OSU Methods for measuring above water Remote Sensing Reflectance (R_{rs})

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Background and Theory

Above-water remote sensing reflectance (R_{rs}) spectra are measured using a Spectral Evolution (Lawrence, MA) hand-held PSR-1100-F Spectroradiometer. For each "sample" the PSR-1100-F makes 10 measurements each proceeded by a dark measurement. It then averages the 10 dark-subtracted measurements to make a "sample". A sample is measured in 5-10 seconds depending on the lighting and the reflectance of the target sampled. The procedure for measuring reflectance is a modified version of Carder and Steward (1985). We make 5 sample measurements of a 5 inch square white Lambertian diffuser 99% reflectance Spectralon plaque (Labsphere, Inc., North Sutton, NH), followed by 7 samples of the sea surface, and then 5 samples of the section of the sky that would be reflected off the sea surface. The sequence of measurements is made in rapid succession in less than 5 minutes. The measurements are made at approximately 90° azimuthal angle to the sun and at a 40° angle relative to the vertical to minimize reflected sunlight (Mobley 1999, 2015). Measurements are made with the 8 Deg. Field-of-view lens on the end of the fiber and then attach lens end to the holder on the end of the stick. The tip is attached to a wooden stick at a 40° angle. The stick is held horizontally with the probe pointing down at a 40° angle from nadir for the Spectralon plaque and water measurements, and then rotated 180 degrees on its long axis so that the probe is pointing 140° from nadir for the sky measurement. Measurements are made 3-5 meters above the sea surface (depending on the ship) and 0.1 to 0.15 meters (4-6 inches) above the plaque.

The spectroradiometer is calibrated for spectral radiance by Spectral Evolution using NIST-traceable standards. The resulting radiance measurements are in units of μW/cm2/nm/sr.

The SE PSR-1100-F Spectroradiometer measures light at 1.5 nm sampling and 3.2 nm spectral resolution over the 320 nm to 1100 nm spectral range. However, due to the difficulty in calibrating the 99% Spectralon plaque below 360 nm and the low signal-to-noise ratio received from the water above 850 nm, we generally only output spectra in the 360-850 nm range.

R_{rs} is estimated from the above-water data using the formula,

$$R_{rs} = (S_{w+s} - S_{sky}\,\rho(\theta))/(\,\pi S_p/\text{refl}),$$

where S_{w+s} is the measured signal from the water and includes both L_w and reflected skylight. S_{sky} is the measured signal from the sky, S_p is the average measured signal from the white Spectralon Plaque, and refl is the reflectivity of the plaque (approximately 99%; actual measured spectral values used in the calculation). Pi (π) converts the reflected radiance values to irradiance for this Lambertian diffuser. The measured sky radiance is multiplied by $\rho(\theta)$ which is the proportionality factor that relates the radiance measured when the detector views the sky to the reflected sky radiance measured when the detector views the sea surface.

The value of $\rho(\theta)$ is dependent on wind speed and direction, detector FOV, and sky radiance distribution. Only in the case of a level sea surface and a uniform sky radiance distribution does ρ(θ) equal the average of the Fresnel reflectance over the detector FOV. For our measurement angles under nominal sky and wind conditions, calculate ρ(θ) from table 1 (Mobley, 2015). Note that these values are always significantly higher than the value 0.023 used for conditions of complete overcast.

[However, it has been shown that the value of ρ(θ) can vary both in magnitude and spectrally as a function of sea and sky conditions, wind speed and water type (Mobley, 1999; Gould et al. 2001). To address this variation we are using a model by Lee *et al*. (2010) which was provided by Z. Lee in the form of an Excel spreadsheet. This model uses the Morel (1980) chlorophyll based (type 1 water) model for the water properties. The model derives R_{rs} for 360 – 850 nm. It works well for the clear waters around Platform Eureka, CA, but it does not accurately model the highly turbid waters of San Francisco Bay.]

References

Carder, K. L. and R. G. Steward, "A remote sensing reflectance model of a red tide dinoflagellate off West Florida," Limnology and Oceanography, 30(2), 286-298, 1985.

Gould Jr., R. W., R.A. Arnone, and M. Sydor, "Absorption, scattering, and remote-sensing reflectance relationships in coastal waters: Testing a new inversion algorithm." Journal of Coastal Research, 17(2): 328-341, 2001.

Lee, Z-P.,Y-H Ahn, C. Mobley and R. Arnone, “Removal of surface-reflected light for the measurement of remote-sensing reflectance from an above-surface platform,” Optics Express, 18:(25) 26313-26324 (2010).

Mobley, C. D., "Estimation of the Remote-Sensing Reflectance from Above-Surface Measurements," Appl. Opt. 38, 7442-7455, 1999.

Mueller, J., C. O. Davis, *et al*. “Above-Water Radiance and Remote Sensing Reflectance Measurement and Analysis Protocols”, NASA Ocean Optics Protocols For Satellite Ocean Color Sensor Validation, Revision 4, Volume III NASA/TM 2002-210004, J. L. Mueller and G. S. Fargion, eds., 2002, pp.171-182.

Mobley, C. D., 2015, Polarized Reflectance and Transmittance Properties of Wind-blown Sea Surfaces, Appl. Opt. 54(15):4828-49, 2015.

Table 1. Values of ρ(θ) as a function of wind speed (0-8 m/sec) and solar zenith angle (0-80°) for the standard view angles of 40° nadir angle and 90° azimuthal angle, and alternatively 40° nadir angle and 90° azimuthal angle relative to the sun. It is not recommended to take above water Rrs data at wind speeds above 8 m/s (16 knots) due to the abundance of whitecaps at higher wind speeds. For other viewing conditions see Mobley (2015) and the tables referenced in that article.

Wind Speed	Solar Zenith Angle	ρ(θ) 40, 90	ρ(θ) 40,135
0	0	0.0306	0.0306
0	10	0.0301	0.0325
0	20	0.0287	0.0338
0	30	0.0264	0.0345
0	40	0.0232	0.0342
0	50	0.0194	0.0327
0	60	0.0151	0.0302
0	70	0.0112	0.0272
0	80	0.0083	0.0245
2	0	0.0338	0.0361
2	10	0.0324	0.0364
2	20	0.0308	0.0376
2	30	0.0284	0.0382
2	40	0.0250	0.0379
2	50	0.0210	0.0361
2	60	0.0168	0.0330
2	70	0.0131	0.0293
2	80	0.0107	0.0260
4	0	0.0370	0.0451
4	10	0.0345	0.0398
4	20	0.0322	0.0395
4	30	0.0298	0.0401
4	40	0.0261	0.0398
4	50	0.0220	0.0378
4	60	0.0176	0.0344
4	70	0.0138	0.0305
4	80	0.0115	0.0270
6	0	0.0422	0.0541
6	10	0.0387	0.0425
6	20	0.0340	0.0408
6	30	0.0306	0.0414
6	40	0.0267	0.0409

6	50	0.0225	0.0389
6	60	0.0181	0.0353
6	70	0.0143	0.0312
6	80	0.0120	0.0276
8	0	0.0492	0.0712
8	10	0.0454	0.0522
8	20	0.0376	0.0433
8	30	0.0333	0.0435
8	40	0.0280	0.0430
8	50	0.0236	0.0408
8	60	0.0190	0.0370
8	70	0.0151	0.0326
8	80	0.0128	0.0287

Detailed Procedures for Above Water Reflectance Data Collection

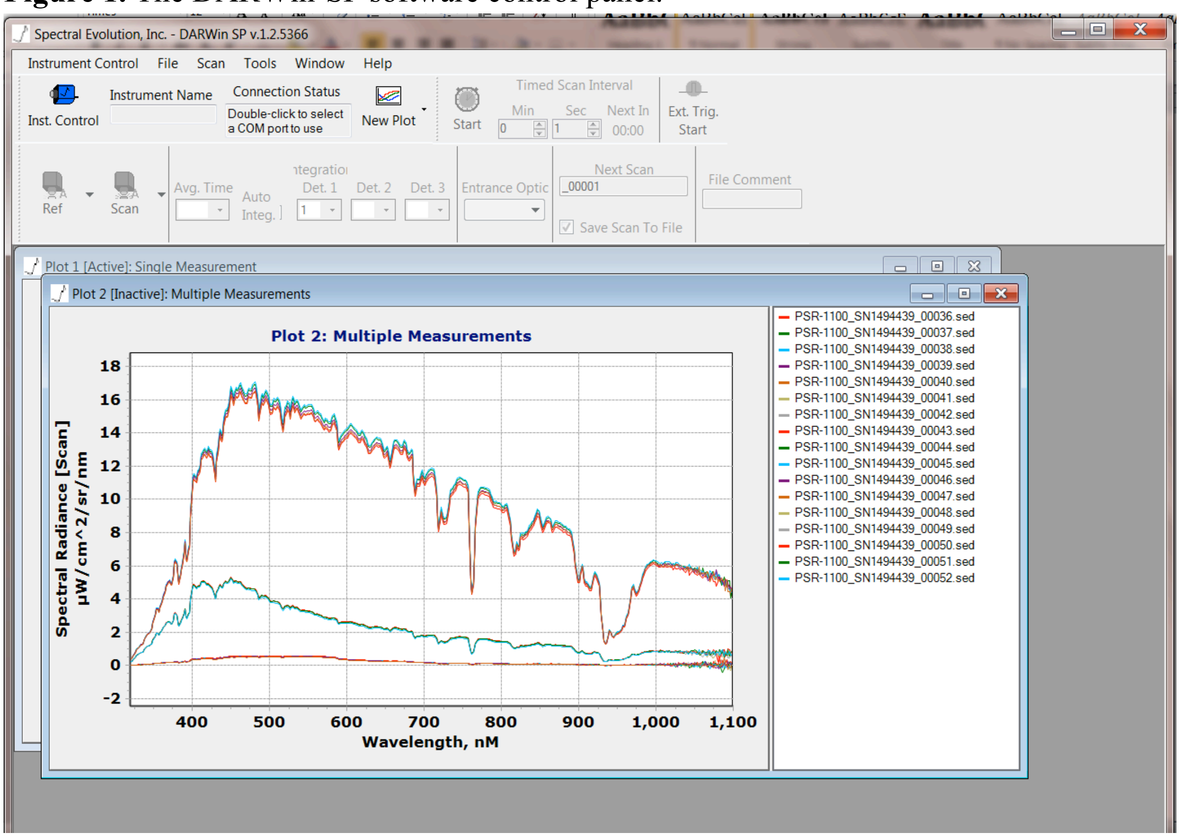
1. Hardware Setup

Set up computer in a secure place (rubber mat, tie down as needed) near the back of the lab next to the fantail. Attach the power supply and turn on computer, make sure it has the Bluetooth adapter plugged in. Set out PSR-1100F in a secure place and turn on 15 minutes before first station. Check voltage, if 8.0V or less turn the PSR-1100F off and take the battery out and replace it with a fully charged battery. **(Always make sure the PSR-1100F is off when replacing the battery.)** Set up battery charger and charge spare battery. Attach carry strap to PSR-1100F. Attach the small end of the fiber optic probe (in case lid) to the PSR-1100F Attach the 8 Deg. Field-of-view lens to the end of the fiber and then attach probe end to the holder on the end of the stick. Secure the fiber optic cable to the holder with electrical tape. Place the PSR-1100F in secure location for storage between stations making sure to protect the fiber-optic cable from damage. Get the white plaque out and make sure it is clean. Leave it in the plastic bag in a secure location. Set up your camera for taking pictures for each station.

2. Software Setup

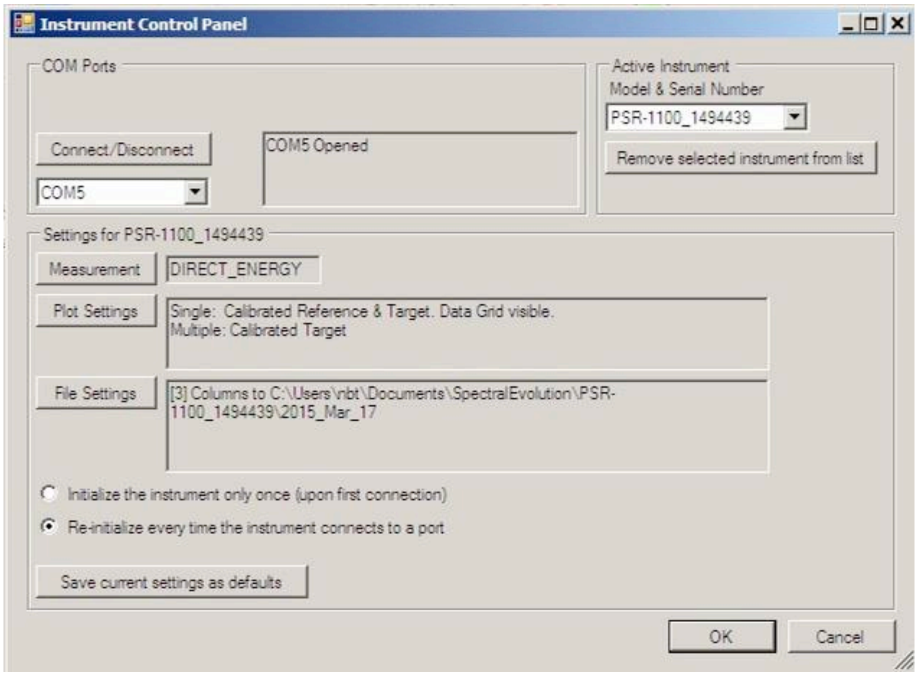
Turn on Computer. Turn on DARWin-SP software (Figure 1).

Figure 1. The DARWin-SP software control panel.



Open the instrument control panel (Figure 2). Set to use the calibration file for the 8 Deg. Lens. Make sure the measurement is set on DIRECT ENERGY. Connect to PSR-1100F using com port 5. It will take two tries. Once it is connected click ok.

Figure 2. The DARWin-SP Instrument Control Panel.



3. Shipboard Arrangements

Talk to the captain and explain the measurements you will be making. After you arrive on station you need the ship to be settled into a position where the sun is on the aft portion of the ship so that you can make the measurements at 90° azimuthal angle relative to the sun while avoiding any shadows from the ship. Explain that the measurements will take about 5 minutes. Recruit someone from the scientific party to click the **scan** button for each sample you collect, 5 samples with the white plaque, 7 samples of the sea surface and then 5 samples of the sky.

4. Data Collection

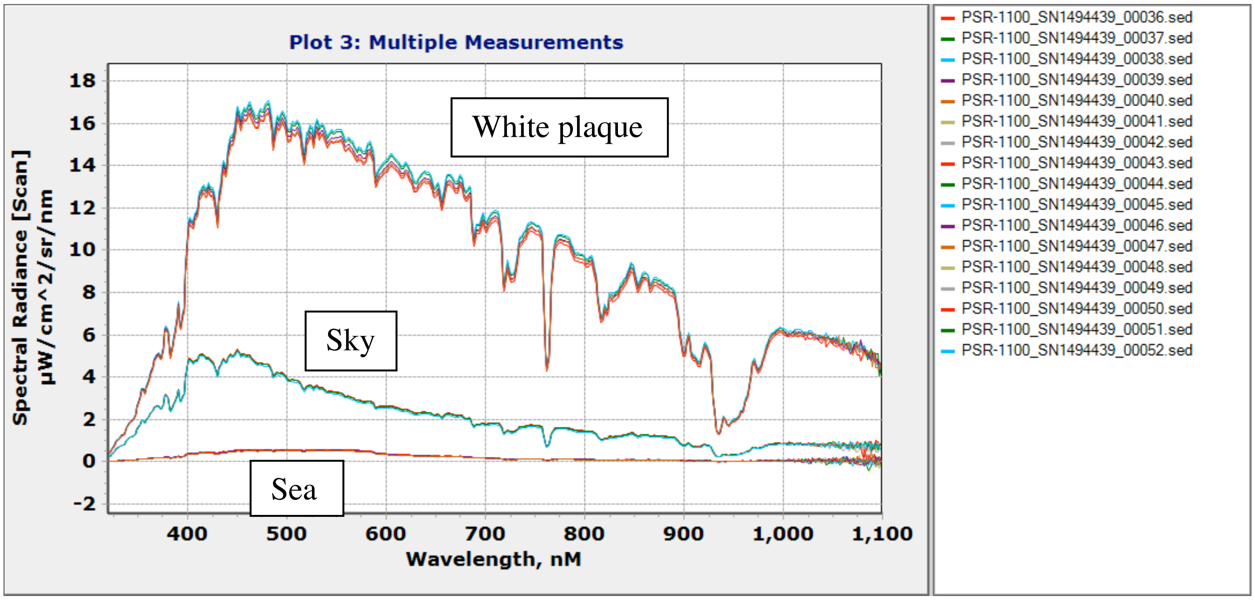
Once the ship is settled into a good position on station figure out where on the deck and in what direction you will take the samples. Find the 90° azimuthal angle relative to the sun then take a picture of the sea surface at approximately 40° nadir angle, the sky at 140° nadir angle, both zoomed in to approximate the 25° FOV of the fiber optic. Then take a wide view to show the horizon and if possible pick a feature on the shore to align to for the 90° angle. Log the station number, latitude and longitude, time of day, temperature and salinity, number of pictures taken and the first file number for the PSR-1100F files to be taken on that station.

Put on the PSR-1100F holding the stick with the fiber optic probe and take it and the white plaque out to the sample position and take 10 samples of the white plaque using the standard view angles of 40° nadir angle and 90° azimuthal angle relative to the sun. The wooden handle is cut at the 40° nadir angle, so when it is level you are at the correct angle. Have someone click the scan button for each sample you collect. You will see that it is collecting data on the screen of the PSR-1100F and count the 5 collections. Return the white plaque to its storage position in the cabin. Return to the sampling station and collect 10 samples of the sky at the 140° nadir angle and 90° azimuthal angle relative to the sun. then keeping it level rotate the stick 180° along the long axis so that it is pointing to the sea at the 40° zenith angle, 90° azimuthal angle relative to the sun and take 10 samples of the sea.

Figure 3. left to right, taking measurements of the white plaque, sea surface and sky. For the white plaque measurements the probe tip should be 4 to 6 inches from the plaque surface.

When sampling is complete return the instrument to a safe storage location. In the DARWin-SP software open the **file** pull down menu and select open stored data files and select all 17 files you just collected. Open a new multiple measurement plot window and it should look something like Figure 4. If you see any wildly different spectra then click on them and remove them. Then decide after removing them if you still have enough valid measurements. If for some reason you do not have at least three good measurements for each type of spectra then consider retaking the data for that station.

Figure 4. Example multiple measurements plot for a station with 17 good measurements.



5. Wrap up

After the last station for the day turn the PSR-1100F off and take the battery out and replace it with a fully charged battery. (Always make sure the PSR-1100F is off when replacing the battery.) Put the used battery on the charger, it will take about 2-3 hours to fully charge. Back up all of the data and pictures for the day on a USB drive. At the end of the day secure the computer and all of the equipment in the travel cases and store it out of sight or take it off the ship.

Above Water Reflectance Daily Log Sheet

Cruise Name: **Date:**
Project and PI:
Ship:
Chief Scientist:
Instrument Operator:

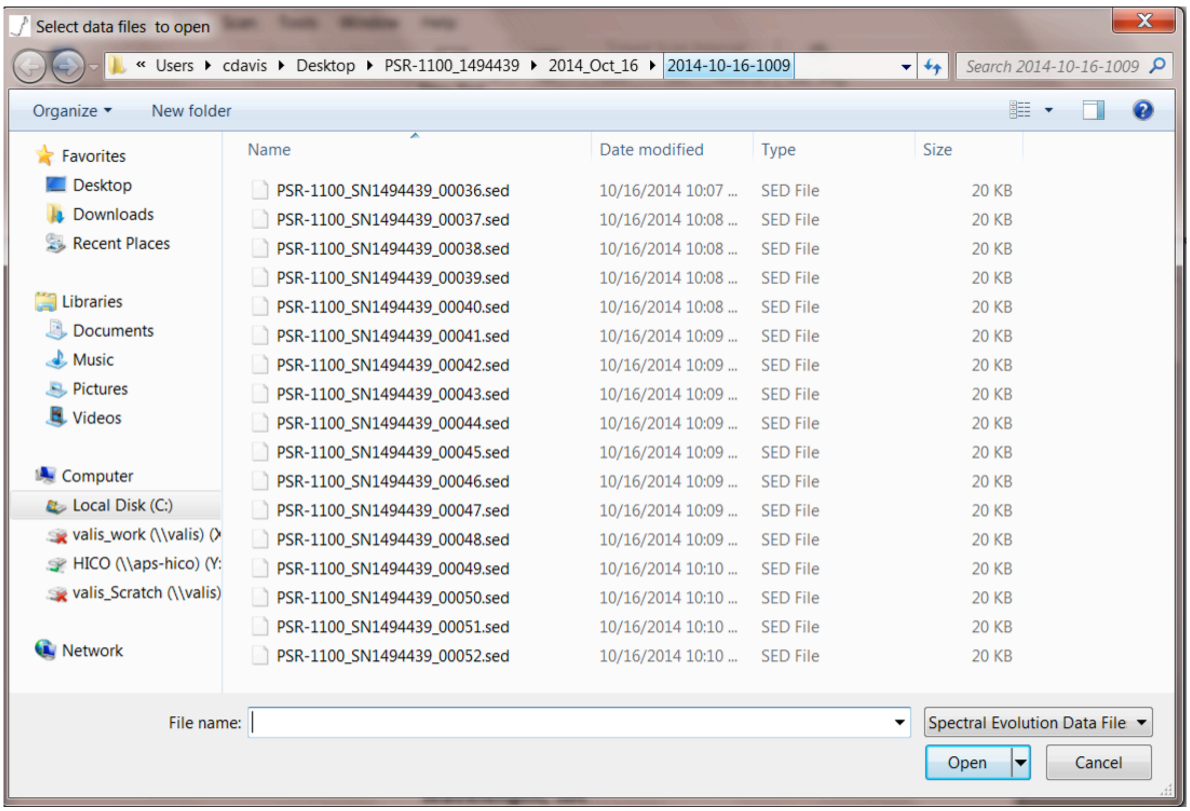
Time	Station	T° C	PSU	HPLC	Latitude	Longitude	File #s	# Photos

NOTES:

Processing using DARWin-SP and Rrs_process-Opt-10-17-1117-new2 EXCEL Workbook

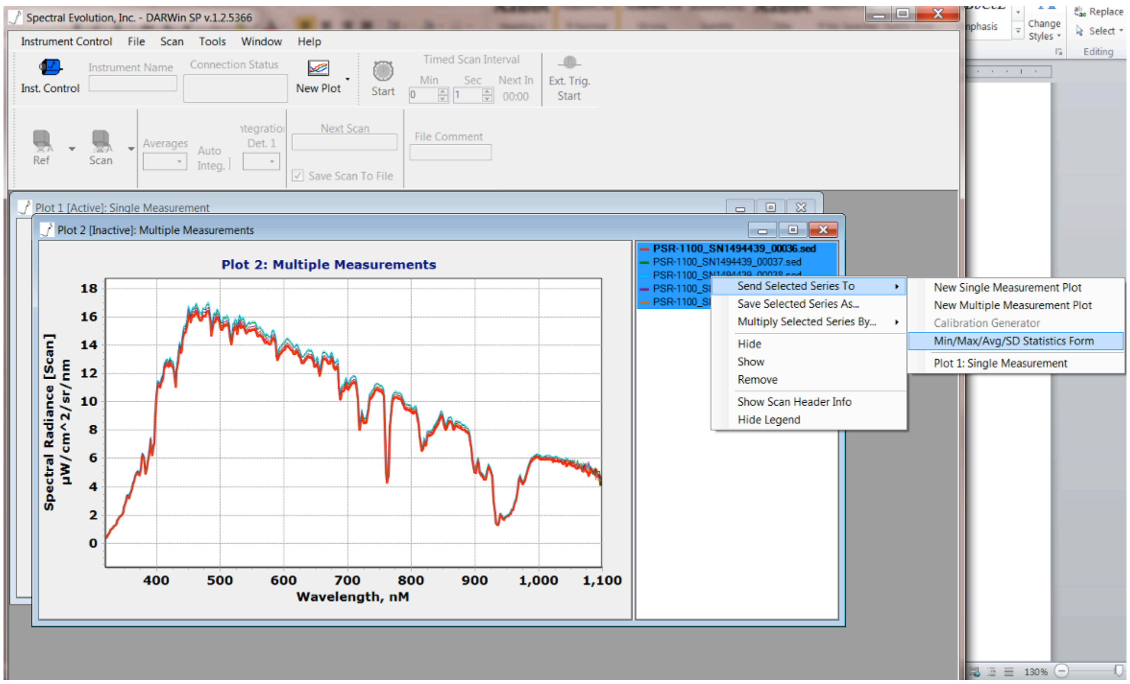
1. The DARWin-SP software automatically creates a folder for the data collected each day. At the end of the day go into that folder and create a folder for each station identified by year-month-day and time of day inside of that folder (Figure 5). Then move the files associated with that station into the new folder. Add a copy of Rrs_process-Opt-10-17-1117-new2 and rename it for the station you are processing e.g. for the example below it would be Rrs_process-Opt-2014-10-16-1009. I also add the pictures taken for that station to this file.

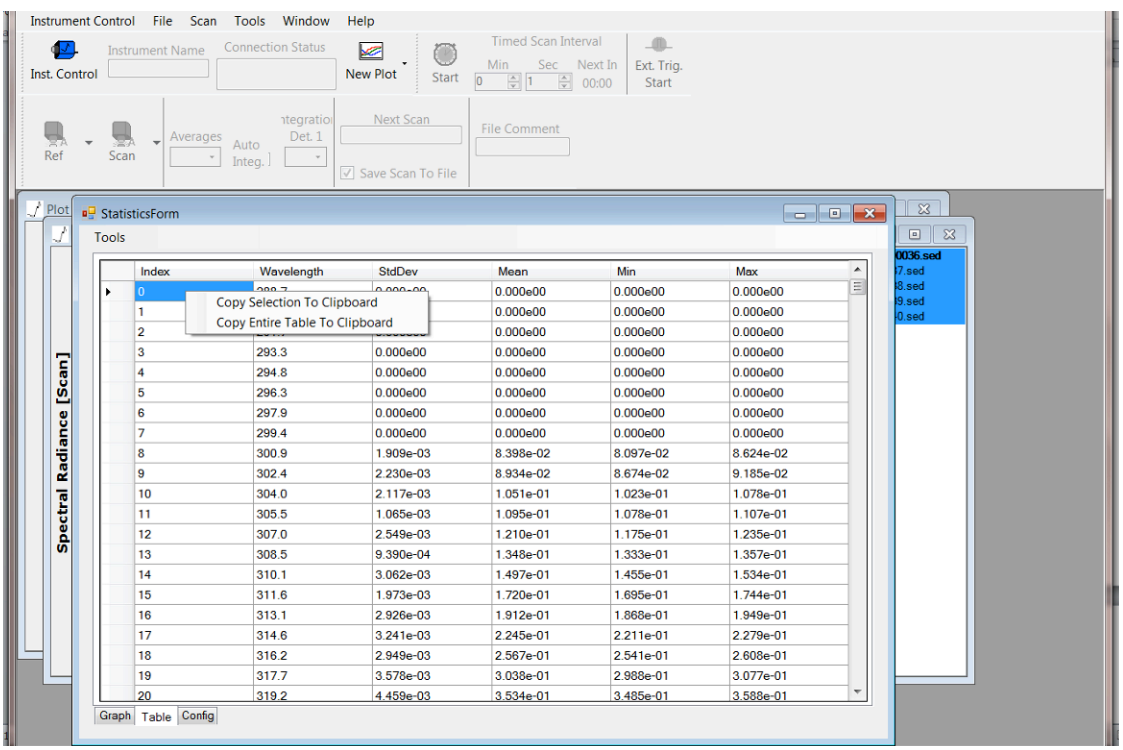
Figure 5. Example subfolder for one station opened in DARWin-SP using file pull down menu > open data file.



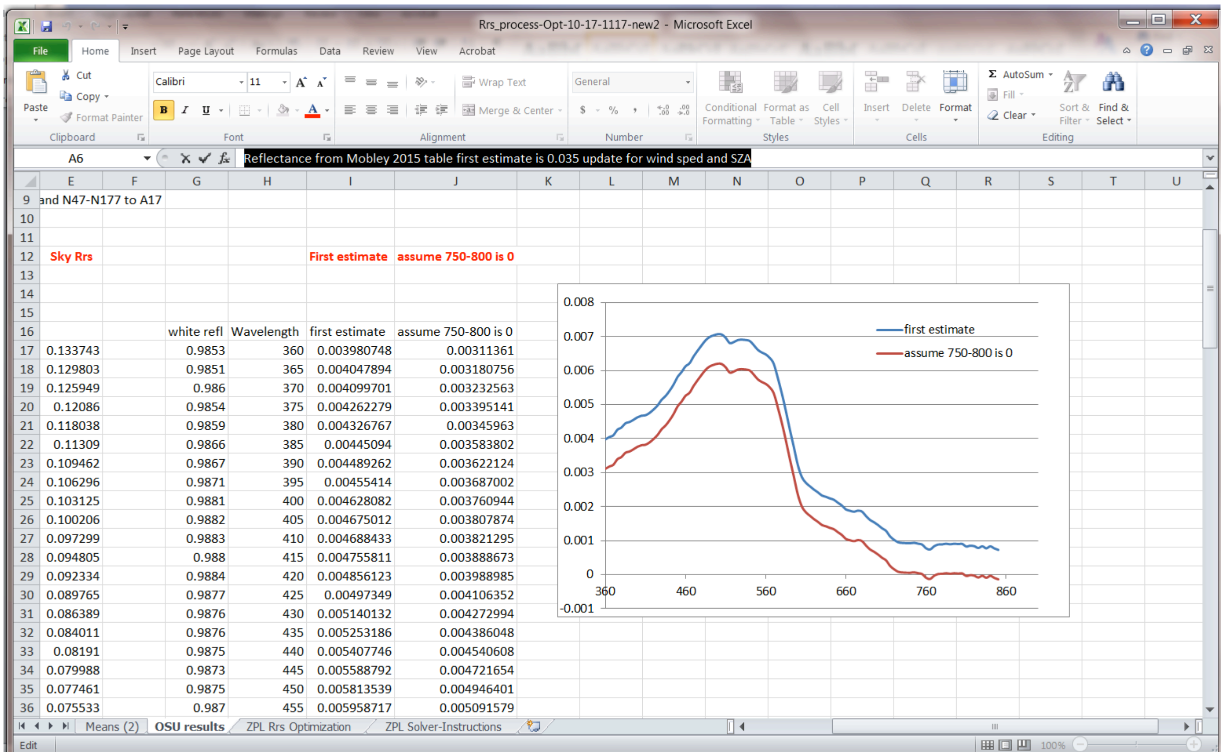
Use the DARWin-SP file pull down menu > open data file tool and then select the 5 white plaque files and view them in a multiple plot window. Remove any obvious outliers and then select all of the remaining ones and right click on the group and send them to the Max/Min/AVG/SD Statistics form. When the form comes up go to the bottom left corner of it and click on table. Then left click on the upper right corner of the table and select copy entire table to clipboard.

On the first page (means(2)) of the Rrs_process-Opt-10-17-1117-new2 workbook click on A27 where it says index under the title Mean White and paste the entire table. Do the same thing for the Mean Sea and Mean Sky tables. Now copy and **paste value** from Means (2) from M47-177 and N47-N177 onto the second spread sheet (OSU results) A17 (the entire table should go into the correct cells when you do this). **Be sure to use paste value; if you paste the formula there will be errors**. Then use the reflectance from Mobley 2015 (Table 1 in this document) update the value for wind speed and SZA for this station. The first estimate is 0.025 in cell I6 update that value for the conditions at this particular station.





The OSU results spread sheet calculates two results a first estimate and then a corrected estimate assuming that the minimum value from 750-800 nm should be 0 and subtracting that value (cell J6) from all wavenlengths.



To use the ZPL Rrs Optimization model follow the directions on that sheet and the solver instructions.