The Automated Satellite Data Processing System

in situ Data Processing

Naval Research Laboratory, Stennis Space Center, MS
Paul Martinolich
Theresa Scardino

The Automated Satellite Data Processing System: in situ Data Processing

by Naval Research Laboratory, Stennis Space Center, MS, Paul Martinolich, and Theresa Scardino

Publication date 18 November 2009

Table of Contents

Part I. In situ Data Processing

The chapters in Part I form a User's Guide for the processing of *in situ* data within Automated Processing System.

Currently, this software suite can only process remote sensing reflectance from ASD or SPECTRIX radiometers.

Chapter 1. Remote Sensing Reflectance

The **rrs** program calculates the remote sensing reflectance, R_{RS}, from spectra files obtained from Analytical Spectral Devices' (ASD) field-portable FieldSpec™ Spectroradiometer, or Labsphere's Spectrix. Additionally, the input spectra may be read from an NRL SIMBIOS ASCII file previously created with this program or anther. The program uses spectra collected from taking readings from the sky, a gray card (of known reflectance - the reference), and the sea surface (which includes the sky reflectance upon its surface) to determine the remote sensing reflectance. This follows Method 2 of Chapter 3, *Above-Water Radiance and Remote Sensing Reflectance Measurement and Analysis Protocols* from NASA/TM-2003-21621/Rev-Vol III, *Ocean Optics Protocols For Satellite Ocean Color Sensor Validation, Revision 4, Volume III: Radiometeric Measurments and Data Analysis Protocols*. That is, from uncalibrated radiance and reflectance plaque measurements. Following these protocols, various corrections may be applied to the R_{RS}, Finally, some bio-optical and IOP products are generated (chlorophyll-a, absorption and scattering).

Remote Sensing Reflectance

To compute the reflectance, the sensor response signal, S, is obtained from n readings from each target and normalized to the same consistent integration time (1 sec).

$$S \frac{\sum_{i=0}^{N} N \frac{CI_i}{I_N}}{n}$$

Here, L represents the uncalibrated data read from the instrument, I_i is the integration time used for that reading, I_N is the normalized integration time, and N is the number of readings (3, 5, or 9 in practice depending on instrument protocol).

Following, Chapter 2 of the Optics Protocols, these can express the water-leaving radiance, L_w, and incident spectral irradiance, E_s, in terms:

$$L_W F_L S_{\mathrm{sfc}} S_{\mathrm{sky}} E_S \frac{F_L S_g}{R_g}$$

Here, F_L is the unknown instrument radiance response calibration factor (which will fall out) and R_g is the plaque's bi-directional reflectance function (albedo).

Thus the R_{RS} can be computed from the uncalibrated data using the following equation (correcting sky using Fresnel reflectance rho of 0.021):

$$R_{\mathrm{RS}} \frac{S_{\mathrm{sfc}} S_{\mathrm{sky}}}{S_g R_g}$$

It might also be useful (for some residual reflectance correction algorithms) to divide the above equation into two separate parts (and remove the Fresnel rho part).

$$R_{\mathrm{sfc}} \frac{S_{\mathrm{sfc}}}{S_g R_g}$$

$$R_{\mathrm{sky}} \frac{S_{\mathrm{sky}}}{S_g R_g}$$

Residual Reflectance Corrections (Whitelight)

The computed R_{RS} should be "black" about 750nm. If not zero, then it assumed that the reflected skylight term (S_{sky}) was not estimated correctly. Following the 'quick and easy' algorithm of Carder and Steward (1985), it is further assumed that any error in the skylight reflection term is white (not wavelength dependent) and one may simply subtract the computed R_{RS} (750) from the entire spectrum. In practice, this may lead to negative radiance values R_{RS} near 750 nm are actually lower then R_{RS} (750). So, this program will subtract the smallest R_{RS} in the range from 700 nm to 825 nm.

$$R_{RS} R_{RS} R_{RS}$$

Residual Reflectance Corrections (Gould 2001)

In coastal waters, the assumption that R_{RS} (750) should be zero is not true. There is reflectance from particles at red and near-IR wavelengths. In the Gould, et al. algorithm, a procedure to determine the true reflectance using *in situ* optical measurments is presented. The surface correction includes a method when the insitu measurements are missing. This method (no *in situ*) is known as Path 1; the *in situ* method is known as Path 2.

For Path 1, start by calculating C_b(735)

$$C_b \frac{R_{sfc} R_{sfc} a_w a_w}{a_w a_w}$$

and

$$R_r \frac{R_{sfc} a_w R_{sfc} a_w}{a_w a_w}$$

Assuming a Fresnel of 2.1%, compute the residual spectrally-flat sunglint and reflected cloud light by R_r (735) - 0.021 R_{sky} (735). Now, our corrected R'_{RS} is simply

$$R'_{RS} R_{sfc} R_{sky}$$

For Path 2, start with the same calculations for C_b(735) and R_r(735) above. Now using the insitu scattering data, compute b(#)/b(735) using linear regression of the insitu data to obtain the insitu shape. And, using the *in situ* absorption values and the relationship, R_{RS} (#) = C_b b(#) / a(#) , compute the remote sensing reflectance at 412, R_{RS^*}(412). The star (*) indicates that this reflectance corresponds to that that the *in situ* data estimates.

Next, B and A are computed. The residual spectrally-flat sunglint and reflectecd cloud light (B) is determined from the *in situ* reflectance by

A (which was set to Fresnel reflectance of 2.1% in Path 1) is now computed

The corrected remote sensing reflectance is now found

Satellite Reflectance

To compare the *in situ* reflectance with satellite derived reflectance, the mean reflectance is computed using the relative spectral response tables for each band of the satellite data.

MODIS reflectance

The MODIS instrument has ten detectors for each ocean color band (1,3-4,8-14) all with individual relative spectral responses. To compute the mean MODIS remote sensing reflectance from the insitu R_{RS}:

$R_{sfc} R_{sky}$

Here, $\#_0$ and $\#_1$ are the lower and upper bounds for the relative spectral response table, S is the relative reponse factor (0.0 to 1.0), and R_{RS} is the input remote sensing reflectance interpolated to the wavelengths of the relative spectral response table.

SeaWiFS reflectance

The SeaWiFS instrument has individual relative spectral responses for each ocean color bands. To compute the mean SeaWiFS remote sensing reflectance from the insitu R_{RS}:

Here, $\#_0$ and $\#_1$ are the lower and upper bounds for the relative spectral response table, S is the relative reponse factor (0.0 to 1.0), and R_{RS} is the input remote sensing reflectance interpolated to the wavelengths of the relative spectral response table.

Inherent Optical Properties

Once the reflectance, R_{RS}, the inherent optical properties can be computed using several methods. The **rrs** program can produce these inherent optical properties from computed remote sensing reflectance, R_{RS}.

Quasi-analytical algorithm

This algorithm is discussed in Lee, et. al. (2002). It computes the following inherent optical properies: total absorption, a_t, detris/CDOM absorption, a_{dg}, phytoplankton absorption, a_p, and backscattering, b_b.

Arnone algorithm

This algorithm is unpublished. It computes the following inherent optical properies: total absorption, a_t, and backscattering, b_b. This algorithm is case dependent. For case 1 waters (defined such that R_{RS} (670) < 0.0003), the chlorophyll-a concentration, $C_{a,}$ is needed. It is computed using the OC4 version 4 algorithm:

The particulate backscatter is computed from C_a

The backscatter from pure-water is now added using a model for b_{bw}.

Now using the $R_{RS} = b_b$ / (a + b_b) relationship, the absorption, a(#) is computed.

For case 2 waters (R_{RS}(670) > 0.0003), the absorption at 670, a_t(670), is first estimated using $a_t = a_w + a_{ph} + a_{dg}$, where a_w is from Pope and Fry (1997). The detris/CDOM component is computed from the Stumpf relationship:

The phytoplankton term is estimated from the C_a (computed using OC4v4) using:

and Lee's (1998) spectral relationship a_{ph}(443) [0.8435 + 0.1595 log (a_{ph}(443))].

Using $R_{RS} = b_b$ / (a + b_b), b_b(670) is computed. For the spectrum, the spectral b algorithm of Gould, et. al. (1999) and Austin and Petzold's b_b to b relationship is used.

Now using the $R_{RS} = b_b$ / (a + b_b) relationship, the absorption, a (#) is computed.

Gould algorithm

The Gould algorithm used in the residual remote sensing reflectance also produces estimates of absorption, a_t, and scattering, b. Using the sky reflected, R_{sky}, at 715 nm and 735nm, $R_{sky} = R_{sky}(715) - R_{sky}(735)$, a relationship to b(555) is computed:

The spectral scattering algorithm of Gould, et. al (1999) is used to compute b(#).

To compute absorption, a:

References

Carder, K. L. and R. G. Steward, 1985, "A remote-sensing reflectance model of a red-tide dinoflagellate off West Florida", *Limnol. Oceanogr.*, Vol. 30, pp 286-298.

Gould, R. W., Jr., R. A. Arnone, P. M. Martinolich, 1999, "Spectral Dependence of the scattering coefficient in case 1 and case 2 waters" *Applied Optics*, Vol. 38, No. 12, pp 2377-2383.

Gould, R. W., Jr., R. A. Arnone, M. Sydor, 2001, "Absorption, Scattering, and Remote-Sensing Reflectance Relationships in Coastal Waters: Testing a New Inversion Algorithm", *Journal of Coastal Research*, Vol. 17, No. 2, pp 328-341.

Lee, Z. P., K. L. Carder, R. G. Steward, T. G. Peacock, C. O. Davis, and J. L. Mueller, 1997, "Remote-sensing reflectance and inherent optical properties of oceanic waters derived from above-water measurments. In: *Ocean Optics XIII* S. G. Ackelson, ed. Proc. SPIE Vol. 2693, pp 483-488.

Lee, Zhongping, Kendell L. Carder, Robert A. Arnone, "Deriving inherent optical properties from water color: a multiband quasi-analytical algorithm for optically deep waters", *Applied Optics*, Vol. 41, No. 27, pp 5755-5772.

Mueller, James L., Giulietta S. Fargion and Charles R. McClain, Editors, "Ocean Optics Protocols For Satellite Ocean Color Sensor Validation, Revision 4, Volume III: Radiometeric Measurments and Data Analysis Protocols", *NASA Technical Memorandum*, NASA/TM-2003-21621/Rev-VolIII.

Chapter 2. NRL SIMBIOS Data Files

The output files are ASCII files that follow the SIMBIOS format. They are designated NRL since the **rrs** program will write NRL specific products to each file.

Average Uncalibrated Sensor Response

This output file writes the wavelength, #; the uncalibrated sensor reponse of the sky target, S_{sky}; the uncalibrated sensor repsonse of the sea surface target, S_{sfc}; the uncalibrated sensor response of the plaque, S_g; and the downwelling irradance, E_s.

The default extension for this output file is `.L0`

Part of an example is give here:

```
/begin_header
 ...
/fields=wavelength,Ssfc,Ssky,Sg
/units=nm,sr^-1,sr^-1,sr^-1
/end_header
  330.7      247.907513     3611.141304      416.642360
  331.9      246.839257     3574.539855      419.755197
  333.0      245.919928     3535.271739      423.860787
  334.1      250.682165     3533.850242      430.700870
 ...
```

Remote Sensing Reflectance

This output file contains the remote sensing reflectance as computed from this program. The columns in this file contain the wavelength, #; the 'standard' remote sensing reflectance, R_{RS}; the 'white' corrected remote sensing reflectance; the Gould Path 1 reflectance; the Gould Path 2 reflectance (or -99 in this column if no insitu data provided); and finally the Lee corrected reflectance.

The default extension for this output file is `.rrs`

Part of an example is give here:

```
/begin_header
 ...
/fields=wavelength,rrs_sfc,rrs_fresnel,rrs_white,rrs_lee,rrs_gould1,rrs_gould2
/units=nm,sr^-1,sr^-1,sr^-1,sr^-1,sr^-1,sr^-1
/end_header
  326.6    0.008171    0.004670    0.002747    0.003900 -99.000000  -0.000624
  328.1    0.009650    0.005755    0.003832    0.004985 -99.000000   0.000967
  329.5    0.009011    0.005395    0.003472    0.004626 -99.000000   0.000437
 ...
```

MODIS Reflectance

This output file contains four or five columns and ten rows, one for each wavelength.

The default extension for this output file is `.mod`

Part of an example is give here:

> **Note**
> FIXME: get updated table

```
/begin_header
 ...
/fields=lambda,modrrs,modrrs_lee,modrrs_gould1,modrrs_gould2
/units=nm,none,sr^-1,sr^-1,sr^-1
/end_header
 412.00  0.008519    0.006602    0.007785    0.007785
 443.00  0.009310    0.007729    0.008576    0.008576
 469.00  0.009310    0.007729    0.008576    0.008576
 488.00  0.011932    0.010671    0.011198    0.011198
 532.00  0.015990    0.014913    0.015256    0.015256
 551.00  0.009310    0.007729    0.008576    0.008576
 555.00  0.017728    0.016705    0.016994    0.016994
 645.00  0.009310    0.007729    0.008576    0.008576
 667.00  0.011419    0.010586    0.010685    0.010685
 678.00  0.010602    0.009778    0.009868    0.009868
```

SeaWiFS Reflectance

This output file contains five colums and eight rows, one for each SeaWiFS length.

The default extension for this output file is `.swf`

Part of an example is give here:

```
/begin_header
 ...
/fields=lambda,swfrrs,swfrrs_lee,swfrrs_gould1,swfrrs_gould2
/units=nm,sr^-1,sr^-1,sr^-1
/end_header
 412.00    0.004102    0.003383    0.003333  -99.000000
 443.00    0.004139    0.003702    0.003370  -99.000000
 490.00    0.004843    0.004648    0.004073  -99.000000
 510.00    0.005339    0.005196    0.004570  -99.000000
 555.00    0.007233    0.007168    0.006463  -99.000000
 670.00    0.005908    0.005855    0.005138  -99.000000
 765.00    0.002284    0.002190    0.001514  -99.000000
 865.00    0.004232    0.004120    0.003462  -99.000000
```

QAA Absorption and Scattering

This output file contains the total absorption, detris/CDOM absorption, phytoplakton absorption and backscattering using the Quasi-Analyitical Algorithm of Lee, et al (2002). The output file contains the wavelength, #; total absorption, a_t; detris/CDOM absorption, a_{dg}; phytoplankton absorption, a_p; and backscattering, b_b.

The default extension for this output file is `.qaa`

Part of an example is give here:

```
/begin_header
 ...
/delimeter=space
/fields=wavelength,a_qaa,adg_qaa,aph_qaa,bb_qaa
/units=nm,none,m^-1,m^-1,m^-1,m^-1
/end_header
  330.7    0.180825    0.348048   -0.196919    0.057522
  331.9    0.181993    0.342252   -0.189540    0.057220
  333.0    0.183624    0.336554   -0.181793    0.056922
 ...
```

Arnone Absorption and Scattering

This output file contains the total absorption and backscattering using the Arnone algorithm (unpublished). The output file contains the wavelength, #; total absorption, a_t; and backscattering, b_b.

The default extension for this output file is `.arnone`

Part of an example is give here:

```
/begin_header
 ...
/delimeter=space
/fields=wavelength,a_arnone,bb_arnone
/units=nm,none,m^-1,m^-1
/end_header
  330.7        0.095494        0.042797
  331.9        0.097022        0.042754
  333.0        0.098914        0.042710
 ...
```

Gould Path Absorption and Scattering

This output file contains the total absorption and scattering using the Gould et al (2001). The output file contains the wavelength, #; total absorption, a_t; and backscattering, b_b.

The default extension for this output file is `.g1`

Part of an example is give here:

```
/begin_header
 ...
/delimeter=space
/fields=wavelength,a_gould1,b_gould1,a_gould2,b_gould2
/units=nm,none,m^-1,m^-1,m^-1,m^-1
/end_header
  326.6    1.158913   10.429392    9.950456   10.547236
  328.1    1.280780   10.415924   24.997312   10.531180
  329.5    1.187971   10.402457    9.008693   10.515123
  330.9    1.146506   10.388989    7.664831   10.499066
 ...
```

Chapter 3. Plots

The output files are ASCII files that follow the SIMBIOS format. They are designated NRL since the **rrs** program will write NRL specific products to each file.

Remote Sensing Reflectance

Inherent Optical Properties

Part II. Command Line Reference

The chapters in Part II form a reference guide for each program available in the Automated Processing System for *in situ* data processing.

Name

fldspec — in situ reflectance processing

Synopsis

`fldspec [options] basename`

`fldspec - < listfile`

Description

The **fldspec** program calculates the remote sensing reflectance, R_{RS}, from spectra files obtained from Analytical Spectral Devices' (ASD) field-portable FieldSpec™; Spectroradiometer, or Labsphere's Spectrix. Additionally, the input spectra may be read from an NRL SIMBIOS ASCII file previously created with this program or anther. The program uses spectra collected from taking readings from the sky, a gray card (of known reflectance - the reference), and the sea surface (which includes the sky reflectance upon its surface) to determine the remote sensing reflectance. This follows Method 2 of Chapter 3, *Above-Water Radiance and Remote Sensing Reflectance Measurement and Analysis Protocols* from NASA/TM-2003-21621/Rev-Vol III, *Ocean Optics Protocols For Satellite Ocean Color Sensor Validation, Revision 4, Volume III: Radiometeric Measurments and Data Analysis Protocols*. That is, from uncalibrated radiance and reflectance plaque measurements. Following these protocols, various corrections may be applied to the R_{RS} Finally, some bio-optical and inherent optical products are generated (chlorophyll-a, absorption and scattering).

The results are written to several simple ASCII files (with SIMBIOS headers) that include uncalibrated sensor response signal for the sky, S_{sky}, the plaque or grey-card, S_g, and the sea surface, S_{sfc}, (Level-0); the standard remote sensing reflectance, R_{RS}, (Level-1); reflectance that has been corrected for Sun glint and skylight (Level-2); and bio-optical and inherent optical products derived from the reflectance (Level-3). See the *In situ* Data Processing User's Guide for file formats and examples.

Additionally, two plots are created. One contains the remote sensing reflectance inputs and results (Level-0 through Level-2). The second plot contains the inherent optical properties (Level-3) from several of the algorithms. See the *In situ* Data Processing User's Guide for format and examples of the plots.

Operations

During normal data collection multiple measurements (5) are taken of each target (sky, grey card, sea) usually with different intergration times to maximize the SNR of the data. During collection, the ASD uses the extension to automatically number each saved spectra (basename.001 ... basename.014). By default, the sky files range from .000 to .004, the refrence files range from .005 to .009, and water files range from .010 to .014. These can be changed with the use of options described below, however.

Options

-albedo idx

which reference (gray) card was used:

0	Alan's 18% spectralon
1	Bob's 4-inch 12% spectralon (pre-June 1998)
2	Curt's 12% spectralon
3	Bob's 4-inch 12% spectralon (post-June 1998)

4	White spectralon
5	Kodak spectralon
6	Bob's 10-inch spectralon (pre-April 2006)
7	Curt's 10% spectralon
8	Alan's 10-inch 20% spectralon
9	Bob's 10-inch spectralon (April 2006 to June 14, 2007)
10	Bob's 10-inch spectralon (post-June 14, 2007)
11	Bob's replacement 10-inch spectralon (post-June 14, 2007)
12	Alan's 10-inch 20% spectralon

-spx_cal idx — which spectrix spectral calibration used:

idx	Date	a	b	c
0	7 July 1999	890.6004	-1.072443	-4.527694E-05
1	30 July 2002	889.8159	-1.068666	-4.975897E-05
2	19 Jan 2009	887.1015	-1.06601	-3.319692E-05

-sky_st idx — starting index of sky spectra

-sky_num num — number of sky spectra to proces

-ref_st idx — starting index of reference spectra

-ref_num num — number of reference spectra to proces

-water_st idx — starting index of water spectra

-water_num num — number of water spectra to proces

-o basename — use 'basename' for the output basename

-out_dir directory — use 'directory' for the output directory

-temp temperature — *in situ* temperature used in Gould algorithm (Celsius)

-salinity salinity — *in situ* salinity used in Gould algorithm (PSU)

Simbios Options

These options are required for the SIMBIOS header which is normally output by program to all ASCII files.

For each required parameter, the user must either provide a value using (1) the command line option; (2) another SIMBIOS header file from which the value may be obtained; or (3) accept the default value if present.

For each optional parameter, if set by the user either from the command line or from another SIMBIOS header, it will be written to the output file. No default value is provided as these are not required SIMBIOS parameters.

`-investigators investigators`	name of investigators (required). Defaults to 'Robert Arnone'.
`-affiliations affiliations`	affilications of investigators (required). Defaults to 'NRL Code 7333'.
`-contact contact`	e-mail address of contact (required). Defaults to 'arnone@nrlssc.navy.mil'
`-experiment experiment`	name of experiment (required). No default. Cannot be set to "SIMBIOS"
`-cruise cruise`	name of cruise (required). No default. Cannot be set to "SIMBIOS"
`-station station`	name of station (optional).
`-documents documents`	documents (required). Defaults to "N/A".
`-calibration_files calibration_files`	name of experiment (required). Defaults to "N/A".
`-data_type data_type`	data type (required). Defaults to "above_water".
`-water_depth value`	water depth (required). Defaults to bathemetry file.
`-data_status data_status`	data status (optional).
`-cloud_percent value`	percent cloud cover (optional).
`-measurement_depth value`	measurement depth (optional).
`-secchi_depth value`	secchi depth (optional).
`-wind_speed value`	wind speed (optional).
`-wave_height value`	wave height (optional).
`-date YYYYMMDD`	date of collection (required). If the input file is an ASD or SIMBIOS file, this information is read from the file.
`-time HH:MM:SS`	time of collection (required). Default values are read from the input file.
`-lat lat`	latitude of station (required). No default, unless user provides a previous SIMBIOS header that contains this value.
`-lon lon`	longitude of station (required). No default, unless user provides a previous SIMBIOS header that contains this value.