Table of Contents

1. Remote Sensing Reflectance 1
..... 1
Remote Sensing Reflectance 1
Residual Reflectance Corrections (Whitelight) 1
Residual Reflectance Corrections (Gould 2001) 2
Satellite Reflectance 2
MODIS reflectance 2
Sensor-specific reflectance 3
Inherent Optical Properties 3
Quasi-analytical algorithm 3
Arnone algorithm 3
Gould algorithm 3
References 4
2. NRL SIMBIOS Data Files 5
Average Uncalibrated Sensor Response 5
Remote Sensing Reflectance 5
MERIS Reflectance 6
MODIS Reflectance 6
OCM Reflectance 7
OCM2 Reflectance 7
SeaWiFS Reflectance 7
VIIRS Reflectance 8
QAA Absorption and Scattering 8
Arnone Absorption and Scattering 9
Gould Path Absorption and Scattering 9
3. Plots 11
Remote Sensing Reflectance 12
Inherent Optical Properties 13

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 un-calibrated 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).

Here, L represents the un-calibrated 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:

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 un-calibrated data using the following equation (correcting sky using Fresnel reflectance rho of 0.021):

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).

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.

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 measurements 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)

and

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

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, $R_{RS\ (\lambda)} = C_b\ b(\#) / a(\#)$, 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 sun glint and reflected 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}:

Here, λ_0 and λ_1 are the lower and upper bounds for the relative spectral response table, S is the relative response 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.

Sensor-specific reflectance

The various ocean-color instruments have individual relative spectral responses for each ocean color bands. To compute the mean sensor remote sensing reflectance from the insitu R_{RS}:

Here, λ_0 and λ_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.

The relative spectral response of each sensor is contained an a SIMBIOS type file located under the `cal` directory for each sensor.

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 properties: 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 properties: 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 (λ) 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 measurements. In: *Ocean Optics XIII* S. G. Ackelson, ed. Proc. SPIE Vol. 2693, pp 483-488.

Lee, Zhongping, Kendell L. Carder, Robert A. Arnone, 2002, "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, λ; the un-calibrated sensor reponse of the sky target, S_{sky}; the un-calibrated sensor repsonse of the sea surface target, S_{sfc}; the un-calibrated 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, λ; 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 (non-normalized).

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
 ...
```

MERIS Reflectance

This output file contains four or five columns and fifteen rows, one for each wavelength. The full remote sensing reflectance is convolved with the (camera averaged) MERIS relative spectral response.

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

Part of an example is give here:

```
/begin_header
 ...
/fields=wavelength,merrrs,merrrs_lee,merrrs_gould1
/units=nm,sr^-1,sr^-1,sr^-1
/end_header
 412.00    0.006443    0.004658    0.006405
 443.00    0.007410    0.005837    0.007372
 490.00    0.009597    0.008302    0.009560
 510.00    0.010304    0.009091    0.010267
 560.00    0.011935    0.010877    0.011897
 620.00    0.005665    0.004720    0.005627
 665.00    0.003668    0.002762    0.003630
 681.00    0.003341    0.002449    0.003303
 709.00    0.001600    0.000739    0.001562
 754.00    0.000534   -0.000280    0.000496
 761.00    0.001115    0.000312    0.001077
 779.00    0.000547   -0.000254    0.000509
 865.00    0.000572   -0.000203    0.000534
 885.00    0.000727   -0.000130    0.000689
 900.00    0.003302    0.001209    0.003264
```

MODIS Reflectance

This output file contains four or five columns and ten rows, one for each wavelength. The full remote sensing reflectance is convolved with the MODIS relative spectral response.

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

Part of an example is give here:

```
/begin_header
 ...
/fields=lambda,modrrs,modrrs_lee,modrrs_gould1,modrrs_gould2
/units=nm,none,sr^-1,sr^-1,sr^-1
/end_header
 412.00    0.006617    0.004845    0.006579
 443.00    0.007410    0.005836    0.007373
 488.00    0.009505    0.008196    0.009467
 531.00    0.011264    0.010127    0.011226
 547.00    0.011742    0.010654    0.011704
 667.00    0.003628    0.002710    0.003590
 678.00    0.003391    0.002482    0.003353
 748.00    0.000614   -0.000208    0.000576
```

```
 865.00    0.000622   -0.000180    0.000584
```

OCM Reflectance

This output file contains five colums and eight rows, one for each OCM length. The full remote sensing reflectance is convolved with the OCM relative spectral response.

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

Part of an example is give here:

```
/begin_header
 ...
/fields=wavelength,ocmrrs,ocmrrs_lee,ocmrrs_gould1
/units=nm,sr^-1,sr^-1,sr^-1
/end_header
 412.00    0.006535    0.004749    0.006497
 443.00    0.007359    0.005743    0.007321
 490.00    0.009438    0.008119    0.009400
 510.00    0.010278    0.009037    0.010240
 555.00    0.011753    0.010657    0.011715
 670.00    0.003633    0.002693    0.003595
 765.00    0.000670   -0.000149    0.000632
 865.00    0.000659   -0.000147    0.000621
```

OCM2 Reflectance

This output file contains five colums and eight rows, one for each OCM2 length. The full remote sensing reflectance is convolved with the OCM2 relative spectral response.

The default extension for this output file is `.ocm2`

Part of an example is give here:

```
/begin_header
 ...
/fields=wavelength,ocm2rrs,ocm2rrs_lee,ocm2rrs_gould1
/units=nm,sr^-1,sr^-1,sr^-1
/end_header
 415.00    0.006535    0.004749    0.006497
 442.00    0.007359    0.005743    0.007321
 491.00    0.009438    0.008119    0.009400
 512.00    0.010278    0.009037    0.010240
 557.00    0.011753    0.010657    0.011715
 620.00    0.003633    0.002693    0.003595
 745.00    0.000670   -0.000149    0.000632
 866.00    0.000659   -0.000147    0.000621
```

SeaWiFS Reflectance

This output file contains five colums and eight rows, one for each SeaWiFS length. The full remote sensing reflectance is convolved with the SeaWiFS relative spectral response.

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
```

VIIRS Reflectance

This output file contains five colums and eight rows, one for each VIIRS length. The full remote sensing reflectance is convolved with the VIIRS relative spectral response.

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

Part of an example is give here:

```
/begin_header
 ...
/fields=wavelength,viirsrrs,viirsrrs_lee,viirsrrs_gould1
/units=nm,sr^-1,sr^-1,sr^-1
/end_header
 412.00    0.006371    0.004568    0.006333
 445.00    0.007476    0.005913    0.007438
 488.00    0.009402    0.008083    0.009364
 555.00    0.011642    0.010558    0.011604
 672.00    0.003576    0.002671    0.003538
 746.00    0.000578   -0.000244    0.000540
 865.00    0.000601   -0.000189    0.000563
```

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, λ; 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, λ; 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, λ; 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
 ...
```

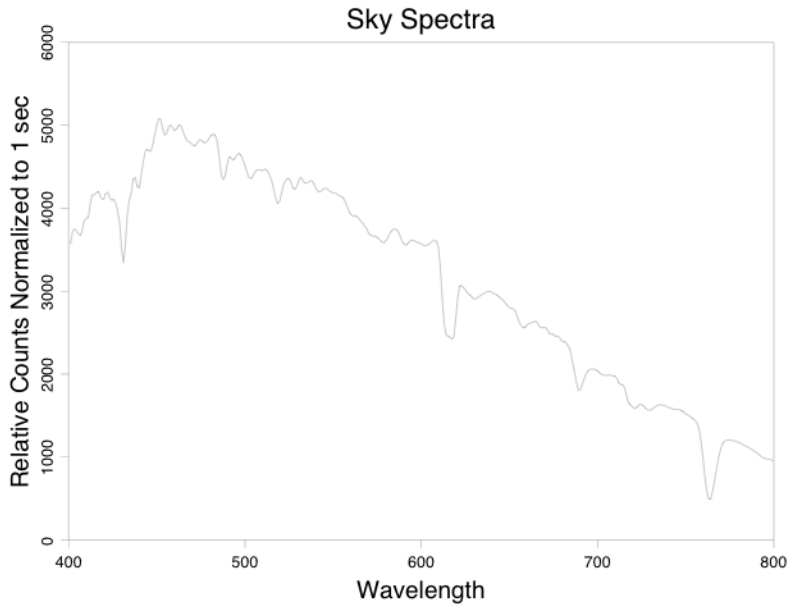
Chapter 3. Plots

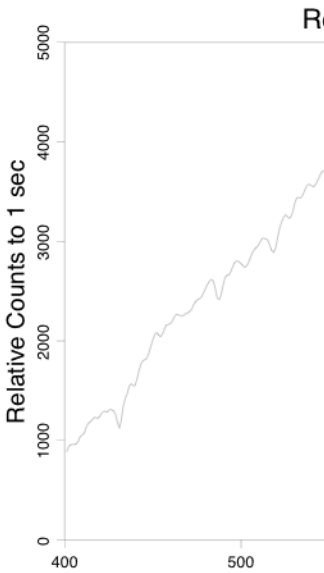
The output files are ASCII files that follow the SIMBIOS format. They are designated NRL since the **rrs** program will write NRL specific products to each file.

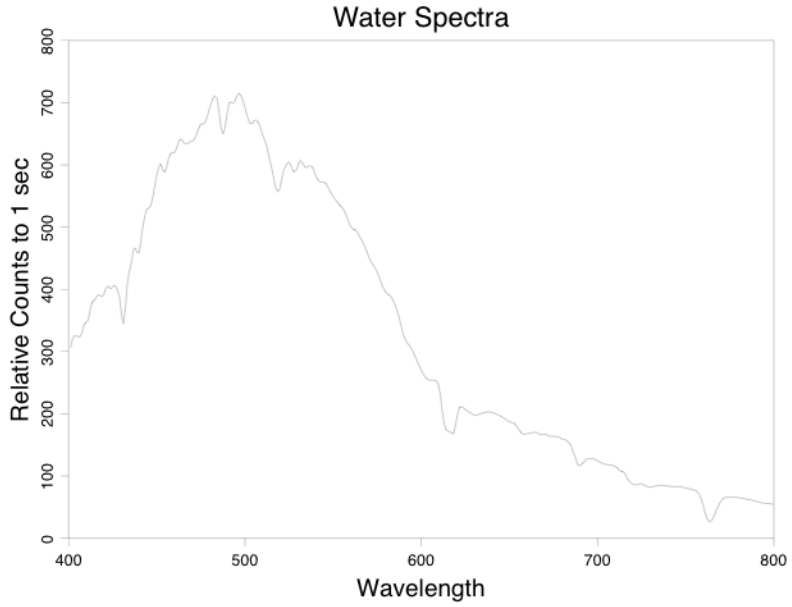
Remote Sensing Reflectance

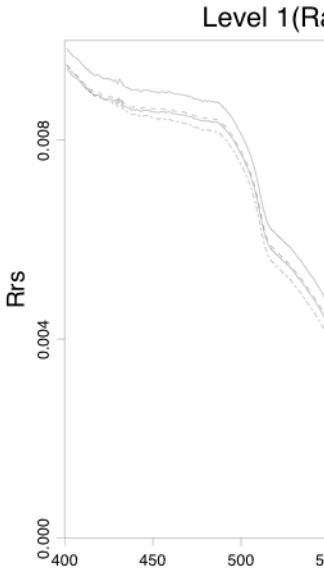
Experiment: Adriatic
Station: ADRs03

Time: 20030223 14:55:0
Lat/Lon: 44.0696/14.068





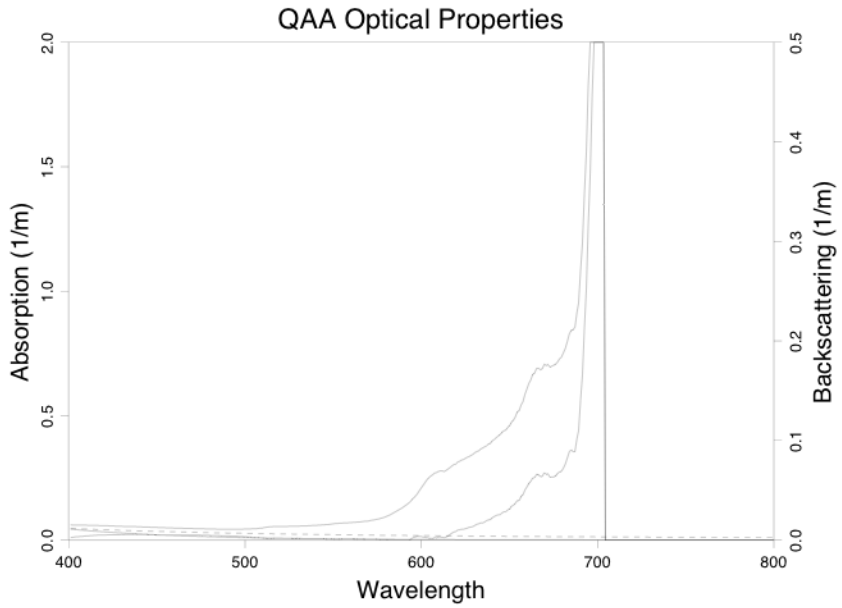


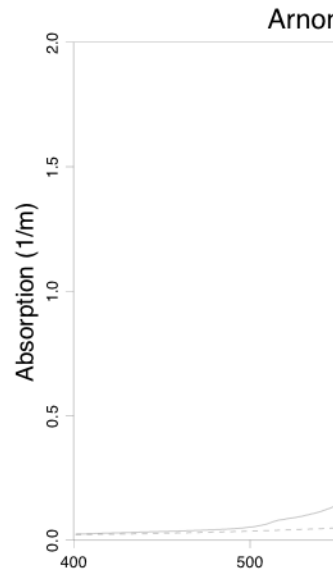


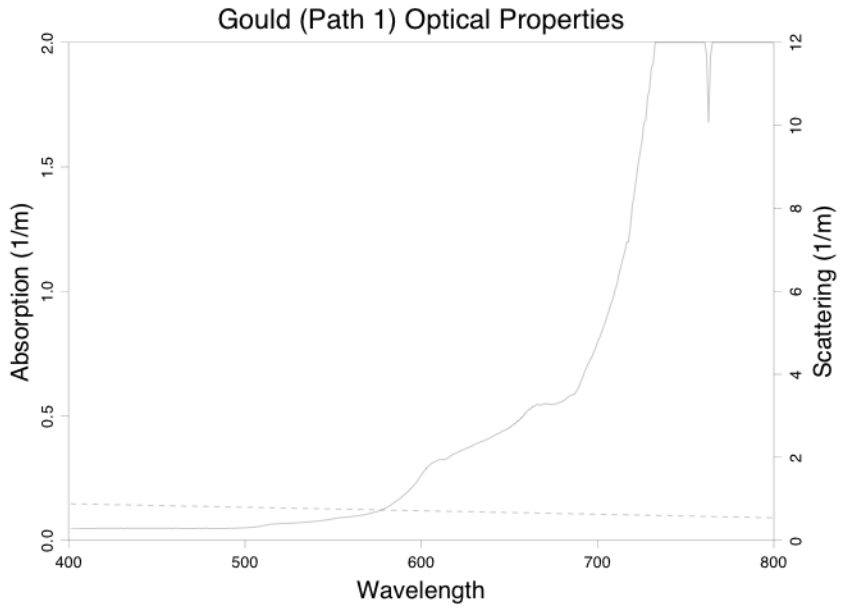
Inherent Optical Properties

Experiment: Adriatic
Station: ADRs03

Time: 20030223 14:55:0
Lat/Lon: 44.0696/14.068







Goul
Not