ProSoft 7.7 User Manual

Rev. I: May 5, 2011

Document: SAT-DN-00228

Prepared by:	Satlantic Incorporated 3481 North Marginal Road, Richmond Terminal, Pier 9 Halifax, Nova Scotia B3K 5X8 Tel (902)492-4780 Fax (902)492-4781

Table of Contents

List of Equations

1. Introduction

ProSoft is a data analysis package for processing data collected from oceanographic measurement systems. The primary goal of the program was to create a package that would be able to process optical data in an automated manner so that processing of data was not subjective and any two investigators would get the same results from the same data set. With the increasing number of different instrument types that can be used from autonomous buoys, ships, or airborne platforms, a demand for a generalized approach for processing all optical data has emerged. To meet this demand, ProSoft has been created. The most important changes have been related to data and metadata organization, which is now based on the Hierarchical Data Format (HDF 4), developed by The National Center for Supercomputing Applications at University of Illinois at Urbana-Champaign http://HDF.ncsa.uiuc.edu/. At the same time, the principles of data processing have not changed. Any principle changes that will be introduced in the future will be stated explicitly (they can be found in the program under menu 'Help->About'). ProSoft allows users to read, calibrate, average and inspect data sets collected from their instrumentation.

The program is currently supported by Satlantic Inc. and is available at:

ftp://ftp.satlantic.com/pub/sensors/software/ProSoft/

2. System Requirements

ProSoft's source code is written and compiled using MatLab® version 6.5.0.

The minimum system requirements for ProSoft are as follows:

Operating System: Microsoft® Windows® 2000/2003/XP/Vista

Processor (CPU): 1 GHz 32-bit (x86)

Memory (RAM): 512 MB

Free Disk Space: 50 MB

3. Installation

ProSoft is available as a standard Microsoft® Windows® 2000/2003/XP/Vista install and is supplied on CD or as a single self-extracting program from our Internet site at the above ftp address. One should run the ProSoft#.#_Setup.exe program and follow the instructions on the screen.

4. Revisions

4.1 ProSoft 7.7

1. Changed graphics renderer mode to zbuffer which renders 3-D graphics in much less time.

2. When graphing HDF file data, users are now able to select which independent variables to graph as well as the range of the dependent variable.

3. New graphical overlay option allows users to graph data from different Dependant variables belonging to the same instrument group onto the same graph.

4. Any number of ECO Sensor IOP sensors can now be processed for an instrument. Most calibration file definitions are acceptable for an ECO Sensor IOP.

5. Improved reliability of sensor distances from surface and pressure reference distances.

6. Sample delay time correction has now been applied to timer values where appropriate at level 2 processing.

7. Transmissometer sensor has been added to level 2s and 3a data processing.

8. Added Reference Ef Ev and Ld optical sensors to level 2s and 3a data processing.

9. Any kind of profiler can now be used in Reference mode. The mode is indicated in the instrument context by selecting Reference as the instrument type.

10. Improved dynamic data processing at levels 2s and 3a.

11. All GPS telemetry definitions are now supported.

12. Added the ability to process upcasts and downcasts within the same telemetry file.

13. ECO Series IOP sensors with backscatter sensors can now process backscattering coefficients as a Level 4 data product.

14. Added new tool that allows conversion of ProSoft generated HDF files into Matlab binary files (*.mat) which can be imported directly into the Matlab workspace.

15. Level 4 chlorophyll profile estimates updated to Morel 2001 model.

16. Added derived profiler velocity and absolute tilt values to level 2 HDF files.

17. Added use of the HDF4 limit of 512 data fields for writing Vdata tables to prevent invalid HDF files.

18. Improved the equation used to calculate Ed(0+).

19. Added the calculation of Q(0-) based on calculated Eu(0-) and Lu(0-) to level 4.

20. Added the level 4 processing parameter ET Solar Irradiance.

21. Added the ability to import processing parameters from a file.

4.2 ProSoft 7.6

1. GPS sensor data integrated into profiler/reference configurations. GPRMC, GPGLL and GPGGA only are supported.

2. TSRB mode added for all profiler/reference configurations including HyperPro II.

3. Level 4 water properties data product enabled. Instrument must have a profiler with Temp and Cond sensors.

4. Level 2s depth integration resolution is now adjustable to 0.01, 0.02, 0.05 and 0.10m through parameters settings.

5. SAS integration time interval is now derived on the interval of the optical sensor with the highest rate instead of the standard of 0.1sec.

6. Conductivity sensor data included to level 3a.

7. Temperature sensor data included to level 3a.

8. Fluorometer sensor data included to level 3a.

9. File batch processing sequence changed. Instead of processing all files together at one level (i.e. process all files at level 1a before processing all files at level 1b), each file is processed separately from level 1a to selected level.

10. Calibration files can now be added or removed from configuration files that are created from *.sip files.

11. Imported configuration files can now be saved with their original file name by clicking on 'Save' in the configuration utility.

12. Reference only or TSRB mode data are now integrated onto the time interval derived from the Es sensor instead of the previous standard of 0.1 sec.

13. Added Reference Ev optical sensor to processing at all levels.

4.3 ProSoft 7.5

1. Added support for level 2s GPS integration for the following GPS formats $GPRMC, $GPGLL and $GPGGA.

2. SAS GPS data is now averaged at level 3a.

3. GPS data is not available for viewing below level 2s in the HDF viewer but can be extracted using the ASCII data extractor.

4. Added support for the ECO Series IOP sensor for the new HyperPro II instrument.

5. Faster ASCII data extraction of HDF files.

6. Fixed bugs preventing processing of TSRB data.

4.4 ProSoft 7.4

1. Processing parameters have been incorporated into one file. Access to the file is through the new processing parameters utility.

2. Processing parameters can be easily edited through the new parameters interface. All four levels of parameters are viewed and edited at once.

3. Processing parameters have been separated from the instrument context. The new 'Processing Context' consists of both the current instrument and current processing parameters.

4. HDF viewer now includes the ability to save the graph image as a file using the png graphic format.

5. Updated ProSoft main menu. Processing level commands have been moved to the main menu for easier use. Ascii data extractor and HDF viewer are now accessible through the menu selection 'Tools'.

6. Instrument context creation/edit utility now allows adding or removing calibration files from the instrument context.

4.5 ProSoft 7.3

1. New level 2s file is introduced for all instruments. The Level 2s file shows the interpolated data just prior to averaging at Level 3a.

2. Introduction of 'Instrument Context' creation and loading for easy data processing and selection between different instruments.

3. Added processing support for Satlantic Satnet instruments.

4. Easier to use Ascii data extraction utility.

5. Updated ProSoft main menu interface.

6. Addition of completely revised HDF graphical viewer utility which makes it possible to graph all HDF files in 2-D or 3-D graphical views.

7. Updated and easier to use configuration file creation/edit utility.

8. Level 4 chlorophyll a profile estimates using Morel 98 model added.

9. Level 4 chlorophyll a surface estimates using SeaBAM OC2 model (Rrs) added.

10. Level 4 chlorophyll a surface estimates using Gordon 88 model (Lwn) added.

11. Level 4 energy profile/surface fluxes added.

12. SAS data can now be processed to level 3a.

5. Overview

Edit current
instrument context

Create new
instrument context

Edit current
parameters

Create new
parameters

Process data from
raw to level 2

Process data from raw
to level 2s

Process data from raw
to level 3a

Process data from raw
to level 4

Process data from raw
to level 1a

Process data from
level 1a to level 1b

Process data from
level 2 to level 2s

Process data from
level 3a to level 4

Delete current instrument
context

Import existing instrument
context from a file

Delete current
parameters

Import existing
parameters from a file

Process data from level
1b to level 2

Process data from level
2s to level 3a

5.1 Processing Context

The processing context defines all the parameters necessary for processing of instrument data. The processing context is made up of two parts, the current instrument and the current parameters. The current instrument defines the instrument used for gathering the raw data. See instrument context for details. The current parameters

defines all the processing variables for level 1 to level 4 data processing. See parameters context for details.

5.1.1 Current Instrument

Displays the currently loaded instrument context. All instrument configuration information is loaded and ready for processing. See instrument context for details.

5.1.1.1 New

Starts the process for creating a new instrument context. The user is asked to supply the location of the calibration file(s) or sip file(s) for the instrument, which are then used to create the instrument context. **Note: All calibration file(s) (*.cal) or sip file(s) (*.sip) for the instrument context must remain in the same directory as the instrument context (*.cfs) file.**

5.1.1.2 Import

Allows the user to import an existing instrument context file (*.cfs) for use in a new instrument context.

5.1.1.3 Edit

This option loads the current instrument context into the instrument context utility for editing. The user can choose to save the file under the existing instrument context name ('Save') or create a new instrument context ('Save As').

5.1.1.4 Delete

Permanently deletes the current instrument context. The context file (*.cfs) associated with the instrument context is not deleted.

5.1.2 Current Parameters

Displays the currently loaded parameters context. All processing parameters are loaded and ready for processing. See parameters context for details.

5.1.2.1 New

Starts the process for creating a new processing parameters context. The processing parameters utility will display with default values automatically loaded.

5.1.2.2 Import

Allows the user to import an existing parameters file (*.mat) for use in a new processing parameters context.

5.1.2.3 Edit

This option loads the current processing parameters into the processing parameters utility for editing. The user can choose to save the file under the existing processing parameters context name ('Save') or create a new parameters context ('Save As').

5.1.2.4 Delete

Permanently deletes the loaded processing parameters context. The original parameters file (*.mat) associated with the processing parameters context is also deleted.

5.2 Multi-Level Processing

Multi-level processing enables the user to process raw data up to level 2s, level 3a or level 4. All intermediate processing levels are automatically processed with accompanying files (*.HDF) being produced. To use this feature select the command button according to the ending processing level as desired. ProSoft will prompt the user to select the directory and choose file(s) (*.raw) of raw data.

5.3 Single Level Processing

Single level processing enables the user to process data over a single level. For example from level 1a to level 1b. To use this feature select the command button according to the starting processing level and ending processing level as desired. ProSoft will prompt the user to select the directory and choose file(s) (*.HDF or *.raw) for the starting processing level.

5.4 File Menu

5.4.1 Options

Select this option to specify the ProSoft options for Data Files.

The "Dynamic File Structure" option enables/disables the use of a separate folder for each processing level for the writing its output data file(s).

The "Enable Raw File Parsing" option enables/disables the splitting of each selected raw data file into sections that can be processed separately.

The "Raw File Parsing Size (Mb)" option allows the user to select the size of each section when the option to split raw data files is enabled.

5.4.2 Exit

Select this option to exit the current ProSoft session. The last loaded instrument context and processing parameters context will be automatically loaded next time ProSoft is started.

5.5 Tools Menu

5.5.1 MAT Data Extractor

This utility converts HDF files into a Matlab data structure. This structure is then saved into Matlab binary format (*.mat) which can be directly imported into the Matlab workspace for further analysis and manipulation. See mat data extraction for details.

5.5.2 HDF Viewer

Select this option to access the HDF viewer utility which allows the user to view HDF files in 2-D or 3-D graphical format. The utility will open in the empty state. Simply select 'File -> Open' to load HDF files for viewing. See HDF data viewer for details.

5.6 Ascii Menu

5.6.1 General Data Product

This utility converts HDF files to tab separated ASCII file format. ProSoft will prompt the user to select the directory and choose file(s) (*.HDF) for ASCII data extraction. HDF files at any level can be extracted. See ASCII data extraction for details.

5.7 Help Menu

5.7.1 Definitions

Select this option to view a list of definitions of ProSoft terms. See appendix A term definitions for list of definitions.

5.7.2 About

Select this option to view the history of revisions for ProSoft versions. This lists the latest changes made to ProSoft. See revisions for details.

6. Instrument Context
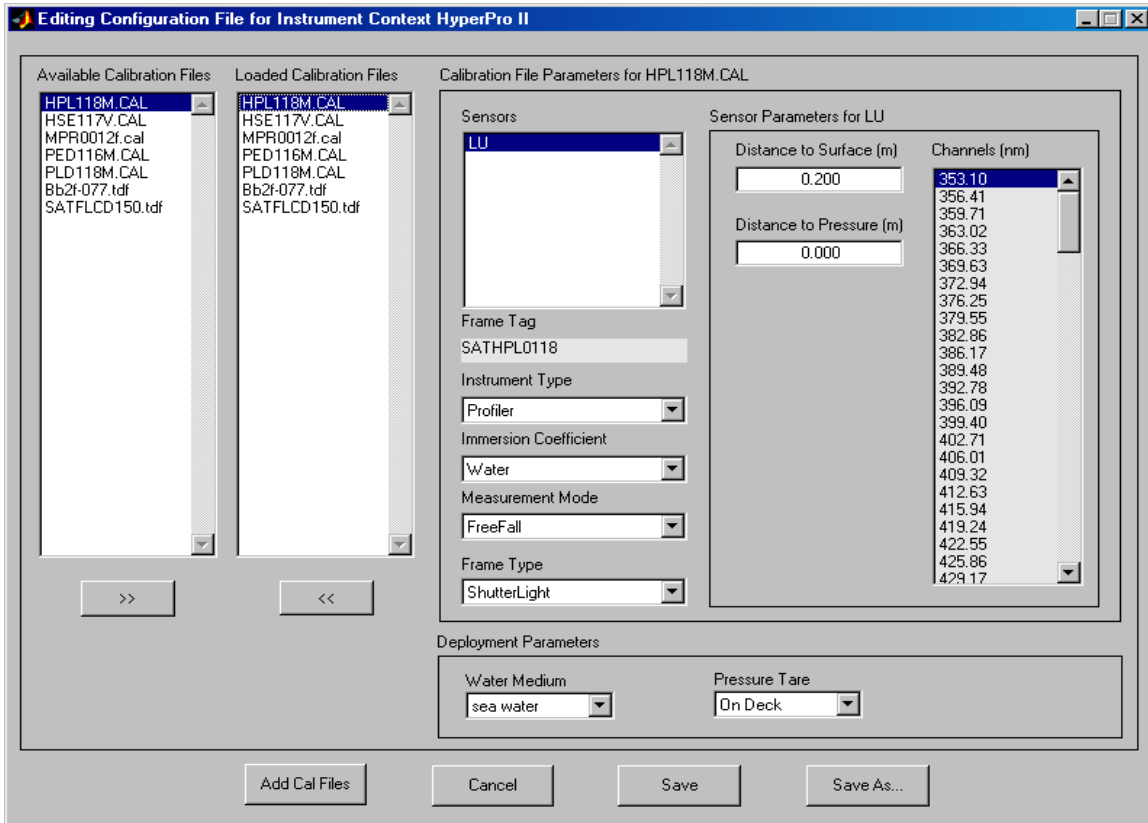
Instrument Context Utility

Instrument Context is defined as the current instrument package (i.e. profiler + reference) and deployment parameters loaded into ProSoft that will be used for data processing. The instrument context file (*.cfs) used to describe this instrument deployment is loaded into memory ready to be recalled when necessary for processing.

The user can switch between instrument packages easily by clicking on the drop down box and selecting from the list of instrument contexts that have been defined by the user. When an instrument is chosen the instrument context file associated with the instrument package is automatically loaded and ProSoft is ready to process data.

6.1 Deployment Parameters

The Instrument Context deployment parameters are used to specify required information related to the instrument's deployment when the raw data to be processed was acquired. These parameters are: "Water Medium" and "Pressure Tare".

Deployment Parameters

Parameter Name	Parameter Value	Comments
Pressure Tare	In Water, On Deck	Method used to obtain pressure tare for a profiler.
Water Medium	Sea water, Fresh water	Water type in-situ.

6.1.1 Water Medium

The Water Medium parameter is used to specify the type of water the instrument was deployed in when the raw data to be processed was acquired. This parameter is required for the "ECO Series IOP" instrument type for calculating the total backscattering coefficient.

6.1.2 Pressure Tare

The Pressure Tare parameter is used to specify the method used to obtain the pressure tare measurement when a profiler instrument was deployed. The possible pressure tare methods are "On Deck" and "In Water". In either case the pressure tare is performed just prior to deployment of a profiler.

The "On Deck" method is performed with the profiler instrument held upright on deck in the vertical position. The "In Water" method is performed with the profiler instrument upright in the water with the top of the irradiance sensor at the surface of the water.

Note: The "In Water" method is no longer recommended, better accuracy and ease of use can be achieved using the "On Deck" method.

6.2 Available Calibration Files

This is a list of all calibration files (*.cal and .tdf) located in the current directory or files associated with a sip file (*.sip). In the case of creating a new instrument context the current directory or sip file(s) are selected prior to displaying the instrument context utility. When editing or importing, the current directory is the directory that the instrument context file is located in.

6.3 Loaded Calibration Files

This is a list of all calibration files (*.cal and *.tdf) that are loaded in the instrument context. These are the calibration files which will be associated with the instrument context. These can be added or removed as needed.

6.4 Calibration File Parameters

The 'Calibration File Parameters' displays all current configuration information on the calibration file selected in the 'Loaded Calibration Files' selection box. See table 'Calibration File Settings'.

6.4.1 Sensors

This is a list of optical sensors defined within the selected calibration file.

6.4.2 Frame Tag

Indicates the frame tag associated with the calibration file as it appears in the raw or level 1 telemetry data.

6.4.3 Instrument Type

Select the type of instrument represented by the calibration file. For a list of possible values see instrument context parameters and calibration file settings tables.

6.4.4 Immersion Coefficient

Select which calibration coefficients to use for processing depending on instrument immersion mode (i.e. Air or Water).

6.4.5 Measurement Mode

Select which mode of measurement to use for processing the calibration file and it's associated raw data.

6.4.6 Frame Type

Select the frame type for the calibration file for dark current correction calculations.

6.4.7 Instrument Context Parameters

The instrument context parameters table indicates all the possible combinations of selectable configuration parameters based on the instrument type.

6.4.8 Calibration File Settings

The calibration files settings table indicates the instrument parameters settings based on calibration file prefix. The prefix is obtained from the first three letters of the calibration file name which is listed in 'Loaded Calibration Files' in the instrument context utility.

Instrument Context Parameters

Instrument Type	Immersion Coefficient	Measurement Mode	Frame Type
Profiler	Water	FreeFall	ShutterLight ShutterDark Anc LightAncCombined
Reference	Water Air	Surface	ShutterLight ShutterDark Anc LightAncCombined
TACCS	Water	Chain	LightAncCombined
SAS	Air	VesselBorne AirBorne	ShutterLight ShutterDark Anc LightAncCombined
GPS	Not Required	Not Required	Not Required
ECO Series IOP	Not Required	FreeFall Surface	Not Required

Calibration File Settings

Cal File Prefix	Instrument Type	Sensors	Immersion Coefficients	Measurement Mode	Frame Type	Notes
BB2F	ECO Series IOP	Fluor	Not Required	[FreeFall Surface]	Not Required	Wetlabs Fluorometer
DI4	Profiler/Reference	[Ed Eu]/[Es Ev Ef] **	Water/Air	FreeFall/Surface	LightAncCombined	4 channel irradiance sensor
DR4	Profiler/Reference	[Lu Ld]/Ls	Water/Air	FreeFall/Surface	LightAncCombined	4 channel radiance sensor
DI7	Profiler/Reference	[Ed Eu]/[Es Ev Ef]	Water/Air	FreeFall/Surface	LightAncCombined	7 channel irradiance sensor
DR7	Profiler/Reference	[Lu Ld]/Ls	Water/Air	FreeFall/Surface	LightAncCombined	7 channel radiance sensor
HED	Reference/SAS	Es/Es	Air/Air	Surface/VesselBorne	ShutterDark	Hyperspectral
HLD	Reference/SAS	Ls/Lt	Water/Air	Surface/VesselBor	ShutterDark	Hyperspectral

				ne		
HSE	Reference/SAS	Es/Es	Air/Air	Surface/VesselBorne	ShutterLight	Hyperspectral
HSL	Reference/SAS	Ls/[Lt Li]	Water/Air	Surface/VesselBorne	ShutterLight	Hyperspectral
HPE	Profiler	Ed	Water	FreeFall	ShutterLight	Hyperspectral
HPL	Profiler	Lu	Water	FreeFall	ShutterLight	Hyperspectral
HSD	Reference	Lu	Water	Surface	ShutterDark	Hyperspectral TSRB
HST	Reference	Lu	Water	Surface	ShutterLight	Hyperspectral TSRB
MPR*	Profiler/Ancillary	Lu Ed Eu Ld/Tilt Press T	Water/[Water Air]	FreeFall/[FreeFall Surface]	LightAncCombined/ Anc	Multispectral/ Ancillary
MRF	SAS	Ls Lt Es	Air	VesselBorne	LightAncCombined	Multispectral
MVD	Reference	Es Ls Ef Ev	Air	Surface	LightAncCombined	Multispectral
OCP	Profiler	Lu Ed Eu Ld	Water	FreeFall	LightAncCombined	Multispectral
PED	Profiler	Ed	Water	FreeFall	ShutterDark	Hyperspectral
PLD	Profiler	Lu	Water	FreeFall	ShutterDark	Hyperspectral
PRO	Profiler	Lu Ed Eu Ld	Water	FreeFall	LightAncCombined	Multispectral
REF	Reference	Es Ls Ef Ev	Air	Surface	LightAncCombined	Multispectral
TAC	Taccs	Lu Ed Es	Water	Chain	LightAncCombined	Multispectral

* MPR calibration files can be either a profiler or ancillary instrument. It's most common use is as an ancillary instrument which can be determined by it's lack of optical sensors (i.e. Lu Ed). When used as an ancillary instrument it's measurement mode can be either FreeFall if attached with a profiler or Surface if attached with a reference. The frame type when used as ancillary should be Anc.

** [ ] Brackets indicate mutually exclusive sensors. For example [Lu Ed] indicates only Lu or Ed sensor will be present but never both.

6.5 Sensor Parameters

The 'sensor parameters' displays all current configuration information on the sensor selected in the 'Sensors' selection box.

6.5.1 Channels

All the channels available from the selected optical sensor are displayed here. For optical sensors this will be a list of all sensor wavelengths.

6.5.2 Configuring Sensor Distances

The sensor head distances are needed in order to compensate for the fact that the pressure sensor is not located at the same position as the sensor heads. In order to calculate the pressure at the sensor head this geometrical difference must be known and included in the instrument context file (all units must be in meters).

When configuring a profiler it is assumed that the Ed sensor head is located at the 'top' of the instrument. In other words it is the last sensor to be immersed when profiling. For the profiler it is important to include the distance between each sensor head and the Ed sensor head (top of the instrument). This value is entered into 'Distance to Surface'. The 'Distance to Pressure' value is only required for the Ed sensor when taking the pressure tare on deck as outlined below in 'Distance to Pressure'. In all other cases leave this value at zero.

   ◆   SAS instruments do not need to specify any distances.

   ◆   ECO Series IOP sensors should always specify the distance to surface.

The following diagram shows how the sensor distances to surface and pressure are to be measured for the following instruments: MicroProfiler, HyperProfiler II.
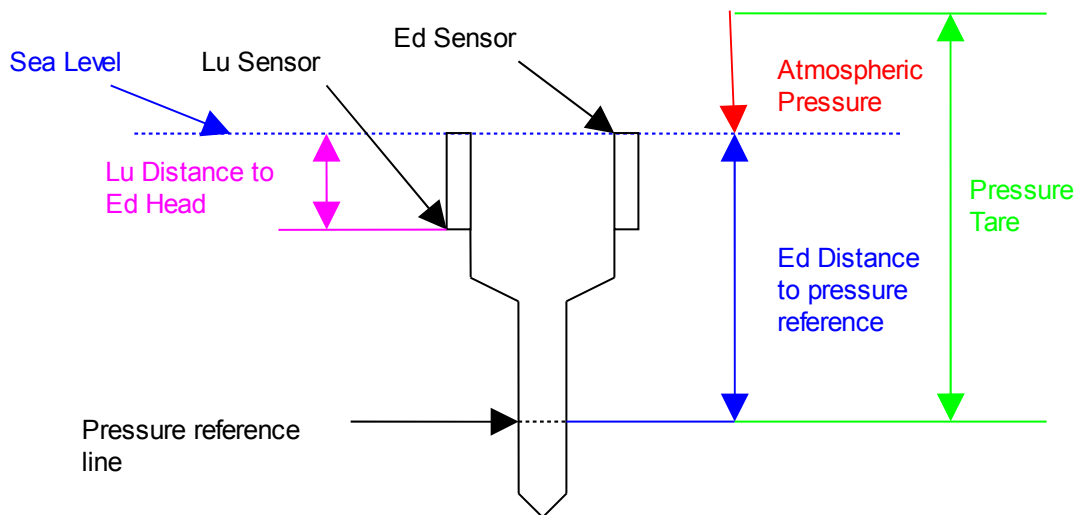
Note: Please refer to the illustrations provided in the appendix for the most common instrument configurations. Instrument configurations and distances may not be the same for your instrument. Always measure distances when creating an instrument context file for your instrument.

6.5.2.1 Distance to Surface

This is the physical distance between the sensor head and the top of the instrument for profilers, and the distance between the sensor head and the surface of the water, if immersed, for references. This positive value should always be specified for sensors located below the top of the instrument (i.e. Lu sensor, ECO Series IOP sensor, Ls sensor).

6.5.2.2 Distance to Pressure

This positive value is used only for profiler sensors to indicate the physical distance between the sensor head and the pressure reference line on the profiler and should only be given values when the **On Deck** method was used to obtain the pressure tare.
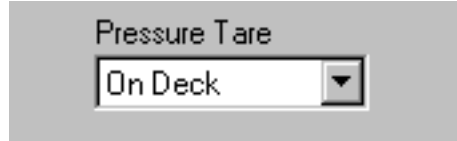
Pressure Tare Method

6.5.2.3 In Water Pressure Tare Method

Pressure tare is taken when the Ed sensor is located at the surface of the water. For this method the pressure tare then becomes a combination of the atmospheric pressure and the pressure of the water column from the surface (Ed head) to the pressure sensor reference line. The pressure value at Ed is calculated by subtracting the pressure tare value from the measured pressure values. The pressure value at Lu is calculated by subtracting the pressure tare value from the measured pressure values, as calculated for Ed, and then adding the distance between the Lu sensor head and the Ed sensor head. (i.e. Lu "Distance to Surface")

When using this pressure tare mode it is very important that you <u>do not</u> specify a value other then zero for 'Distance to Pressure' for any sensors.

Pressure Ed = Measured Pressure – Pressure Tare

Pressure Lu = Measured Pressure – Pressure Tare + Distance to Surface (Lu)

Example sensor distance values for "In Water" Method:

MicroPro (7 channel)	*Ed*	*Lu*
Distance To Surface	0.0	0.101346
Distance To Pressure	0.0	0.0

MicroPro (14 channel)	*Ed*	*Lu*
Distance To Surface	0.0	0.28575
Distance To Pressure	0.0	0.0

HyperPro II	*Ed*	*Lu*
Distance To Surface	0.0	0.315
Distance To Pressure	0.0	0.0

HyperPro II (surface mode)	*Ed*	*Lu*
Distance To Surface	0.200	0.200
Distance To Pressure	0.0	0.0

STOR-X Plus (2 x HyperPro)	Ed	Lu
Distance To Surface	0.0	0.021
Distance To Pressure	0.0	0.0

6.5.2.4 On Deck Pressure Tare Method

Pressure tare is taken when the profiler is located on deck. In this case the pressure tare is equal to the atmospheric pressure. The pressure tare value is then added to the distance from the Ed head to the pressure sensor reference line. For this reason it is crucial to specify a 'Distance to Pressure' for the Ed sensor in the instrument context utility.

Pressure Tare = Pressure Tare (Atmospheric Pressure) + Distance to Pressure (Ed)

Pressure Ed = Measured Pressure – Pressure Tare

Pressure Lu = Measured Pressure – Pressure Tare + Distance to Surface (Lu)

Example sensor distance values for "On Deck" Method:

MicroPro (7 channel)	Ed	Lu
Distance To Surface	0.0	0.100
Distance To Pressure	0.697	0.0

MicroPro (14 channel)	Ed	Lu
Distance To Surface	0.0	0.287
Distance To Pressure	0.796	0.0

HyperPro II	Ed	Lu
Distance To Surface	0.0	0.316
Distance To Pressure	0.786	0.0

HyperPro II (surface mode)	Eu (not recommended)	Lu
Distance To Surface	0.200	0.200
Distance To Pressure	0.470	0.0

STOR-X Plus (2 x HyperPro)	Ed	Lu
Distance To Surface	0.0	0.021
Distance To Pressure	0.079	0.0

6.6 Creating a New Instrument Context

When using ProSoft for the first time a warning message is given stating that no instrument context has been defined. **To create a new instrument context use the following steps:**

1. Click on 'New' in the ProSoft main menu.

2. ProSoft will ask the user to point to a directory containing all the calibration files (*.cal) or sip files (*.sip). **Note: The calibration files and instrument context file *.cfs should always remain together in the same directory.**

3. The instrument context utility will then display showing a list of all available calibration (*.cal) and tdf files (*.tdf) located in the directory selected in step 2.

4. Highlight all the calibration files in 'Available Calibration Files' needed for the instrument context and click on add '>>' to load the calibration files. For sip files this step is not necessary as the calibration files are automatically loaded.

5. Configure all calibration file and sensor parameters as necessary and click on 'Save As'.

6. The user is then prompted to enter an instrument context name. Once entered click on 'Ok'.

7. A dialogue box will then display confirming that the instrument context has been successfully created. Click on 'Ok' and ProSoft will load the instrument context just created.

Whenever the user exits the program, ProSoft remembers the last instrument context that was loaded and automatically reloads that context when starting ProSoft.

6.7 Configuring GPS

To include GPS data in processing, several *.tdf and *.sip files have been included in the ProSoft installation directory. Simply copy these files into the same directory as the *cal or *.sip files being used for the instrument processing. When the instrument calibration files are bundled into *.sip files then use the gps.sip file exclusively, or if using *.cal files for the instrument then use any of the *.tdf GPS files. More than one type of GPS *.tdf file may be included in the 'Loaded Calibration Files' column. Sensor dimensions are not required for GPS.

6.8 Instrument Context Examples

6.8.1 Hyperspectral Profiler/Reference (HyperPro)

The hyperspectral profiler/reference configuration is very common and usually contains a large number of calibration files (*.cal) and some tdf files (*.tdf). When working with hyperspectral instruments each optical sensor has two calibration files, one for shutterlight and the other for shutterdark frames.

Calibration File	Instrument Type	Immersion Coefficient	Measurement Mode	Frame Type
Hed117g.cal	Reference (Es)	Air	Surface	ShutterDark

Hpe116h.cal	Profiler (Ed)	Water	FreeFall	ShutterLight
Hpl118h.cal	Profiler (Lu)	Water	FreeFall	ShutterLight
Hse117g.cal	Reference (Es)	Air	Surface	ShutterLight
Mpr012b.cal*	Profiler (Anc)	Water	FreeFall	Anc
Ped116h.cal	Profiler (Ed)	Water	FreeFall	ShutterDark
Pld118h.cal	Profiler (Lu)	Water	FreeFall	ShutterDark
Bb2f-054.tdf	ECO Series IOP	Not Required	FreeFall	Not Required
Gprmc.tdf	Gps	Not Required	Not Required	Not Required

* The Mpr012b.cal file is an ancillary sensor attached to the profiler and is therefore given Profiler as instrument type and FreeFall as measurement mode. The FrameType is set as Anc to distinguish it from an optical sensor.

6.8.2 Hyperspectral Profiler Acting as Reference (Buoy Mode)

It is possible to add a floatation collar to the profiler sensors to have it remain at the surface collecting data and acting in buoy mode. Using the same calibration files when used as a profiler, each calibration file is set to Reference as instrument type.

It is important to note that if an Ed sensor is present and functioning as a reference instrument then it will be re-labeled as an Es sensor at level 2s data processing. Therefore it is important to <u>not include</u> the Ed calibration files. There must only be one source of Es sensor data, so the user should choose to use the Es sensor and exclude the calibration files for the Ed sensor by removing them from the 'Loaded Calibration Files'.

In the same way as above if an Lu sensor is present and functioning as a reference instrument then it will be re-labeled as an Ls sensor at level 2s data processing. There must only be one source of Ls sensor data, so the user must choose to use either the Lu or Ls sensor and exclude the calibration files for the one not in use.

Calibration File	Instrument Type	Immersion Coefficient	Measurement Mode	Frame Type
Hse117g.cal	Reference (Es)	Air	Surface	ShutterLight
Hpl118h.cal	Reference (Lu)	Water	Surface	ShutterLight
Mpr012b.cal	Reference (Anc)	Air	Surface	Anc
Hed117g.cal	Reference (Es)	Air	Surface	ShutterDark
Pld118h.cal	Reference (Lu)	Water	Surface	ShutterDark
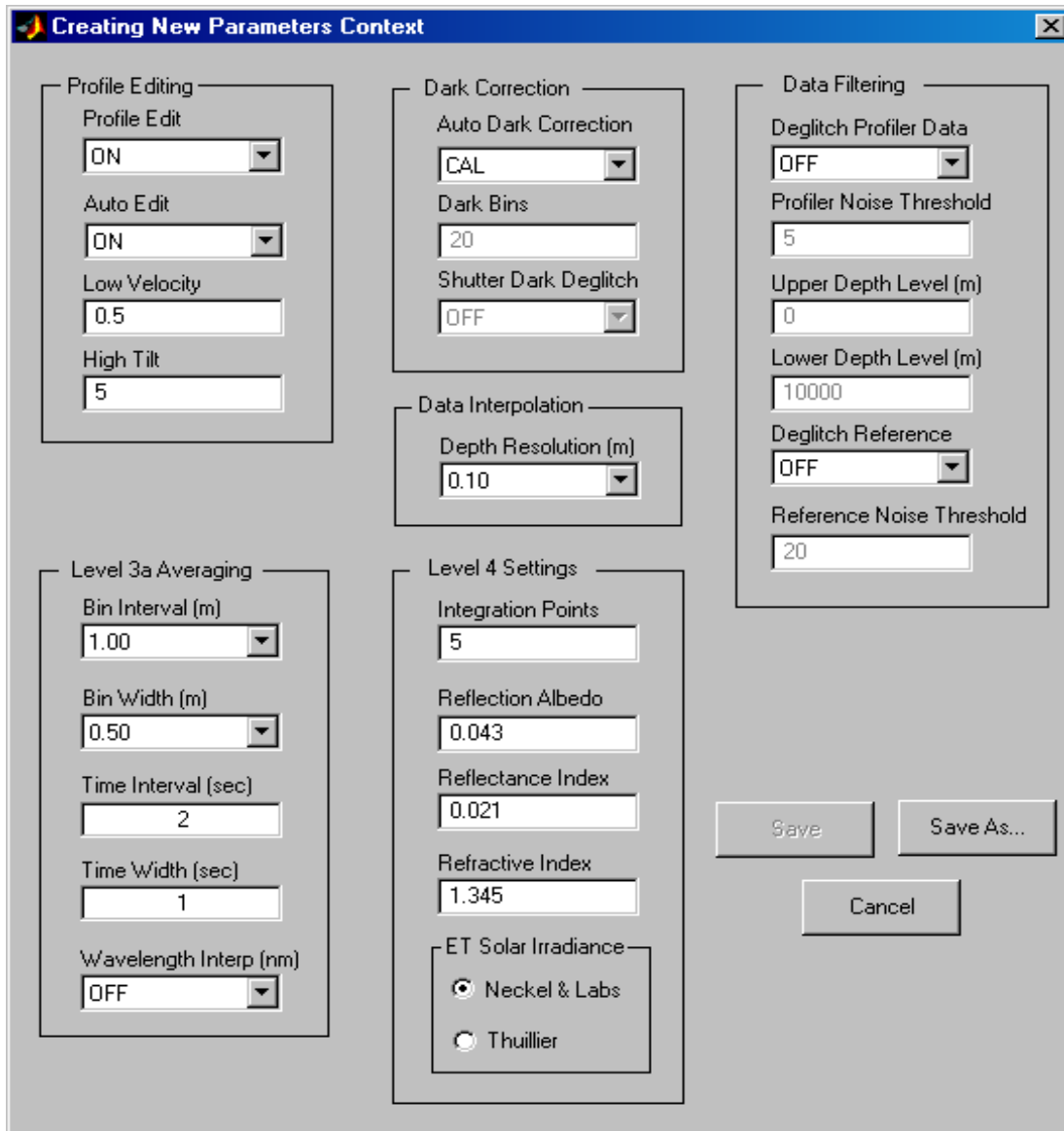
6.8.3 Multispectral Profiler/Reference (MicroPro)

Non-hyperspectral optical sensors usually use a LightAncCombined frame type. In many cases one calibration file will contain more than one optical sensor.

Calibration File	Instrument Type	Immersion Coefficient	Measurement Mode	Frame Type
DI7106a.cal	Reference (Es)	Air	Surface	LightAncCombined

DI7112a.cal	Profiler (Ed)	Water	FreeFall	LightAncCombined
DI7113a.cal	Profiler (Ed)	Water	FreeFall	LightAncCombined
DR7112a.cal	Profiler (Lu)	Water	FreeFall	LightAncCombined
DR7113a.cal	Profiler (Lu)	Water	FreeFall	LightAncCombined
Mpr049a.cal	Profiler (Anc)	Water	FreeFall	Anc

7. Parameters Context

Processing Parameters Utility

Near the top of the main menu is a section labeled 'Current Parameters'. Parameters context is defined as the parameters that are loaded into memory to be used for data processing. For example they determine what type of dark correction to apply or how many data points to use when averaging.

The user can easily switch between parameters contexts by clicking on the drop down box and selecting from the list of parameters contexts that have been defined by the user. When a parameters context is chosen the parameters file associated with the parameters context is automatically loaded and ready to process data.

A detailed listing of all the processing parameters are given in the tables below.

Dark Correction Parameters

Parameter Name	Parameter Values	Comments
Auto Dark Correction	CAL	Darks from cal file
	BIN	Darks from profile
	SHUTTER	Darks from shutter frames
Dark Bins	Positive Integer	Number of data points that are used to obtain bin darks from profile. Thus Dark Bins is used only if Auto Dark Correction is set to BIN.
Shutter Dark Deglitch	ON OFF	ON – First difference filter will be supplied to deglitch shutter dark frames of optical data.

Profile Editing Parameters

Parameter Name	Parameter Values	Comments
Profile Edit	ON OFF	Toggles profile edit mode on or off.
Auto Edit	ON OFF	Automated profiler data editing using tilts or falling velocity when Profile Edit is ON. ON – automatic editing OFF – interactive editing
Low Velocity	Positive integer	If profile edit and auto edit are turned ON, low velocity will be used for automatic editing only if tilt sensor is missing.
High Tilt	Positive integer	If profile edit and auto edit are turned ON, high tilt will be used for automatic profile editing.

Data Filtering Parameters

Parameter Name	Parameter Values	Comments
Deglitch Profiler Data	ON OFF	If ON, profiler data is deglitched using the value of Profiler Noise Threshold.
Profiler Noise Threshold	Positive Integer	Adjusts the sensitivity of profiler data deglitching.
Upper Depth Level	Positive Integer	Sets shallow depth level below which profiler data is deglitched.

Lower Depth Level	Positive Integer	Sets deep depth value above which profiler data is deglitched.
Deglitch Reference Data	ON OFF	If ON, reference data is deglitched using the value of Reference Noise Threshold.
Reference Noise Threshold	Positive Integer	Adjusts the sensitivity of reference data deglitching.

Data Interpolation Parameters

Parameter Name	Parameter Value	Comments
Depth Resolution	0.01m, 0.02m, 0.05m or 0.10m	Controls the depth resolution used for data integration at level 2s.

Level 3a Averaging Parameters

Parameter Name	Parameter Value	Comments
Bin Interval	The resolution based interval value ranges: 0.01m: 0.01m – 2.0m 0.02m: 0.02m – 2.0m 0.05m: 0.05m – 5.0m 0.10m: 0.10m – 10.0m	Controls the depth interval which is the center point for profiler averaging. The range of possible values is determined by the selected Depth Resolution.
Bin Width	The resolution based width value ranges: 0.01m: 0.0m – 2.0m 0.02m: 0.0m – 2.0m 0.05m: 0.0m – 5.0m 0.10m: 0.0m – 10.0m	Controls the number of data points used in averaging based on depth. The range of possible values is determined by the selected Depth Resolution.
Time Interval	Any 1 second interval (i.e. 1, 2, 10, 17 etc.)	Controls the time interval which is the center point for reference/SAS averaging.
Time Width	Any 1 second interval (i.e. 1, 2, 10, 17 etc.)	Controls the number of data points used in averaging based on time.
Wavelength Interpolation	OFF, 1, 2, 5, 10	Controls the interpolation interval when interpolating onto a constant wavelength. Only applicable for hyperspectral instruments.

Level 4 Settings

Parameter Name	Parameter Value	Comments
Integration Points	Must be an odd number (i.e. 1, 3, 5, 7 etc.)	Number of data points used to calculate K values.
Reflection Albedo	Default value of 0.043	Fresnel reflection albedo for irradiance from sun and sky.
Reflectance Index	Default value of 0.021	Fresnel reflectance index of seawater.
Refractive Index	Default value of 1.345	Fresnel refractive index of seawater.
ET Solar Irradiance	Neckel & Labs, Thuillier	Extra-terrestrial solar irradiance spectrum.

8. ASCII Data Extraction

The ASCII data extractor utility allows the user to convert any ProSoft HDF file into tab separated ASCII file format. This format can be used to import data into an excel spreadsheet or other program that can use ASCII tab delimited files.

To extract HDF files use the following procedure:

1. From the main menu click on menu 'Tools -> General Data Product'.

2. A folder selection dialogue will appear from which the user selects a folder with the HDF files to be extracted.

3. Next a list of all HDF files in the directory selected in step 2 will be displayed. The user can select as many HDF files as desired.

4. Click on 'Ok' to start the file extraction process.

All the extracted ASCII files will be place in a directory called 'Ascii Files'. This directory will be located in the same directory as the HDF files selected in step 2. If the 'Ascii Files' directory cannot be created then the ASCII files will be located in the same directory as the HDF files selected in steps 2 and 3.

ProSoft will write up to a maximum of 256 columns per row after which the data will wrap to the next section of rows. This ensures the ASCII file can be imported to excel without loss of data.

Included in the ASCII file is the HDF file header which includes metadata important for data interpretation.

9. MAT Data Extraction

The mat data extractor utility allows the user to convert any ProSoft HDF file into a Matlab structure which is saved into a Matlab binary file (*.mat). This format can be used to import the HDF data structure directly into a Matlab workspace for further analysis and manipulation.

To extract HDF files use the following procedure:

1. From the main menu click on menu 'Tools -> MAT Data Extractor'.

2. A folder selection dialogue will appear from which the user selects a folder with the HDF files to be extracted.

3. Next a list of all HDF files in the directory selected in step 2 will be displayed. The user can select as many HDF files as desired.

4. Click on 'Ok' to start the file extraction process.

All the extracted .mat files will be place in a directory called 'Mat Files'. This directory will be located in the same directory as the HDF files selected in step 2. A Mat file has the same file name as it's corresponding HDF file but with the .mat file extension.

To import the HDF data structure into the Matlab workspace use the 'load' command or simply double click on the *.mat file when viewed in the 'Current Directory'. The structure called 'hdfdata' will load into the Matlab workspace and is now available for analysis. The field names in the hdfdata structure are representative of the vdata table names in the HDF file.

10. HDF Data Viewer
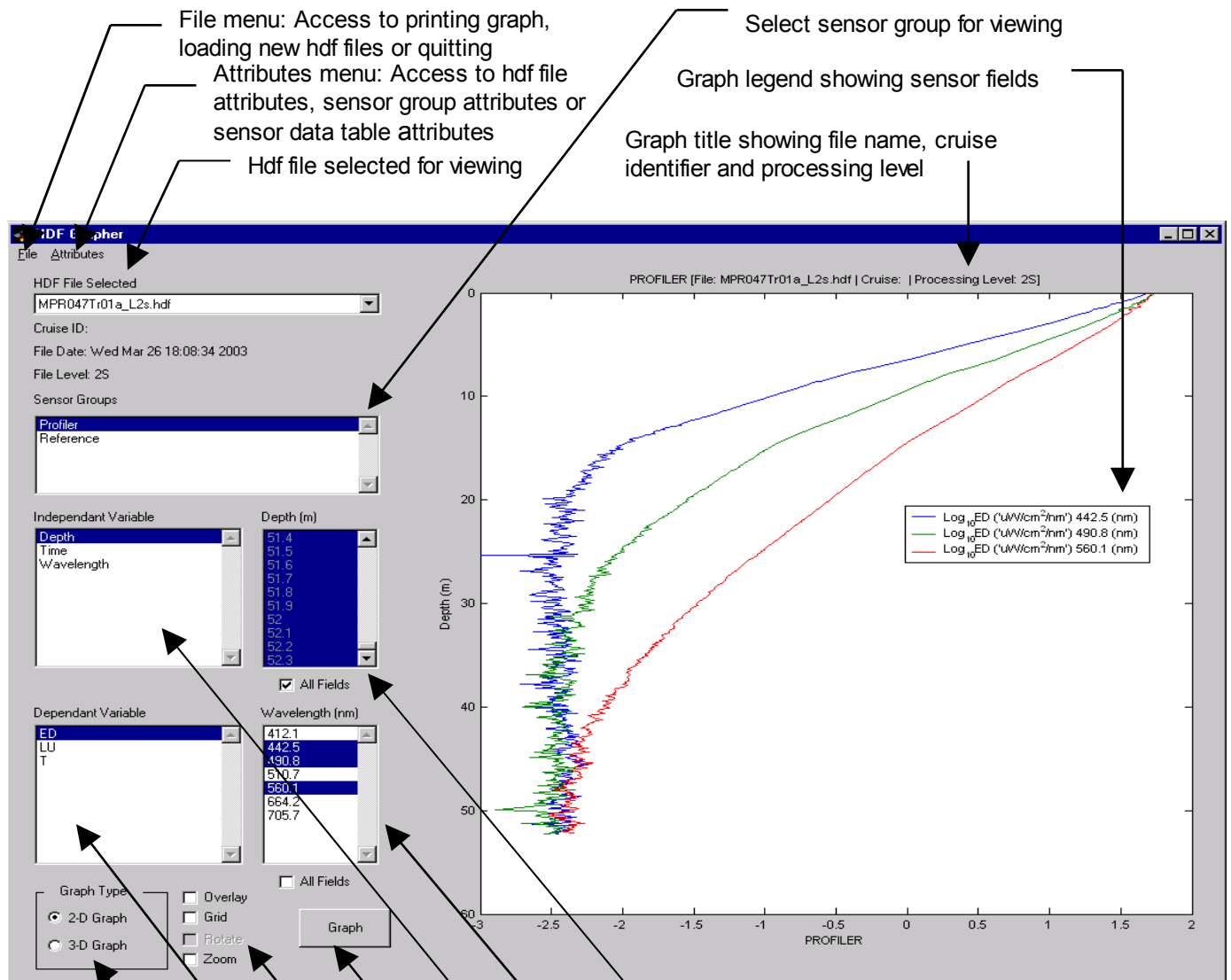
File menu: Access to printing graph, loading new hdf files or quitting

Attributes menu: Access to hdf file attributes, sensor group attributes or sensor data table attributes

Hdf file selected for viewing

Select sensor group for viewing

Graph legend showing sensor fields

Graph title showing file name, cruise identifier and processing level

Select range of independent variable

Select range of dependent variable

Select independent variable

Click to graph sensor fields

Graphing options All Fields, Grid, Rotate, Zoom

Select dependent variable

Select graph type, 2-D or 3-D

HDF Viewer

The HDF viewer enables the user to view ProSoft data in graphical format. To use the HDF viewer simply apply the following steps:

1. To start, from the main menu, select menu 'Tools -> HDF Viewer'.

2. The HDF Viewer utility will open but with no HDF files loaded. To load files select menu 'File -> Open'.

3. A folder selection dialogue box appears from which the user selects the folder containing HDF files for viewing.

4. Next a list of all HDF files in the directory selected in step 2 will be displayed. The user can select as many HDF files as desired then click on 'Ok'.

The HDF viewer controls are outlined as follows:

10.1 File Menu

10.1.1 Open

Loads a new set of HDF files for viewing.

10.1.2 Save As

Save the graph to a file using the png graphic format.

10.1.3 Print

Prints the graph currently displayed in the graph axes.

10.1.4 Exit

Exits the HDF viewer utility and returns to the ProSoft main menu.

10.2 Attributes Menu

10.2.1 HDF File

Select to view the HDF file attributes or metadata applicable to the entire HDF file such as cruise id, date, processing level etc.

10.2.2 Sensor Group

Select to view the attributes or metadata applicable to the selected sensor group such as instrument type, media, measurement mode etc.

10.2.3 Sensor Data Table

Select to view the attributes or metadata applicable to the selected sensor data table such as units for each sensor field.

10.3 HDF File Selected

This drop down box displays the current HDF file being viewed. All HDF files that were selected for viewing are listed in this drop down box. To switch files simply click on the drop down box and choose an HDF file.

10.4 Sensor Group

This control lists all the sensor groupings for the selected HDF file. Each sensor group corresponds to an instrument calibration file. Common sensor groups are Profiler, Reference, SAS, ECO Series IOP etc.

10.5 Independent/Dependant Variables

These controls list all the independent and dependent variables available for the chosen sensor group.

10.6 Graph Type

Use the graph type buttons to select which type of graph is required. Note: Certain sensor data tables are not available for viewing in 3-D. In this case the option for selecting 3-D will be grayed out and unavailable for selection.

10.7 Graphing Options

10.7.1 Overlay

When this option is selected any subsequent graphing will overlay each other. This useful for comparing data from different dependant variables.

10.7.2 Grid

When this option is selected a grid overlay will be drawn on the graph. This option is only available for 2-D graphs as it is always on by default for 3-D graphs.

10.7.3 Rotate

When this option is selected the user is able to hold down the left mouse button while over the graph and move the mouse to rotate the graph view. This option is only available for 3-D graphs.

10.7.4 Zoom

When this option is selected the user is able to zoom in or out of the graph. To zoom in left click the mouse button while over the graph and to zoom out right click the mouse button. To select a portion of the graph to zoom, left click and hold the mouse button while over the graph and drag the area selection box. When completed release the mouse button and the graph will zoom on the area selected. This option is only available for 2-D graphs.

10.7.5 Graph

When all the desired independent/dependant ranges are selected click on 'Graph' to draw the graph in the axes. When zooming or rotating a graph simply click on 'Graph' to return the graph to it's original view.

10.7.6 Legend

In 2-D graphing mode a legend is displayed on the axes showing the field color-coding scheme for the graph. The legend can be moved by left clicking and dragging the legend to a different location on the axes. Make sure the zoom option is turned off when moving the legend. In 3-D graphing mode a color contour legend is displayed outside the axes, relating color with z-axis value for easier viewing.

11. Data Processing Equations

Processing Levels Supported

	Profiler	Reference	SAS	TSRB	TACCS
1a	X	X	X	X	X
1b	X	X	X	X	X
2	X	X	X	X	X
2s	X	X	X	X	
3a	X	X	X	X	
4	X	X		X	

Note: Includes both multispectral and hyperspectral instruments

This section is intended to give an overview of the main steps of radiometric data $L(z, \lambda)$ processing carried out by ProSoft. It is assumed that the radiometric data has been collected using an optical instrument with a raw data format that is in compliance with Satlantic Log File Standard (SLFS).

ProSoft processing is segmented into 4 main levels:

Level 1 - Raw binary data file from an instrument. File extension is RAW.

Level 1a - Binary data is extracted from raw data under the control of the instrument (calibration and/or telemetry definition) files. Extracted information is grouped along with its calibration information and is placed into Level 1a HDF files. File nametag is _L1a.

Level 1b - Level1b data is calibrated. If selected, CAL, BIN or NULL dark correction is applied. File nametag is _L1b.

Level 2 - Includes Level 1b data, which is further modified per request (i.e. depending on settings of processing parameters and on instrument context). File nametag is _L2.

1. Reference and dark data deglitching is applied.

2. If selected, SHUTTER dark correction is applied.

3. If a profiler instrument exists, profile editing is performed.

Level 2s – Level 2 data is interpolated onto a common co-ordinates vector, which is either depth (Profiler) or time (Reference only or SAS). File nametag is _L2s.

Level 3a – Includes averaging of Level 2s data as defined by the processing parameters. File nametag is _L3a.

Level 4 – Includes higher level data products (users choice) calculated from level 3a data. This includes products such as normalized water leaving radiances, reflectance profiles, photosynthetically available radiation etc. File nametag is _L4.

11.1 Level 1a - Level 1b Data Processing

11.1.1 Application of Calibration Data to Level 1a Files

11.1.1.1 Optical Data Calibration

Standard optical sensor data formats are processed differently based on the capabilities of the various types of acquisition systems. These are referred to in Satlantic Instrument Files Standard (SIFS) as OPTIC1 (high-resolution gain switching 24 bit systems), OPTIC2 (standard 12, 16, 24 or 32 bit systems), and OPTIC3 (hyperspectral systems with adaptive integration). Application of the calibration data to all optical and ancillary sensors is carried out in accordance to the procedures detailed in SIFS for conversion from binary (or ASCII) digital counts into engineering units. In general, optical data is converted into engineering units in accordance to the calibration equation:

Equation 1 General Calibration Equation

$$L_{LightDat}(z,\lambda) = \left(L_{CountsLightDat}(z,\lambda) - L_{CalDarkDat}(\lambda)\right)\cdot a(\lambda)\cdot ic(\lambda)$$

where a is a calibration coefficient and ic is an immersion coefficient obtained from a calibration file. To simplify notation, in the following dependence on wavelength (λ) will be omitted. $L_{CalDarkDat}\cdot a\cdot ic$ is the dark current in engineering units that can be obtained from a calibration file or using one of the dark current correction (DCC) methods described below.

ProSoft currently implements DCC other than calibration dark or shutter dark only in OPTIC1 (high resolution 24 bit systems) fitting mode (see SIFS for detailed explanation of the fitting modes). Dark current can change under changing thermal conditions on these high-resolution systems. Dark current correction has to be adjusted accordingly. ProSoft provides the different DCC methods that will be described in the following sections.

It is important to note that DCC other than based on the calibration file (except hyperspectral) can only be used for the measurement frames obtained with gain switch 1 or higher in OPTIC1 fitting mode (in gain switch 0, or low gain, the CAL darks are used). In OPTIC1 fitting mode, ProSoft first analyses the measured frames according to the gain switches and applies the DCC according to the Dark Current Correction scheme selected by the user. In OPTIC2 fitting mode there are only two options available, CAL and NULL.

11.1.1.2 CAL darks

DCC method with calibration darks is given by the general calibration equation. This is the default mode for both OPTIC1 and OPTIC2 data types.

11.1.1.3 NULL darks

NULL dark is a special mode in which no darks are subtracted during data calibration (note that in the fitting mode OPTIC1, cal darks will be still subtracted for the frames with gain switch 0).

Equation 2 NULL Dark

$$L_{LightDat}(z,\lambda) = L_{CountsLightDat}(z,\lambda) \cdot a(\lambda) \cdot ic(\lambda)$$

11.1.1.4 BIN darks

If the profiler reaches a depth for which all the optical sensors reach their dark level, then the darks can be computed from the average of a number of samples at the bottom of the profile. For each wavelength λ, the value of DCC is obtained from a layer where average minimum light values $\min\left(\langle L_{LightDat}(z,\lambda)\rangle\right)$ are observed.

Equation 3 BIN Dark

$$L_{LightDat}(z,\lambda) = L_{LightDat}(z,\lambda) - \min\langle L_{LightDat}(z,\lambda)\rangle$$

$$z = z_{min},...,z_{max}$$

11.1.1.5 Dark Current Correction of hyperspectral (OPTIC3) Data

Usually hyperspectral data is dark corrected with the values obtained from shutter darks to obtain the most accurate correction. Shutter darks are continuously recorded during the measurements by occulting the input fiber with an optical shutter, typically after every five light samples. Hyperspectral calibration and subsequent DCC is carried out in the following steps:

1. Correct shutter dark counts obtained from a log file by dark offset (obtained as the difference between shutter darks and capped darks).

Equation 4 Hyperspectral Dark

$$L_{CountsDarkDat} = L_{CountsDarkDat} - L_{CountsDarkOffset}$$

2. Convert data counts into engineering units in accordance to the calibration equations. The calibration equations for optical hyperspectral data is:

Equation 5 Hyperspectral Data Calibration

$$L_{LightDat} = \left(L_{CountsLightDat} - L_{CalDarkDat}\right) \cdot a \cdot ic \frac{it_1}{it_2}$$

$$L_{DarkDat} = \left(L_{CountsDarkDat} - L_{CalDarkDat}\right) \cdot a \cdot ic \frac{it_1}{it_2}$$

where *a* is the calibration coefficient, *ic* is an immersion coefficient, it_1 is the integration time during calibration and it_2 is the integration time during the measurement. *a, ic* and it_1 are taken from a calibration file, it_2 is obtained from the same log file as optical data.

3. Deglitch dark data using a first difference filter (optional).

4. Interpolate shutter darks as a function of measurement time to match the number of dark and light data measurements.

5. Correct light data using shutter darks.

Equation 6 Hyperspectral Dark Correction

$$L = L_{LightDat} - L_{DarkDat}$$

Note: SAS Instrument

GPS UTC time that was presented at Level 1a in HHMM (hours, minutes) format is recalculated into seconds from the start of the current day. GPS date that was presented at Level 1a in DDMMYY (day, month, year) format is recalculated into days since start of the current year.

Note: Profiler
If one wants to use other than shutter dark (can be applied only to hyperspectral profiler) correction (e.g. NULL) then AUTODARK settings should be changed for all profiler sensor groups respectively i.e. one should change AUTODARK from SHUTTER to NULL in the profiler sensor group that contains Lu as well as in the profiler group that contains Ed. One will get wrong results if one group will have AUTODARK set to SHUTTER, and the other group to NULL. However, one could use any of CAL, BIN, or NULL dark corrections in any of the groups.

11.2 Level 1b – Level 2 Data Processing

All optical data sensors are checked for wavelength sequence. The columns of optical data are organized from left to right as a function of the increasing wavelength.

Optical data can be also deglitched if respective settings in processing parameters are set. As a rule the deglitching is not required. If selected, SHUTTER dark correction is applied.

11.2.1 Dark Data Deglitching

Optional deglitching module is applied to data to remove obvious glitches in dark data. First, a first difference operator is applied to the time series of N frames of optical data at each channel:

Equation 7 Dark Data Deglitching

$$dL_{\lambda}(i) = L_{\lambda}(i + 1) - dL_{\lambda}(i), i = 1,...,N - 1$$

Second, the standard deviation is calculated for each channel:

Equation 8 Standard Deviation

$$stdL(\lambda) = \sqrt{\frac{1}{N - 2} \sum_{i=1}^{N-1} \left(dL_{\lambda}(i) - \langle dL_{\lambda} \rangle \right)^2}$$

Third, any data which values are higher than $10 \, stdL(\lambda)$ is blanked by a blanking constant Nan.

11.2.2 Data Deglitching

This optional module can be toggled on/off using the processing parameters Deglitch Profiler Data and Deglitch Reference Data. For details on how it works see profiler/reference deglitching.

11.2.3   Profiler Data Level 1b - Level 2 Processing

Profiler data has a number of corrections and checks before the level 2 data files are created.   These include pressure tare (offset) correction, wavelength sequence check and profile editing that uses either tilt or velocity thresholds for quality control.

11.2.3.1   Pressure TARE Correction

Pressure sensors often have a small offset value that will change with atmospheric pressure. The offset is removed by a pressure tare. This value is stored in the header records by SatView when the data is collected. The pressure tare is defined as the pressure value that is measured when a profiler's Ed sensor is located just at the surface. This value has to be later subtracted from the measured pressure values of a profile. If the profiler measurements were logged with SatView, the pressure tare value is automatically inserted into the file header. If no information is obtained, pressure tare value is set to 0.

11.2.3.2   Profile Editing

Profiler measurements can be edited interactively or automatically removing any tilt contaminated records. In manual mode, a plot is shown with profiler tilts (if available) and profiler velocity as a function of depth. With the interactive graphical editor the user defines an upper z_{min} and lower depth z_{max} (we assume that z co-ordinate is directed downwards i.e. depth is z_{min} surface and z_{max} at the bottom of a profile). Data above z_{min} or below z_{max} will be removed. A tilt $Tilt(z)$ threshold $Tilt_{limit}$ (default is 5 degrees) usually is used for estimation of z_{min} and z_{max}. In a case of missing tilt sensor, the freefall velocity of the profiler can be used (zero or negative velocity is assumed to be high tilt). Automated editor module determines z_{min} and z_{max} in 10% of the upper and lower part of profiler measurements. The upper depth and the lower depth are defined as the first depth level (z) where the following conditions are met:

$$Tilt(z) < Tilt_{\lim it}$$
$$\min(z) \le z < 0.1\max(z) \quad \text{for top layer of the profile}$$
$$\left(\max(z) - 0.1\max(z)\right) < z \le \max(z) \quad \text{for bottom layer of the profile}$$

If a reference instrument is present, then the matching records in the reference data are also removed.

11.2.3.3   Reference Instrument

Reference data is checked before the level 2 data files are created.   These checks include wavelength sequence check and a spike deglitch.

11.3 Level 2 – Level 2s Processing

```
┌─────────────────────────────┐
│      Read Level 2 Data       │
└─────────────────────────────┘
               │
               ▼
┌─────────────────────────────┐
│  Calculate Master Co-ordinates │
└─────────────────────────────┘
       │                 │
       ▼                 ▼
┌──────────────┐   ┌──────────────┐
│ Calculate    │   │ Calculate    │
│ Pressure     │   │ Time         │
│ Co-ordinates │   │ Co-ordinates │
└──────────────┘   └──────────────┘
       │                 │
       └────────┬────────┘
                ▼
┌─────────────────────────────┐
│   Co-ordinate Interpolation  │
└─────────────────────────────┘
                │
                ▼
┌─────────────────────────────┐
│      Write Level 2s File     │
└─────────────────────────────┘
```
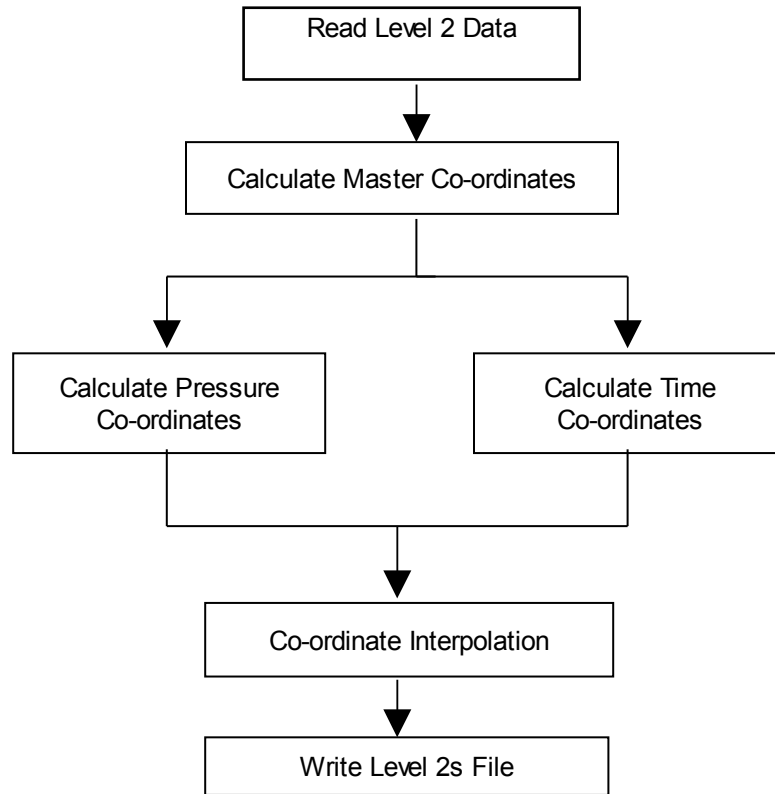
11.3.1 Read Level 2 Data

Data from the Level 2 HDF file is read and organized depending on the type of instrument (i.e. Satnet Hyperspectral Profiler/Reference).

11.3.2 Calculate Master Co-ordinates

At level 3a processing, the averaging of data is done within intervals based on a system of co-ordinates. For systems with a profiler the co-ordinates are based on pressure (averaging in depth). For systems with a reference only or SAS the co-ordinates are based on time (averaging in time).

11.3.2.1 Calculate Pressure Co-ordinates

There exists in most instruments a difference in distance between sensors. For example in an SPMR profiler the distance between the Ed sensor at the top and the Lu sensor at the bottom is approximately 1.412 m. This presents a problem when defining a pressure co-ordinate system that is common to all sensors that make up the instrument. When processing optical data, the data closest to the surface is usually of greater importance than data at the deepest of the profile. Therefore it makes sense to choose the sensor nearest the surface which in all profiler cases is the Ed sensor. The pressure values for the Ed sensor, hereafter referred to as master pressure, are then used to derive the pressure co-ordinates. It should be noted that if no Ed sensor is present then the Lu sensor pressure must be used instead.

The master pressure is then filtered to eliminate frames where pressure is not increasing.

Equation 9 Pressure Filtering

$$depth(n+1) - depth(n) \leq 0$$

The pressure co-ordinates are created by rounding up the first master pressure value to the nearest 0.1 m then increasing the pressure by intervals equal to the depth resolution until reaching the highest (deepest) master pressure value which is rounded down to the nearest 0.1 m. For example:

Master Pressure From Ed	Pressure Co-ordinates
2.2657	2.3
2.3727	2.4
3.0684	2.5
4.2028	2.6
4.7808	etc.
5.4015	6.3
5.8510	6.4
6.3326	6.5
6.6323	6.6

11.3.2.2 Calculate Time Co-ordinates

Almost all reference instruments have an Es sensor which ProSoft uses to calculate the time co-ordinate system. In the case of SAS instruments, an Lt sensor is always present which is used to calculate the time co-ordinate system. There are three possible ways to calculate the time values, hereafter referred to as master time, for each frame of the Es or Lt sensor. They are listed below in order of precedence:

1. If a timer sensor is part of the instrument, then this is the most accurate way to calculate the master time. The master time for the very first frame is taken as the first Timetag2 value if available else Time Stamp, the time at which logging data begins, is

used. The timer values give the elapsed time for each frame since the time of the first frame which is used to calculate the absolute time for each frame. Note that timers are available in Satnet systems as well as Hyperspectral systems.

2. If Timetag2 values were appended to the logged data then those values are used as the absolute time for each frame.

3. The absolute time for the first frame is taken as the Time Stamp. The rate for the sensor is then used to calculate the elapsed time for each frame which in turn is used to calculate the absolute time for each frame.

The time co-ordinates are created by taking the first master time value and then increasing it by an interval determined from the Es time data until reaching the last master time value. For SAS data the time interval is determined from the optical sensor operating at the fastest rate.

 For example: (interval = 0.100 sec)

Master Time from Es	Time Co-ordinates
17:57:41.167	17:57:41.167
17:57:41.333	17:57:41.267
17:57:41.500	17:57:41.367
17:57:41.667	17:57:41.467
17:57:41.833	etc.
17:57:42.000	17:57:42.167
17:57:42.167	17:57:42.267
17:57:42.333	17:57:42.367
17:57:42.500	17:57:42.467

11.3.3 Coordinate Interpolation

The data to be averaged is interpolated onto the master co-ordinates ensuring that all the data is mapped to a common co-ordinate system prior to averaging. The co-ordinates are based on either pressure or time. The interpolation method used for both Profiler and Reference instruments is 'linear' and for SAS instruments 'spline' is used.

11.3.4 Write Level 2s HDF File

The interpolated data is written to the corresponding level 2s HDF file.

11.4 Level 2s – Level 3a Processing

```
┌─────────────────────────────┐
│      Read Level 2s Data      │
└─────────────────────────────┘
               │
               ▼
┌─────────────────────────────┐
│    Wavelength Interpolation  │
└─────────────────────────────┘
               │
               ▼
┌─────────────────────────────┐
│     Natural Log Transform    │
└─────────────────────────────┘
               │
               ▼
┌─────────────────────────────┐
│         Average Data         │
└─────────────────────────────┘
               │
               ▼
┌─────────────────────────────┐
│      Write Level 3a File     │
└─────────────────────────────┘
```
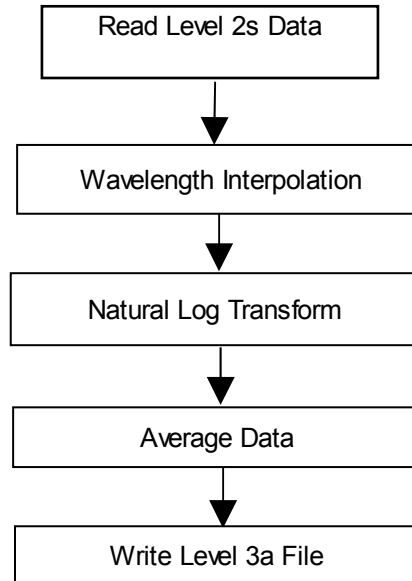
11.4.1 Read Level 2s Data

Data from the Level 2s HDF file is read and organized depending on the type of instrument (i.e. Satnet Hyperspectral Profiler/Reference).

11.4.2 Wavelength Interpolation

Profiler, Reference and SAS data can be interpolated onto a constant wavelength interval by setting the level 3 parameter Wavelength Interpolation to the desired interval. Wavelength interpolation should only be used for Hyperspectral instruments because Multispectral instruments have too few wavelength channels to provide an accurate interpolation. It is highly recommended to use wavelength interpolation for Hyperspectral profilers/references as it will help maximize the number of matching wavelengths for Level 4 processing.

Note: Hyperspectral data that includes interpolated wavelength sensor fields is limited to the HDF4 maximum field limit of 512. If this limit is exceeded the wavelength sensor fields will be reduced so that the total number of sensor fields is 512.

11.4.3 Natural Log Transform

Optical sensor data (Lu, Es etc.) are natural log transformed to "straighten" the data prior to averaging.

11.4.4 Average Data

The data is then averaged based on the level 3 parameters Bin Interval and Bin Width for pressure co-ordinates and Time Interval and Time Width for time co-ordinates. The Bin Interval or Time Interval determine the points at which to average with the Bin Width or Time Width determining the number of data points to use for averaging.

For example: BIN_INTERVAL = 0.5 m BIN_WIDTH = 0.3 m

11.4.5 Write Level 3a HDF File

The averaged data is written to the corresponding level 3a HDF file.

11.5 Level 4 Data Processing

When using the level 4 processing menu a dialog box allows the user to specify which level 4 products to include in the level 4 HDF file. Each option selected will be included as a separate sensor within the HDF file. The first two options, 'Diffuse Attenuation Coefficient' and 'Propagate Optical Variables to Surface' are sometimes needed to process other selections such as Water Leaving Radiance and will therefore be automatically selected when needed.

Notes On Wavelength Differences: When processing calculations that involve data from two different sources (e.g. comparing Lu and Ed sensors) the wavelengths from the two sources will never be exact (e.g. Lu 489.8nm and Ed 490.1nm), unless wavelength interpolation was selected at level 3a. Therefore ProSoft uses a matching tolerance between wavelengths in order for the channels to be used in the calculation. For example if Lu is 489.8nm and the closest Ed channel is 490.1nm (490.1 – 489.8 < tolerance) these two channels can be used together in a calculation. In Level 4 data presentation the wavelength shown is the mean value between the two wavelengths (e.g. 489.95nm from the above example). Tolerances are set as follows, multispectral 2 nm and hyperspectral 0.5 nm.

11.5.1 Diffuse Attenuation Coefficient

Overview: Under typical conditions for which incident lighting is provided by sun and sky, the various radiance and irradiance all decrease exponentially with depth, at least far enough below the surface (and far enough above the bottom in shallow water) to be free of boundary effects. This effect can be generally expressed as:

Equation 10 Diffuse Attenuation Coefficient

Ocean Optics Protocols for SeaWiFS eqn. 26 pg. 49

$$E_d(z,\lambda) = E_d(0^-,\lambda)e^{-\int_0^z k_d(z',\lambda)dz'}$$

$E_d(z,\lambda)$ - downwelling irradiance as a function of depth and wavelength.

$E_d(0^-,\lambda)$ - surface value of downwelling irradiance as a function of wavelength.

$e^{-\int_0^z k_d(z',\lambda)dz'}$ - effect of the diffuse attenuation coefficient as a function of depth and wavelength.

The traditional method of k analysis (Smith and Baker 1984 and 1986) is to estimate k(z) as the local slope of measured ln(Ed(z)) in an interval of a few meters centered on depth z_m.

Equation 11 Traditional Method of K Analysis

Ocean Optics Protocols for SeaWiFS eqn. 31 pg. 50

$$\ln(E_d(z)) \cong \ln(E_d(0^-)) - (z - z_m)k(z_m)$$

The slope k and the intercept Ed(0⁻) are calculated using a least squares regression fit of the data over the number of regression points selected.

p = polyfit(x, y, 1) MatLab function.

The degree of the resulting polynomial is one.

For the shallowest and deepest depths of a profile there is not enough data points to meet the required number of points for regression. In this case the k value is calculated by selecting the required number of points nearest to the depth upon which the k value is centered. For example if 1m is the shallowest depth then the k value for 1m is based on level 3a data taken from 1m to 3m, if Integration Points = 5, and the k value for 2m is based on level 3a data taken from 1m to 4m. Therefore k values at the shallow and deep sections of the profile are unreliable and are not used for Level 4 data calculations.

11.5.1.1 Integration Points

Integration points is the processing parameter that determines the number of data points to use for regression analysis. Only odd number values can be used (e.g. 3,5, 7 etc.) in order for depth z to be centered on the level 3a depth interval (e.g. 3m, 5m, 7m etc.).
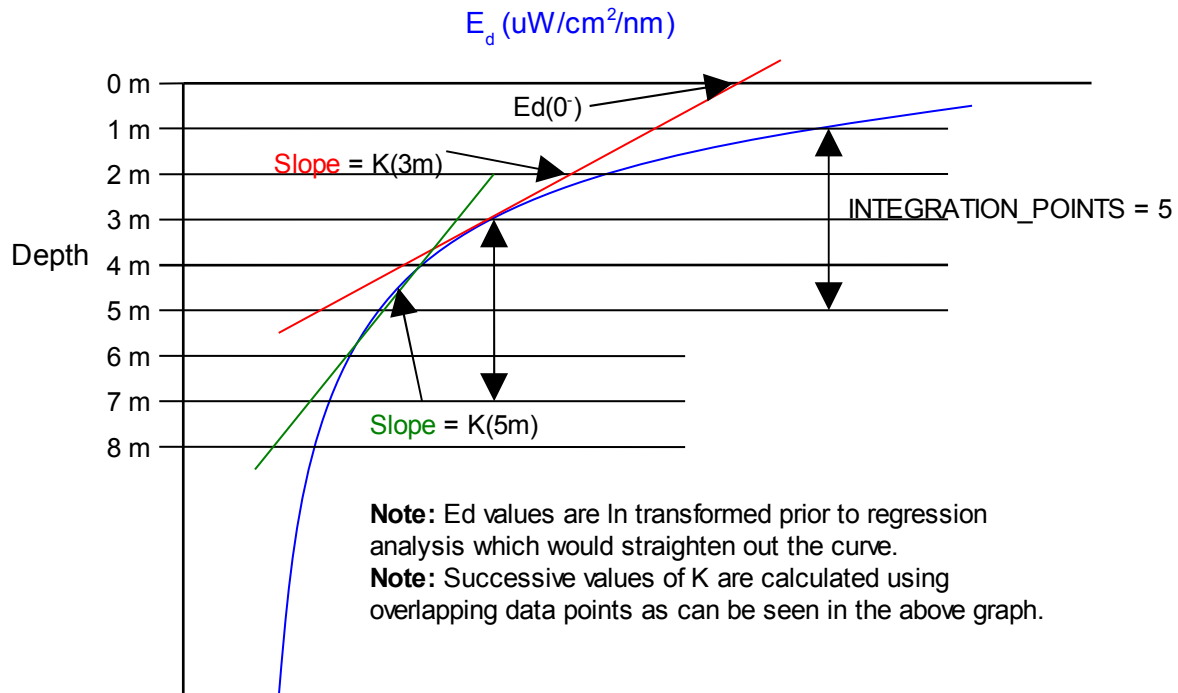
K Analysis

In cases where there is only a reference instrument and no profiler, therefore no K_Lu, K_Ed or K_Eu, to propagate Ls to surface, then K is estimated from a time series of upwelling radiance measured at a fixed depth below the surface. In this case ProSoft estimates the spectrum of K(λ) in three steps:

1. Following the Austin Petzold (1981) model, K is estimated at the wavelengths 443nm and 550nm.

Equation 12 Austin Petzold 490nm

$$K(490) = 0.0833 \left(\frac{Lu(443)}{Lu(550)} \right)^{-1.491} + 0.022$$

Equation 13 Austin Petzold 520nm

$$K(520) = 0.0663 \left(\frac{Lu(443)}{Lu(550)} \right)^{-1.398} + 0.044$$

These K values are used in step 2 to obtain the concentrations of pigments C at 490nm and 520nm.

2. Morel's (2001) empirical model for estimation of K is inverted to obtain the concentration of pigments (Chl a and Pheo):

Equation 14 Morel 2001

$$C = \left(\frac{K(\lambda) - K_w(\lambda)}{\chi_c} \right)^{\frac{1}{e(\lambda)}}$$

$K_w(\lambda)$ - diffuse attenuation coefficient of water. Obtained from file MOR2001KW.FIT

$\chi_c(\lambda)$ - coefficient determined empirically. Obtained from file MOR2001CHI.FIT

$e(\lambda)$ - coefficient determined empirically. Obtained from file MOR2001EPS.FIT

C is obtained as the average value of the two C's calculated at 490nm and 520nm and is used in step 3.

3. The spectrum of K(λ) is obtained using Morel's equation 9 (2001):

Equation 15 Morel 2001 Equation 9

$$Kap(\lambda) = K_w(\lambda) + \chi(\lambda) C^{e(\lambda)}$$

To calculate Kap within 700-800nm, ProSoft uses the following steps:

i. The values of $K_w(\lambda)$ within 700-800nm are obtained from Smith and Baker (1981) MOR2001KW.FIT.

ii. It is assumed that χ(λ) and e(λ) decrease linearly from the values given at χ(700) and e(700) to 0 and 800nm respectively.

iii. Using the above assumption and K_w within 700-800nm, $K(\lambda)$ can be estimated at λ = 700-800nm interval.

The K values calculated depend on the instrument configuration. Possible values are:

> K_Ed
>
> K_Lu
>
> K_Eu
>
> Kap_Ls – K is calculated using the Austin Petzold model

11.5.2 Propagate Optical Variables to Surface

The surface values of the profiler optical variables are obtained as the intercept of a least squares regression fit based on the shallowest depth centered on Z_m.

Equation 16 Surface Variables

Ocean Optics Protocols for SeaWiFS eqn. 31 pg. 50

$$\ln\left(E_d(z)\right) \cong \ln\left(E_d\left(0^-\right)\right) - \left(z - z_m\right)K\left(z_m\right)$$

The calculated intercept is a product of the diffuse attenuation coefficient (K_d) calculation. As a result, if optical variables are propagated to the surface, the K_d profile for each optical variable (Lu, Ed and Eu) will be calculated and included with the level 4 HDF file. In cases of shallow depths that do not meet the required number of points for regression, the surface variable is calculated based on the intercept of the k slope from the first depth value that has the required number of points. For example in k analysis the surface optical variable Ed(0-) will be calculated on the intercept of the slope based on the k value at 3m and not at 1m or 2m.

Possible values include:

> Profiler:
>
>> Ed(0⁻) calculated from K_Ed
>>
>> Lu(0⁻) calculated from K_Lu
>>
>> Eu(0⁻) calculated from K_Eu
>
> Reference:
>
>> Es(0⁻) if Es is measured above the surface then Es(0⁻) is calculated using:
>>
>> #### Equation 17 Es(0-)
>>
>> $$E_s\left(0^-\right) = \frac{E_s(\lambda)}{1 + \alpha}$$
>>
>> α – Fresnel reflection albedo for irradiance from sun and sky. Default value of 0.043 which can be changed as a level 4 parameter.
>>
>> Ls(0⁻) is calculated using one of the following (whichever one is available starting with the top):
>>
>> K_Lu

K_Ed

K_Eu

Kap_Ls – K is calculated using the Austin Petzold model

Example:

Equation 18 Ls(0-)

$$Ls(0^-,\lambda) = Ls \cdot e^{z \cdot k}$$

If both Eu(0-) and Lu(0-) have been calculated then the Q factor is also calculated.

Equation 19 Q(0-)

$$Q(0^-,\lambda) = \frac{E_u(0^-,\lambda)}{L_u(0^-,\lambda)}$$

11.5.2.1 Reflection Albedo

Processing parameter that sets the value for the Fresnel reflection albedo for irradiance from sun and sky. A default value of 0.043 is used and can be changed as a level 4 processing parameter.

11.5.3 Water Leaving Radiance

Normalized water leaving radiance is estimated with the following equation:

Equation 20 Normalized Water Leaving Radiance

Ocean Optics Protocols eqn. 63 pg. 54

$$L_{wn} = L_w(\lambda)\frac{F_o(\lambda)}{E_s(\lambda)}$$

$F_o(\lambda)$ – the mean extraterrestrial solar irradiance (Neckel and Labs 1984)

$E_s(\lambda)$ – downwelling spectral irradiance at $z(0^+)$

$L_w(0^+,\lambda)$ – upwelling radiance propagated through the surface $z(0^+)$ using:

Equation 21 Water Leaving Radiance

$$L_w(0^+,\lambda) = L_u(0^-,\lambda)\frac{1-\rho(\lambda,\theta)}{\eta_w^2(\lambda)}$$

$\rho(\lambda,\theta)$ – Fresnel reflectance index of seawater. Default value of 0.021 for seawater which can be changed as a level 4 global variable.

$\eta_w(\lambda)$ – Fresnel refractive index of seawater. Default value of 1.345 for seawater which can be changed as a level 4 global variable.

Es(λ) from water leaving radiance is usually obtained from an above water reference, but in cases where no reference data is available Ed(0⁻,λ), measured by a profiler, is used. Ed is extrapolated through the surface using:

Equation 22 Ed(0+)

$$E_d\left(0^+,\lambda\right) = E_d\left(0^-,\lambda\right)/\left(1-\alpha\right)$$

α – Fresnel reflection albedo for irradiance from sun and sky. Default value of 0.043 is used which can be changed as a level 4 processing parameter.

If Lu(0⁻,λ) from water leaving radiance is not available then Ls(0⁻,λ) is used instead. Ls(0⁻,λ) is calculated when propagating variables to the surface.

The values used for $F_o(\lambda)$ (Neckel and Labs) can be found in the file Solar10.dat.

11.5.3.1 Reflectance Index

Fresnel reflective index for seawater. A default value of 0.021 is used and can be changed as a level 4 processing parameter.

11.5.3.2 Refractive Index

Fresnel refractive index for seawater. A default value of 1.345 is used and can be changed as a level 4 processing parameter.

11.5.4 Surface Remote Sensing Reflectance's

Remote sensing reflectance's $R_L(0^+,\lambda)$ are calculated using:

Equation 23 Surface Remote Sensing Reflectance

$$R_L\left(0^+,\lambda\right) = \frac{L_W\left(0^+,\lambda\right)}{E_d\left(0^+,\lambda\right)}$$

Ed(0⁺,λ) – denotes downwelling spectral irradiance measured just above the surface (Es) or extrapolated through the surface Ed(0⁺). For Es the median of the time series data is taken for each wavelength.

Lw(0⁺,λ) – denotes upwelling spectral radiance propagated through the surface.

The remote sensing reflectance's calculations produce several possible combinations depending on the instrument configuration. Possible values include:

i. for Lu and Ed sensors Lu(0⁺,λ)/Ed(0⁺,λ)

ii. for Lu and Es sensors Lu(0⁺,λ)/Es(λ)

iii. for Ls and Es sensors Ls(0⁺,λ)/Es(λ)

Ed is extrapolated through the surface using:

Equation 24 Above Surface Ed(0+)

$$E_d\left(0^+,\lambda\right) = E_d\left(0^-,\lambda\right)/\left(1-\alpha\right)$$

α – Fresnel reflection albedo for irradiance from sun and sky. A default value of 0.043 is used and can be changed as a level 4 processing parameter.

Lw is calculated using:

Equation 25 Water Leaving Radiance

$$L_w\left(0^+,\lambda\right) = L_u\left(0^-,\lambda\right)\frac{1-\rho\left(\lambda,\theta\right)}{\eta_w^2\left(\lambda\right)}$$

ρ(λ,θ) - Fresnel reflectance index of seawater. Default value of 0.021 is used.

$\eta_w(\lambda)$ - Fresnel refractive index of seawater. Default value of 1.345 is used.

11.5.5 Remote Sensing Reflectance Profile

Remote sensing reflectance profile is calculated as the ratio of upwelling radiance to downwelling irradiance with changing depth. Only Lu is used for upwelling radiance and Ed for downwelling irradiance.

Equation 26 Remote Sensing Reflectance Profile

$$RSR = \frac{L_u\left(z,\lambda\right)}{E_d\left(z,\lambda\right)}$$

11.5.6 Surface Reflectance's

Surface reflectance is calculated as the ratio of upwelling irradiance just above the surface to downwelling irradiance just above the surface.

Upwelling irradiance can be derived from several sources depending on the instrument configuration and include Eu(0$^+$), Lu(0$^+$) converted to Eu(0$^+$), Ev(0$^+$) and Ls(0$^+$) converted to Ev(0$^+$).

Downwelling irradiance can be derived from several sources depending on instrument configuration and include Ed(0$^+$) and Es.

Equation 27 Surface Reflectance

$$RFL = \frac{Upwelling\_Irradiance\left(0^+,\lambda\right)}{Downwelling\_Irradiance\left(0^+,\lambda\right)}$$

The following sensor combinations are possible:

i. Eu and Ed sensors: Eu and Ed are propagated above the surface using

Equation 28 Above Surface Ed(0+)

$$E_d\left(0^+,\lambda\right) = E_d\left(0^-,\lambda\right)/\left(1-\alpha\right)$$

α – surface albedo (default = 0.043)

RFL = Eu(0$^+$,λ)/Ed(0$^+$,λ)

ii. Lu and Ed sensors: Lu is propagated above the surface and converted to Eu using:

Equation 29 Above Surface Eu(0+)

$$E_u\left(0^+,\lambda\right) = 4.5 \cdot L_u\left(0^-,\lambda\right)\frac{1-\rho\left(\lambda,\theta\right)}{\eta_w^{~2}\left(\lambda\right)}$$

ρ – reflective index (default = 0.021)

η_w – refractive index (default = 1.345)

RFL = Eu(0+,λ)/Ed(0+,λ)

iii. Lu and Es sensors: Lu is propagated above the surface and converted to Eu using equation Eu(0+,λ).

RFL = Eu(0+,λ)/Es(λ)

iv. Ev and Es sensors : Ev is propagated above the surface using equation Ed(0+,λ).

RFL = Ev(0+,λ)/Es(λ)

v. Ls and Es sensors: Ls is propagated above the surface and converted to Ev using equation Eu(0+,λ).

RFL = Ev(0+,λ)/Es(λ)

11.5.7 Reflectance Profile

The reflectance profile is calculated as the ratio of upwelling irradiance to downwelling irradiance. The most preferred method of calculation is to use upwelling irradiance Eu from the profiler and downwelling irradiance Ed, also from the profiler.

Equation 30 Reflectance Profile

$$RFL = \frac{E_u\left(z,\lambda\right)}{E_d\left(z,\lambda\right)}$$

11.5.8 Photosynthetically Available Radiation

Photosynthetically available radiation is a measure of the number of photons available for photosynthesis by chlorophyll. Units of PAR are expressed as quanta/cm^{2}s and is estimated using the following:

Equation 31 Photosynthetically Available Radiation

$$PAR = \int_{400nm}^{700nm} \frac{\lambda}{hc} E_d\left(\lambda\right)d\lambda$$

λ – wavelength

h – Planck's constant 6.625×10^{-34} Js

c – speed of light 3×10^8 m/s

Ed(λ) – downwelling spectral irradiance (μW/cm^2 /nm)

Prior to integration Ed(λ) is interpolated onto a constant 1nm interval and subject to the following rules:

if λ_1 > 400nm then Ed(400) = Ed(λ_1)

if λ_n < 700nm then Ed(700) = Ed(λ_n)

Included with the PAR data is the percentage of PAR for various depths. This ratio is calculated as:

Equation 32 Percentage PAR

$$\% PAR = \frac{PAR(z)}{PAR(0^+)}$$

The attenuation coefficient of PAR (K_PAR(0$^-$)) is also calculated near the surface using the same methods as described under the diffuse attenuation coefficient. This value is included in the data table attributes as K_PAR(0$^-$).

If reference Es data is available then PAR is calculated as:

Equation 33 Reference Par

$$PAR = \int\limits_{400nm}^{700nm} \frac{\lambda}{hc} E_s(\lambda) d\lambda$$

The median value of PAR is then calculated and included in the vdata table attributes and called Reference PAR.

11.5.9 Chlorophyll a Profile Estimates Morel 2001 Model

The estimation of chlorophyll a concentration (μg/l) in profile is estimated for each depth level given from the level 3a HDF file. The method used is as follows:

Equation 34 Morel 2001 Chlorophyll Model

$$C = \left(\frac{K(\lambda) - K_W(\lambda)}{\chi_C(\lambda)} \right)^{1/e(\lambda)}$$

χ_C, K_W and e(λ) are taken from the Morel 2001 model. These values can be seen in the files MOR2001CHI.DAT, MOR2001KW.DAT and MOR2001EPS.DAT located in the ProSoft installation directory.

The Morel 2001 model is derived from equation 9 pg. 10753 from:

"Optical Modeling of the Upper Ocean in Relation to Its Biogenous Matter Content"

Andre Morel

Journal of Geophysical Research Volume 93 No. C9, pg. 10749-10768

11.5.10   Chlorophyll a Surface Estimates SeaBAM OC2 Model

Chlorophyll a concentration is estimated at the water surface using the remote sensing reflectance values calculated previously.

Equation 35 Chlorophyll a Surface Estimate SeaBAM OC2 Model

$$C = 10^{\left(0.2974 - 2.2429R + 0.8358R^2 - 0.0077R^3\right)} - 0.0929$$

Equation 36 Calculation of R Coefficient

$$R = Log_{10}\left(Rrs490nm\middle/Rrs555nm\right)$$

The calculation of R coefficient uses the remote sensing reflectance values at 490nm and 555nm to calculate the value of R. Therefore several different calculations of Chlorophyll a are possible depending on how the remote sensing reflectance was calculated. The possible combinations are Lu(0+)/Es, Lu(0+)/Ed(0+) and Ls(0+)/Es.

The value of R is then used in to calculate the chlorophyll a concentration (μg/l) at the surface.

Equations for chlorophyll a surface estimate and calculation of R coefficient are derived from:

"Ocean Color Chlorophyll Algorithms for SeaWiFS"

O'Reilly et al.

Journal of Geophysical Research, Volume 103, No. C11, pg. 24937-24953

11.5.11   Chlorophyll a Surface Estimates Gordon 88 Model

Chlorophyll a concentration is estimated at the water surface using the normalized water leaving radiance's calculated previously.

Equation 37 Chlorophyll a Surface Estimate Gordon 88 Model

$$C = 1.15\left(Lwn443nm\middle/Lwn560nm\right)^{-1.42} \quad C \leq 1^{\mu g}\middle/_l$$

Equation 38 Chlorophyll a Surface Estimate Gordon 88 Model

$$C = 3.64\left(Lwn500nm\middle/Lwn560nm\right)^{-2.62} \quad C > 1^{\mu g}\middle/_l$$

The equations for Chlorophyll a surface estimate use normalized water leaving radiance's values at 443nm, 500nm and 560nm. Therefore several different calculations of chlorophyll a are possible depending on how the normalized water leaving radiance was calculated. The possible combinations are Lu(0+)/Ed(0+), Lu(0+)/Es and Ls(0+)/Es.

Equations for Chlorophyll a surface estimates are taken from:

"Ocean Color Remote Sensing Systems: Radiometric Requirements"

H. Gordon

Processing for Remote Sensing, pg. 151-167

11.5.12   Estimation of Energy Fluxes

Energy fluxes are estimated using the following equation:

Equation 39 Estimation of Energy Fluxes

$$F = 100 \int_{400}^{700} Ed(\lambda)d\lambda$$

ProSoft uses Matlab's trapezoidal numerical integration routine 'trapz.m' to perform the integration. Prior to integration, a minimum-maximum wavelength check is performed then the irradiance data is interpolated onto a constant 1nm interval. Since irradiance data is measured in units of $\mu Wcm^{-2}nm^{-1}$, a scaling factor of 100 is used to convert from cm^{-2} to m^{-2}.

11.5.13 Backscattering Coefficients

Backscattering values are derived from an ECO Series IOP instrument which contains a scattering meter to measure backscattering at 117 degrees within a volume of water.

$\beta(117°,\lambda)$ Values represent total volume scattering as measured by the instrument. To obtain the volume scattering of particles only, subtract the volume scattering of water, $\beta_w(117°,\lambda)$ from the total volume scattering:

Equation 40 Volume Scattering of Particles

$$\beta_p(117°,\lambda) = \beta(117°,\lambda) - \beta_w(117°,\lambda)$$

$\beta_w(117°,\lambda)$ is obtained from (from Morel 1974):

Equation 41 Volume Scattering of Water

$$\beta_w(\theta,\lambda) = 1.38(\lambda/500nm)^{-4.32}(1+0.3S/37)10^{-4}\left(1+\cos^2\theta\left(1-\delta\right)/(1+\delta)\right)m^{-1}sr^{-1}$$

$\delta = 0.09$

S = Salinity obtained from water properties

Particulate backscattering coefficients, $b_{bp}(\lambda)$ with units of m^{-1}, can be determined through an estimation from the single measurement of $\beta_p(117°,\lambda)$ using an X factor. This factor estimates b_{bp} with an estimated uncertainty of 4%.

Equation 42 Particulate Backscattering Coefficient

$$b_{bp} = 2\pi X\beta_p(117°)$$

X = 1.1 (Boss, E, and S. Pegau, 2001. The relationship of scattering in an angle in the back direction to the backscattering coefficient, *Applied Optics*)

Water backscattering coefficients, b_w with units of m^{-1} can be determined by either of the following two equations:

Equation 43 Backscattering Coefficient Pure Water

$$b_w(\lambda) = 0.0022533(\lambda/500nm)^{-4.23}$$

Equation 44 Backscattering Coefficient Sea Water

$$b_{sw}(\lambda) = 0.0029308(\lambda/500nm)^{-4.24}$$

To compute the total backscattering coefficients, $b_b(\lambda)$ with units of m^{-1}, the backscattering from pure water, $b_{bw}(\lambda)$ needs to be added to $b_{bp}(\lambda)$:

Equation 45 Total Backscattering Coefficient

$$b_b(\lambda) = b_{bp}(\lambda) + b_{bw}(\lambda)$$

$$b_{bw}(\lambda) = b_w(\lambda)/2 \text{ or } b_{sw}(\lambda)/2$$

12. Appendix A: Term Definitions

12.1 File Naming Convention

HDF File – ProSoft input or output data file where meta-information and data have been organized using Hierarchical Data Format following the principles of data organization and processing.

Instrument File – A calibration (*.cal) file or a telemetry definition file (*.tdf) (for details see Satlantic Instrument File Standard).

File Nametag – Last letters or numbers which follow underscore ('_') in a file name.

Level 1 – Binary logged data file with the RAW extension.

Level 1a – Binary data is extracted from RAW data under the control of the instrument (calibration) files. Extracted information is grouped along with its calibration information and placed into Level 1a HDF files. File nametag is _L1a.

Level 1b – Level 1a data is calibrated. If selected, CAL, BIN or NULL dark correction is applied. File nametag is _L1b.

Level 2 – Includes Level 1b data, which is further modified per request basis. File nametag is _L2.

1. Reference and dark data deglitching is applied.
2. If selected, SHUTTER dark correction is applied.
3. If a profiler instrument exists, profile editing is performed.

Level 2s – Level 2 data is interpolated onto a common co-ordinate vector, which is either depth (Profiler) or time (Reference only or SAS). File nametag is _L2s.

Level 3a – Averages level 2s data as defined by level 3 processing parameters

Level 4 – Data products produced from level 3a data.

12.2 Optical Sensors

Ed - Profiler downwelling plane irradiance

Lu - Profiler upwelling radiance

Eu - Profiler upwelling plane irradiance

Ld - Profiler downwelling radiance (special applications only)

Es - Reference downwelling plane irradiance

Ls - Reference upwelling radiance

Ev - Reference upwelling plane irradiance

Ef - Reference downwelling plane diffuse irradiance (special applications only)
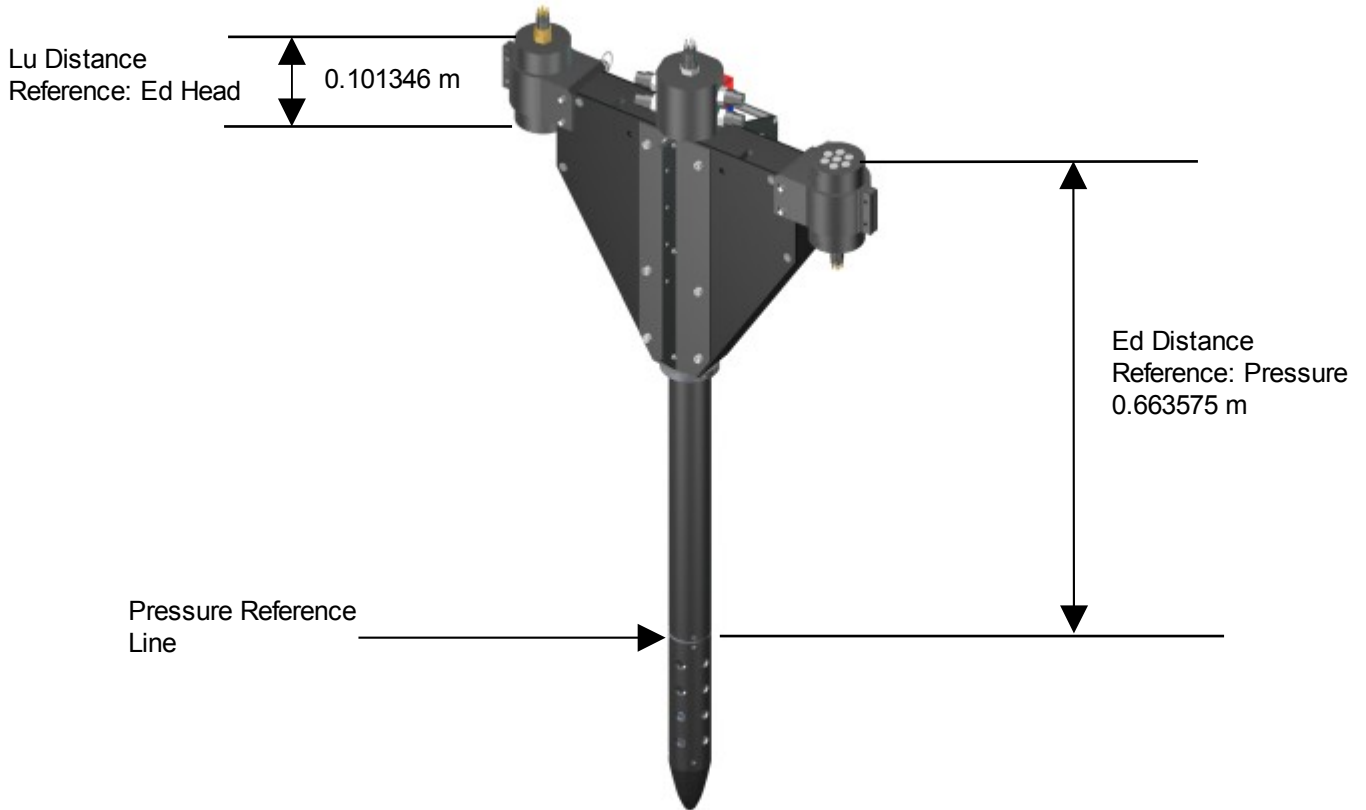
Li - SAS sky radiance

Lt – SAS water leaving radiance

Units: Irradiance - $\mu W/cm^2/nm$

Radiance - $\mu W/cm^2/nm/sr$
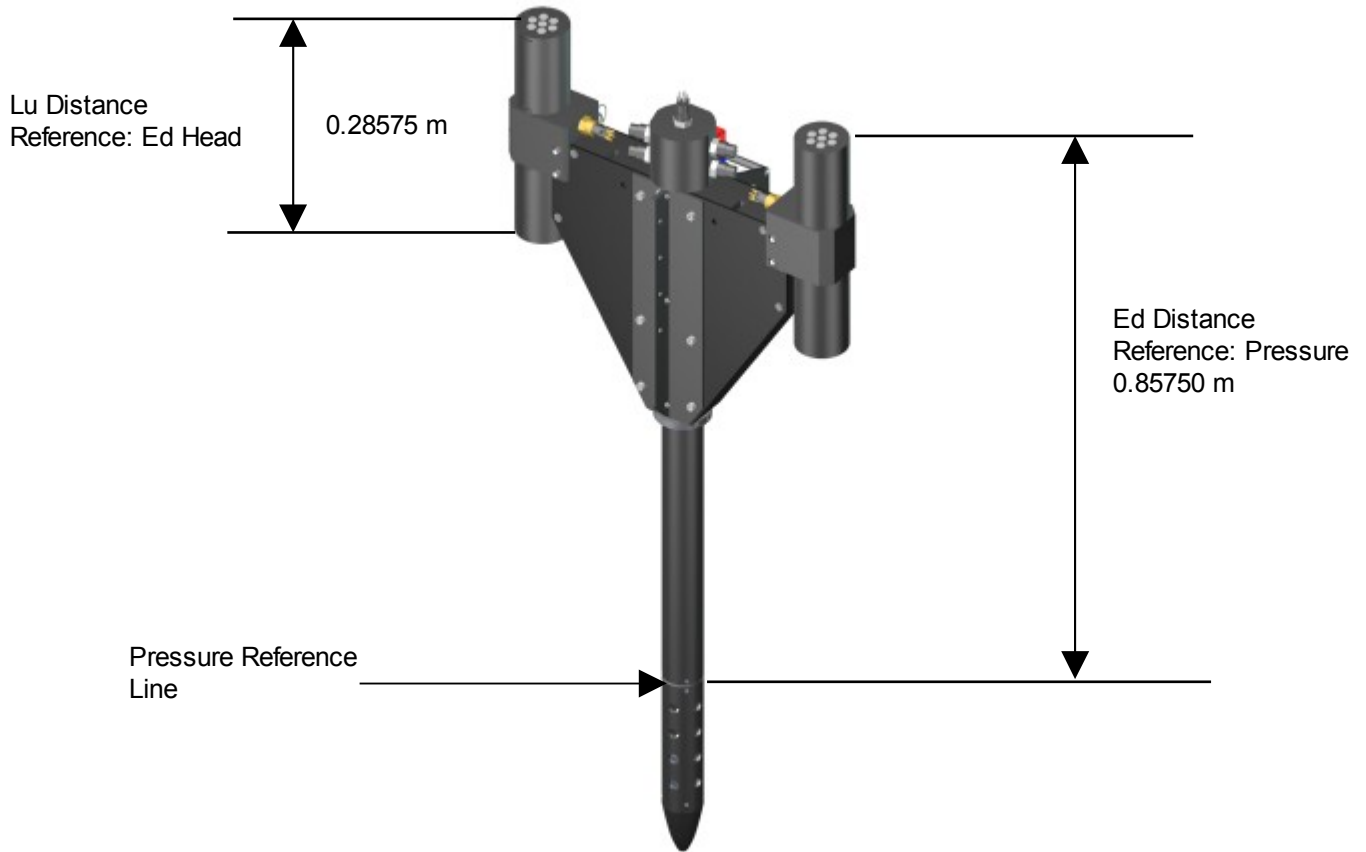
12.3 Ancillary Sensors

Tw   - External water temperature (^{o}C)

Ti   - Internal irradiance sensor array temperature (^{o}C)

Tr   - Internal radiance sensor array temperature (^{o}C)

Pres   - Profiler depth (m)

TiltX - Sensor tilt on X axis (deg)

TiltY - Sensor tilt on Y axis (deg)

Rtilt - Reference tilt about vertical axis (deg)

Ptilt - Profiler tilt about vertical axis (deg)

Pitch - Sensor tilt along horizontal axis (deg)

Roll   - Sensor tilt about horizontal axis (deg)

Cond   - Seawater conductivity (mmho/cm)

Fluor - Fluorometer (μg/l)

Trans - Transmissometer (/m)

Comp   - Flux gate compass (deg)

Altim - Altimeter (distance from bottom) (m)

PAR   - PAR sensor (μE/m^2)

Time   - system time (decimal hours)

Vel   - profiler descent velocity (m/sec)

Frame - Instrument frame counter (0..255)

LuDark - Profiler radiance dark detector OCR-1000 only (counts)

EdDark - Profiler irradiance dark detector OCI-1000 only (counts)

EsDark - Reference irradiance dark detector OCI-1000 only (counts)

LsDark - Reference radiance dark detector OCR-1000 only (counts)

13. Appendix B: Instrument Sensor Distances

Lu Distance
Reference: Ed Head

0.101346 m

Ed Distance
Reference: Pressure
0.663575 m

Pressure Reference
Line

MicroPro (7 channel) Sensor Distances

Lu Distance
Reference: Ed Head

0.28575 m

Ed Distance
Reference: Pressure
0.85750 m

Pressure Reference
Line

MicroPro (14 channel) Sensor Distances

Lu Distance
Reference: Ed Head

0.315 m

Ed Distance
Reference: Pressure
0.868 m

Pressure Reference
Line
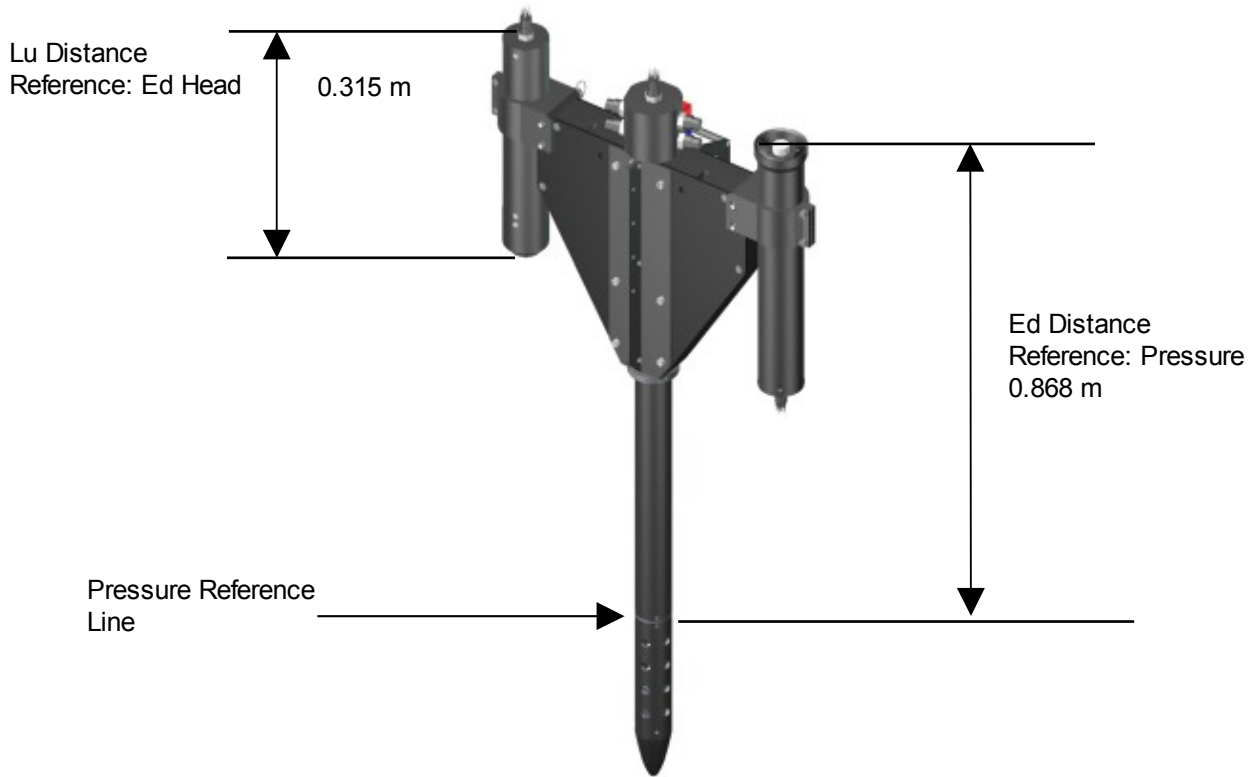
HyperPro II Sensor Distances
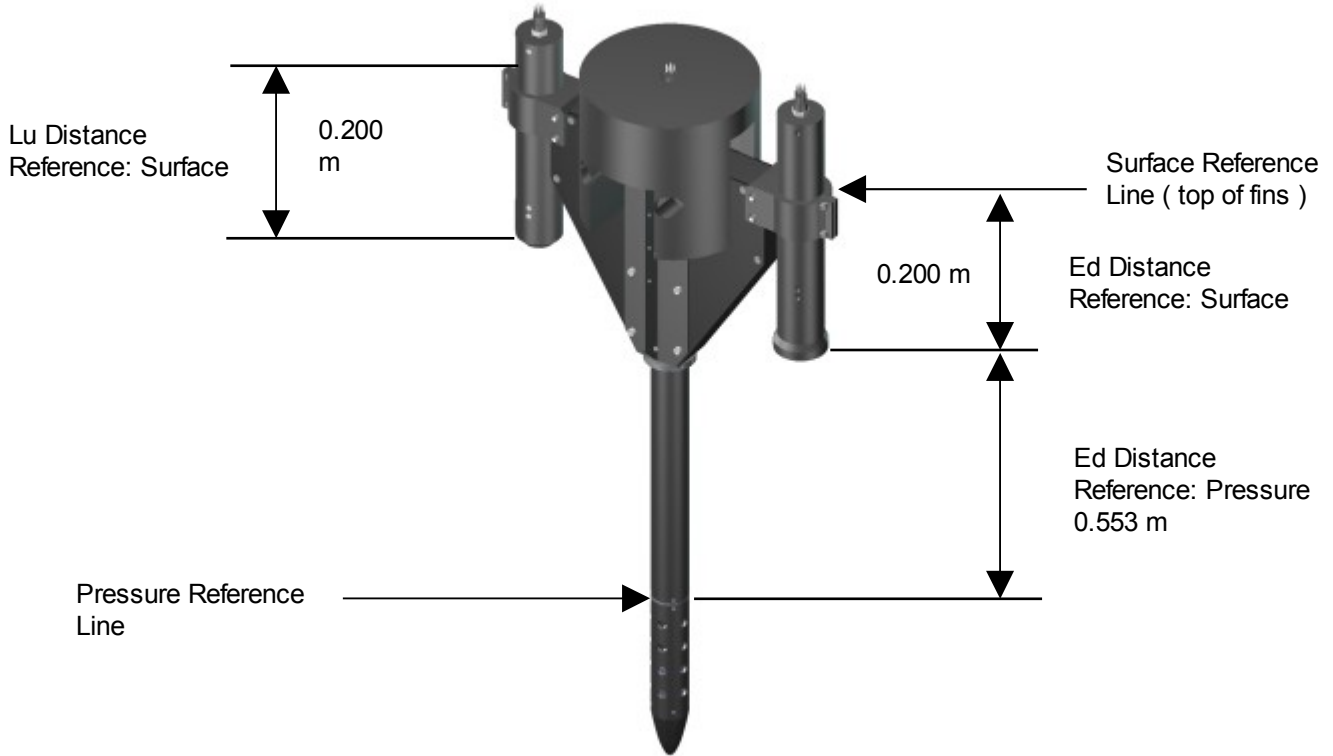
HyperPro II (surface mode) Sensor Dimensions

Ed Distance
Reference: Pressure
0.079 m

Pressure Reference
Point

Lu Distance
Reference: Ed Head
0.021m
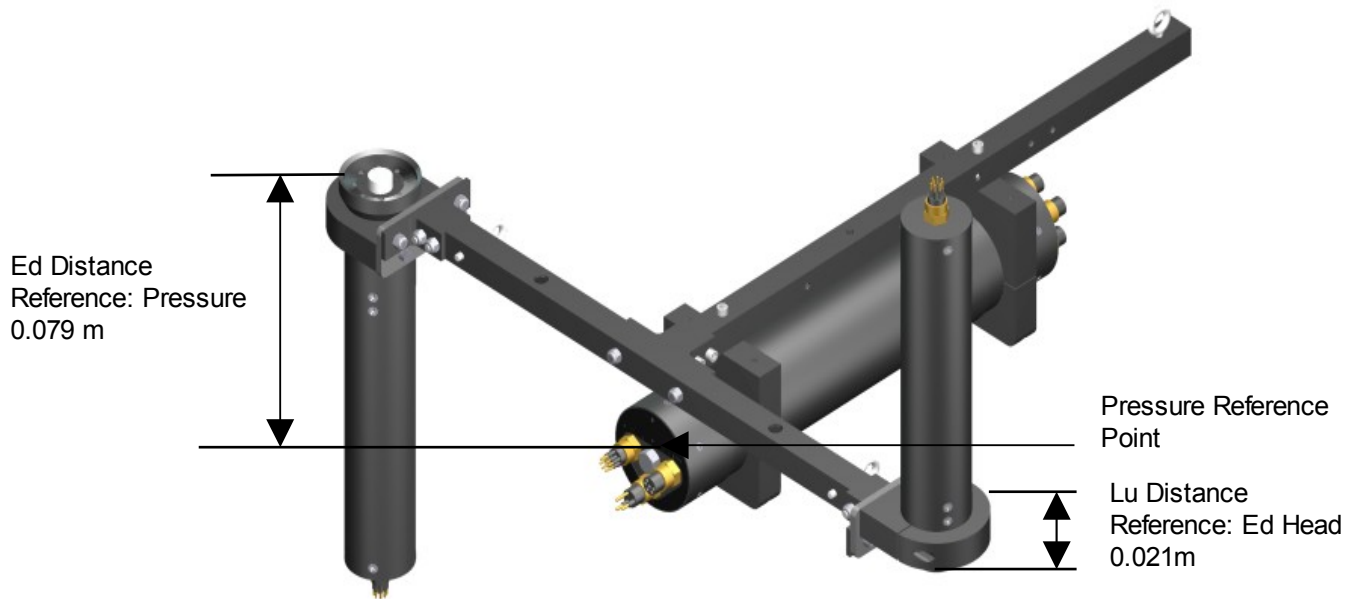
STOR-X Plus (2 x HyperPro) Sensor Distances

14. Appendix C: Data Formats

Table 1 File Header

File Header	Units	Description
PROSOFT	None	ProSoft software version used in analysis
CRUISE-ID	None	Identifies the cruise on which the current series of log files is taken.
OPERATOR	None	Identifies the operator of the data acquisition software for the current log file.
LATITUDE	Decimal Degrees	Identifies the latitude coordinates of the instrument for the current log file.
LONGITUDE	Decimal Degrees	Identifies the longitude coordinates of the instrument for the current log file.
ZONE	None	Identifies the data acquisition time zone of the current log.
COMMENT	None	Comment field for ancillary sky and sea observations
STATION-ID	None	Identifies the station for the current series of log files.
CAST	None	Identifies the current log file in a series of related log files.
TIME-STAMP	None	Identifies the time on the data acquisition computer as of the beginning of the current log file.
MODE	None	Identifies the data acquisition software mode.
PRESSURE-TARE	Meters (m)	Pressure tare taken at the surface for current log file.
TIMETAG	None	Obsolete.
DATETAG	(YYYYDDD)	Switch to include date/time tagging.
TIMETAG2	(HHMMSSsss)	Switch to include timetag2 tagging.
PROFILER	None	Identifies the status of the profiler instrument.
REFERENCE	None	Identifies the status of the reference instrument.
PRO-DARK	None	Profiler dark correction method.
REF-DARK	None	Reference dark correction method.
PRO-ID	None	This field is the identifier for the profiler.
PROCESSING_LEVEL	None	Identifies the processing level of the current file.

FILE_CREATION_TIME	None	Date of file creation.
DEGLITCH_PRODAT	None	Switch to include deglitching of profiler data.
DEGLITCH_REFDAT	None	Switch to include deglitching of reference data.
PRESS_TARE_CORRECTION	Meters (m)	Pressure tare value applied to current log file.
DEPTH_RESOLUTION	Meters (m)	Depth resolution used for Level 2s data interpolation.
BIN_INTERVAL	Meters (m)	Level 3a variable that determines which depth interval to average.
BIN_WIDTH	Meters (m)	Level 3a variable that determines depth range within which to average.
TIME_INTERVAL	Seconds	Level 3a variable that determines which time interval to average.
TIME_WIDTH	Seconds	Level 3a variable that determines the time range within which to average.
WAVEL_INTERP	(nm)	Level 4 variable that determines wavelength interpolation interval.
INTEGRATION_POINTS	None	Level 4 variable that determines number of data points to use for regression analysis.
REFLECTION_ALBEDO	None	Reflection albedo value used in level 4 processing.
REFLECTANCE_INDEX	None	Reflectance index value used in level 4 processing.
REFRACTIVE_INDEX	None	Refractive index value used in level 4 processing.

Table 2 Level 1-2 Table Descriptors

Table Label	Units	Description
PRES	Meters (m)	Used to define a pressure sensor measurement. Pressure measurements are usually used with submersible instruments to gauge their depth.
ALTIM	Meters (m)	Used to define an altimeter sensor measurement. Altimeter measurement is normally used to gauge the distance from a submersible instrument to the ocean floor.
FRAMECOUNTER	None	The value of a frame counter is simply a numerical counter that can help ensure all frames received are sequential.
CHECKSUM	None	The value of the check sum is the last byte of the sum of all bytes, up to but not including the check sum sensor, in a frame of telemetry subtracted from 0.

INTTIME	Seconds	Defines the adaptive or adjusted integration time for all subsequent optical sensors for which the sensor was defined.
DARK	None	Some optical sensors are shielded from light exposure to establish a dark noise floor for a related optical sensor grouping.
DARK_SAMP	None	Indicates the number of dark sensors used to calculate a dark average.
DARK_AVE	None	Defines the actual average dark value.
T	Degrees Celsius (°C)	Used to define a temperature sensor measurement. Temperature sensors can be placed anywhere on an instrument.
TILT	Degrees	Used to define a tilt or attitude measurement for an instrument. A tilt measurement is normally used to determine the alignment of an instrument with the vertical.
PITCH	Degrees	Used to define a tilt sensor along the horizontal axis. A pitch sensor can be used to determine an instruments orientation relative to the horizon.
ROLL	Degrees	Used to define a tilt sensor about the horizontal axis. A roll sensor can be used to determine an instruments orientation relative to the horizon.
COMP	Degrees	Used to define a flux gate compass sensor measurement. These sensors measure magnetic flux to establish a compass direction.
COND	(mmho/cm)	Used to define a seawater conductivity sensor measurement. A conductivity measurement is necessary for calculation of salinity.
FLUOR	(μg/l)	Used to define a Fluorometer sensor measurement.
TRANS	(/m)	Used to define a Transmissometer sensor measurement. A Transmissometer measurement indicates the attenuation of a light beam in a given media.
PAR	(μE/m^2)	Used to define a sensor for measuring photosynthetically active radiation. PAR measurements indicate the total light energy available for photosynthesis per unit area.
TIMER	Seconds	Used to define a timer sensor for indicating the number of seconds that have elapsed since the instrument was powered up.

Table 3 GPS Table Descriptors

Table Label	Units	Description
UTCPOS	None	Used to define the Universal Coordinated Time of the GPS frames
LATPOS	Degrees	Used to define the latitude coordinates of the GPS frames.

LONPOS	Degrees	Used to define the longitude coordinates of the GPS frames.
LATHEMI	None	Used to define the hemisphere of the associated latitude coordinates.
LONHEMI	None	Used to define the hemisphere of the associated longitude coordinates.
SPEED	Knots	Used to define the ground speed of the GPS frames.
COURSE	Degrees	Used to define the course over the ground in degrees true.
MAGVAR	Degrees	Used to define the magnitude of the magnetic variation to be used between true and magnetic degrees.
DATE	None	Used to define the date of the GPS measurements (ddmmyy)
MODE	None	Used to define the position system mode for the GPS sensor (i.e. A = Autonomous, D = Differential)

Table 4 Level 4 Table Descriptors

Table Label	Units	Description
K_Lu , K_Ed, K_Eu	(/m)	K values
Lu(0-), Ed(0-), Eu(0-), Es(0-)	(μw/cm^2/nm) or (μw/cm^2/nm/sr)	Surface optical data
Q(0-)	(sr)	Q Factor
Lw-Lu(0+), Lw-Ls(0+)	(μw/cm^2/nm/sr)	Water leaving radiance.
Lwn-Lu(0+)/Ed(0+), Lwn-Lu(0+)/Es, Lwn-Ls(0+)/Es	(μw/cm^2/nm)	Normalized water leaving radiance.
RSR-Lu(0+)/Ed(0+), RSR-Lu(0+)/Es, RSR-Ls(0+)/Es	(/sr)	Surface remote sensing reflectance.
RSR-(Lu/Ed)	(/sr)	Remote sensing reflectance profiles.
RFL-Eu(0+)/Ed(0+), RFL-Eu(0+)/Es	(/sr)	Surface reflectance's.
Profiler Par	(μMol/m^2/s)	Photosynthetically available radiation
Morel 2001 Chlorophyll Profile, SeaBAM OC2 Surface Chlorophyll, Gordon 88 Surface Chlorophyll	(μg/l)	Chlorophyll Estimates
Profiler Flux, Reference Flux	(w/m^2)	Energy fluxes
Water Properties Table	Depth (m) Temp ($^\circ$C) Conductivity (μmho/cm) Conductivity Ratio (None) Salinity (psu) Density (Kg/m^3)	Water Properties

15. Appendix D: Profiler/Reference Data Deglitching Function

15.1 Background

Deglitching of optical data measured in sea environment is not a trivial task. Data glitches that can be caused by power instabilities, inconsistencies between data transfer baud rates and data logging speed, and other reasons that are not caused by changes in the natural environment. On the other hand, noise in optical data can be also be caused by wave-focusing effects, random changes in profiler's tilts, and the noise caused by dark current.

We make difference between the data glitches and remaining part of unwanted noise mainly to make possible differential data treatment depending on the cause of a noise. In a case of glitches, we want the respective part of data simply removed. In a case of wave focusing, dark current (DC) influence and profiler tilts, one may try to reduce their influence by some sort of data filtering. In an extreme case, data with significant tilts, DC etc can be also removed.

15.2 Description of data distribution with depth

1. Profiler's optical data changes exponentially with depth. Changes in signal values can be as large as 8 orders e.g. from 1 to 1e-8.

2. Part of the data changes that can be regarded as noise, also change significantly. Moreover, noise distribution with depth is not homogeneous The causes for noise in the different parts of a profiler are different e.g. if in the surface layer wave focusing and tilt effects are dominating then with the depth increase, dark current noise contribution increases, and finally starts to dominate.

15.3 Problem

To identify glitches, one should divide measured data profile (S) into two parts: signal ($<S>$) and noise (E).

$$S = \langle S \rangle + E \qquad\qquad\qquad (1)$$

where operator <> means some sort of data averaging. From equation (1) it is clear that noise definition $E = S - \langle S \rangle$ depends on a meaning of operation of data averaging. The measurements with $E > Threshold$ will be declared glitches. Mean signal <S> can be estimated using various approaches. E.g. FFT, wavelet transform, measured data fit with a semi-empirical or empirical model (e.g. simple exponential or polynomial fit), simple moving average etc. In all these cases, distribution of E with depth will remain statistically inhomogeneous i.e. one could expect that p.d.f of E will change as a function of depth. **The outlined inhomogeneous error distribution constitutes the main problem for glitches identification and their subsequent removal**.

15.4 Approach for the Problem Solution

1. We assume that we have data S measured at fixed time or depth interval. For simplicity we will use data frame number *'i'* instead of a time or space co-ordinate. Thus we have

S(i), where i = 1,…, N, where N is number of measurements

2. From S(i) we calculate the ratio

dS(i) = S(i+1)/S(i), i = 1, …, N-1

3. Sort dS in an ascending order

dS_sorted = sort(dS)

4. Calculate a measure of data deviation

stdS = dS_sorted(n1) - dS_sorted(n2), where

n1 = 0.2*nn

n2 = 0.75*nn

nn = length of dS

5. Calculate median value of dS

medN = median(dS)

6. Find data invalid data values

| dS(i) – medN | > NoiseThresh*stdS

The default values for a profiler and a reference instrument are 5 and 20 respectively. They should be adjusted according to a concrete situation.

From Step 6 it follows that all values that lie above NoiseThresh*stdS, should be removed.

15.5 Examples

Figures 1 and 2 show the examples of measured upwelling radiance signal Lu without glitches (Figure 5b) and with glitches (Figure 6b). The position of the vertical red lines in the figures 1a, 1c and 2a indicate the levels below or above which data will be declared as a glitch. Figure 5 shows data that had not any glitches in a sense defined above. However, one can see that significant part of data dominated by dark noise at the bottom of the profile is declared as the glitches. Although, usually this is not a problem to reject data dominated by DC, the given example demonstrates a potential problem in making difference between different causes of noise. In some cases wave focusing effects (practically not visible in the present examples) are also clearly visible in the upper part of a profile, and can be easily misinterpreted by a program as glitches in data. For this reason, sometimes it could be advantageous to perform data deglitching analysis only to some parts of a profile by identifying upper and lower depth boundaries of a profile. The deglitching function appended to this document enables a user to define the respective boundaries using ProSoft's configuration file (see the last section of this note). In this way, depending on an aim of deglitching analysis, one could also remove or not touch significant amount of data affected dark noise or wave focusing.

Figure 8 Distribution of upwelling Lu radiance

 with depth with no data glitches. (a) Distribution ratio of Lu(i+1)/Lu(i), two vertical red lines stay for medN | +/- NoiseThresh*stdS, (b) distribution of Lu as a function of pressure, (c) and (d) – the same as (a) and (d) but for downwelling irradiance.
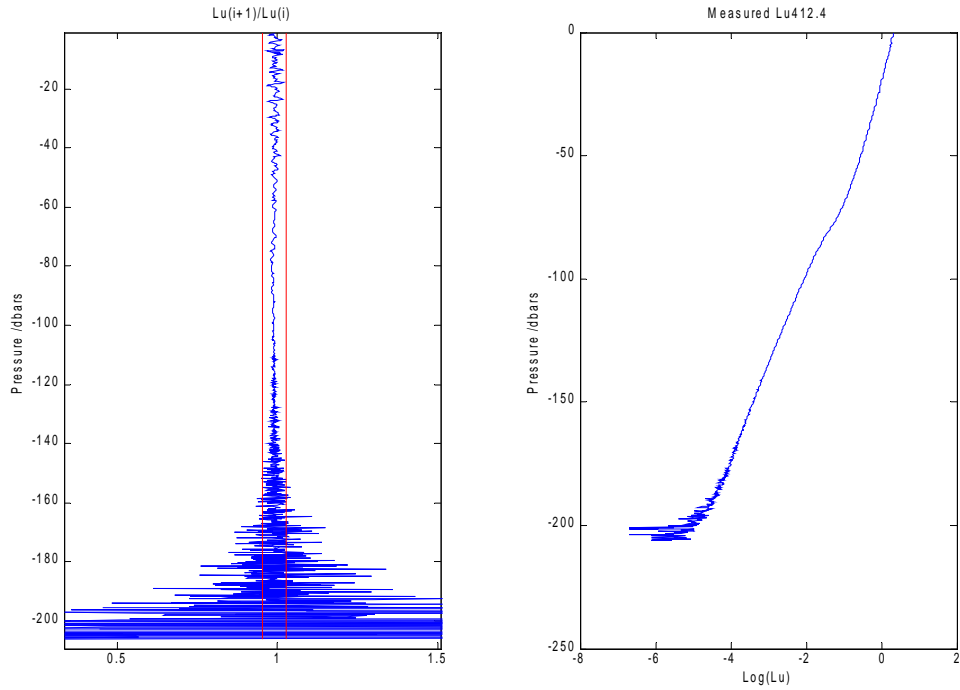
Figure 9 The same as Figure 5 (a) and (b) but with apparent data glitches.
(c) distribution of deglitched Lu as a function of depth.