LISST-Deep
Particle Size Analyzer

User's Manual

For serial numbers 4056 and higher
Built March, 2022 and later

Version 5.02

January, 2023

Store Software USB Card Here

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Welcome to the LISST-Deep Particle Size Analyzer

Using this manual

I. Introduction & Quick Start provides an overview of the LISST-Deep's operating principles and basic functions.

II. Operation Details provides details and step-by-step instructions for using and caring for the instrument.

The **Appendices** contain specialized details, specifications, and information about options.

IMPORTANT NOTE: The LISST-Deep design was extensively upgraded in 2022. This manual only applies to units with serial number 4056 or higher.

Warranty

See the product warranty at:
http://sequoiasci.com/support/warranty

Technical assistance

For technical assistance please contact your local Distributor or Sequoia. Please include the instrument serial number with any correspondence.

Sequoia Scientific, Inc. contact information:
Telephone: (+1) 855-753-3313
Email: support@sequoiasci.com

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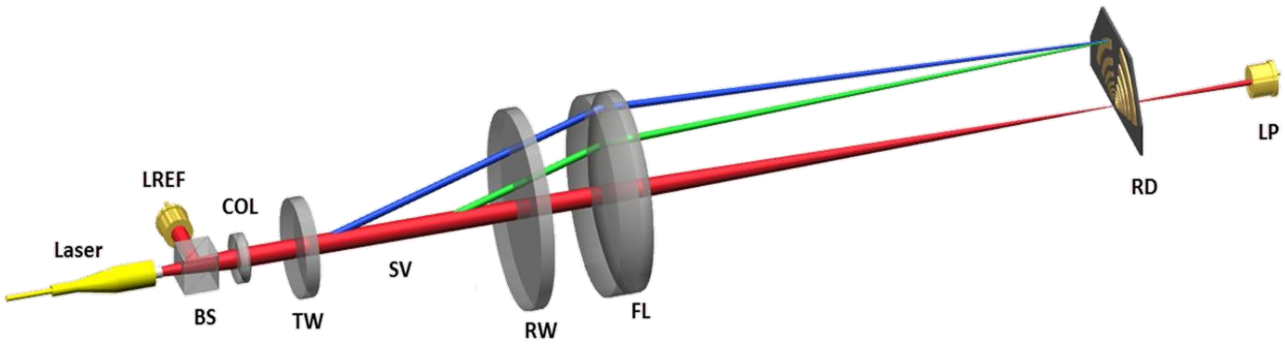
I. Introduction & Quick Start

A. Laser Diffraction and the LISST-Deep

Measurement Principle and Optics

Particle sizing by laser diffraction is currently the most widely prevalent method in research and industry. It is a multi-parameter measurement. Just as a set of 3 equations can be solved for 3 unknowns, a measurement of light scattering at multiple angles can be solved for equally as many *concentrations* in different sizes. For example, the LISST-Deep measures scattering into 36 angles; consequently, one obtains concentrations in 36 size classes of particles. This is called the particle size distribution (PSD).

To measure scattering at multiple angles, the LISST-Deep sends a collimated beam of light into the water. Laser light scattering at an angle from the beam arrives, through a daylight rejection filter, at the focal plane of a receive lens at the same angle from lens axis (see figure). Distance from lens axis in the lens focal plane corresponds to scattering angle. The photodetectors in the LISST series instruments are a series of silicon rings spanning 60-degree arcs. Each ring covers a small range of scattering angles. Rings are used to achieve stability of *inversion* – converting of set of multi-angle scattering measurements to the PSD.



Notice that the laser beam itself is focused by the receive lens and passes through a small aperture in the ring detector, centered on the rings. This beam is sensed by a photodiode placed behind the ring detector. This is the *transmission* sensor. As light is removed from the laser beam by scattering, the beam is attenuated, i.e. the light transmitted through water is reduced in intensity. A similar attenuation also affects the light that is scattered by particles and sensed by ring detectors. Thus, the transmission sensor provides a vital measurement to de-attenuate the measured scattered light.

Clean Water Backgrounds

Scattering originates not only from particles in the water, but also from the water itself, and from the windows and internal optics of the LISST-Deep. This non-particle scattering constitutes a *Background.* (Formerly this was called *zscat,* meaning scattering by zero concentration of scatterers). Accurate measurements require subtracting the background scattering from the total signal seen by ring detectors.

The background scattering typically changes gradually throughout the life of the instrument, due to small changes in the laser and optics, and wear on the exposed window surfaces. It is also very sensitive to cleanliness of the windows. Therefore, high-quality measurements require careful background measurements by the user. A *factory background* acts as a reference for comparison. The LISST-Deep stores its factory background data in its memory, as well as the user's acquired background data.

Background Quality Control

Because the background measurement is so important, the LISST-Deep firmware and software include procedures for measuring and evaluating the background scattering. The software checks for signs of problems such as laser degradation, optics misalignment, contamination of data by thermal microstructure in the water used for background, bubbles or particles in the supposedly clean water, scratches on windows etc.

For details on the background measurement procedure, see Saving and Evaluating Clean Water Backgrounds on page 23.

Ambient Light

The laser diffraction method requires that the light arriving on the detector be due entirely to scattering of light that originates with the laser beam. Therefore, bright light from the sun is an interfering signal that can degrade the measurements. The firmware includes an ambient light rejection (ALR) option that measures and subtracts ambient light. However, ALR also takes time that could otherwise be used to perform more signal averaging. Because the LISST-Deep physically shields the detector from most ambient light, and because ambient light is not a factor over most of the LISST-Deep's range of operating depths, ALR is turned off by default. For more about ALR, see Ambient Light Rejection on page 58.

Quick Estimates of Total Concentration and Mean Size

Converting the LISST-Deep's measurements of scattering to PSD requires extensive computations that are time-consuming for a small microprocessor. However, a much simpler computation, easily done in real time, provides estimates of the total particle volume concentration and mean particle size. These quantities are not as accurate as the fully-processed PSD, but are useful for quick characterization of water conditions. For example, if used in conjunction with a CTD package in profiling applications, the CTD software could display the concentration and mean size as a depth profile, revealing any vertical structure in the particle distribution. (Note that real-time interface to a CTD requires

proper configuration of the LISST-Deep's auxiliary connector; see Configuring the LISST-Deep as a Sensor for a CTD on page 43.)

The quick estimates are based on weighted sum of the net scattered light. One set of weight factors yields the total volume concentration; the other yields the area concentration of particles. The volume/area ratio provides mean diameter, also known as the Sauter Mean Diameter (SMD). Notably, SMD can be quite different from D_{50} in broad or multi-modal size distribution situations. The SMD output is set to zero in very clear waters, i.e. when transmission is above 98%, because the SMD can become erratic when the relative scattering signal is small. [*For an explanation of this method of SMD derivation, see: Shaped Focal Plane Detectors for Particle Concentration and Mean Size Observations*; Agrawal, Y.C. and O.A. Mikkelsen, (2009), Optics Express, v 17, n 25, pp 23066-23077].

Calculating the full PSD in real time

Newer LISST-Deeps can do full PSD processing in real time. The processed data can be stored in the instrument's memory, or transmitted through its serial port. This is especially useful for unattended deployments, such as buoys or remote moorings, where it is not possible to connect a Windows computer to the instrument for data offloads. For full details, see Autonomous Real-time Data Processing on page 40.

Particle Shape Models – Spheres or Irregular Shape

The multi-angle scattering can be interpreted via inversion as arising from spherical particles, or from irregularly shaped particles. Provided software gives you the choice and the resulting PSD files are named differently to distinguish them. As to which particle model to use, we suggest that when working with natural waters, use the irregularly shaped model. The spherical model is appropriate only in exceptional circumstances. For more details see Appendix F: Particle Shape Models on page 74.

B. General Description

Instrument Overview

The LISST-Deep is a submersible laser-diffraction particle size analyzer. It consists of optics for producing a collimated laser beam, a specially constructed photodetector array, electronics for signal pre-amplification and processing, and a digital processor with large nonvolatile storage.

The principal measurement—angular scattering distribution— is obtained with 36 ring-detectors whose radii increase logarithmically from 102 to 20,000 microns. The detector is placed in the focal plane of the receiving lens. The rings cover an angular range from 0.00085 to 0.34 radians.

The resulting small-angle scattering data are processed through iterative matrix inversion to produce the particle size distribution (PSD) over a size range of 1.00 to 500 µm. See Appendix B: Particle Size Bins on page 64 for the exact sizes.

The PSD inversion process can be performed by the instrument firmware, by Windows software, or with MATLAB scripts that are available for download from Sequoia's website: www.SequoiaSci.com.

In addition to its primary scattering measurements, the LISST-Deep measures optical transmission, depth, and temperature, at depths up to 4,000 meters.

The LISST-Deep is capable of autonomous operation when used with external batteries. Windows software is provided to program the instrument for a specific sampling schedule.

An auxiliary connector can be configured for recording data from an external devices such as fluorometer, or for producing summary data (mean size and total concentration) as analog voltages.

The LISST-Deep does not have internal batteries. Its watertight housing need not be opened for any normal use.

Data Storage and Interface

The LISST-Deep includes high-capacity data logging and storage. The logging functions are programmed via the provided software. It can be programmed with different start and stop conditions as well as different sampling rates and average durations. The data logger stores the data in non-volatile Compact Flash memory which can be later downloaded and processed into size distributions and concentration using the provided software.

The data logger will also accept commands via the RS232 interfaces. These commands can be used to program the instrument or to exchange data with another instrument.

Depth and Temperature

In addition to measuring the particle size and concentration, the LISST-Deep also has depth and temperature sensors. The depth sensor has a 6000 psi full-scale range and is calibrated to 4000 meters depth. The temperature is measured using a high precision thermistor imbedded in the connector end cap. Both values are stored automatically in the LISST-Deep data file.

External I/O Port

The LISST-Deep also has an auxiliary 6-pin connector for interfacing to other devices This port can be configured to produce analog outputs, or to receive analog inputs.

The Analog Output Configuration allows the LISST-Deep to receive power from a CTD, and to send two analog voltages indicating the mean size and total concentration to the CTD, while the detailed size distribution data is stored internally for later downloading. For more details about this application, see Configuring the LISST-Deep as a Sensor for a CTD on 43.

The Analog Input Configuration enables operation with additional sensors such as fluorometers and turbidity sensors. It provides 12V regulated power, and accepts two or three analog inputs (0 to 5 V) from sensors. The digitized analog values are stored in the same files as the LISST-Deep's particle size data.

Battery-powered operation

The LISST-Deep does not contain internal batteries (except a small battery to maintain the real-time clock), but can be powered from batteries supplied by Sequoia, or external systems such as a CTD.

The optional LISST-Deep alkaline battery pack provides about 200 hours of sampling time or 200 days of stand-by. Powering down the instrument between samples can greatly extend the deployment times. The provided software contains a battery life calculator on the Configuration page.

USB Power and Data connection

For laboratory or tethered usage, power can be supplied through the communications connector on the endcap. A 2-meter USB cable is provided that will power the instrument from the computers USB port. No additional power is required to operate the instrument.

Cables up to 50 meters can be provided to supply external power and communication with the instrument. This can allow real-time observation of the size distributions.

C. Quick Start Tutorial

This section gives quick instructions for getting started, with references to more detailed information in section II.

Contents of Shipping Case

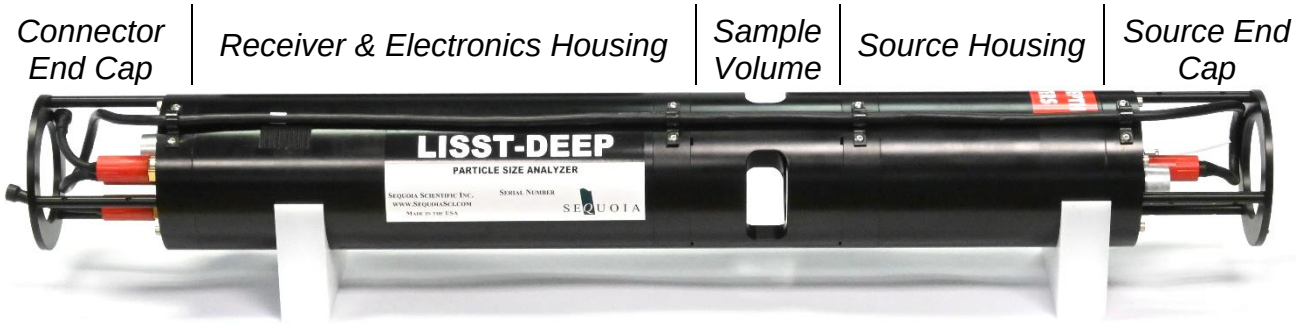
When opening the LISST-Deep shipping case for the first time, you will find:

- LISST-Deep instrument,
- Magnet, attached by Velcro
- Printed User's Manual,
- USB memory card (credit card size) with the software,
- Plastic Instrument stands,
- USB Communications cable,
- Insulated stainless steel hose clamps,
- Plastic sheet with foam strips, used with hose clamps to make watertight chamber.

Step 1: Remove Instrument from Shipping Case.

Start by removing the white plastic instrument stands and set them on a flat working surface. Remove the LISST-Deep from the case and set it on the stands.

Below, we briefly describe the parts of the instrument.



Connector Endcap

The connector endcap has two main connectors:

5-pin: The primary connector; for serial communication and external power.

6-pin: Auxiliary input/output connector, for interfacing with external devices.

See Appendix E: Connectors on page 70 for a full description of the wiring of the underwater connectors and mating cables.

A third connector is used to carry signals between the two housings. You should never disconnect this cable during normal use.

This end cap also holds the thermistor used to measure instrument temperature. Due to the mechanical requirements of the depth rating, the thermistor is embedded in the end cap, so its response time is slowed by the thermal mass of the end cap.

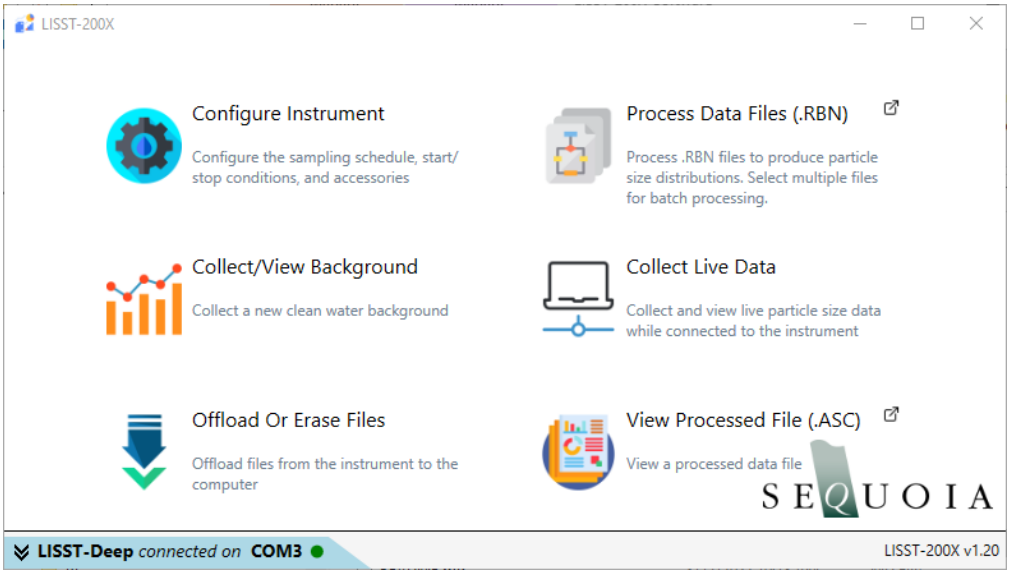
	Finally, the end cap also holds a zinc anode to prevent galvanic corrosion.
Receiver & Electronics Housing	This housing contains the receiving optics, 36-segment optical detector, and most of the instrument's electronics. Between this housing and the sample volume is a very thick tempered window that admits light from the water into the optics, while resisting the massive force of water pressure at 4000 meters depth.
Sample Volume	The sample volume is the 50 mm space between the windows on the source and receiver housings. The spacer between the housings must be extremely stiff in order to maintain optical alignment, while also allowing water (and particles) to flow freely through.
Source Housing	The source housing contains the laser, and optics that expand and form its beam before it enters the water, through a window identical to the one on the receiver housing.
Source End Cap	This end cap holds the pressure sensor used for depth measurements, protected by a stainless steel fitting and small tube. The tube and fitting are filled with silicone oil to protect the pressure sensor against direct contact with corrosive contaminants. This end cap also holds a connector for the cable that carries signals between the housings. This cable should never be disconnected in normal use. This end cap also has a zinc anode for corrosion prevention.
Step 2: Install Software	Sequoia's LISST-200X software, for Microsoft Windows, also supports the newer LISST-Deep version described in this document. It is supplied with the LISST-Deep on a USB memory card (about the size of a credit card). It is also available for download from Sequoiasci.com. This installation process is similar to that of most other Windows software. For a detailed description, see Installing Software on page 21.
Step 3: Attach Communication and Power Cable	The communication and power cable is approximately 2 meters long with a USB connector on one end and 5-pin female waterproof connector on the other. • Plug the USB cable into the computer. The first time you connect it to a computer, there may be a delay while the operating system locates and activates the necessary driver. • Remove the protective cap from the 5-pin communications connector on the LISST-Deep connector end cap. When end cap is oriented with the zinc anode at the 6 o'clock position, the communications connector is at the 10 o'clock position. • Carefully connect the communications cable with the proper connector orientation. Power for the LISST-Deep will be drawn from the USB port.

- For more information on establishing and troubleshooting communication with the LISST-Deep see page 22.

Step 4: Start LISST-200X Application

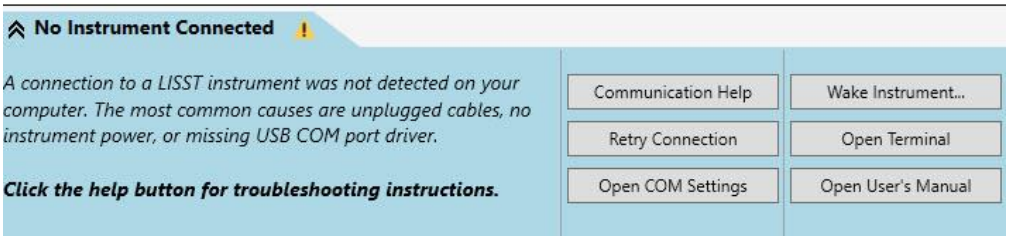
Start the LISST-200X software by selecting the shortcut the installer placed on your desktop.

The LISST-200X software will automatically detect and connect to a LISST-Deep instrument if it is connected to the computer.



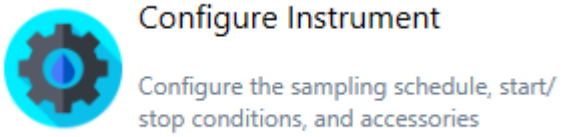
The light blue tab in the lower left corner of the window should show that the instrument was found and connected.

If your instrument is connected to the computer, but not found by the software, click on the ‘No Instrument Connected’ message to see list of options. Click on the ‘Communication Help’ button for troubleshooting help.

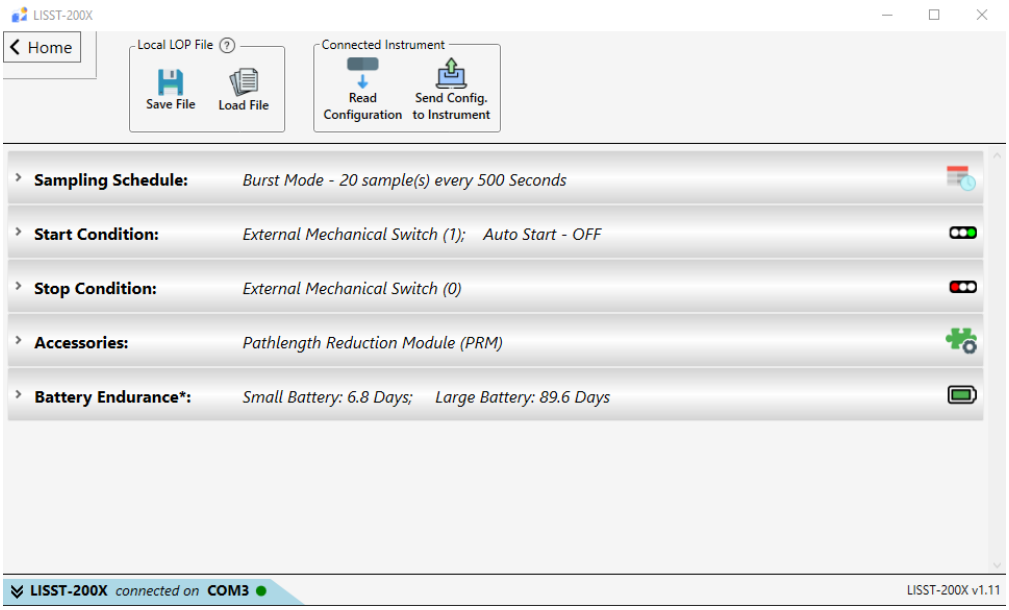


Step 5: Configuring Instrument for Deployment

The Configure Instrument window is used to configure the deployment parameters. To open the window, choose *Configure Instrument* from the home page.



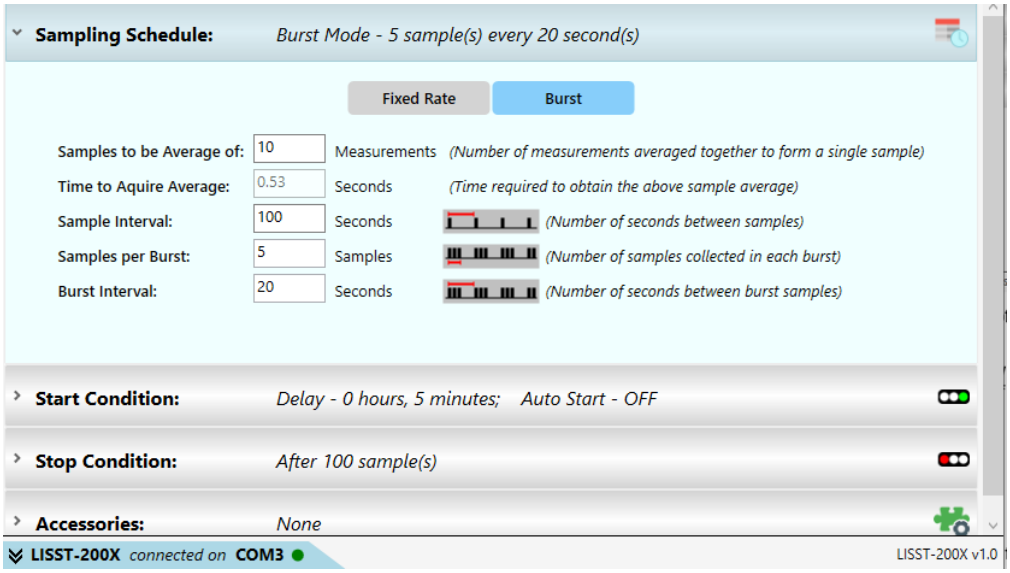
A window similar to the one shown below will appear. The window has four accordion style tabs: Sampling Schedule, Start Condition, Stop Condition, and Accessories.



With the accordion tabs collapsed, the page shows a summary of the instrument's current configuration.

Step 6: Setting Operating Mode

By selecting the *Sampling Schedule* Tab at the top of the main window the screen below appears. This screen is used to set the type of sampling; Fixed Sample Rate or Burst. You can also select the samples per average and sample rates on this screen.



Burst and Fixed Rate Modes

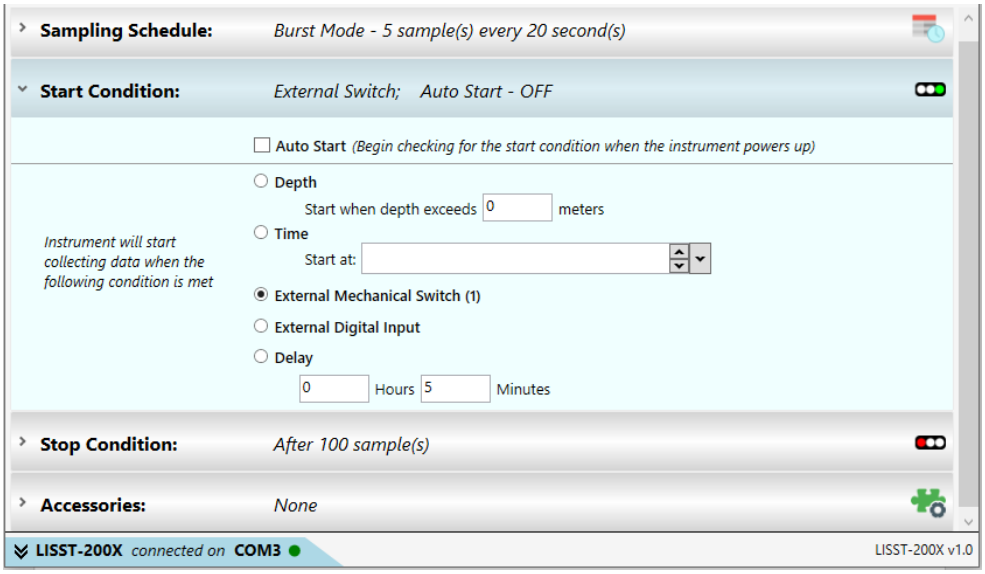
The Burst and Fixed Sample Rate modes are used to save data to a raw data file on board the instrument. The icons next to the various values give a better understanding of their meaning. The software automatically checks the values entered to make sure that there is no conflict. For example, when a 'Sample to be Average of' value is entered, the minimum sample interval is computed. If this value is less

than the minimum permitted the value will be changed to the minimum and the text will turn red.

The LISST-Deep measures internally many times per second, but these individual measurements are averaged into periodic samples, and these averaged values are stored at a maximum rate of 1 Hz. For the example shown above, the instrument is set to sample in the Fixed Sample Rate mode at a 1 Hz rate with 10 measurements per average. This average is obtained in 0.53 seconds.

Step 7: Setting Start Conditions

After selecting the sampling schedule, the start and stop conditions can be selected. Choose the *Start Condition* tab.



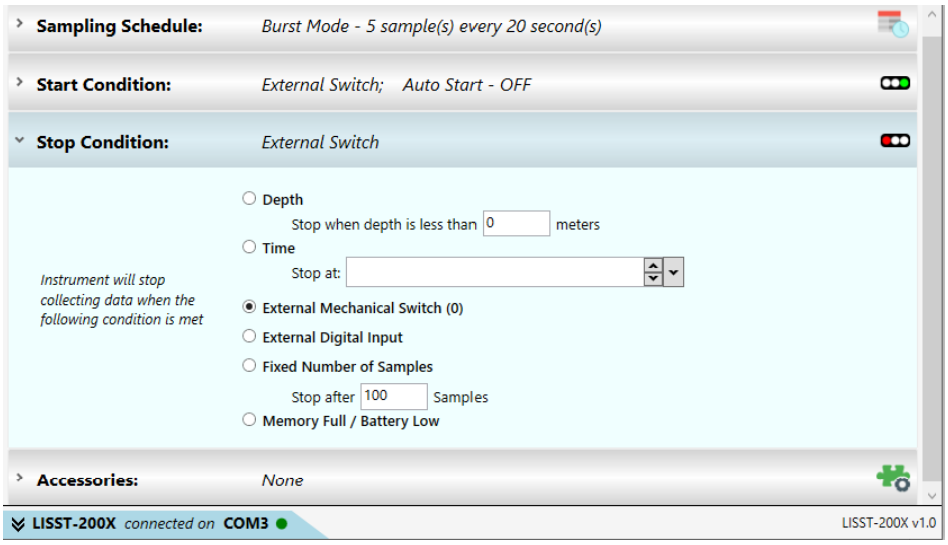
There are five options: Depth, Time, External Magnetic Switch, External Digital Input, and Time Delay. Select the mode by clicking on the button next to its label. Select the correct parameters as required. For this tutorial select the External Switch Start Condition.

AutoStart

If the AutoStart check box is selected, the LISST-Deep will start the sampling program whenever power is first applied to the instrument. **NOTE: for AutoStart to detect the application of power, all power sources (including the USB cable) must first be disconnected for at least 6 seconds.** If AutoStart is not selected the user must select the 'Run Sample Program' button from the instrument status bar or send the 'GO' command to start the sampling programing after applying power.

Step 8: Setting Stop Conditions

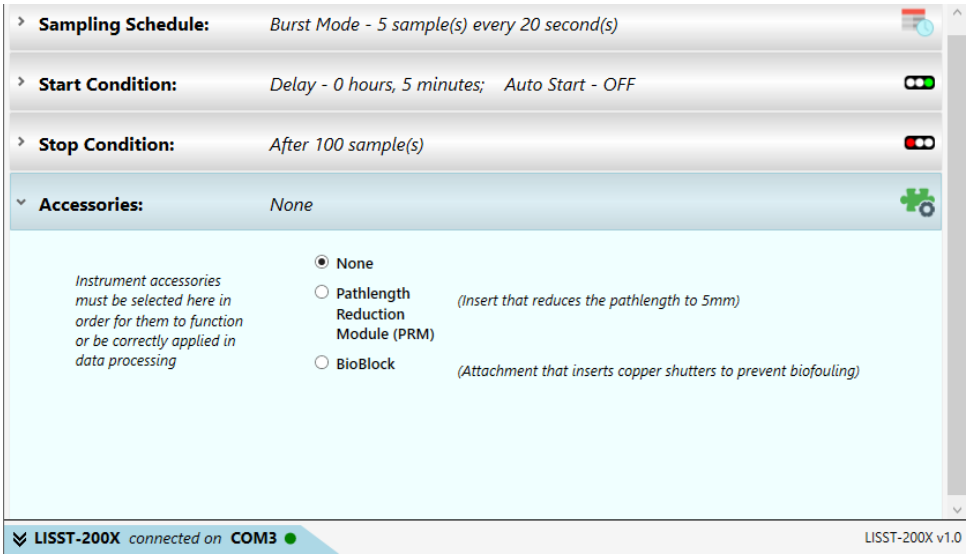
Similarly, the Stop conditions can also be selected. Click on the *Stop Condition* Tab to open the Stop Condition window. The available stop conditions are: Depth, Time. External Magnetic Switch, External Digital Input, Fixed number of Samples, and Memory Full/Battery Low



For this example, choose External Switch as the Stop condition.

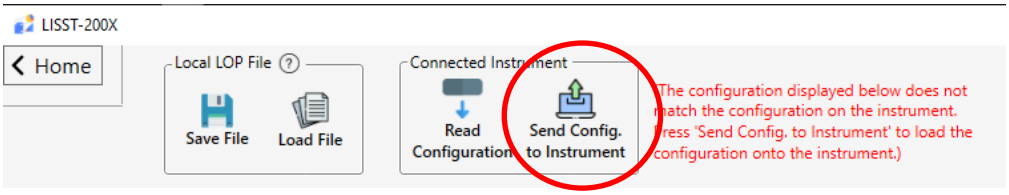
Step 9: Configure Accessories

The accessories tab allows you to select which LISST-Deep accessories are connected to the instrument. The accessories must be selected here for them to function properly. If there are no accessories, select 'None'.

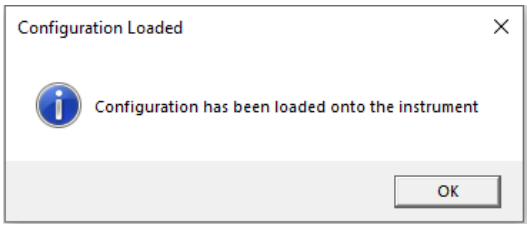


Step 10: Upload Configuration to Instrument

After configuring the instrument settings, they must be uploaded to the instrument. A message will be displayed on the top of the screen when you have unsaved changes to the instrument configuration



Click on the ‘Upload to Instrument’ button to load the configuration onto the LISST-Deep. A confirmation message will be displayed when the upload is finished.



The instrument is now configured for deployment, however, it is not yet running. Before collecting data, a high-quality background scattering measurement is required.

Step 11: Acquiring Clean Water Background Measurement

The background scattering measurement is critical to good instrument performance, and is also a good test of the overall health of the instrument.

This measurement requires forming a temporary watertight chamber around the LISST-Deep’s sample volume. The chamber consists of a flexible sheet of transparent plastic with foam-lined edges, which partially wraps around the sample volume, held in place by two hose clamps. The plastic sheet is shipped from Sequoia with a white protective layer, which should be removed before use.

Cleaning

Before installing the chamber, clean and inspect the windows. Cleaning is best done over a sink or tub. Use a bright light to visually inspect the window surfaces for visible contamination. Clean with a mild liquid soap or lens-cleaning solution, and rinse with plenty of particle-free water.

Chamber installation

Install the chamber by sliding the hose clamps over the end of the LISST-Deep, wrapping the plastic sheet as shown in the photo below. Tighten the clamps only enough to make a leak-proof seal. Overtightening could damage the inter-housing cable.

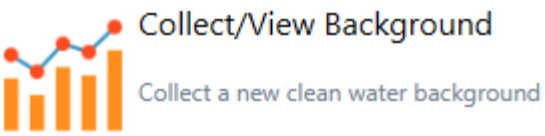
Filling

Use water that is free of particles and bubbles, and preferably has been at room temperature and pressure for some time. Cold or

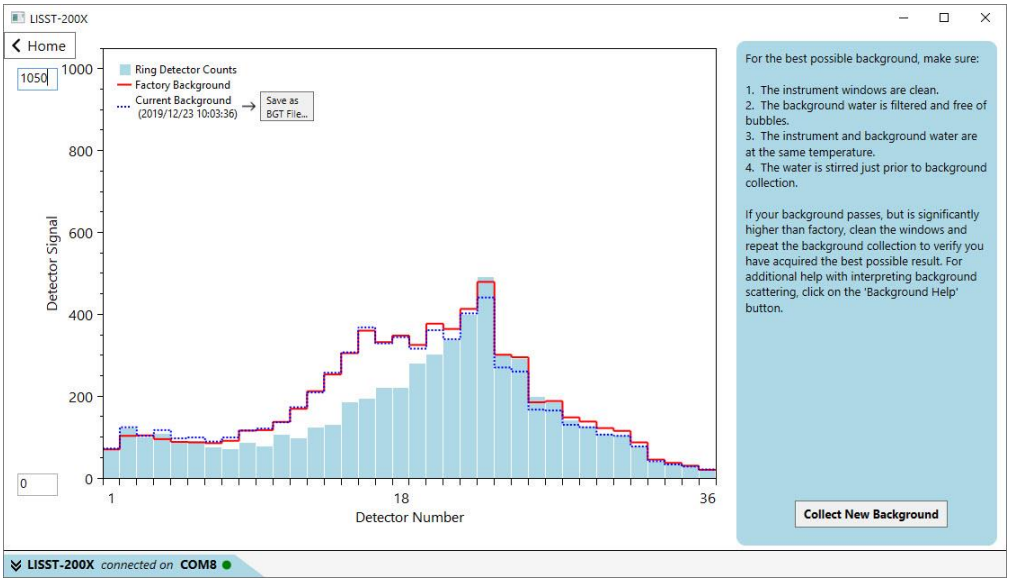
recently pressurized water may contain dissolved air that will form bubbles as it warms.

Measurement

In the LISST-200X software home screen, click the Collect/View Background button:



This will acquire data from the instrument and display a comparison:



Evaluation of the background

The plot shows the factory background and the “current” background, meaning the most recent previously collected. Tips for collecting a background are also displayed on the screen. Pressing the ‘Background Help’ button will open a PDF with additional information about background measurements. When the *Collect New Background* button is pressed, 20 samples will be collecting. The average of these measurements will be displayed as a black line on the screen.

The graph shows the value of the 36 light scattering detectors. The red line is the factory values, the black line is the average of all 20 measurements. If the background is close to factory levels the message displayed will indicate a pass or acceptable background.

If the water or windows are not clean or if there is a problem with the instrument, error messages and suggested actions will be displayed. Dirty water or windows will generally cause higher values across the middle rings. Large bubbles or particles in the water can cause higher values on the inner rings or left hand side of the display. High values on the inner rings combined with a lower transmitted laser power value can also be an indication of optical misalignment.

If needed you can update the background, such as after cleaning the windows or replacing the water, by pressing the *Collect New Background* button again.

In general, the lower the background values the better the background. The goal is to get values that are at the same values as factory line. However, as the instrument is used and ages, the background may increase due to small scratches and slight alignment changes. It may not be possible to get the background down to the original factory values.

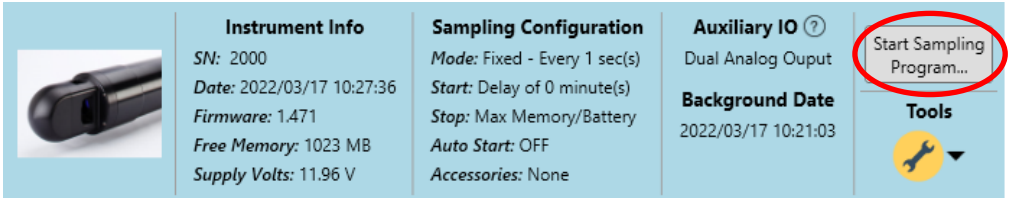
If the values are acceptable, the background can be saved onboard the instrument and, optionally, to a file on your computer. The background stored in the instrument is saved as part of every data file, so it is not necessary to save a separate background file. The background stored on the instrument will continue to be saved in new data files until a new background is recorded.

For tutorial purposes, you can leave the sample chamber in place through the remainder of the steps.

Step 12: Start Sampling Program

Regardless of the start condition you selected, you MUST explicitly start the sampling program to enable starting. If you do not do that, the LISST will never start sampling or react to the start and stop conditions.

To start the sampling program. Click on the 'Run Sample Program…' button in the instrument status bar.



You will be asked to confirm your sampling program, start/stop conditions, accessories, and background date.

After the sampling program is started, you will see the status bar change to 'Sample Program Running' as shown below. At this point the instrument is running and ready for deployment.

Sampling may or may not start immediately, depending on the start condition you selected. For example, if you have selected the magnetic switch as the start condition, the instrument will only react to the switch after the sampling program has been started. If you want sampling to begin immediately, select a start condition of "Delay" with zero as the delay time.

Once the program has been started, you can disconnect the LISST-Deep from the computer, but are not required to.

Step 13: Using the magnetic switch

If you followed the suggestion above to set the start and stop conditions to Magnetic Switch, you can now test this. Locate the magnetic actuator, shown below.

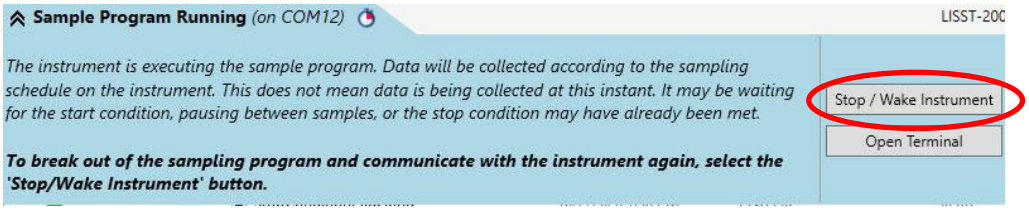
Due to mechanical constraints, the actuator for the magnetic switch is not permanently attached to the LISST-Deep. It attaches to a patch of Velcro fastener, at the location shown below. To improve its visibility, it is attached to a white lanyard.

The logic sense of the removable switch may be counter-intuitive: when the magnetic switch is designated as the start condition, the **presence** of actuator will cause the program to **wait**. The start of data will be triggered by **removal** of the actuator. This prevent the possible loss of the actuator from inappropriately halting or preventing data collection.

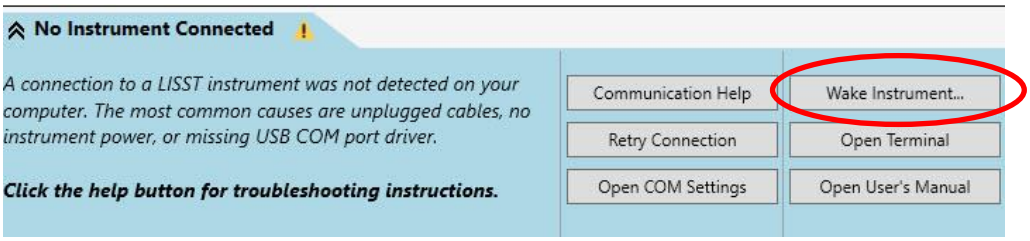
To start data collection, remove the actuator. If it was already removed at the time you started the sampling program in step 12, the LISST-Deep will have started immediately.

You can stop data collection by placing the actuator as shown. You can start and stop it multiple times without connecting to the Windows software (but there is no harm in leaving it connected).

To stop data collection directly from the Windows software, or to wake from low power sleep mode, use the ‘Stop / Wake Instrument’ button from the status bar.

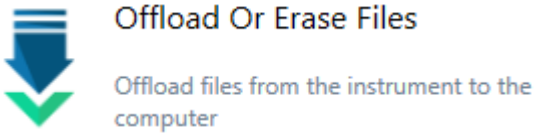


Note that the above options will only be available if you started the sample program from the software. If you plug in an instrument that is already executing a sampling program, the software cannot detect it, and you will need to select the 'Wake Instrument…' button and choose the COM port the instrument is connected to.



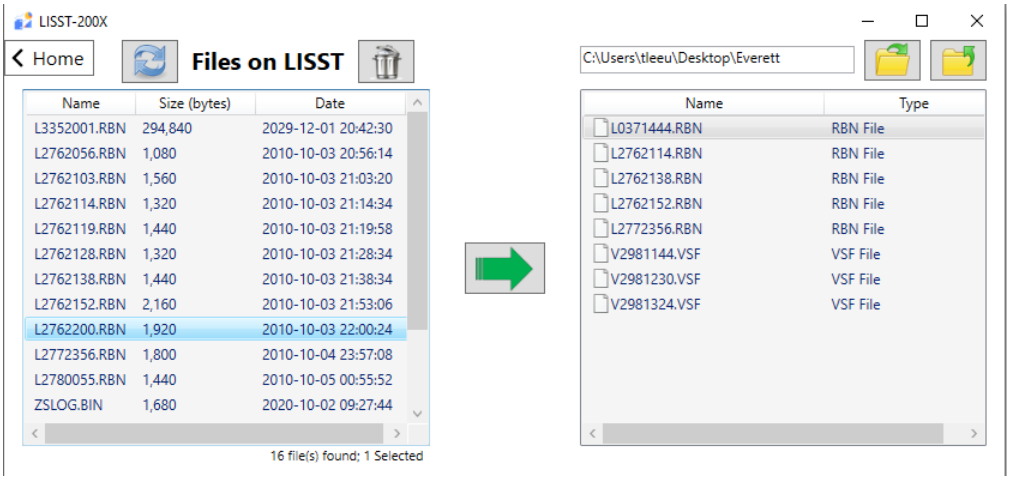
Step 14: Downloading Data

Assuming the start conditions were met, in the previous step, the instrument has now stored data in the on-board memory. Select 'Offload Or Erase Files'. A list of files will appear:



LISST files are named in the following format: L*dddhhmm*.RBN, where *ddd* is the day of the year, *hh* is the hour, and *mm* is the minute that the file was first written to.

Choose the files to offload by clicking on them while holding down the CTRL key. The Shift key can also be used to select a range of files. Choose a location to offload the files to on the right side.



As the data is downloading a the status bars at the bottom will update. The data is offloaded at 115K baud.

Step 15: Processing Raw Data

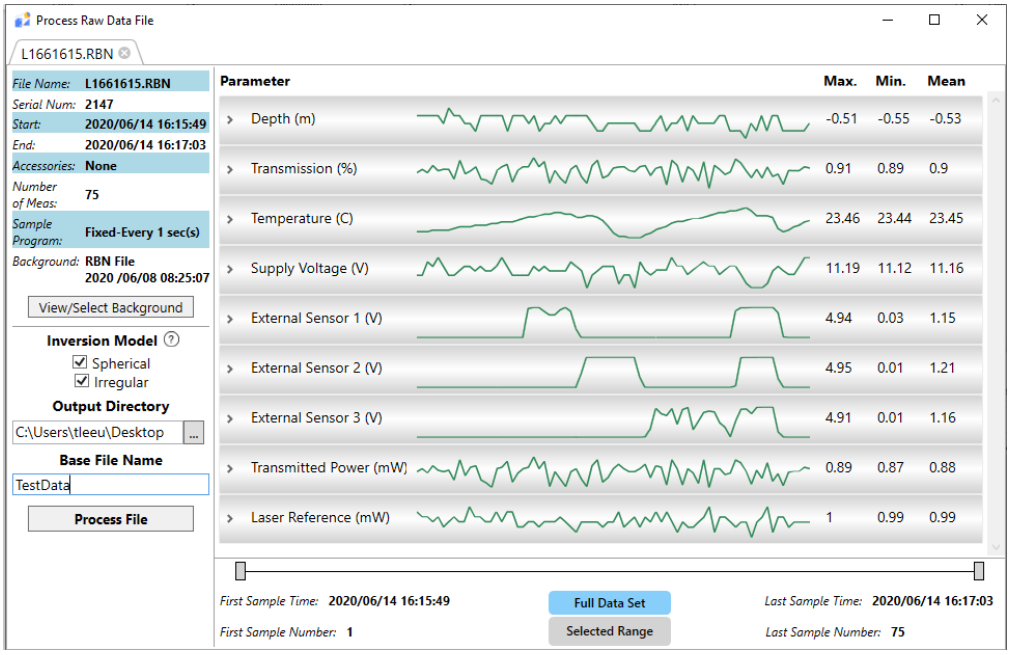
We now have the data transferred from the instrument to the PC. To process the data file choose *Process Data Files* from the home page.

You will be prompted to select the raw data file to open (selecting multiple files will open up the batch processing window). Raw data files have the extension .RBN, and are offloaded directly from the LISST-Deep data logger. Below is list of the file types you can expect to see when using the LISST-Deep.

Extension	Data type	Format
.RBN	Raw	Binary
.RTX	Raw	ASCII
.CSV	Processed	ASCII
.BGT	Background	ASCII

Every LISST-Deep data file contains all the necessary information to process the file. Therefore, the software will automatically determine the instrument serial number, factory background, current background and other instrument specific parameters.

A raw data file display will be generated for your selected data file.



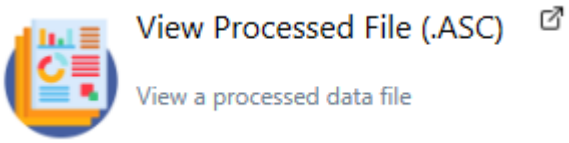
The range of samples to process can be selected by moving the sliders at the bottom of the display. This can be used to exclude data

from the beginning or the end of the file. The default selection is to process the complete file.

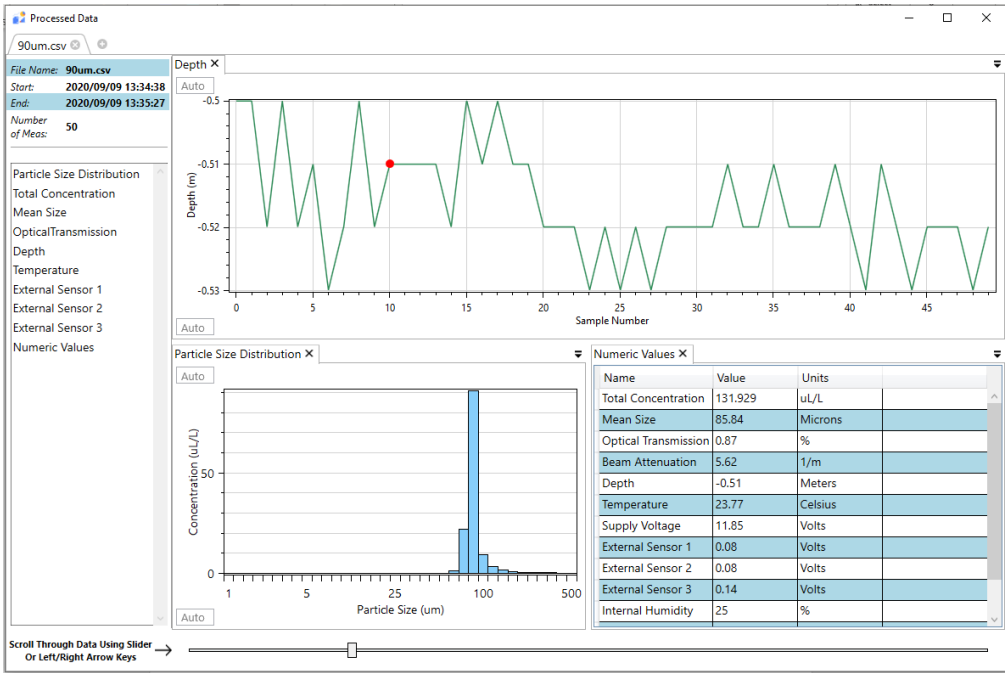
Select the output directory and choose a base file name. Press the *Process File* button to convert the raw file into processed size distributions. For more details on the available options when this window is open, see the detailed Instructions starting on page 31. When the processing is complete a new tab will open, showing the processed results. You can navigate back to the raw data tab if you'd like to change the processing settings and process the data file again.

Step 16: Viewing Processed Results

Processed data files are stored as ASCII files (.CSV). When a raw file is processed the resulting .CSV file is displayed automatically. You can also open any LISST-Deep .CSV file by selecting the View Process File button from the home page.



A display similar to the one below will open. A list of available parameters is displayed on the left. Clicking one of the parameters will open a new window where the parameter will be displayed. The parameter windows can be reorganized by dragging and dropping. The slider at the bottom is used to scroll through the data file. A red point on some graphs will indicate which sample is being displayed.



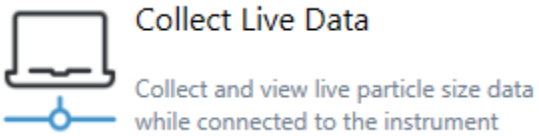
Step 17: Opening a Real Time Session

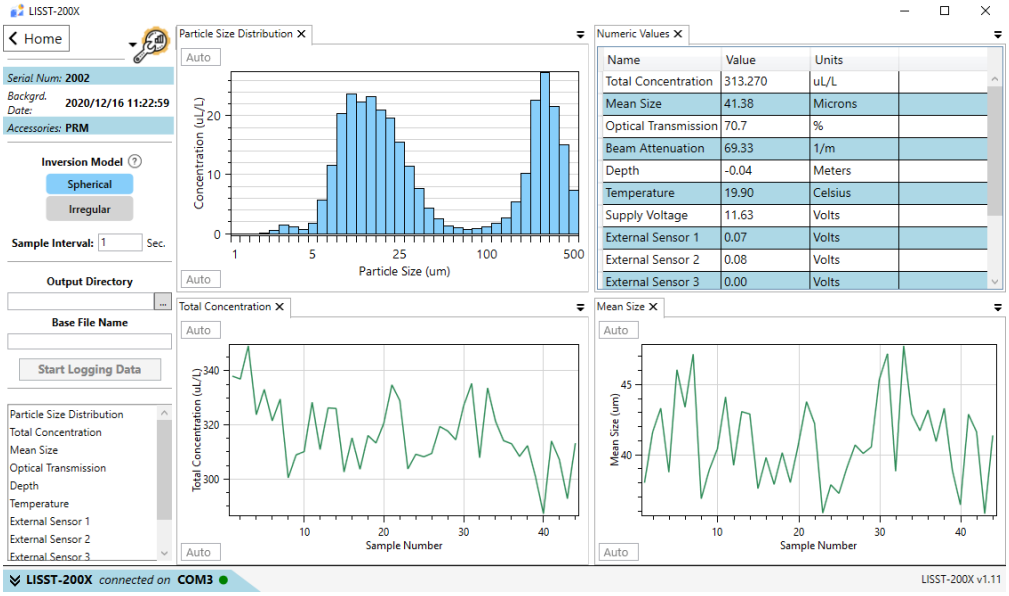
The LISST-Deep software also supports the ability to acquire, process, and display size data it in real time. The Start and Stop conditions will not be used and therefore their settings are not relevant.

Before opening a real time session, you should collect a new background and store it onboard the instrument. The real time session

will use the last background stored on the instrument to process the data in real time. Therefore, you must ensure the background on the instrument is up to date before continuing.

To open the Real-Time session, choose *Collect Live Data* from the home page.





Choose a location to save the data by filling out the output directory and the base file name. The sample interval can also be adjusted by entering the number of seconds between sample in the sample interval text box.

Even though data is displayed to the screen, it is not saved until you select the Start Logging Button.

The Spherical / Irregular Shape radio buttons can be selected in order to display the results as being processed under the assumption that the particles are spheres or randomly shaped (natural grains) particles.

Data using both models is saved and the buttons only represent what is displayed on the screen.

A list of available parameters is displayed on the left. Clicking one of the parameters will open a new window where the parameter will be displayed. The parameter windows can be reorganized by dragging and dropping.

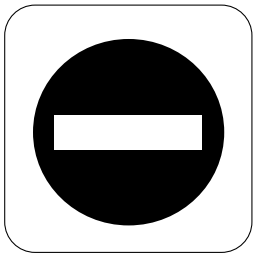
II. Operation Details

Section Organization

This section contains detailed instructions for performing various procedures. These are either in the form of step-by-step instructions or detailed descriptions of the various aspects of instrument operation (e.g. command list, instrument mounting and deployment).

General Precautions

- LISST-Deep is a sensitive optical instrument – please handle it gently as you would handle a very expensive camera.
- Critical alignments may be disturbed if the instrument is subjected to shock or rough handling.
- Evidence of shock/rough handling will void the warranty.
- Whenever in transit, store the instrument in the provided padded shipping case.
- If placing the instrument vertically on the standoffs, be sure to do so gently as the Compact Flash Memory Card inside may otherwise come loose.



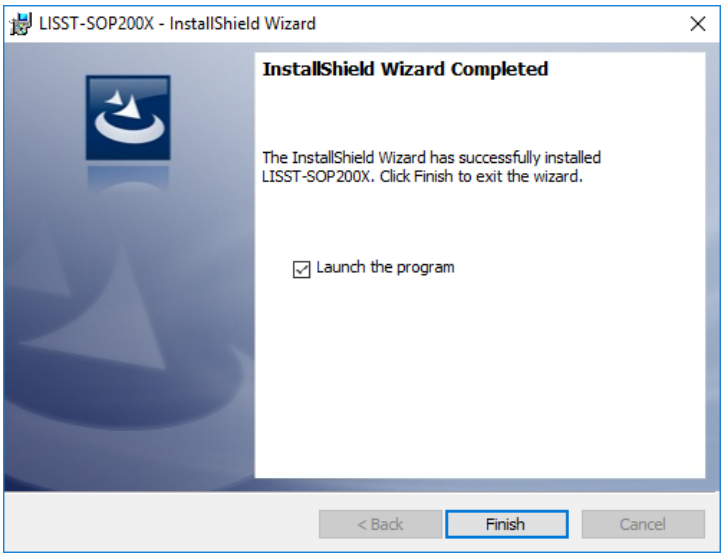
WARNING-Class 3R laser – AVOID DIRECT EYE EXPOSURE

The LISST-Deep uses a laser diode emitting a maximum of 1 mW of visible (red) light at a wavelength of 670nm. Under normal circumstances the laser travels only within the 2.5 cm sample volume. However, if reflective objects are placed in the path of the laser beam, the light could be redirected. Avoid conditions that could direct the beam toward an eye.

A. Step by Step Procedures

1. Installing Software

Software for Windows is used to configure the LISST-Deep and for downloading and processing the size distributions. The software is called LISST-200X, but also supports the revised version of the LISST-Deep described in this manual (it does not support older LISST-Deeps).

STEP	ACTION	RESULT
1	• The LISST-Deep comes with a USB memory card. Plug the provided memory card into a USB port on your computer. Locate the 'LISST-200X_Installer.exe' executable on the memory card. Note that this software it is not compatible with Mac or Linux operating systems. Your operating system must be Window XP or newer to run the software.	Installer was found on LISST-Deep memory card
2	• Double click the 'LISST-200X_Installer.exe.' Follow the onscreen instructions and the installer will transfer the necessary files to your computer and place a shortcut on your desktop and start menu. Do not remove the memory card from your computer until the installation is fully completed: 	Software installation complete

2. Establishing Communication with the LISST-Deep

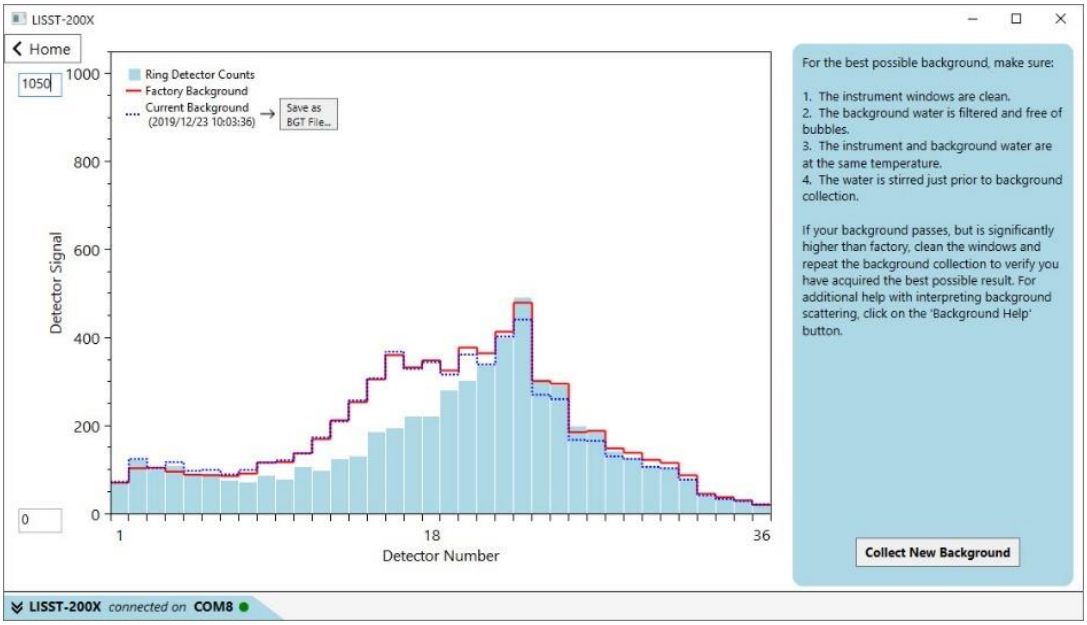
Establish communication with LISST-Deep using the supplied software and USB cable. Communicating with the LISST-Deep via the software should be automatic. If you have trouble, try following these steps exactly.

STEP	ACTION	RESULT
1	• If the LISST-200X software is open, close the program, then unplug the USB communication cable from your computer.	LISST-Deep will be powered on
2	• After plugging the USB cable back into your computer, the drivers for the USB to serial converter should install automatically, if not already installed. You should see a notification on the task bar that drivers are being installed. If you are unsure if the drivers installed, you can install the drivers manually by running 'CDM USB Drivers.exe', located on the memory card that came with your instrument.	Computer is now set up to communicate with the LISST-Deep
3	• After the driver installation is compete, open the LISST-200X software.	Software appears onscreen
4	• The software should automatically search and locate your LISST-Deep instrument among the serial ports on your computer • If no instrument is found you will see "No Instrument Connected" displayed in the lower left corner. • Try selecting the 'Retry Connection' button or try to wake the instrument using the 'Wake Instrument' button.	Software will attempt to automatically connect to the instrument
5	• If further troubleshooting is needed click on the 'Communication Help' button to explore the communication troubleshooting document.	Open Troubleshooting Document

3. Saving and Evaluating Clean Water Backgrounds

In order to properly compute the size distribution, it is necessary to remove the light scattering from the internal optics and window surfaces so that only the light scattering from the particles of interest are used to compute the size distribution.

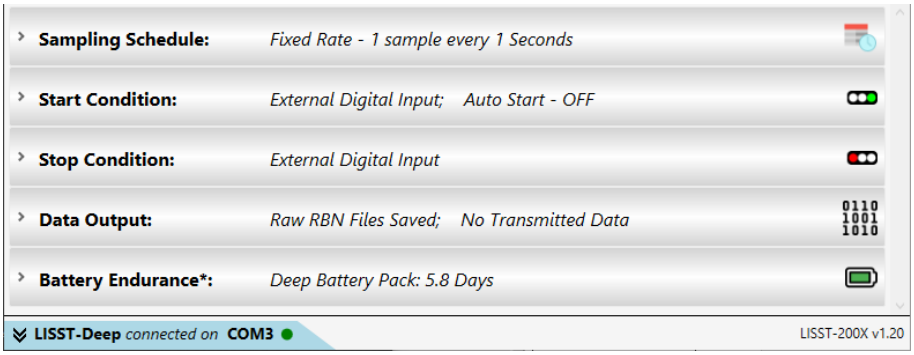
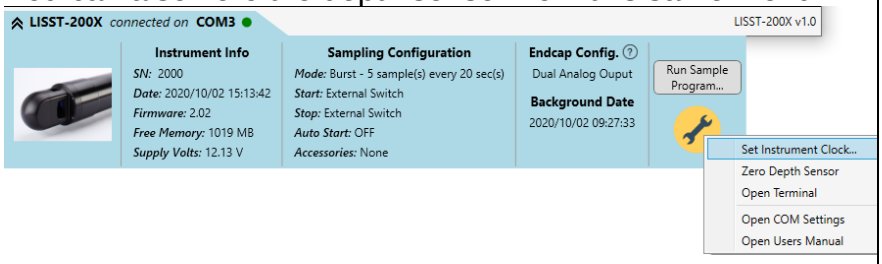
STEP	ACTION	RESULT
1	• Place the LISST-Deep on its plastic stands, preferably over a sink or tray that can collect spilled water. • Connect the instrument to the computer and establish communication in the LISST-200X program (page 22)	Software open, communicating with LISST-Deep.
2	• Clean the windows of the LISST-Deep, and the areas near the windows including the outer housing. This is very important, to avoid contaminating the background measurement with extraneous particles. • Locate the supplied clear plastic sheet with foam along its edges, and accompanying hose clamps. • Wrap the plastic sheet around the LISST-Deep with the foam strips against the housing. Slide the hose clamps over the end of the LISST-Deep, then over the edges of the plastic sheet. • Tighten the clamps just enough to provide a water-tight seal. Excessive tightening can damage the inter-housing cable. 	Optics clean and sample chamber ready for addition of water
3	• Fill with clean, filtered water at room temperature, and make sure no bubbles are in the water or on the windows. • Allow the water to stand for a few minutes to be sure it is at the same temperature as the LISST-Deep.	Ready for background measurement
4	• From the software home page, select *Collect/View Background*. The factory background file will be automatically recalled from the instrument and displayed on the screen.	Background collected and displayed on the screen

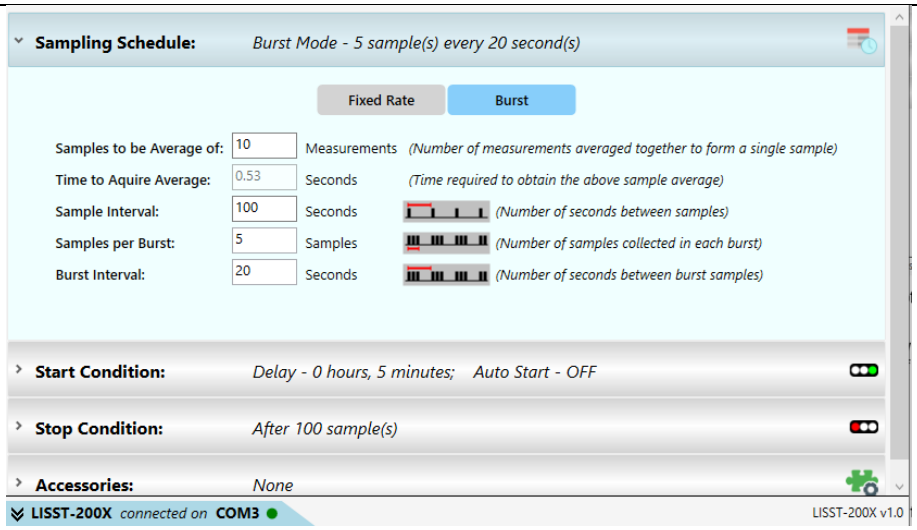
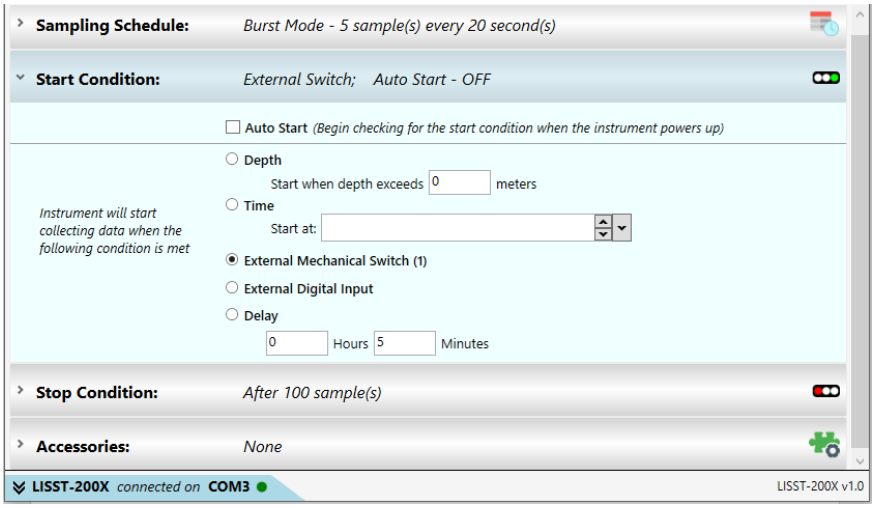
	• The live signal from the 36 ring detectors will also be displayed in real time. • Stir the water briefly with a clean plastic or metal object, to ensure it is not thermally stratified. • When the ring detector plot is stable, press the *Collect New Background* button. 20 samples will be collected, and their average displayed to the screen.	
		
	• The graph shows the value of the 36 light scattering detectors. The red line is the factory values, the blue line the current background saved on the instrument. A newly collected background will be displayed as a solid black line.	
	• If the background is close to factory levels, the message displayed will indicate a pass or acceptable background. Even if your new background passes, but is significantly higher than factory, clean the windows and repeat to verify you have acquired the best possible result. The general goal is to achieve the lowest possible background level, similar to the factory background. However, it is typical for the background to rise somewhat over the life of the instrument. Increased background is acceptable as long as it is stable and repeatable when measured carefully.	Acceptable Background
	• If the water or windows are not clean, or if there is a problem with the instrument, error messages and suggested actions will be displayed. Dirty water or windows will generally cause higher values across the middle rings. Large bubbles or particles in the water can cause higher values on the inner rings or left hand	Unacceptable Background

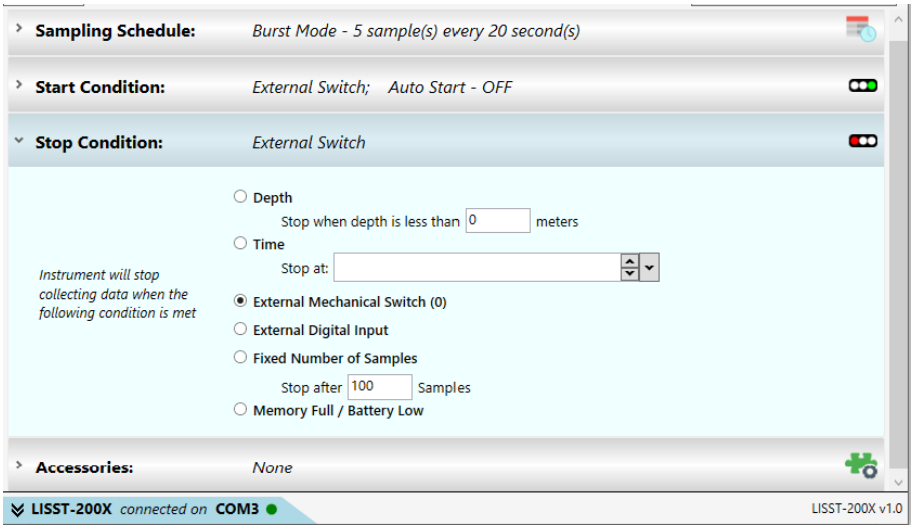
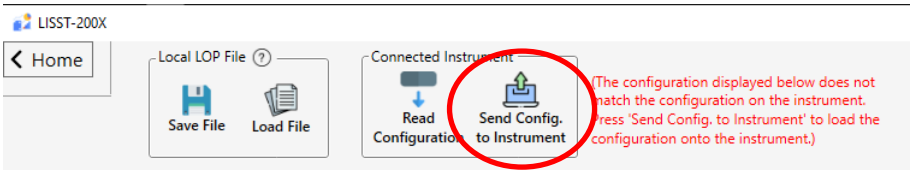
	side of the display. High values on the inner rings combined with a lower transmitted laser power value can also be an indication of optical misalignment. If needed you can update the background, such as after cleaning the windows or replacing the water, by pressing the *Collect New Background* button again.	
5	• When you have an acceptable background press the Save button to store the background on the instrument. The background file is stored on the instrument and is saved as part of every data file that is recorded. When processing a data file the background will be automatically extracted and used during processing. The background stored on the instrument will continued to be saved in new data files until a new background is recorded. • You also have the option, not required, to save the background to a file on your computer. After the background is saved, select the 'Save as .BGT File' button.	Background Accepted and saved.

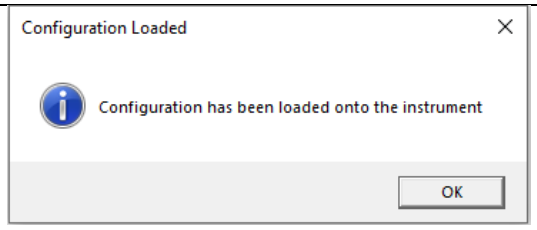
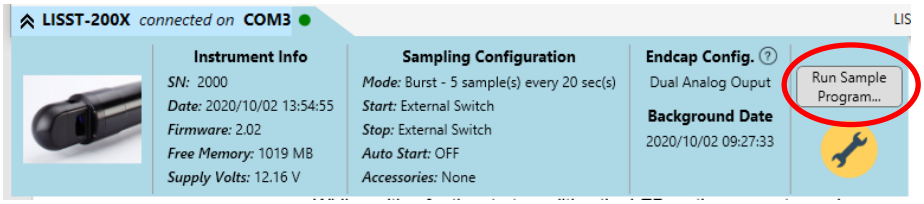
4. Configuring Data Collection

The LISST-200X software can be used to configure the Start and Stop Conditions, Fixed Rate or Burst sampling and sample rates.

STEP	ACTION	RESULT
1	• Connect the instrument to the computer and establish communication in the LISST-200X program (page 22).	Software open, communicating with LISST-Deep.
2	• Open the Sampling Programs window by choosing *Instrument Configuration* from the home page.  • To set the LISST-Deep clock to the computer clock, open the status bar, click the wrench icon, and select 'Set Instrument Clock'. • You can also zero the depth sensor from this same menu.  • For information about the *Data Output* tab, see Autonomous Real-time Data Processing on page 40.	Instrument Status Displayed. Clock set
3	• By selecting the *Sampling Schedule* Tab at the top of the main window the screen below appears. This screen is used to set the type of sampling: Fixed Rate or Burst. You can also select the samples per average and sample rates on this screen.	Operating Mode set

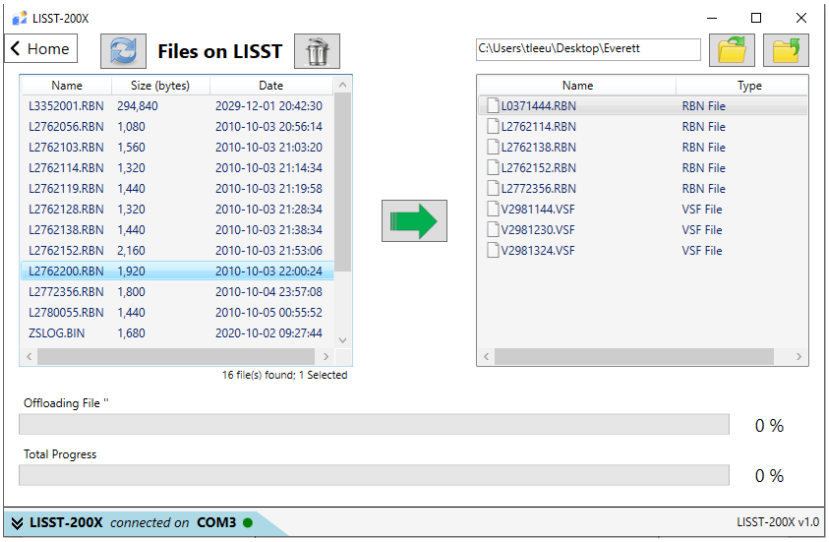
	 • The Burst and Fixed sample rate modes are used to set up a sampling program that will save data onboard the instrument. The icons next to the various values give a better understanding of their meaning. The software automatically checks the values entered to make sure that there is no conflict. For example, when a Samples per Average value is entered, the minimum sample interval is computed. If this value is less than the minimum permitted the value will be changed to the minimum and the text will turn red. A similar test is done on the Burst Interval setting.	
4	• Select the Start Conditions tab to configure when the instrument will begin sampling. • There are five options: Depth, Time, External Magnetic Switch, External Digital Input, and Time Delay. Select the mode by clicking on the button next to the its label. Select the correct parameters as required. 	Start Condition Set
	• If the AutoStart check box is selected, the LISST-Deep will start the sampling program when power is applied to the instrument. If this is not selected the user must send the	

	‘GO’ command to start the sampling programing after applying power. • NOTE: With either AutoStart or GO, logging is always subject to the start condition set above.	
5	• Choose the Stop Conditions Tab to select the conditions when sampling should stop. • The available stop conditions are: Depth, Time, External Magnetic Switch, External Digital Input, Fixed number of samples, and Memory Full.  • If the Stop Condition is Depth, External Magnetic Switch, or External Digital Input and the Start Condition is also one of these three options the Base Program on the instrument will return to waiting for the Start condition. For example, if the start and stop conditions were set to External Magnetic Switch then multiple sampling sessions can be obtained by flipping the switch on and off. This is useful when doing profiles. It eliminates the need to communicate with the instrument between profiles.	Stop Condition Set
6	After configuring the instrument settings, they must be uploaded onto the instrument. A message will be displayed on the top of the screen when you have unsaved changes to the instrument configuration  Click on the ‘Upload to Instrument’ button to load the configuration onto the LISST-Deep. A confirmation message will be displayed when the upload is finished.	Upload Configuration

		
7	• The instrument is now configured for deployment, **however, the sampling program is not yet running**.  • You MUST run the sampling program in order to collect data. But even when running, the sampling program will wait for the programmed start condition before collecting data. See Start and Stop Conditions on page 44, and the steps above, for details about start conditions. • When the sampling program is running, you will receive a confirmation message that the program has started, and the instrument will become disconnected from the computer. At this point the instrument is ready to be deployed.	Run Sampling Program

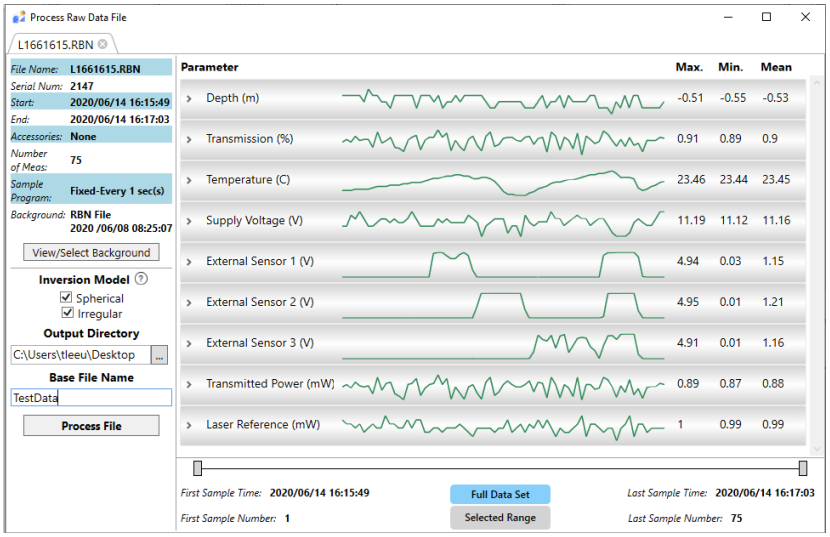
5. Offloading and Deleting Data Files from Internal Memory

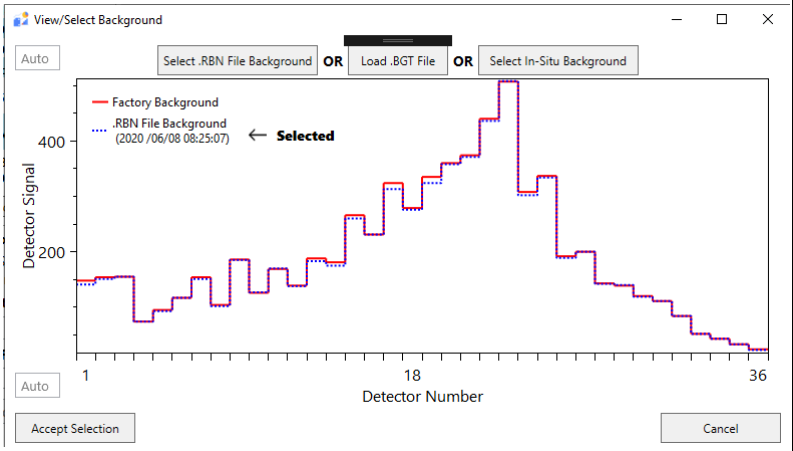
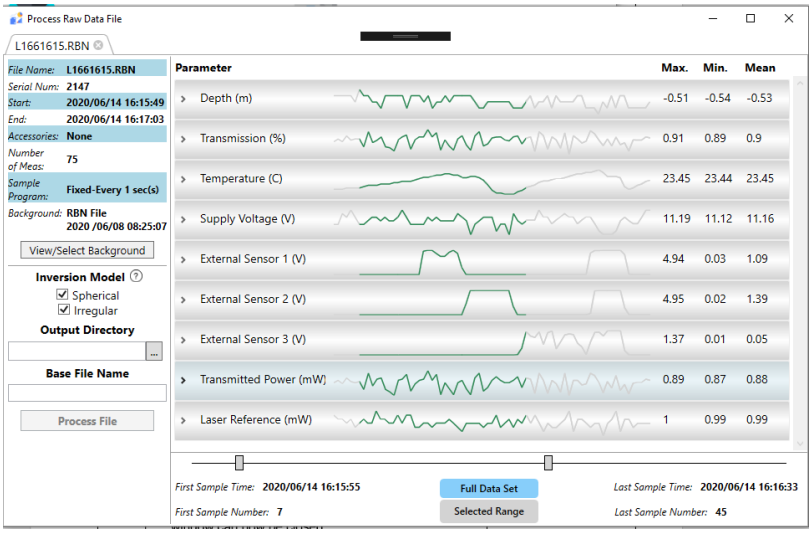
Data collected using the LISST-Deep is stored on the internal data logger. This section describes how to offload and delete files from the internal data logger.

STEP	ACTION	RESULT
1	• Connect the instrument to the computer and establish communication in the LISST-200X program (page 22).	Software open, communicating with LISST-Deep.
2	• Select *Offload Or Erase Files* from the home page. 	Shows a list of files currently stored onboard the instrument
3	• Select a directory to save the offloaded files on the right side. Select individual or multiple files on the LISST to delete or offload (by holding down either shift or ctrl). Press the green arrow.	Select files to delete or offload
4	• The progress bars at the bottom of the screen will update as files are offloaded or deleted	Files are offloaded or deleted

6. Processing a Single Raw Data File

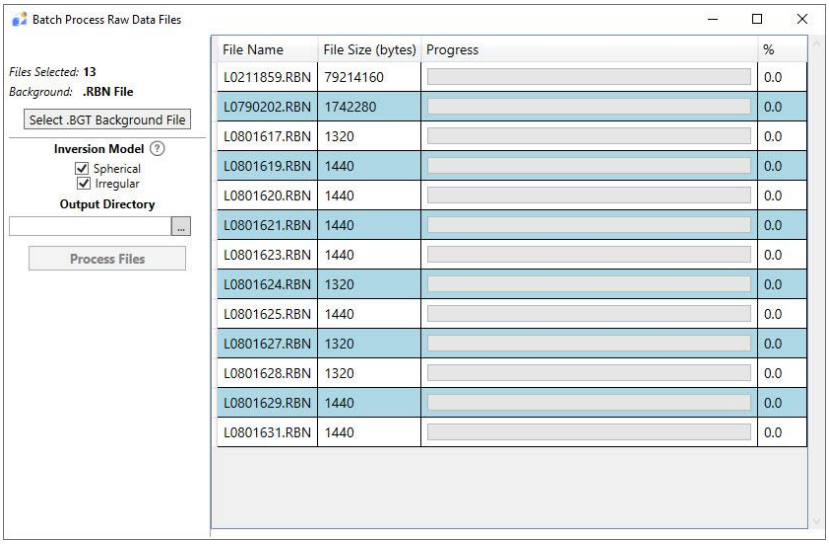
Data that has been downloaded from the datalogger is in a raw binary file (.RBN extension). It must be processed into particle size by the LISST-200X program.

STEP	ACTION	RESULT
1	• Start the LISST-200X program	Program started.
2	• Select *Process Data Files* from the home page. Select the file you want to process. A display similar to the one shown below will appear.  • A summary of auxiliary data is shown on the screen. More detailed plots can be viewed by clicking on the parameter.	Select file types to be created.
3	• You must also select the inversion model to be used when processing the data: Spherical, randomly shaped, or both (see Appendix F: Particle Shape Models on page 74). • Files processed with the Randomly shaped Particle Inversion Model will have an' _rs' suffix	Select inversion method(s) to be used – spherical, randomly shaped or both.
4	• Standard raw data processing will use the background file contained in the .RBN file. If you would like to use a different background file than the one in the RBN file, or use a data record as a background, select the 'View/Select Background' button	Select to process a file using the background in the data file or an external .BGT file

	 You can view and make background selections from this window.	
5	• Next, select the output data file name. Fill in the output directory and the base file name. Several files will be created. • The CSV file is a space delimited ASCII file containing the fully processed and calibrated data. This is useful for loading into spreadsheets such as Excel etc. • The RTX file is a space delimited ASCII file containing the raw data from the LISST-Deep data logger. This is useful for looking at the raw data in a spreadsheet such as Excel etc.	Name out output file.
6	• To select the range of raw data to process, move the sliders at the bottom of the display. 	Range to process selected.
7	• After selecting the range to process, press the *Process File* button. The display will show the processing progress and the resulting data will be displayed when processing is complete.	Processing Completed.

7. Batch Processing Multiple Raw Data Files

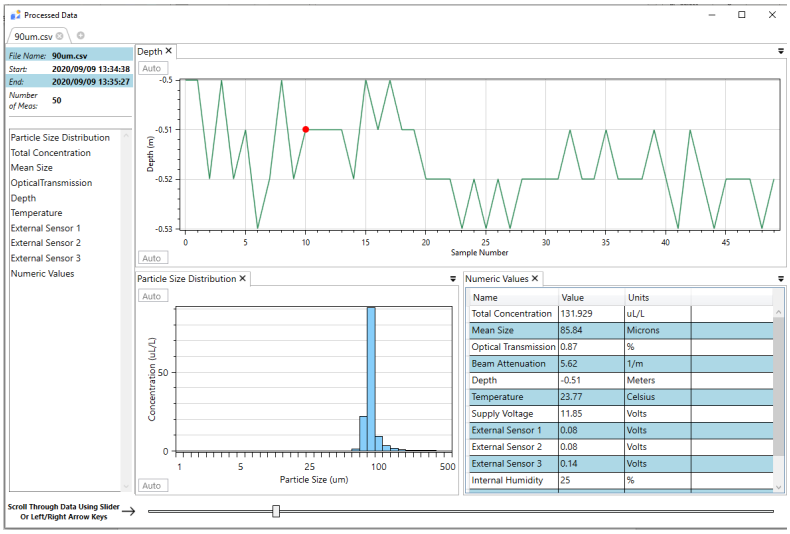
Data that has been downloaded from the datalogger is in a raw binary file (.RBN extension). It must be processed into particle size by the LISST-200X program. If you have multiple raw data files to process (e.g. from a series of profiling deployments), follow these processing steps that allows you to process all files in one operation.

STEP	ACTION	RESULT
1	• Start the LISST-200X program	Program started.
4	• Select *Process Data Files* from the home page. Select multiple files to process (by holding down either shift or ctrl). 	Select Files
5	• By default, batch processing will use the background stored in the raw data files to process the data. If you would like to use an external .BGT file, press the 'Select .BGT Background File' button.	Select source of background files
6	You must also select the inversion model to be used with the real time data processing: Spherical, randomly shaped or both. For a description of the two particle models, see on page 71. • If you have selected Randomly shaped Particle Inversion Model, the processed files will have an' _rs' suffix	Select inversion method(s) to be used – spherical, randomly shaped or both..
7	• Select the Output Directory for the processed files. • Files will be named with the same name as the raw data files but with different extensions. Several files will be created. • The CSV file is a space delimited ASCII file containing all the processed data.	Select Output Directory

	• The RTX file is a space delimited ASCII file containing the raw data from the LISST-Deep data logger.	
	• Press the “Process Files” button. • The files will be processed in order and the progress bars will indicate the status of each file	Process files

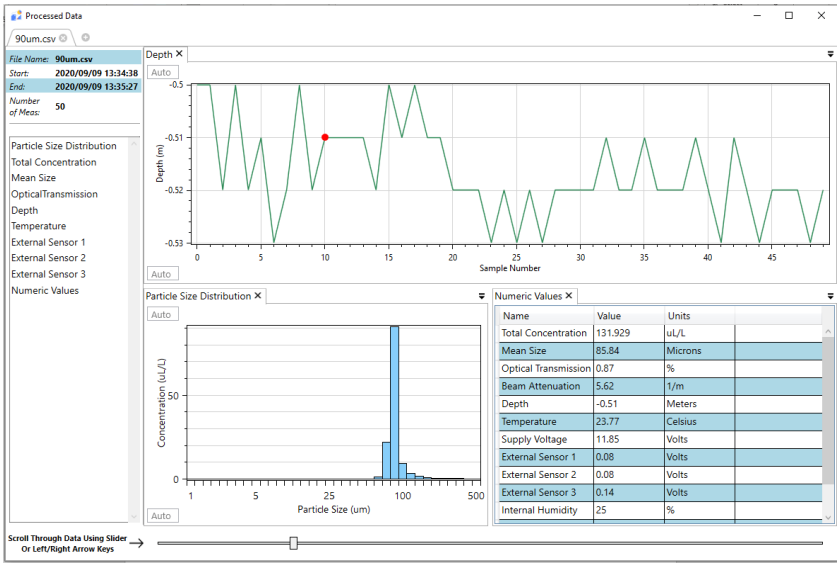
8. View Processed Data File

After processing of the data into a .CSV, the data can be viewed to the screen. This step-by-step procedure covers the viewing of data and optional displays.

STEP	ACTION	RESULT
1	• Start LISST-200X program	Program started.
2	• Select View Processed File from the home page	
3	• Select the processed data file (.CSV) from the file selection window. Double click the file or type the file name and press Open.	Processed data file selected.
4	• After selecting the processed file, a window similar to the one shown below will appear.  • A list of available parameters is displayed on the left. Clicking one of the parameters will open a new window where the parameter will be displayed. The parameter windows can be reorganized by dragging and dropping. The slider at the bottom is used to scroll through the data file. A red point on some graphs will indicate which sample is being displayed.	Particle size distribution displayed on screen
5	• Additional processed files can be opened simultaneously by pressing the plus button next the open tab at the top left of the screen. • When multiple tabs are open, the tabs can be dragged out into their own windows, allowing for easy comparison between files.	Open additional Files

9. Data Quality Control

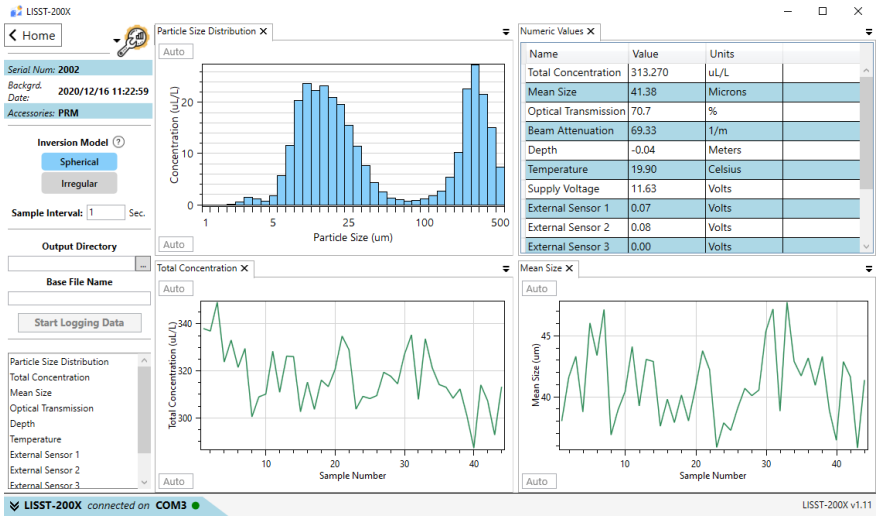
Making sure your data make sense.

STEP	ACTION	RESULT
1	• Follow steps 1-5 in the previous section: View Processed Data File.	Data file loaded
2		
3	• The first value to inspect is the Optical Transmission. By definition, transmission must be a number between 0 and 1 (except that electronic noise may cause it to be slightly higher than 1 in particle-free water) • Tip: The transmission value is in column 60 of the .CSV file. • If transmission shows up as being larger than 1 (one), then your measurement is most likely taken in very clear water and/or you have a bad background measurement obtained with dirty water and/or dirty windows. • If your background measurement was obtained using dirty water, it may be possible to redo the background using clean water and re-process the data, then check to see if the transmission values drop below 1 (one).	Transmission values much greater than 1 or less than 0 indicate bad data.
4	• If your transmission values generally are in the 0.98-1.0 range, your measurements are taken in very clear water. • This means that the signal-to-noise ratio will be low, and the data may have a lot of noise in them, but can most likely still be used.	Transmission values very close to 1 yield noisy data.

6	• If your transmission values are < 0.10 (or 10%), the water is too turbid. Disregard these data.	Data with transmission values < 10% should be disregarded.
7	• If your transmission values are > 0.995 (or 99.5%), the water is too clear. Disregard these data.	Data with transmission values > 99.5% should be disregarded.
8	Summarizing • Disregard data if transmission is > 0.995 (> 99.5%). • Disregard data if transmission is < 0.10 (< 10%). • Be wary of data collected at transmission values between 0.98 and 0.995 – low signal-to-noise ratio. • Be wary of data collected at transmission values between 0.30 and 0.10 – generally decreasing data quality as the transmission decreases below 0.30 (30%).	

10. Real-Time Data Processing with LISST-200X Software

This procedure covers the acquisition, display and storage of processed data in real time, using the LISST-200X software. For on-board processing by the LISST-Deep firmware, see Autonomous Real-time Data Processing on page 40.

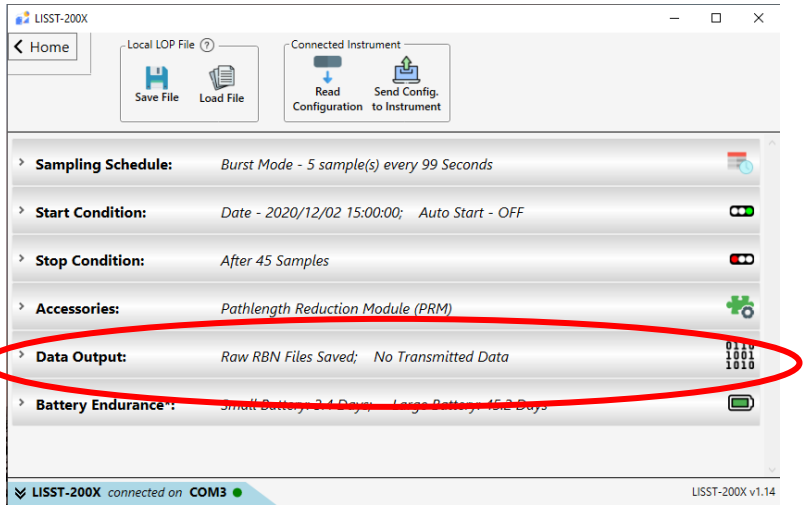
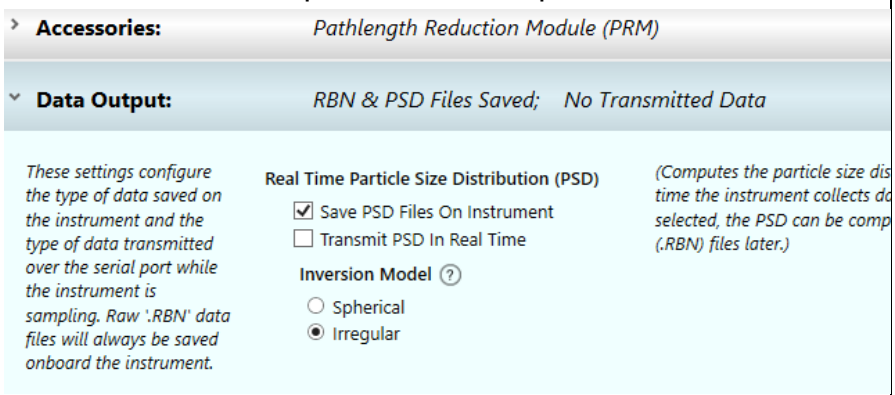
STEP	ACTION	RESULT
1	• Connect the instrument to the computer and establish communication in the LISST-200X program (page 22).	Communication established.
2	• The background currently stored onboard the instrument will be used to process the data as it is collected in real time. • Be sure to collect a new background and store it onboard the instrument before beginning a real time session	Background is current
3	• Select *Collect Live Data* from the home page	Open Instrument selected.
4	• A display will appear on the screen. It is similar to the main window of the View Processed Data function. 	
	• A list of available parameters is displayed on the left. Clicking one of the parameters will open a new window where the parameter will be displayed. The parameter windows can be reorganized by dragging and dropping. • The 'Sample Interval' text box allows you to adjust the time between samples in seconds.	

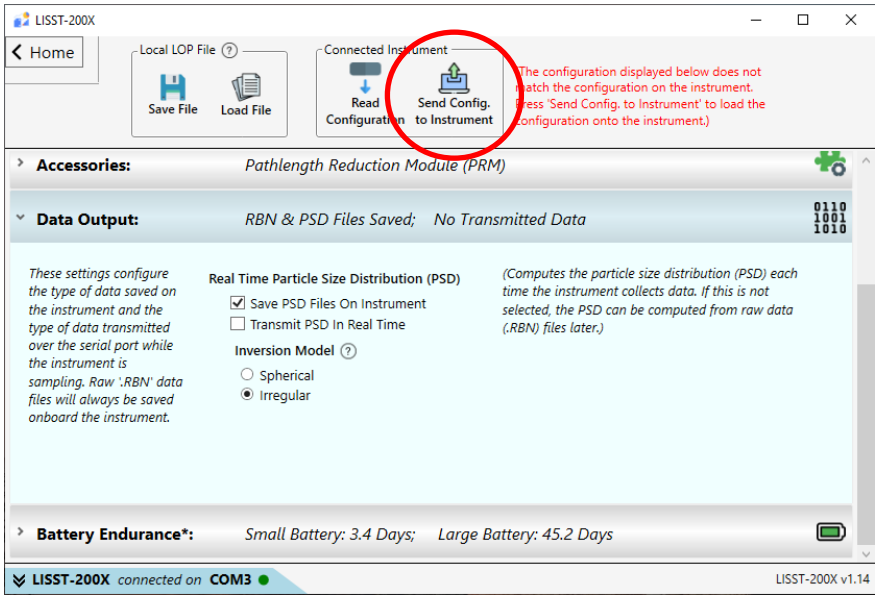
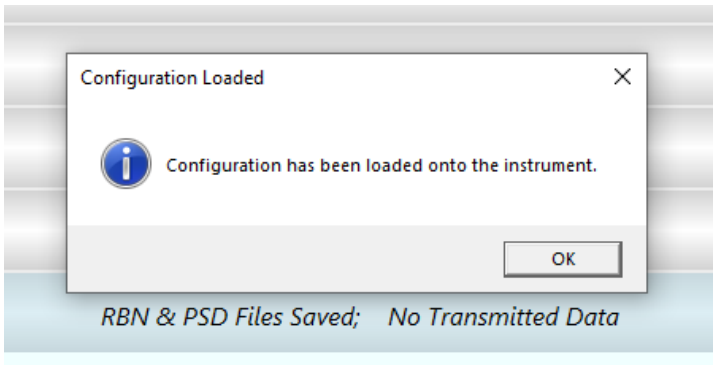
	• The Sample Number value displayed underneath the plots will increment each time a sample is saved. • The buttons labeled ‘Spherical’ and ‘Irregular’ allow you to display the volume distribution calculated with either the spherical or random shape particle model. The buttons only effect the display and have no effect on the data that is saved in the .CSV file. Data from both particle models is always saved.	
5	• Select an output directory and a base file name. Several files will be created. • The CSV file is a space delimited ASCII file containing all the processed data. • The RTX file is a space delimited ASCII file containing the raw data from the LISST-Deep data logger.	Select output directory and file name
6	• Data will not be saved until the ‘Start Logging Data’ button is pressed.	Start Data Logging

11. Autonomous Real-time Data Processing

LISST-Deeps with serial number 4056 or higher have enough computational power to do PSD processing autonomously, without requiring a connection to a Windows computer.

You may choose to save the processed data files (.CSV) in the LISST-Deep memory, or transmit them in real time through the serial port, or both. Note that processing slows the maximum sampling rate. Without it, the LISST-Deep can sample continuously once per second. Depending on the settings you select, the time per sample may be up to 2 seconds.

To use real-time processing		
STEP	ACTION	RESULT
1	• Connect the instrument to the computer and establish communication in the LISST-200X program. (see Establishing Communication with the LISST-Deep on page 22).	Communication established.
2	• Navigate to the Configure Instrument page. If your instrument's hardware and firmware support it (see above), you will see a Data Output category. 	Configure Instrument page open.
3	• Click on Data Output to make its options visible.  • 'Save PSD Files On Instrument' – if checked:	Instrument configuration selected.

	▪ PSD is computed onboard in real time ▪ PSD is saved in a file onboard the instrument, in .CSV format (see Appendix C: Data File Formats on page 65) • 'Transmit PSD In Real Time' – if checked: ▪ PSD is computed onboard in real time ▪ A PSD data record is transmitted over the serial port immediately after each measurement is collected • 'Inversion Model': Select the inversion model that will be used for onboard PSD processing (see Appendix F: Particle Shape Models on page 74)	
4	• **IMPORTANT**: after you have selected the desired configuration, press the 'Send Config. To Instrument' button to load the configuration onto the instrument.  • A message box will confirm the upload has been completed.  	Configuration uploaded to instrument. Configuration complete.

12. Collecting Data from External Analog Sensors

The LISST-Deep can supply regulated 12V power to external sensors, and measure one to three analog voltages, depending on its firmware settings. If the 12V power output is activated, it will turn on each time the 200X collects a sample or burst of samples, and turn off each time the 200X goes into a waiting state of more than a few seconds. If using the 12V output, you can specify how long it should turn on before sampling, as a warmup time for the sensor.

To provide these functions, the auxiliary connector on the LISST-Deep must be in the Analog Input configuration. For more about the configuration options, see Auxiliary I/O Connector on page 71.

Remember that power consumed by an external sensor will reduce battery endurance, in a battery-powered deployment. It might also exceed the capacity of the USB-powered data cable. You may need to power the LISST-Deep from a battery or other source.

STEP	ACTION	RESULT
1	• Determine current configuration of Auxiliary connector: in LISST-200X Software, open the instrument status bar. Look for the Endcap Configuration. If it is not one of the analog-input configurations, it must be changed; see page 71.	Auxiliary Connector configuration determined
2	• Make the appropriate connections between the 6-pin auxiliary connector of the LISST-Deep and your sensor. To see the pin assignments, type the CONFIG command in the LISST-200X terminal window; page 48). Or see page 71.	External sensor connected
3	• Type SENSORPOWER into the terminal window, and respond to its prompt to select the appropriate option. • Type SENSORWARM in the terminal window to set a warmup time (in seconds). • **WARNING: a USB cable may not provide enough power for external sensors**. Use a battery housing or other power source to provide enough power to run external sensors.	Configured for analog collection
4	• Set the standard sampling parameters to control the sampling schedule and other options (see Configuring Data Collection on page 26).	Ready to collect data

13. Configuring the LISST-Deep as a Sensor for a CTD

The LISST-Deep can operate as an analog-output auxiliary sensor for a CTD. For this purpose the LISST-Deep's auxiliary six-pin connector must be in its "Dual Analog Output" configuration. The two analog outputs represent the total volume concentration of particles, and the Sauter mean diameter (SMD). These values are approximations for the convenience of real-time display. For highest-quality data you will still need to offload and process the detailed data from the LISST-Deep after deployment.

The LISST-Deep updates its analog outputs each time it collects a sample, at a maximum of 1 Hz.

STEP	ACTION	RESULT
1	• Determine current configuration of Auxiliary connector: in LISST-200X software, open the instrument status bar. Look for the Endcap Configuration. If it is not in the Dual Analog Output configuration, see Viewing and Setting the Auxiliary I/O Configuration on page 72.	Auxiliary Connector configuration determined
2	• Make the appropriate connections between the 6-pin auxiliary connector of the LISST-Deep and your CTD. **Verify the connections carefully**.	Connected to CTD
3	• In LISST-200X software, set the sampling parameters as follows (see Configuring Data Collection on page 26) ○ Operating mode: Fixed sample rate ○ Sample to be average of 20 measurements ○ Sample interval: 1 second ○ Automatically start sampling program upon power up Start condition: delay 0 minutes ○ Stop condition: memory full	200X will collect data at 1 Hz whenever the CTD supplies power to it
4	• See Appendix G: Analog Outputs on page 75 for information about interpreting the measured voltages.	

B. Start and Stop Conditions

Overview

The LISST-Deep can be set up to start and stop data collection according to various conditions. The most obvious is the white switch lever on the connector end cap. However, the switch is only one of several options. The start condition and stop condition can be different from each other. Also see Configuring Data Collection on page 26.

Start Conditions

The five possible start conditions are:

1. Depth,
2. Time,
3. External Magnetic Switch,
4. External Digital Input, and
5. Time Delay.

The details of each are described below. Note that regardless of which start condition is selected, the LISST-Deep will not start checking for the start condition until the sample program is run from the Windows software (see page 26), by the GO command (see Acquisition/Action commands on page 56), or by automatic start after power-up.

Depth Start

The LISST-Deep checks its depth every 3 seconds. If the depth exceeds the threshold, the program will start data collection. When setting the threshold, remember that atmospheric pressure, temperature, and even the orientation of the LISST-Deep can affect the offset of the pressure sensor. Therefore, it is best to zero the sensor (see page 26) immediately before starting, and to set the threshold to at least 1 meter, to avoid incorrect triggering.

Time Start

The LISST-Deep will go into lower-power sleep until the programmed time. (If the programmed time has already passed, it will start immediately.)

External Mechanical Switch Start

The LISST-Deep will wait until the white plastic lever on its endcap is moved to the “1” position. (If it is already in that position, it will start immediately.)

External Digital Input Start

If the auxiliary connector is configured with the digital trigger input function (see Auxiliary I/O Connector on page 71), pin 2 of the 6-pin connector is the digital input. The program will check the status of the digital input once a second. If the digital input is greater than 2 volts (relative to digital ground, pin1), data collection will start.

Time Delay Start

The time delay start condition will cause the program to wait the specified number of minutes.

Stop Conditions

The possible stop conditions are:

1. Depth,
2. Time,
3. External Magnetic Switch,
4. External Digital Input,
5. Fixed number of samples, and
6. Memory full or power lost

When storing data in the Fixed Sample Rate mode the Stop conditions are checked after each averaged sample has been saved. When storing data in the Burst mode the Stop conditions are only checked after a full Burst has been completed. The Start and Stop conditions have no effect on the real-time sampling mode (Real-Time Data Processing with LISST-200X Software on page 38). The details of each condition are described below.

Depth Stop

If the depth is less than the threshold, sampling will stop. If the Start Condition is Depth Start the program will return to checking for the start depth, and will start a new file each time the start threshold his crossed. For all other Start Conditions the when the current depth is less than the threshold the LISST-Deep will stop and go into deep sleep.

If using depth for both start and stop conditions, consider whether the start and stop thresholds should be different, depending on your deployment scenario. For example, if the instrument might be suspended from a winch at a depth near the start and stop thresholds, there could be “false” starts and stops due to wave motion. This could be prevented by setting the start depth deeper than the stop depth.

Time Stop

After each sample or burst, if the given date and time have passed, the LISST-Deep will stop and go into low-power sleep.

External Magnetic Switch Stop

After each sample or burst, if the switch lever is in the off or “0” position, sampling will stop. If the Start Condition is Switch Start, the program will return to checking the start condition. For all other Start conditions the instrument will stop and go into deep sleep.

External Digital Input Stop

The status of the digital 1 input is checked after each sample or burst. If the voltage at the input is less than 0.7 volts the sampling will stop. If the Start Condition is a Digital Input Start the program will return to checking the start condition. For all other Start conditions the instrument will stop and go into deep sleep.

Fixed Number of Samples

When the number of samples to be saved has been reached the program will stop and go into deep sleep (regardless of start condition).

Memory Full or Voltage Low

Sampling will continue until the memory is full, or the power input falls. If the memory fills, the instrument will go into deep sleep.

NOTE: the memory capacity is large enough that it should never be necessary to fill it. We recommend deleting files from the LISST-Deep as soon as they have been offloaded to a backed-up computer or other storage.

C. Instrument Communication

Overview

The cables Sequoia supplies with the LISST-Deep send data through a standard USB port. However, the LISST-Deep itself communicates through RS-232 serial protocol. The 5-pin male connector on the LISST-Deep carries the RS-232 signals (and power). The cables incorporate adapters that convert between RS-232 and USB.

If you use a different cable that does not include the RS-232-to-USB adapter, you can use an external adapter, or connect directly to an RS-232 port if your computer has one (rare on any recent computer). In Windows, both RS-232 and USB connections will appear as COM ports.

If interfacing to a data logger or controller system other than a Windows computer, you will likely also use a direct RS-232 connection.

The RS232 link communicates at 9600 baud, 8 data bits, No parity, and 1 stop bit. For offloading data files, the LISST-200X software uses YMODEM protocol at 115K or 230K baud. The transfer rate can be changed in the settings of the LISST-200X software. A slower speed may be required when downloading data over cables longer than a few meters.

Using the Terminal Window

In the LISST-200X software, you can open a terminal window to directly view communications with the LISST-Deep, and enter commands. When the LISST-Deep is connected and the terminal window is the front window, the LISST-Deep should respond to pressing the enter key with the LDeep:> prompt. If the instrument is in the deep sleep mode, you can wake it by pressing the Stop button.

Direct Commands

In most cases, LISST-200X software will be used to configure and operate the LISST-Deep. However, some functions are available only through direct commands in the terminal window. Also, in some applications the LISST-Deep may need to communicate to another datalogger or custom program. For this purpose, a large set of commands is available to operate the instrument. See the following sections for detailed descriptions of each command.

D. Direct Command Summary

Display Commands	
CONFIG	Display instrument hardware configuration information
DD, DIR	Display current disk directory
DEPTH	Display current depth
DS, DS 1	Display current instrument status information
DT	Display current time and date
HELP, ?	Display general help messages and command list
SW	Display Magnetic switch position
TEMP	Display current temperature
VIN	Display input supply voltage
Setup Commands	
AMBISUB x	Set ambient light subtraction (ALR) on or off
AS x	Set autostart
BI x	Set burst interval
MA x	Set samples per average equal to x
MODE, OM x	Set operating mode (burst or fixed-rate)
PD x, STOPDATA x	Set stop condition Data
PSDMODEL x	Set model used for PSD processing (if active)
SAVEPSD x	Set whether PSD data will be saved in on-board memory
SI x	Set sample interval
SP x, STOPCOND x	Set stop condition
ST x, STARTCOND x	Set start condition.
SB x	Set samples per burst
SC yyyy/mm/dd hh:mm:ss	Set clock with time and date
SENDDATA x	Control real-time transmission of data via RS232
SENSORPOWER x t	Set whether power output turns on during logging
SENSORWARM t	Set external sensor power warmup time
TD x, STARTDATA x	Set start condition data
ZD	Reset depth sensor offset
Acquisition/Action Commands	
DL filename	Delete file
GO	Start data collection using current parameters
GX	Grab sample and transmit it
ZS	Acquire 20 samples and evaluate them for quality.
ZZ	Go into deep sleep mode (minimum power consumption)

E. Command Details

NOTE: Command are shown in upper case for clarity, but are not case-sensitive.

1. Display Commands

CONFIG	Display instrument hardware configuration
Syntax:	CONFIG
Description:	The current hardware configuration including Auxiliary I/O connector configuration
Example:	LDeep:> CONFIG Serial Number: 2001 Firmware Version: 1100 (1.100) VCC: 59371 Full Path Length: 2500 (25 mm) Eff. Path Length: 2500 (25 mm) BioBlock Installed: 0 Start Condition: Digital input (4) Start Condition Data: 0 Stop Condition: Switch (3) Stop Condition Data: 0 Measurements Per Average: 10 Sample Interval: 1 seconds Burst Mode: 0 Samples Per Burst: 5 Burst Interval: 25 minutes Transmit Raw Data: 0 Lifetime Sample Count: 529554 Lifetime Laser On Time: 1703980 seconds Endcap Configuration: 0 (Analog & digital in) Wiring of MCBH6MP connector: 1: Ground 2: Digital input 1 3: Digital input 2 4: +12V output 5: Analog input 1 6: Ground

DD, DIR	Display File Directory
Syntax:	DD or DIR
Description:	Display current disk directory in DOS type format. Includes total bytes used and bytes available.
Example:	LDeep:> DD . <DIR> 2099-03-14 03:35:48 .. <DIR> 2099-03-14 03:35:48 L2390658.RBN 1,612,440 2019-08-29 14:55:28 L2411501.RBN 3,253,800 2019-09-03 07:58:20 L2480807.RBN 736,800 2019-09-06 09:40:14 3 file(s) 7,608,360 bytes 2 dir(s) 1,016,381,440 bytes free

DEPTH	Display current depth
Syntax:	DEPTH
Description:	The current depth is displayed to the screen.
Example:	LDeep:> depth 0.000 m (680 counts)

DS	Display current status information
Syntax:	DS
Description:	The instrument settings and status are displayed to the screen. The format may change with different firmware and hardware versions.
Example:	LDeep:> DS LISST-Deep Status and Settings Serial number: 4060 Endcap configuration: 2 (Dual analog out) Firmware Version: 1.470 Feb 8 2022 21:06:43 Current Date/Time: 2019/01/09 22:12:50 Current Day of the Year: 009 Supply voltage: 14.74 V Operating mode: Fixed rate mode AutoStart: OFF. Delay Start with 0 minute delay Stop on full memory or low battery Measurements per Average: 32 Ambient light subtraction: on. Sample Interval: 1 Path length: 25 mm Standard status messages will be sent during logging. Data will be saved in files of unlimited size. AUV mode: off Free memory: 1016 Mbytes

DS 1	Display current status information, compact form
Syntax:	DS 1
Description:	Instrument status displayed in simplified format for reading by software
Example:	LDeep:> ds 1 LISST-Deep Current Status and Settings SN = 0 OM = 0 ST = 5 TD = 0 SP = 6 PD = 0 MA = 32 SI = 1 BI = 1 SB = 1 AS = 0 BIOBLOCK = 0 STUBE = 0

	SENSORPOWER = 0 SENSORWARM = 0 Current Time = 1987/01/09 22:14:00 Battery= 1474 Switch= 0 Memory= 1016381440 Bytes Endcap= 2 PATHLENGTH = 25 Firmware = 1.470

DT	**Display current time and date**
Syntax:	DT
Description:	Displays current time and date to the screen.
Example:	LDeep:> DT Date/time = 2021/01/01 18:16:06

HELP, ?	**Display general help messages and command list**
Syntax:	HELP or ?
Description:	Displays the list of command to the screen.
Example:	LDeep:> HE LISST-Deep Commands ---------- [list of commands]

SW	**Display current Magnetic Switch status**
Syntax:	SW
Description:	The current status of the Magnetic Switch is displayed to the screen. A value of 0 means the magnetic actuator is present in its assigned place on the LISST-Deep housing.
Example:	LDeep:> SW Switch: 0

TEMP	**Display current temperature**
Syntax:	TEMP
Description:	The current temperature is displayed to the screen.
Example:	LDeep:> temp 25.09 C (26629 counts)

VIN	**Display Battery Voltage**
Syntax:	VIN
Description:	The current supply voltage is displayed to the screen.
Example:	LDeep:> vin 14.74 V (2058 counts)

2. Setup Commands

AMBISUB	Enable Ambient Light Subtraction
Syntax:	AMBISUB x, where x is 1 (on) or 0 (off)
Description:	When ALR is on, the laser will be rapidly switched on and off to distinguish its light from ambient background..
Example:	`LDeep:> AMBISUB 1` `Ambient light subtraction is on`
Cautions:	ALR prevents interference from ambient light, but this is only an issue near the water surface under bright sunlight. ALR reduces the number of samples averaged, reducing the signal/noise ratio. See page 58 for more.

AS	Enable Autostart
Syntax:	AS x, where x is 1 (yes) or 0 (no)
Description:	With Autostart enabled, the firmware will immediately start the sampling program when power is applied to the instrument.
Example:	`LDeep:> AS 1` `Autostart upon power-up is on`
Cautions:	If Autostart is enabled, the user cannot communicate with the instrument when powering it up – it will immediately start sampling according to the SD defaults. In order to stop sampling and establish normal communication, the user must issue a stop command, either from the LISST-200X software's graphical interface, or by pressing CTRL-C in the terminal window.

BI	Set Burst Interval
Syntax:	BI x, where x is the number of seconds between the start of 2 consecutive bursts, from 1 to 10,000 seconds.
Description:	In Burst Mode (MODE = 1), the burst interval is the number of seconds between two consecutive bursts, each burst composed of a number of samples per burst (specified by the SB command).
Example:	`LDeep:> BI 900` `New Seconds between Bursts: 900`

IOCONFIG	View or Set Configuration of the Auxiliary Input/Output Connector
Syntax:	IOCONFIG x, where x is a digit indicating the configuration selection.
Description:	Available only in firmware 2.2 or later, this command returns a number indicating the configuration of the 6-pin connector used for interfacing with external devices. In the current LISST-Deep it will return either 5, 6, or 9, and will accept one of those values to set the configuration. For full details, see Viewing and Setting the Auxiliary I/O Configuration on page 72.
Example:	`L200x:> IOCONFIG` `6`

MA	Set measurements per average
Syntax:	MA x

	The exact result depends on whether ambient light rejection (ALR) is active. Starting with firmware version 1.4 (May, 2017), ALR is on by default, and the actual number of samples averaged will be approximately x/10. That is, MA 32 will result in 3 ALR cycles per average. With or without ALR, 32 is the maximum MA value that allows 1 sample per second.
Description:	Each recorded or displayed measurement is based on an average of measurements. MA sets the number of measurements per. If no value follows command, prompts will be displayed for the value.
Example:	`LDeep:> ma 32` `Measurements per average: 32 (3 ambient subtractions)`

OM	**Set Operating Mode**
Syntax:	MODE x or OM x
Description:	Sets the Operating Mode to one of the following types: 0 = Fixed rate 1 = Burst Mode OM command only without a parameter will initiate a prompt for the Operating mode.
Example:	`LDeep:> OM 1` `Operating mode: Burst mode (1)`

PD, STOPDATA	**Set Stop Condition Data**
Syntax:	PD x or STOPDATA x where x is the stop condition data as described below
Description:	The PD command sets the stop condition data to be used when the collection data. The stop condition data is used with the Stop Condition settings as follows. • If the Stop Condition is Depth Stop (option 1) the input will be stop depth in meters. • If the stop condition is set to Time/Date Stop (option 2) the input for PD will be the stop date and time. • If the Stop Condition is Fixed Number Stop (option 5) the input will be the number of samples to collect before stopping. • The PD setting is ignored for Magnetic Switch Stop (option 3), Digital Input Stop (option 4) or Maximum memory or Low Battery Stop (option 6).

Example:	If Stop Condition =1 (Depth Stop):
	`LDeep:> PD 3`
	`Depth stop at 3 meters`
	
	If Stop Condition = 2 (Time/Date Stop):
	`LDeep:> PD 2016/12/31 23:59:59`
	`Time stop at 2016/12/31 23:59:59`
	
	If Stop Condition = 5 (Fixed Number of Samples):
	`LDeep:> PD 100`
	`Stop after 100 samples.`

PSDMODEL	Set particle model used for on-board size distribution calculations (firmware 2.1 or higher)
Syntax:	PSDMODEL x
Description:	If x = 0, PSD processing with use the spherical particle model. If x = 1, the irregular (also called “random”) particle model will apply. This setting applies only when real-time PSD processing is active. It is available only in firmware 2.1 and higher. Also see SAVEPSD, SENDDATA, and Autonomous Real-time Data Processing on page 40.
Example:	`LDeep:> PSDMODEL 1` `Optical Model: 1 (irregular)`

SAVEDATA	Save Data Setting—USE WITH CAUTION
Syntax:	SAVEDATA x, where x is 1 or 0
Description:	SAVEDATA 0 turns off storing of raw data in the instrument’s memory. This is only for unusual circumstances.

Example:	`LDeep:> SAVEDATA 1`
	`1: Raw data will be saved during logging.`
	`LDeep:> SAVEDATA 0`
	`WARNING: Data will NOT be saved during logging!`
	`Is this really what you want [N] ? n`

Cautions:	**Be very careful with this setting!** Issue a DS command to verify the status of the store mode setting. A warning will be displayed as part of the DS status if the store mode is disabled:

SAVEPSD	Control saving of processed PSD files (firmware 2.1 or higher)
Syntax:	SAVEPSD x
Description:	If x = 1, during sampling the instrument will generate a .CSV file containing processed particle size distributions, in addition to the normal raw .RBN file. If x = 0, only the normal .RBN files will be saved. For more details, see Autonomous Real-time Data Processing on page 40. This command requires firmware version 2.1 or higher.
Example:	`LDeep:> SAVEPSD` `PSD data will be saved during logging.`

SB	Set Samples per Burst
Syntax:	SB x, where x is the number of samples per burst. Each sample is taken at the sample interval (in seconds) set by the SI command. If no value follows command, prompts will be displayed for the value.
Example:	`LDeep:> SB 10` `New Samples per Burst: 10`

SC	Set Clock with time and date
Syntax:	SC yyyy/mm/dd hh:mm:ss

	Where yyyy=year, mm=month, dd=day, hh=hour (24 hour format), mm=minute, ss=seconds If no values follow the "**SC**" or "**sc**" command, prompts for entering the time and date will be displayed.
Example:	`LDeep:> SC 2020/12/20 13:20:18` `Time set to 2020/12/20 13:20:18`

SENDDATA	**Transmit data during sampling (firmware 2.1 or higher)**
Syntax:	SENDDATA x
Description:	The value of x sets whether data will be transmitted from the instrument's RS232 interface during sampling. **Only options 0 and 4 are suitable for normal operation.** 0 = Do not send data (default) 1 = Multi-line troubleshooting data 2 = NMEA-format brief data (for glider applications) 3 = Single-line raw (CANNOT be processed by LISST-200X software) 4 = Processed PSD data; activates real-time processing and sends processed data after each sample. For details, see Autonomous Real-time Data Processing on page 40. This option requires firmware version 2.1 or higher.
Example:	`LDeep:> SENDDATA 0` `Setting: 0 (no data)`

SENSORPOWER	**Control 12V power to auxiliary connector during logging**
Syntax:	SENSORPOWER x, where x is 1 or 0
Description:	If x = 1, the 12V power output on the auxiliary connector (if it is suitably configured) will turn on during data collection with the GO command. If running in burst mode, the power will turn off between bursts. Logging will also incorporate a warmup time, set with the SENSORWARM command. If SENSORPOWER is entered without an x argument, it will prompt for a value and for a sensor warmup time.
Example:	`LDeep:> SENSORPOWER 1` `Power output will turn on during logging, with 5 second warmup`

SENSORWARM	**Warmup time when powering external sensors**
Syntax:	SENSORWARM x, where x is in seconds
Description:	If SENSORPOWER is on, SENSORWARM sets the number of seconds the LISST-Deep will wait for external sensors to warm up before it proceeds with sampling.

Example:	`LDeep:> SENSORWARM 10`
	`Power output, when used, will turn on with 10 second warmup.`
	`Power output during logging is on.`

SI	**Set Sample Interval**

Syntax:	SI x, where x is the number of seconds between samples, from 1 to 10,000.
Description:	In either fixed-rate or burst mode, the sample interval is the number of seconds between two consecutive samples, each composed as an average of a number of measurements (specified by the MA command).
Example:	`LDeep:> SI 5` `Seconds between samples: 5`

SP, STOPCOND	**Set Stop Condition**
Syntax:	SP x or STOPDATA x, where x is the stop condition code described below
Description:	The SP command sets the stop condition to be used when collecting data. The stop condition options are: 1 = Depth Stop 2 = Time/Date Stop 3 = Magnetic Switch Stop 4 = Digital Input Stop 5 = Number of Samples Stop 6 = Maximum memory or Low Battery Stop If no value follows command, prompts will be displayed for the value. After setting a stop condition of Depth, Time/Date or Number of Samples, use STOPDATA to enter an appropriate parameter value.
Example:	`LDeep:> SP 5` `Stop condition: 5`

ST, STARTCOND	**Set Start Condition**
Syntax:	ST x or STARTCOND x where x is the start condition code described below
Description:	The ST command sets the start condition to be used when the GO command is issued. The start condition options are: 1 = Depth Start 2 = Time/Date Start 3 = Magnetic Switch Start 4 = Digital Input Start 5 = Delay Start If no value follows command, prompts will be displayed for the value. After setting the start condition to Depth, Time or Delay, use STARTDATA to set the applicable condition value.
Example:	`LDeep:> ST 5` `Start condition: 5`

TD, STARTDATA	**Set Start Condition Data**
Syntax:	TD x or STARTDATA x where x is the start condition data described below
Description:	The TD command sets the start condition data to be used when the GO command is issued. The start condition data is used with the Start Condition setting as follows:

	• If the Start Condition is Depth Start (option 1) the input will be start depth in meters. • If the start condition is set to Time/Date Start (option 2) the input for TD will be the start date and time. • If the Start Condition is Delay Start (option 5) the input will be time delay in minutes. • The TD setting is ignored for Magnetic Switch Start (option 3) or Digital Input Start(option 4). If no value follows command, prompts will be displayed for the value.

Example:	If Start Condition = 1 (Depth Start)
	`LDeep:> STARTDATA 3`
	`Start condition: Depth Start at 3 meters`
	
	If Start Condition = 2 (Time/Date Start)
	`LDeep:> STARTDATA 2020/12/31 23:59:59`
	`Start condition: Time Start at 2020/12/31 23:59:59`
	
	If Start Condition = 5 (Delay Start)
	`LDeep:> STARTDATA 2`
	`Start condition: Delay Start with 2 minute delay`

ZD	**Reset Depth Sensor Offset**
Syntax:	ZD
Description:	The ZD (or zd) command resets the depth sensor offset so that the sensor reads a depth of 0m at zero depth (in air). You must issue the ZD command, then select 1 (yes) or 0 (no) to reset depth sensor

Example:	`LDeep:> ZD`
	
	`Depth sensor offset adjust.`
	
	`Instrument must be at zero depth and similar temperature to field conditions.`
	`Reset depth sensor offset? (1=yes,0=no): [0] ? 1`
	`Previous offset was -140.65.  New offset is  -4.37.`
	`Previous depth was -136.28 meters.`
	`New depth using corrected offset is   0.00 meters.`

3. Acquisition/Action commands

DL	**Delete file from LISST memory**
Syntax:	DL *filename*, where *filename* is the name of the file to be deleted.
Description:	DL command is used to delete file from memory.

Example:	`LDeep:> DL L3231513.RBN`
	`Delete the file 'L3231513.RBN'?`
	`Y for Yes or N for No:  [N] ? Y`
	`Deleting L3231513.RBN`
	`Deleted.`

Cautions:	WARNING: Make sure the file being deleted has already been offloaded. Once the file is deleted it cannot be recovered.

GO	Start Data Collection using current Settings
Syntax:	GO
Description:	Starts Fixed Rate or Burst Mode Data collection using current settings.
Example:	LDeep:> GO Starting sampling. Start condition: Delay Start with 2 minute delay Stop condition: Stop after 100 samples Low-power sleep until 2021/12/10 17:39:56 zzz...Waiting until 2021/12/10 17:39:56
Cautions:	To stop data acquisition before it is complete, send 2 Ctrl-C characters.

GX	Grab sample and transmit it
Syntax:	GX
Description:	Acquires single averaged sample and displays the result to the screen.

Example:	Input: GX
	Output: {
	…. 36 ring values + 24 Aux parameters
	}

Notes:	The GX command does not store the sample to a datafile.

ZS	Collect and transmit background scattering data
Syntax:	ZS
Description:	Acquires 20 averaged sample and displays the result to the screen. Evaluates the data for quality as a background measurement.

Example:	Input: ZS
	Output: {
	…. 36 ring values + 24 Aux parameters
	}
	repeat 20 times, then messages about the quality of the data.

Notes:	The ZS command does not store the sample to a datafile.

ZZ	Go into deep sleep mode (minimum power consumption)
Syntax:	ZZ
Description:	Sends LISST-Deep in to low power sleep mode. Instrument will send a message every 30 seconds to indicate it is sleeping. It can be wakened at any time by sending 2 control-C characters about ½ second apart.
Example:	LDeep:> ZZ Low-power sleep. zzz...Press Stop or <Ctrl>C to wake up. zzz...Press Stop or <Ctrl>C to wake up.

F. Performance Optimization

Background Measurement and its Importance

As discussed in earlier sections, the LISST-Deep measures light scattered at small angles, to characterize particles in water. However, a certain amount of scattering is also generated by pure water, and by the LISST-Deep's own optics and windows. We call this the background scattering. In order to determine the scattering contributed by particles, the background scattering must be accurately measured and subtracted from the total scattering measured. The measurement of background scattering is sometimes called a "zscat", meaning the signal measured in water with zero "scatterers" or particles.

The minimum concentration of particles measurable by the LISST-Deep is very sensitive to the quality of the background scatter file. The lower the concentration in the water being measured, the more important the quality of water and the care used when measuring the background. When measuring in water with high particle concentrations, the relative signal-to-background noise ratio increases, and final results will be less sensitive to flaws the background. However, a background should always be collected before an experiment.

Techniques for measuring background

It is essential to use clean, bubble-free water for the background measurement. The water can be fresh or salt water. For most applications, steam-distilled water works well. Steam-distilled water is typically available in one-gallon containers. We have found that this distilled water tends to be a bit cleaner than typical bottled or packaged water. We buy steam-distilled drinking water and filter it through a 0.2µm filter.

Because not just the windows, but also the nearby parts of the instrument housing are submerged during background measurement, it is important to thoroughly clean and rinse this part of the instrument before acquiring a background.

Cleanliness

Toothbrush, liquid soap and water works well for cleaning the optical parts of the instrument. Do not use abrasive powders, which will scratch the windows and degrade instrument performance.

Watch for Outgassing and Bubbles

Water may contain dissolved air that develops into bubbles as the water warms. Bubbles, especially if they cling to the windows of the LISST-Deep, will greatly modify the scattering pattern, rendering the background useless. Be sure to remove any bubbles from the windows before acquiring a background. Use a squirt bottle or pipette to blow the bubbles off the window.

Ambient Light Rejection

The LISST-Deep firmware includes an option to automatically measure and subtract light that is not produced by scattering from its laser. This Ambient Light Rejection (ALR) prevents sunlight or other bright sources

from contaminating the scattering measurements. Without ALR, as in earlier LISST instruments, high ambient light levels, if not physically blocked from the LISST's optical aperture, could falsely elevate the apparent concentration of small particles.

You can check whether ALR is active by connecting to the instrument with LISST-Deep, then opening the terminal window. Type DS and press enter, and look for "Ambient light subtraction: on" in the output.

ALR works by measuring the signal on the LISST-Deep's 36 detectors first with the laser on, then with the laser off. This on-off process is repeated 3 times per second. Because of the time required for the laser and electronics to change between the on and off states, rapidly changing ambient light may not be completely rejected. Therefore, if working in bright sunlight, near the water surface, and in conditions where the sunlight is rapidly modulated by waves, ambient light could still have an effect. ALR will reduce the average effect, but the changing ambient conditions could increase sample-to-sample noise. In those worst-case conditions it is still advisable to shade the LISST-Deep optics from ambient light. The same is true if operating under intense artificial light modulated by AC power.

Optical Alignment

The background measurement (described step-by-step on page 23) is the best source of information on the current health of the LISST-Deep. It provides information on the current functionality of all of the major systems including laser, ring detector, data collection electronics, and optical alignment. The LISST-Deep is a sensitive optical device. The laser must be aligned such that the focused spot is centered on the hole in the center of the ring detector. If this alignment in not correct the instrument will not function correctly. The LISST-200X software automatically detects and warns of serious misalignment, during the background measurement process.

The first indicator of an alignment problem is a severe drop in the transmitted laser power when compared to the factory laser power. The laser power and laser reference values will change over time but they should track together.

The second indictor of misalignment is high value on the inner rings. The inner rings are shown on the left side of the background display. The most important rings for misalignment indication are rings 1-4 in the background scatter file. If the focused laser starts to move away from the center of the ring detector it will scatter more light onto the inner rings. This will cause the inner ring values to be much higher than the factory values, and cause the transmitted laser power to decrease.

It must be noted that low laser power or high inner rings may not always indicate misalignment. Low laser power can also occur because the windows or water is dirty or if there are bubbles on the window. Large particles or bubbles can cause the inner rings to be

higher than factory values. All of the other possibilities must be eliminated before it can be concluded that the instrument is misaligned.

If necessary, the LISST-Deep can be aligned by Sequoia Scientific or an authorized service representative.

G. Mounting and Orientation, Storage

Prefer Horizontal Mounting

The LISST-Deep measures scattered light to obtain particle size distributions. Therefore, it is important to keep particles from sticking to the window surface. The first line of defense it to keep the window surface vertical by mounting the instrument horizontally. This is most critical when the water motion is slow. When working in rivers or in a towed or profiling application the orientation is not as critical.

Electrical Isolation

To reduce the corrosion of the aluminum parts, a zinc anode is attached to each endcap. This anode must be exposed to the water for it to be effective.

When mounting the instrument be sure to electrically isolate the instrument from all other metal. Any contact with other metal can greatly increase the rate of corrosion. Isolate the instrument with rubber or plastic to keep the LISST-Deep from being the sacrificial anode for the mounting hardware. Failure to properly isolate the instrument from all other metal will void the warranty.

Cleaning the Optical Windows

The condition of the windows is critical to the performance of the LISST-Deep. Care must be taken when cleaning the windows. The windows and the instrument should be rinsed thoroughly with fresh water after each deployment. The windows should be cleaned with a soft cloth or lens tissue. Liquid detergent/soap and water may be used. For removing grease spots, finger prints, etc., alcohol may be used. Do not use stronger solvents such as Acetone or Toluene.

Abrasive powders must never be used near the optics windows; they will scratch the windows and degrade instrument performance.

Orientation Relative to Current Flow

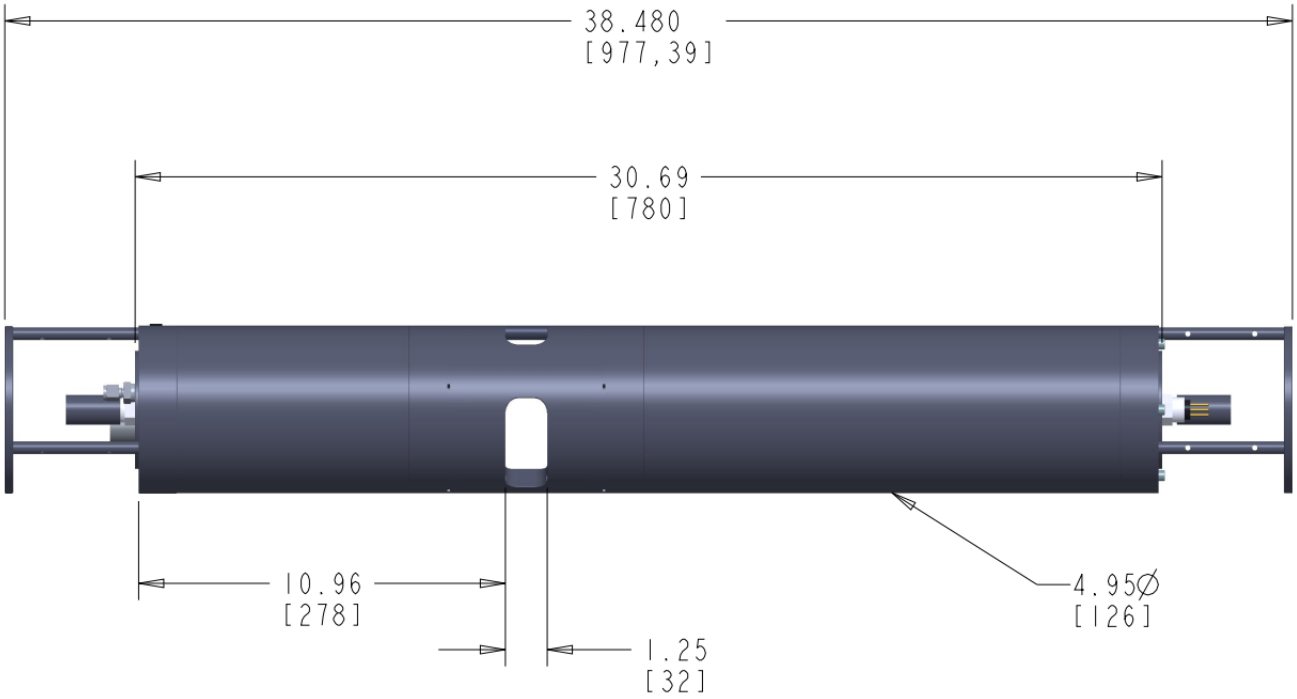
In situations with significant current flow, it is best to orient the instrument perpendicular to the current, so water can flow as directly as possible through the optics end of the instrument.

Storage

For full protection, always store the LISST-Deep in its foam-lined shipping case.

Appendix A: Technical Specifications

- Parameters measured/derived:
  - Particle Size distribution
  - Total Volume Concentration
  - Optical Transmission
  - Depth
  - Temperature
  - Volume Scattering Function
- Particle size range: 1.00 – 500 µm in 36 log-spaced classes
- Optical path length: 5.0 cm
- Analog inputs (availability depends on configuration)
  - Measurement range: 0 to 5.2 V
  - Resolution: 0.1 mV (inputs 1 and 2); 1.5 mV (input 3)
  - Uncertainty: 1.5% of reading + 2 mV
  - Input impedance: 500 kΩ
  - Time constant: 250 ms
- Digital input (availability depends on configuration)
  - Nominal logic levels: 0 and 3V
  - Voltage tolerance without damage: -12 to 12V
- Analog outputs (availability depends on configuration)
  - Output range: 0.1 to 3.0 V
  - Resolution: < 1 mV
  - Output impedance: 1 kOhm
  - Uncertainty: 1.5% of reading + 2 mV
- Data storage memory: 1GB (~12 million measurements)
- Maximum sample speed: 1 size distribution per second
- Temperature sensor
  - Range: -5 to 45 °C
  - Resolution: 0.001 °C
  - Uncertainty: approximately 1 °C
- Depth Sensor
  - Range: 0 to 4000 m of sea water
  - Resolution: 10 cm
  - Uncertainty: approximately 1% of reading (if atmospheric offset zeroed)
- Input power:
  - Operating range: 9 to 24 V
  - Current during active sampling: 120 mA @ 12V
  - Current while waiting for user command: < 50 mA @ 12V
  - Current during low-power sleep (ZZ command): < 3 mA
- Dimensions: 12.6 cm (4.95”) diameter, 96.3 cm (37.9”) long (see dimensional drawing on following page)
- Weight: 18.6 kg (41 lbs.) in air, 9.5 kg (21 lbs.) in water
- Depth rating: 4000 m



LISST-Deep dimensions in inches [mm]

Appendix B: Particle Size Bins

There are 36 size ranges logarithmically placed from 1.00 – 500 microns in diameter. The upper size in each bin is approximately 1.18 times the lower, with the exception of bin 1. The table below shows the lower and upper limit of each size bin in microns, together with the median size (also in microns) for each size bin. The sizes are the same for both Spherical and Randomly Shaped inversions.

Size bin #	Lower	Upper	Median
1	1.00	1.48	1.21
2	1.48	1.74	1.60
3	1.74	2.05	1.89
4	2.05	2.42	2.23
5	2.42	2.86	2.63
6	2.86	3.38	3.11
7	3.38	3.98	3.67
8	3.98	4.70	4.33
9	4.70	5.55	5.11
10	5.55	6.55	6.03
11	6.55	7.72	7.11
12	7.72	9.12	8.39
13	9.12	10.8	9.90
14	10.8	12.7	11.7
15	12.7	15.0	13.8
16	15.0	17.7	16.3
17	17.7	20.9	19.2
18	20.9	24.6	22.7
19	24.6	29.1	26.7
20	29.1	34.3	31.6
21	34.3	40.5	37.2
22	40.5	47.7	43.9
23	47.7	56.3	51.9
24	56.3	66.5	61.2
25	66.5	78.4	72.2
26	78.4	92.6	85.2
27	92.6	109	101
28	109	129	119
29	129	152	140
30	152	180	165
31	180	212	195
32	212	250	230
33	250	297	273
34	297	354	324
35	354	420	386
36	420	500	459

Appendix C: Data File Formats

File Types and Extensions Used by the LISST-Deep.

Extension	Description	Format	Comments
.RBN	Raw Data	Binary	Raw data file produced by the LISST-Deep. In addition to raw scattering data, RBN files contain a complete description of the instrument configuration, its most recent background scattering, and the factory background.
.CSV	Processed Data	ASCII	Comma-delimited file containing size distributions and meta data. Details on page 66. For information about generating these files in the LISST-Deep, see Autonomous Real-time Data Processing on page 40.

Secondary files not used for standard processing			
.BGT	Background File	ASCII	Comma-delimited file containing the raw ring values from a single background measurement (1 column, 59 rows)
.RTX	Raw Data	ASCII	Comma delimited ASCII representation of raw data (59 columns, 1 measurement per row). NOTE: Sequoia software does not process RTX files. They are only for troubleshooting or special applications.

Processed Data Format The values in the processed data file (.CSV extension) are stored in the order shown below. Each sample is stored in one row.

Column #	Parameter
1:36	Volume concentration for size class 1 through 36 [µL/L]
37	Laser transmission Sensor [mW]
38	Supply voltage in [V]
39	External analog input 1 [V]
40	Laser Reference sensor [mW]
41	Depth in [m of sea water]
42	Temperature [C]
43	Year
44	Month
45	Day
46	Hour
47	Minute
48	Second
49	External analog input 2 [V]
50	Mean Diameter [µm] (calculated from fully processed size distribution)
51	Total Volume Concentration [PPM] (calculated from fully processed size distribution)
52	Relative Humidity [%]
53	Accelerometer X [not presently calibrated or used]
54	Accelerometer Y [not presently calibrated or used]
55	Accelerometer Z [not presently calibrated or used]
56	Raw pressure [most significant bit]
57	Raw pressure [least significant 16 bits]
58	Ambient Light [counts – not calibrated]
59	External analog input 3 [V]
60	Computed optical transmission over path [dimensionless]
61	Beam-attenuation (c) [m^{-1}].

ASCII Raw Data Format

The values in the raw ASCII data file (.RTX extension) are stored in the order shown below. Each sample is stored in one row.

RTX files are only useful for troubleshooting or special applications. **Sequoia does not supply software for processing them**.

Column #	Parameter
1:36	Raw ring values [counts]
37	Laser transmission Sensor [counts]
38	Supply voltage [0.01 V/count]
39	External Analog input 1 [10^{-4} V/count]
40	Laser Reference [counts]
41	Depth [0.1 m/count + 100 m]
42	Temperature [1 m°C/count + 5 °C]
43	Year
44	Month
45	Day of month
46	Hour
47	Minute
48	Second
49	External Analog input 2 [10^{-4} V/count]
50	Sauter Mean Diameter [0.1 µm/count] (estimated)
51	Total Volume Concentration [0.1 PPM/count] (estimated)
52	Relative Humidity [%]
53	Accelerometer X [counts] [not presently used]
54	Accelerometer Y [counts] [not presently used]
55	Accelerometer Z [counts] [not presently used]
56	Raw pressure [most significant bit]
57	Raw pressure [least significant 16 bits]
58	Ambient light [counts]
59	External Analog input 3 [10^{-4} V/count]

Appendix D: MATLAB Data Processing

Two Matlab functions for processing data are provided on the instrument USB card. They are also available from the 'Software and Downloads' tab on the LISST-200X webpage. The processing is split into two steps: (1) reading in and applying corrections to raw data files (.RBN) and (2) inverting the corrected scattering to a particle size distribution.

The same results can be achieved by processing data files using the LISST-200X software. However, the following functions allow Matlab users to write their own processing and plotting code.

The first function is used to read in raw data from an RBN file. The function will import the data, apply the necessary corrections, and return the corrected data in a structure. The syntax is as follows:

```
RBNdata = L200X_LoadRBN(datafile)
```

'Datafile' is the path to a binary .RBN file downloaded from a LISST-Deep.

Optionally, you may specify a different clean water background file (.BGT) as a second argument. The data will then be corrected using the specified background file instead of the background contained in the RBN file.

```
RBNdata = L200X_LoadRBN(datafile,backgroundFile)
```

'RBNdata' is a structure with the following fields:

Field	Description
cscat	Corrected scattering
date	Timestamp in Matlab datenum
transmission	Optical transmission
depth	Depth in meters
temperature	Temperature in degrees Celsius
estMeanDiameter	Estimated Sauter mean diameter (µm)
estTotalConc	Estimated total concentration (µL/L)
Lp	Transmitted laser power (mW)
Lref	Laser power reference (mW)
analog1	Analog input 1 (V)
analog2	Analog input 2 (V)
analog3	Analog input 3 (V)

supplyVolts	Supply voltage (V)
humidity	Internal instrument relative humidity (%)
accelXYZ	Accelerometer X, Y, and Z (not presently calibrated or used)
raw	Raw data as it appears in the RBN file
factory_bkgrd	The factory background (corrections applied to aux data)
bkgrd	User collected background (corrections applied to aux data)
ambientLight	Counts of ambient light removed from ring values
config	Structure containing various instrument information
dcal	Ring area coefficients
Ta	Vector to convert cscat to estimated total area concentration
Tv	Vector to convert cscat to estimated total volume concentration

The second function inverts the corrected scattering to a particle size distribution. The syntax is as follows:

```
[vd, dias] = LISST_ComputePSD (Cscat,Random,Sharpen,ShowProgressBar)
```

The first argument is the corrected scattering (**cscat**) from the structure returned from 'getscat_L200X.' The following three argument are set to zero or one.

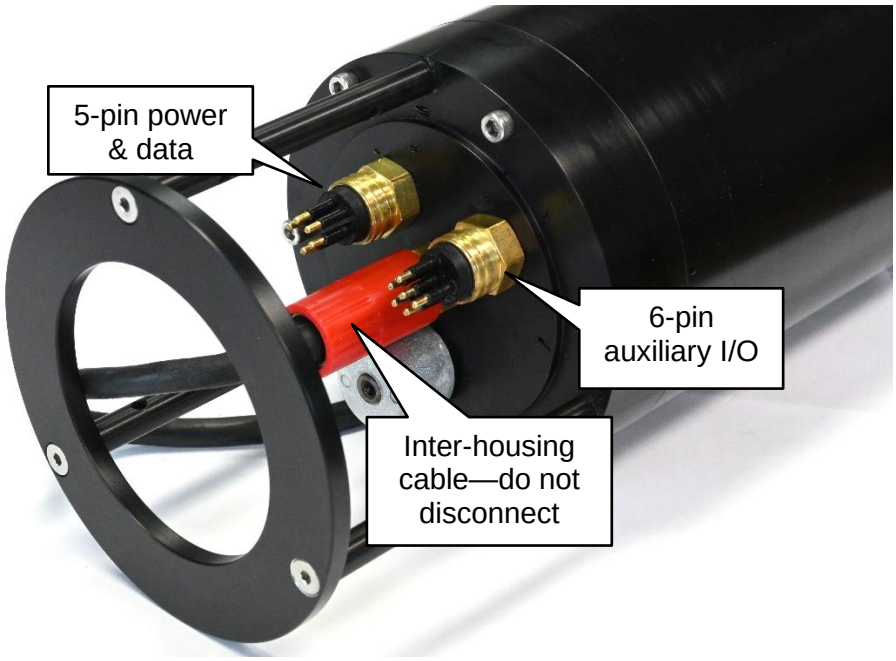
Random – If set to 1, the randomly shaped particle matrix is used to invert the data. If set to zero, the spherical particle matrix is used. See Appendix F: Particle Shape Models on page 74 for more information.

Sharpen – If set to 1, the function checks the width of the size distribution and increases the number iterations if the size distribution is wide (recommended).

ShowProgressBar – If set to 1, a progress bar will display the processing status.

The function will return the volume distribution in µL/L (**vd**) and the midpoint of each size bin in microns (**dias**).

Appendix E: Connectors



The LISST-Deep's main end cap has three connectors:

- 5-pin male, the primary power input and serial data interface
- 6-pin male, for auxiliary input/output functions
- 6-pin female in the center of the end cap, for connections between the LISST-Deep's two pressure housings. The factory-installed cable should never be removed during normal operation.

Communications and Power Connector

Bulkhead connector: SubConn MCBH5M
Mating cable connector: SubConn MCIL5F

Bulkhead Endview

Cable Endview

Connector Pin #	Use
1	Power/Serial Ground
2	External Power In (+9 to 24 V)
3	Power/Serial Ground
4	RS-232 Serial Out
5	RS-232 Serial In

Auxiliary I/O Connector

Bulkhead connector: SubConn MCBH6M
Mating Cable Part Number: SubConn MCIL6F

Bulkhead Endview

Cable Endview

The Auxiliary I/O connector (6-pin) can have one of three different configurations:

Dual Analog Output: for connecting to a CTD or other data system that will supply power and digitize the analog outputs of the LISST-Deep.

Connector Pin #	Function
1	Ground (Power)
2	Analog Output: Mean Size
3	Ground (signal)
4	Analog Output: Total Concentration
5	Ground (signal)
6	Power Input (9 to 24VDC)

Triple Analog Input: for connecting up to 3 analog-output sensors such as fluorometers and turbidimeters, whose outputs will be digitized and stored with the LISST-Deep data.

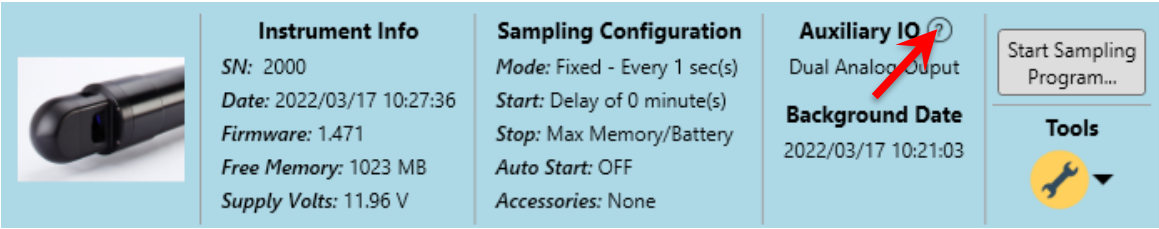
Connector Pin #	Function
1	Ground
2*	Analog In #3 (0 to 5V)
3	Ground
4	+12V out
5	Analog In #1 (0 to 5V)
6	Analog In #2 (0 to 5V)

Dual Analog Input with Trigger: similar to triple analog input, but one input acts as a trigger that allows an external system to start and stop logging by the LISST-Deep.

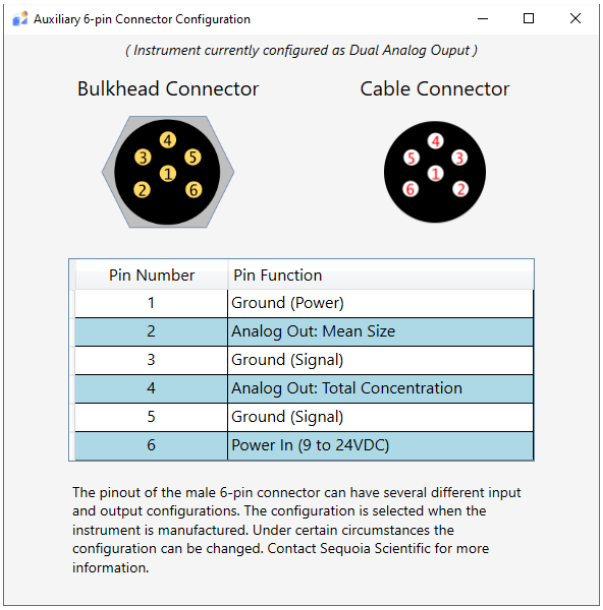
Connector Pin #	Use
1	Ground
2	Digital Input Trigger
3	Ground
4	+12V out
5	Analog In #1 (0 to 5V)
6	Analog In #2 (0 to 5V)

Viewing and Setting the Auxiliary I/O Configuration

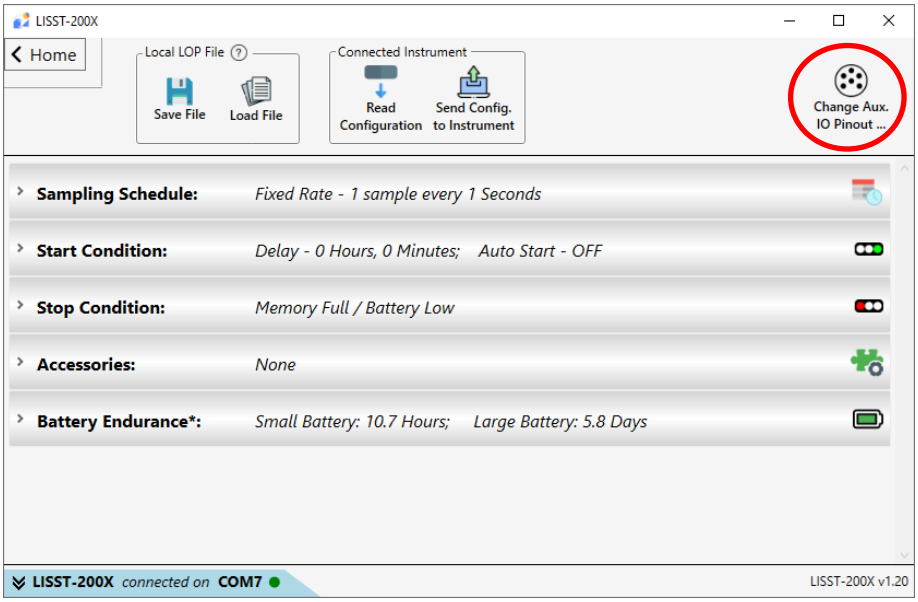
To view the current configuration in the LISST-200X software, once connected (see Establishing Communication with the LISST-Deep on page 22) open the instrument status bar and press the '?' icon next to 'Auxiliary IO', as shown below:



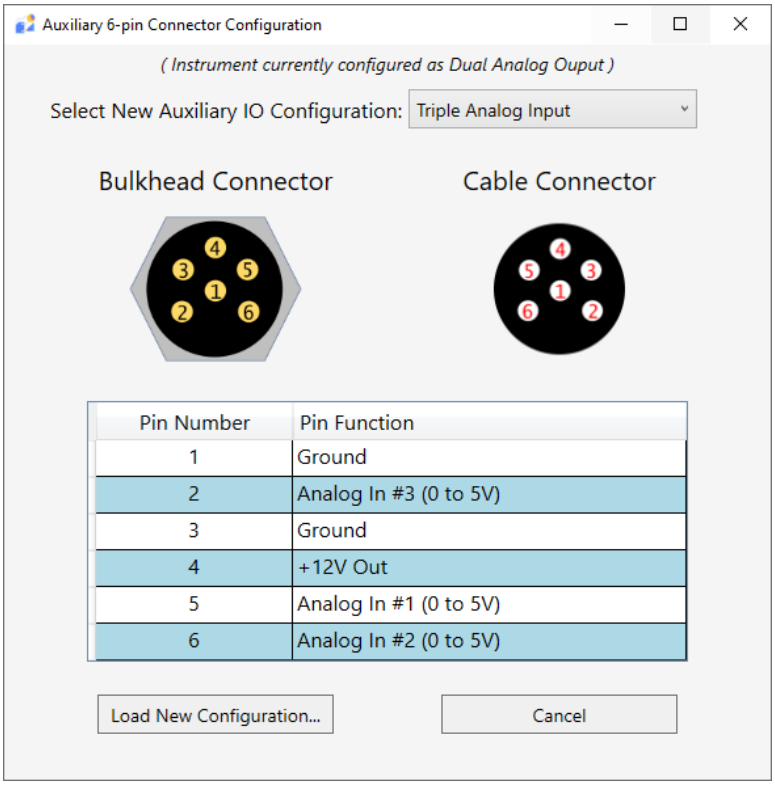
This will open a window showing the pin assignments in the current configuration, for example:



To select a different configuration, open the 'Configure Instrument' page and click the 'Change Aux. IO Pinout' button in the upper-right corner of the screen.



Pressing this button will open a page for viewing and changing the I/O configuration. Use the dropdown menu to select a new configuration, then load it onto the instrument using the 'Load New Configuration…' button. We recommend that nothing be plugged into the connector when changing the configuration.



The configuration can also be viewed through the instrument serial port command line using the CONFIG command (see page 48), and changed through the IOCONFIG command (see page 51).

Appendix F: Particle Shape Models

Particles of different shapes scatter light differently, so the mathematical model used for processing must be appropriate to the particles under observation. Two models are offered by Sequoia: the spherical model, and the random or irregular shape model. The resulting inversion of data will differ slightly for the two models.

The spherical particle model performs the mathematical inversion of scattering data under the assumption that the particles that scattered light are all spheres. Light scattering by spheres of any size and refractive index is modeled by Mie theory. According to Mie theory, the angular scattering depends on the size of the spherical particle, and its refractive index relative to water. Sequoia employs the full Mie scattering model, without simplifications, for inversion of LISST measurement as a distribution of spheres. The Mie solution is a generalized solution to the scattering of light from spheres and is commonly used as the standard model by all laboratory laser diffraction instrument manufacturers. However, it is not completely accurate for non-spherical particles found in nature.

Sequoia provides an alternate model that is derived empirically from natural, irregularly-shaped mineral particles, rather than assuming spheres. The exact details of how this scattering model was established are described in a paper by Agrawal et al. [Light scattering by random shaped particles and consequences on measuring suspended sediments by laser diffraction. Journal of Geophysical Research, Vol. 113, C04023, doi:10.10-29/2007JC004403.], which can be downloaded from the library section on Sequoia's website (www.SequoiaSci.com/library). The method is also briefly described in this article: http://www.sequoiasci.com/article/random-shaped-particles-lissts/. It is noteworthy that no other instrument manufacturer has a scattering model for irregular particles. Instead, they often use a Mie model with large imaginary refractive index, in effect, assuming the particles to be highly absorbing (i.e. black). This is an obvious fudge with consequences!

Which model should you use? Sequoia's software allows you to use both, then compare the results. But in general, the random model is best for any in-situ application.

	Spherical	**Random (Irregular)**
Best use	Particles known to be predominantly spherical, e.g. analytical microspheres	Appropriate for natural mineral particles
Effect of misapplication	If used with natural irregular particles, tends to *invent* fine particles.	If used with spherical particles, tends to underestimate their size.
Relation to other instruments and methods	Usually produces the closest match to other laser diffraction particle sizers (although they may still differ due to index of refraction)	Usually produces the best match to analysis by sieving.

Appendix G: Analog Outputs

Introduction

The LISST-Deep includes two analog outputs for interfacing with CTDs or other data acquisition systems (see Configuring the LISST-Deep as a Sensor for a CTD on page 43). These produce voltages indicating the approximate total concentration and mean diameter of particles.

Whether the analog outputs are accessible on a specific LISST-200X depends on its electronic configuration. The auxiliary connector must be in its dual-output configuration. See Viewing and Setting the Auxiliary I/O Configuration on page 72 for details.

Calculation

The analog output voltages are calculated using one of two methods, depending on the version of the LISST's electronics. Newer instruments with Autonomous Real-time Data Processing capability enabled (see page 40) calculate the full particle size distribution, with the same precision as data post-processed on a PC. Older instruments without that capability use an approximate calculation, based on a weighted sum of the raw signals from the 36-segment detector.

For either calculation method, users of the data should note the inherent limitations in range and precision available from analog outputs. Also, there is in inverse relationship between optical transmission and quality of the mean size calculation. High transmission means few particles are present, so the estimated size may vary widely from sample to sample, and may contain large errors. For this reason, when the particle concentration is very low (with transmission typically0.99 or higher), the mean size analog output will be set to zero. In other words, zero output indicates no valid measurement is possible.

Background quality

As with any application of the LISST, a high-quality background measurement (see page 23) is essential for correct data from the analog outputs.

Interpreting output voltages

The analog outputs can range from 0 to 3 Volts.
The mean size output voltage is 0.005 * (mean size in microns) + 0.5 Volts. Therefore,

$$\text{Mean size} = 200 * (V - 0.5) \text{ micron}$$

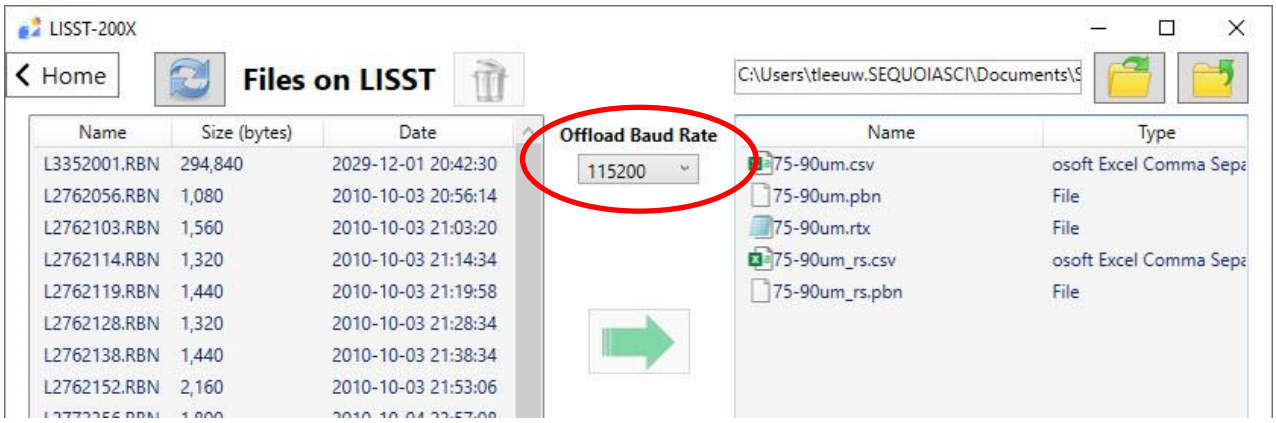
To accommodate a wide range of possible concentration values, the conversion to voltage is logarithmic: V = 0.5 * log10(PPM*100). Therefore,

$$\text{Concentration} = 10^{2V}/100 \text{ PPM}$$

Appendix H: Troubleshooting & Support

Q: I am getting errors offloading data from my LISST-Deep.

A: In some cases the offload baud rate may need to lowered in order avoid offload errors. The offload baud rate can be reduced in the LISST-200X software selecting a lower baud rate from the drop down box on the file offload page:



Select a lower File Offload Baud Rate, then try transfering files again. If the errors persist, even at the lowest baud rate (9600), contact Sequoia Scientific.

Q: I think that I have a problem with my data and/or my data processing and would like you to have a look at them - can you do that? What data do I need to send to you?

A: We'll be happy to look at your data and help you figure out what is going on. In order to troubleshoot the problem, we need the .RBN file(s) that contain the raw data.

Email the data to your local Sequoia distributor, together with a detailed explanation of what you were doing and how the data were collected. If you purchased the instrument directly from Sequoia, email the data to support@sequoiasci.com.

PLEASE NOTE: We *cannot* use the .PBN or .RTX files produced by the LISST-200X software for troubleshooting. We can only help you if you supply .RBN files.

Revision History

Version 5.02 January 2023	Delete obsolete XR command
Version 5.01 August 2022	Add Appendix G: Analog Outputs.
Version 5 March 2022	First version describing the updated design introduced in 2022, starting with LISST-Deep serial number 4056.