS}$$

when measured with particles of 30 µm diameter, and with a high enough concentration to make the clean-water offset V_0 negligible. Put another way, P should have the value that equalizes the acoustic and optical contributions to C_{AOBS} from 30 µm particles.

Measuring Pairing Factor

To determine the pairing factor P in practice, we immerse the AOBS sensors in a suspension of natural particles (Arizona Test Dust) filtered to a range of 20 to 40 µm, that is, centered on the 30 µm optimum size cited above. The outputs of the two sensors provide C_{ABS} and V_{OBS}, and the ratio of those values is the pairing factor P.

Pairing Results

Figure 2 shows the response of a properly paired AOBS sensor to a wide range of particle sizes and concentrations. While obviously imperfect (perfect data would lie on the diagonal blue line), these results are vastly superior to what could be expected from a simple turbidity measurement.

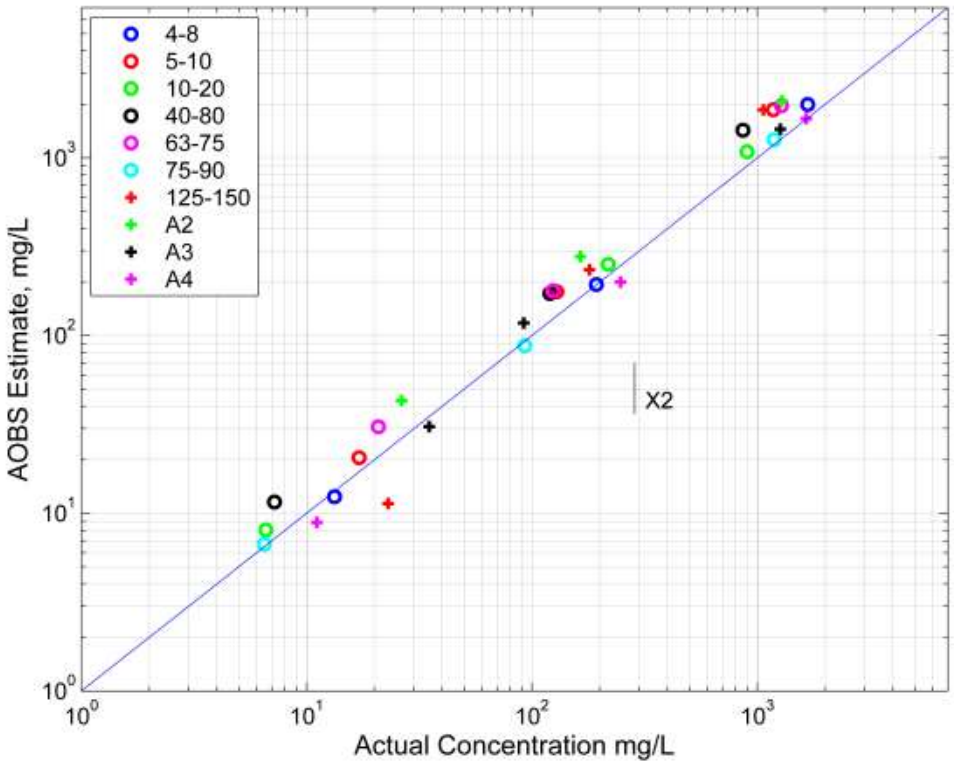


Figure 2: Response of combined AOBS sensor for various particle sizes

Interpreting LISST-AOBS Data

Although the AOBS or Super-Turbidity value is optimum in terms of estimating total concentration across a wide range of particle sizes, the separate ABS and OBS data have value beyond their contribution to the AOBS quantity. Because they have different responses to particle size, the ABS and OBS data can also provide insight into the particle size distribution (PSD). If the ratio of OBS to ABS increases, that indicates the PSD skewing toward smaller particles. If it decreases, the PSD is favoring larger particles. And, in some installations the turbidity from the OBS may also be an important parameter on its own. Therefore, it is generally worthwhile to log all three values.

CONNECTION DETAILS

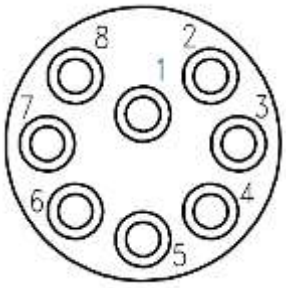
Pin functions

The connector on the LISST-AOBS Y-adapter is a Subconn MCBH8M, wired as shown below. Mating connector is Subconn MCIL8F.

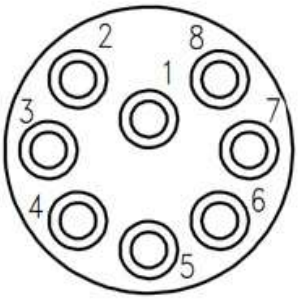
1. Common*
2. Supply voltage, 10 to 15 V
3. Common*
4. RS232 transmit (from AOBS to computer)
5. RS232 receive (to AOBS from computer)
6. SDI-12 input/output
7. No connection
8. Common*

* Common pins are connected inside the Y-cable.

Male connector numbering



Female mating connector numbering



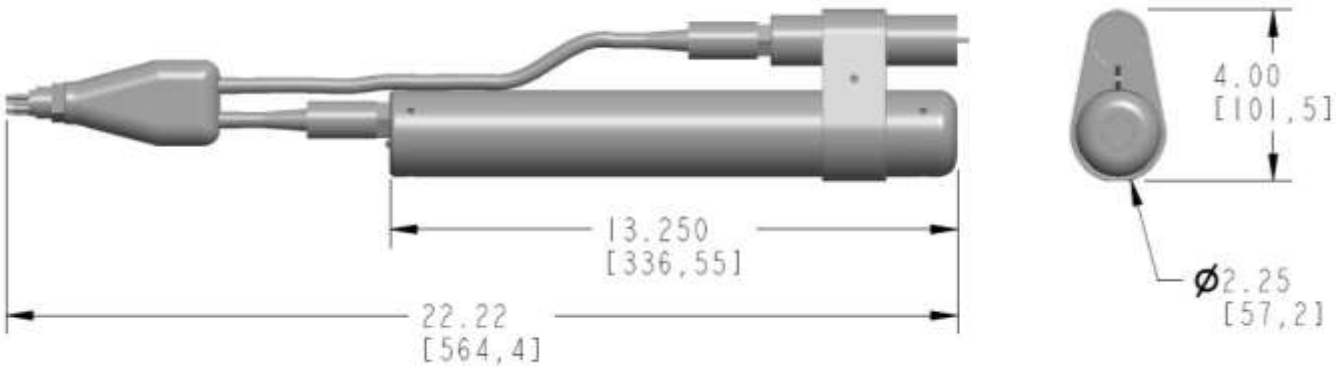
Cables

Green-jacketed cables supplied by Sequoia Scientific for the LISST-ABS are compatible with the LISST-AOBS adapter. See the LISST-ABS manual for details.

SPECIFICATIONS

NOTE: these specifications apply to version 2 of the LISST-AOBS (starting with serial number 6246) and are significantly different from the previous version.

- Power Consumption (typical, 12 V input):
    - Idle: 60 mA
    - Sampling: 75 mA
    - Wiper running (sampling pauses): 68 mA
- Input voltage: 10 to 15 VDC (maximum limited by Turbidity Plus™)
- Maximum depth: 100 meters (limited by LISST-ABS)
- Dimensions: see drawing below
- Concentration measurement range:
    - 1 mg/liter minimum
    - 10 g/liter maximum for particles of any size
    - 30 g/liter maximum for particles 20 µm or smaller
- Weight: 0.9 kg in air; buoyant in water
- Housing materials: Acetal and ABS plastic

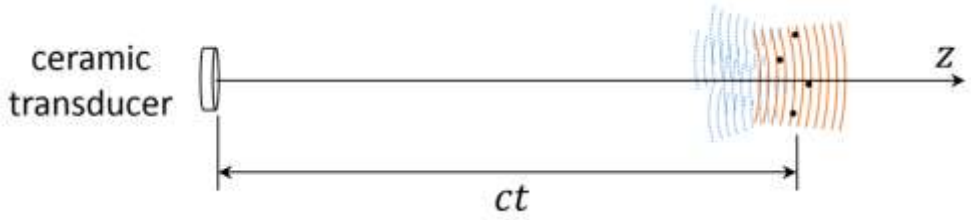


Dimensions in inches [mm]

APPENDIX: HOW THE LISST-ABS WORKS

Basics

The LISST-Acoustic Backscatter Sensor, LISST-ABS operates in a manner similar to radar. A short pulse of high-frequency sound is transmitted by a ceramic transducer, and the same transducer receives signals reflected by particles.



The pulse travels outward, and its location at any time is at a distance equal to the product of speed of sound in water *c*, and time *t* after transmission, *ct*. Particles in the pulse (called 'cell', 'range cell', ' range bin', or 'sample volume') scatter sound in all directions. Some of this sound travels backward toward the transducer. This scattered sound takes the same amount of time *t* to reach back to the transmitter. This is the backscatter signal. The total time for this signal to travel out and back is 2*t*. Thus, the signal sensed at time *2t* after pulse transmission corresponds to scattering from a range cell a distance *ct* from the transmitter. This is the essence of acoustic backscatter. The strength of the backscatter pressure P at the transducer from a range R = *ct* is related to the outgoing pressure pulse P_o, the geometric spreading G(R), and attenuation by the combination of water and sediments. It is helpful now to consider the signal via the sonar equation:

$$\log_{10}[P/P_o] = -G(R) - 2[\alpha_w + \alpha_s]R + \log_{10}(\sigma) + N(R) \qquad (1)$$

This equation shows the weakening of the signal due to geometric spreading G(R), attenuation by absorption by water (α_w) and sediment (α_s), and a noise floor N(R). The signal of interest is the scattering by particles, σ. The LISST-ABS actually measures the backscatter signal from two range cells located at ct_1 and ct_2 from the transducer, so that it can compensate for attenuation by particles in water. To understand, consider the difference of two signals such as above, but with assumption of equal concentration. By difference, we have:

$$\log_{10}[P_1] - \log_{10}[P_2] = [-\Delta G(R) - 2\alpha_w \Delta R] - \alpha_s \Delta R \qquad (2)$$

This shows that the difference in signals from two range bins is equal to the geometric spreading factor, and attenuation. The attenuation term is usually very small for LISST-ABS until sediment concentration becomes high, >1g/L. [we ignore

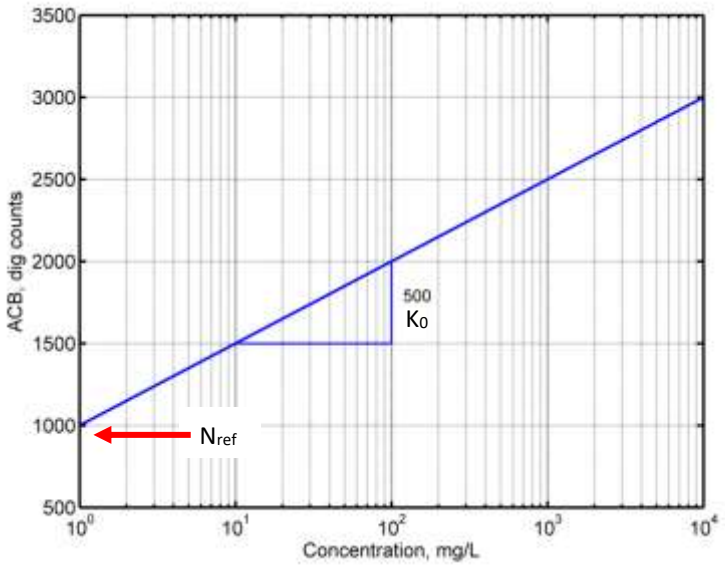
noise floor, it is small]. Thus, the two-point backscatter determines the quantity in square bracket. Any increase in the difference determines water attenuation term.

Knowing the terms in Eq.(2), we simply project the measurement to a small distance from the transducer, i.e. at R ~0 in Eq.(1), yielding the concentration term $\log_{10}(\sigma)$. With a little more arithmetic, that is attenuation-corrected backscattering, or ACB.

In short, the combined geometrical and water attenuation are measured once and are fixed. Temperature related changes in α_w are small and applied subsequently. The sediment attenuation is measured by the change in the difference between two range cells. And then, the measurement is projected to the transducer to get ACB which is then converted to Uncalibrated Concentration

Calibration

The idealized relationship between ACB and sediment concentration is shown in the plot below. Note that this is a log-linear relationship, which is helpful for analysis, as well as matching the characteristics of the detection electronics. ACB counts depend on $\log_{10}(C)$. The slope of the calibration line K_o is fixed by electronics. In practice, the raw signals do not perfectly match this linear characteristic, but each LISST-ABS is calibrated at the factory to measure and correct its non-idealities. The offset at 1mg/L (where $\log_{10}(1) = 0$) is called N_{ref}. For all instruments, $N_{ref} = 1000$.



The factory calibration uses glass beads of diameter 75 to 90 microns, so every LISST-ABS matches this characteristic for those particles. A change in sediment grain-size or other properties does not change the slope, K_o, only the offset, N_{ref}.

While the logarithmic ACB is helpful for theoretical analysis, the LISST-ABS reports final values as the more intuitive linear quantity, milligrams per liter.

REVISION HISTORY

Version 2.2	Added LISST-ABS software section and how LISST-ABS works appendix
Version 2.1	Add note about *USB-powered operation* on page 9.
Version 2.0	Major revision to describe new LISST-AOBS version 2 (Manual version 1.3 still applies to older LISST-AOBS).
Version 1.3	Remove incorrect warranty statement. For warranty information see www.sequoiasci.com/support/warranty
Version 1.2	General revision and formatting, add information about X2 loggers, May 2020
Version 1.1	Improved figure 1. March, 2020
Version 1.0	First released version, March 2020