Uncertainty Budgets and Sources

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Uncertainty Sources in the Calibration and Validation Process

The natural divisions in exploring the uncertainties for the calibration and validation process can be considered as follows:
a) Deep ocean (Case-1) and coastal waters (Case-2)
b) Above- and in-water methods

The uncertainties involved can be considered within four general categories:

1. Calibration
   a) Irradiance (incl. immersion coefficients and cosine response)
   b) Radiance

2. Data Collection
   a) Platform perturbations (shading and reflections)
   b) Instrument perturbations (shading and tilting)
   c) Environmental perturbations (bottom and surface effects)

3. *In Situ* Stability
   a) Equipment
   b) Environment

4. Data Processing
   a) Above-water data (glint filtering, statistical parameters, etc.)
   b) In-water data (extrapolation interval, fitting parameters, etc.)

The SeaWiFS calibration and validation plan (Hooker and McClain 2000) relies on radiometric measurements made at sea by a diverse community of investigators. One of the long-standing objectives of the SeaWiFS Project is to produce spectral water-leaving radiances within an uncertainty of 5% (Hooker and Esaias 1993), and the sea-truth measurements are the reference data to which the satellite observations are compared (McClain et al. 1998). The accuracy of the field measurements are, therefore, of crucial importance.

If a total 5% uncertainty level is to be maintained for a vicarious calibration exercise (remote plus in situ instrumentation), approximately half of the uncertainty budget, i.e., 2.5% (actually if quadrature sums are used, the ground truth component is closer to 3.5%), is available for the ground truth component. Given the number of uncertainty sources, each component must have an uncertainty on the order of 1–2%, which is a state-of-the-art requirement.

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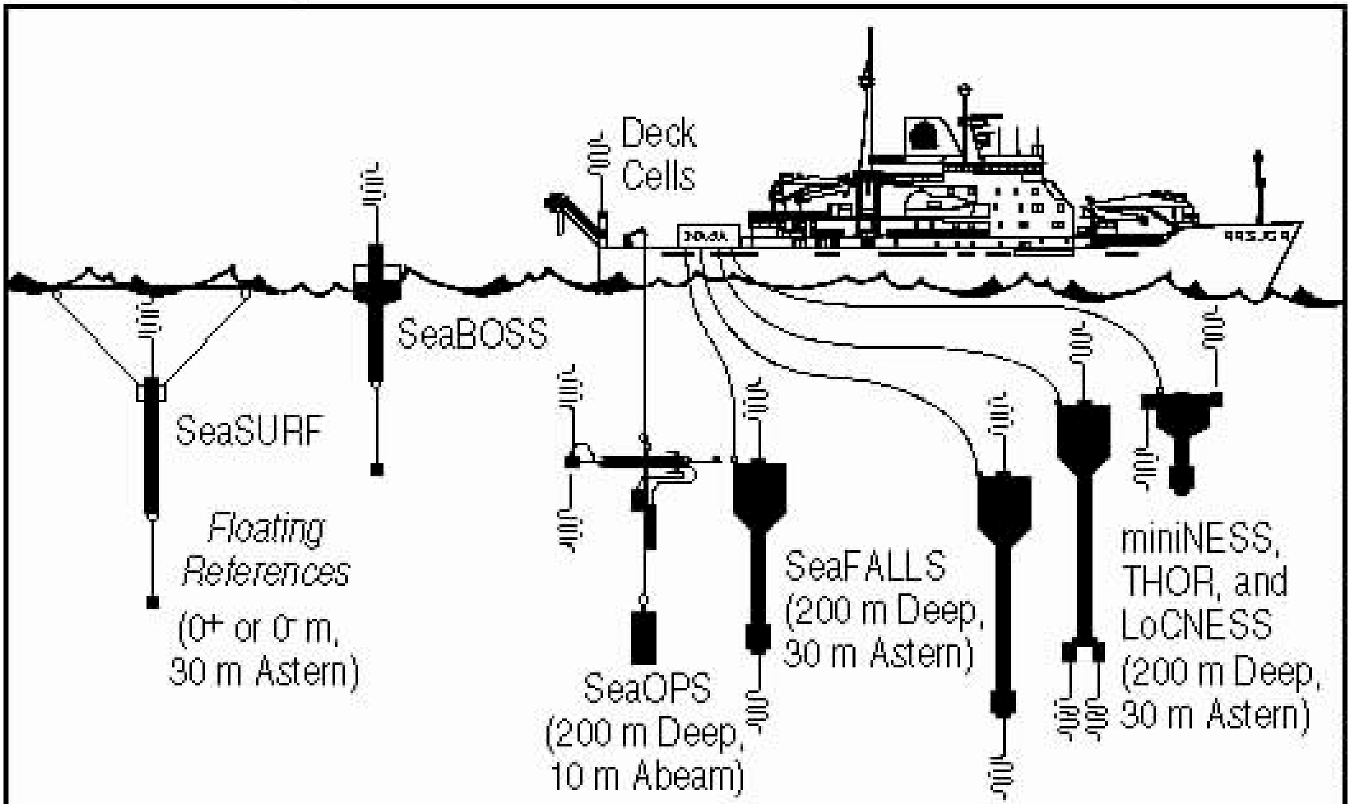
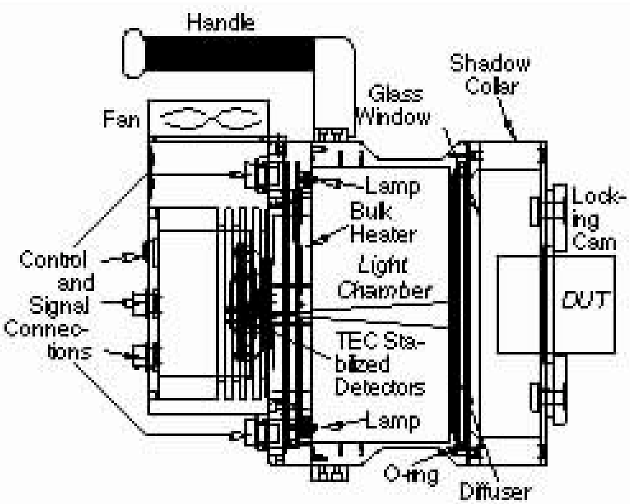
In-Water Data Uncertainties for SeaWiFS Validation





AMT Total Uncertainties

- All instruments calibrated at the same facility (Satlantic, Inc.) before and after all cruises.
- All profiles processed with the same data processor.
- All instruments monitored for stability in the field with the SQM.
- Multiple data collection methods used with a variety of techniques.

Source of Uncertainty	*SeaOPS w/Deck Cell*	*LoCNESS w/Deck Cell*	*SeaFALLS w/SeaSURF*	*SeaFALLS w/SeaBOSS*	*SeaFALLS w/Deck Cell*
Calibration	1.5%	1.5%	2.0%	2.0%	2.0%
Data Processing	2.0	2.0	2.0	2.0	2.0
In Situ Stability	1.0	1.0	1.0	1.0	1.0
Data Collection	2.0	0.5	4.0	2.0	1.0
Quadrature Sum	3.4%	2.7%	5.0%	3.6%	3.2%

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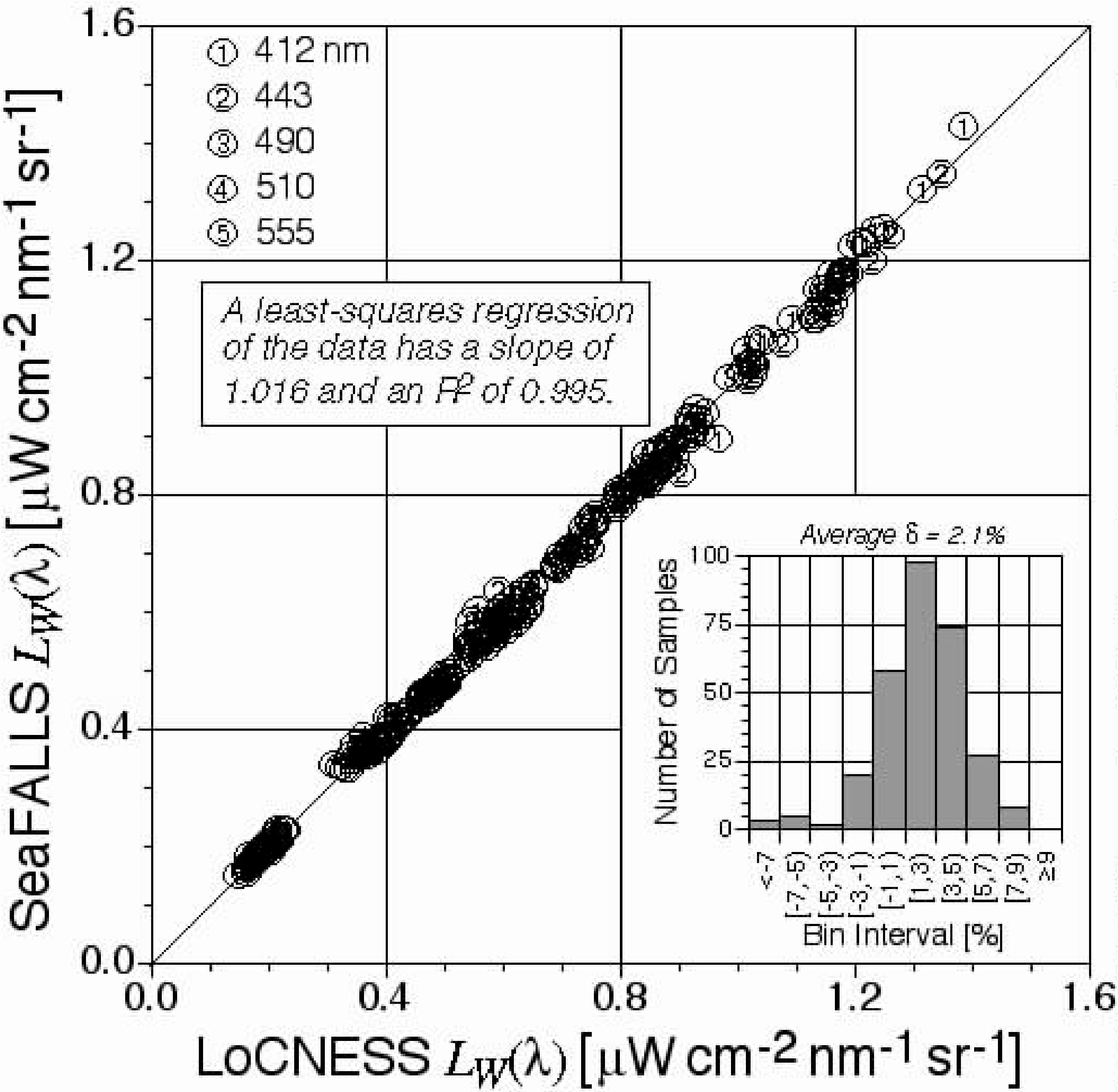
Intracomparison of the PROSOPE In-Water Optical Instruments



The intracomparison of the two in-water, free-fall profilers (LoCNESS and SeaFALLS) shows they agree at approximately the 2% level over the 412–555 nm spectral range for the entire cruise period. This is approximately at the level of the laboratory (Satlantic) calibrations (Hooker et al. 2001), so this represents a state-of-the-art accomplishment. The δ value is the unbiased percent difference (UPD) between the water-leaving radiances derived from the two in-water profilers:

$$\mathrm{UPD} = 200|X-Y|/(X+Y).$$

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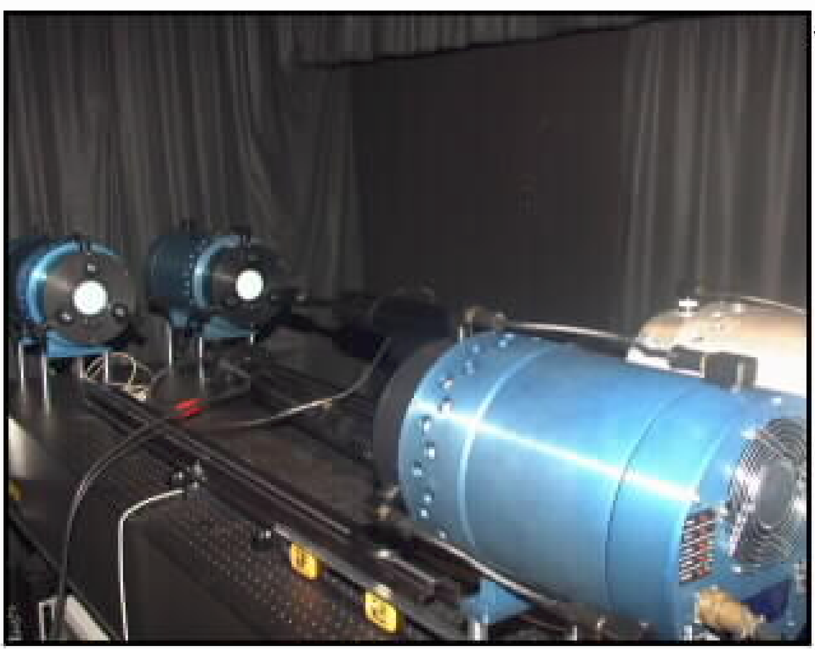
The Seventh SeaWiFS Intercalibration Round-Robin Experiment (SIRREX-7)

Satlantic built a special mapping (narrow field of view) radiometer for determining the homogeneity of the SQM-II exit aperture. This radiometer was used during SIRREX-7 to map the homogeneity of 7 plaques. The plaques had different ages, sizes, color, etc., but all were in use for calibration or field experiments.

The SeaWiFS Transfer Radiometer (SXR) was used as an independent absolute detector to estimate the uncertainties in 1) lamp standards, 2) plaque standards, and 3) radiance calibrations.



Additional experiments were conducted to estimate the uncertainties associated with 4) irradiance calibrations, 5) the absolute calibration of SeaWiFS Quality Monitors (SQM and SQM-IIs), 6) rotation effects, 7) polarization effects, and 8) bidirectional effects.

More than 200 experimental trials were conducted.

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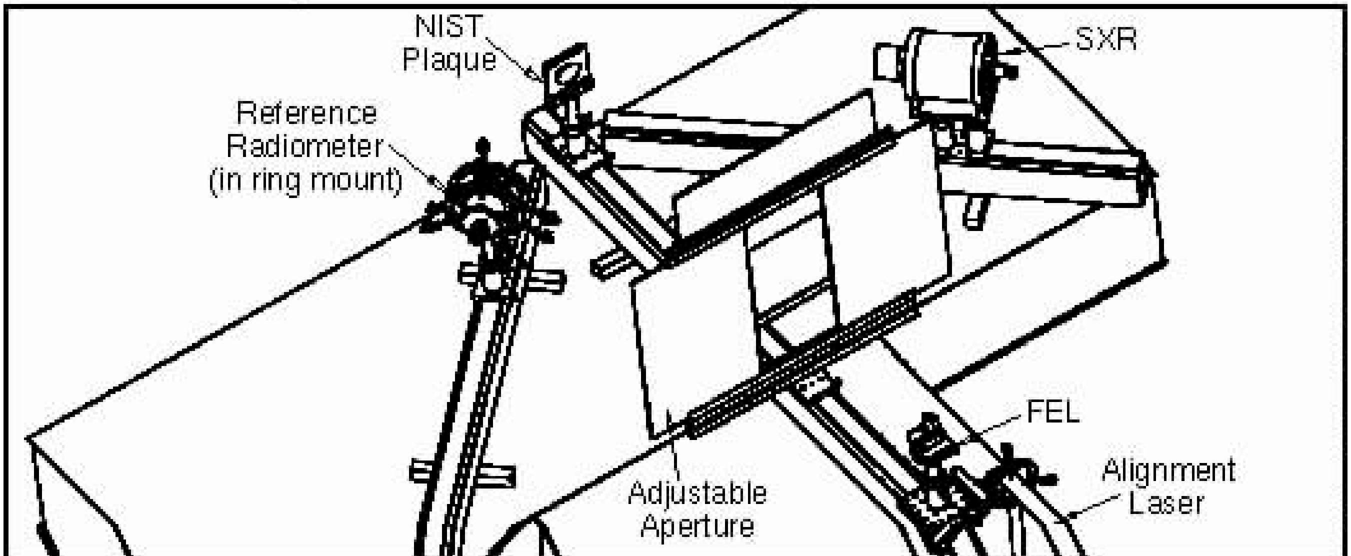
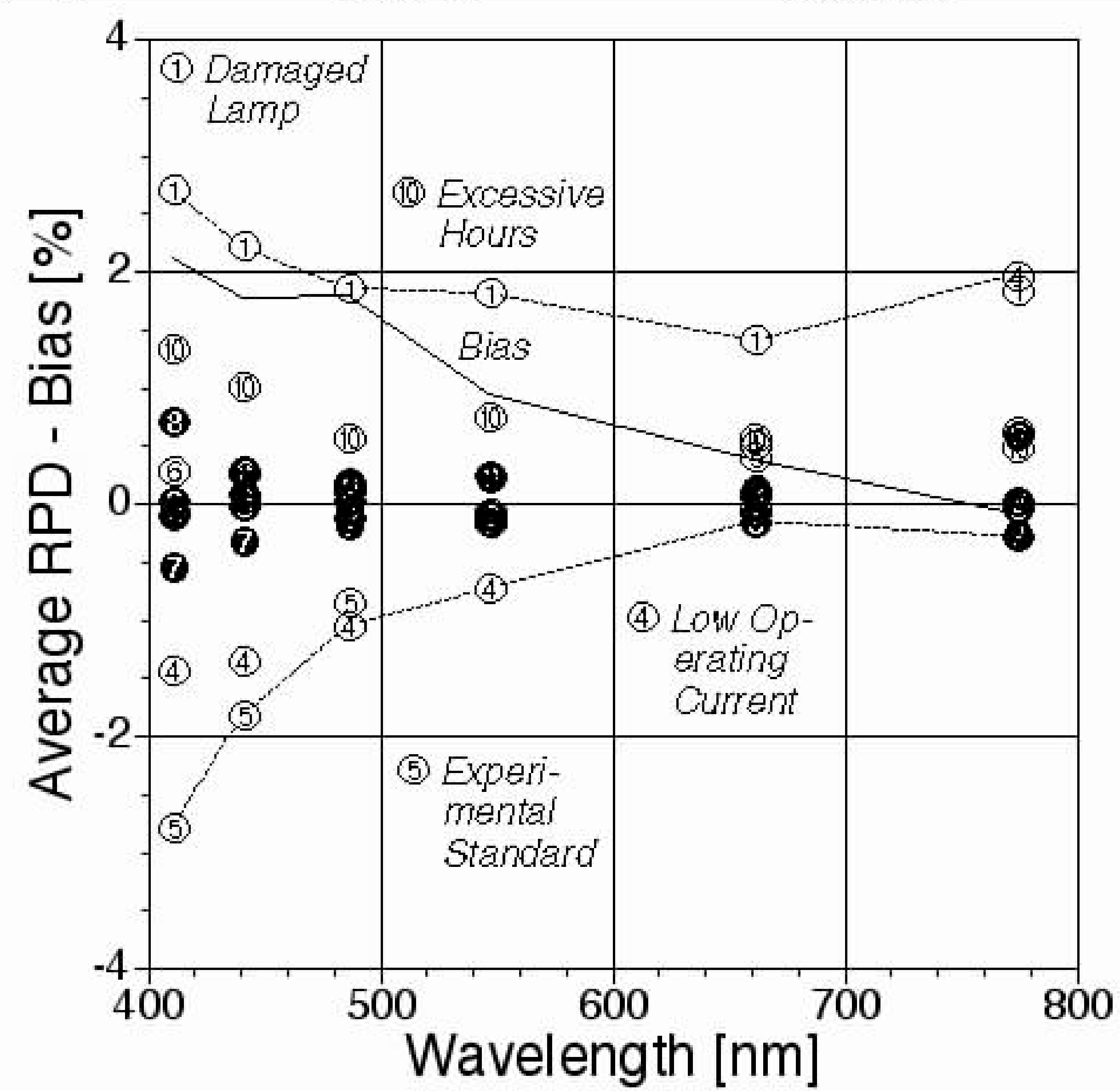
Uncertainties in SIRREX-7 Lamp Irradiances





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Total Uncertainties in SIRREX-7 Radiance and Irradiance Calibrations

A combined uncertainty budget for radiometric calibrations can be constructed from the SIRREX-7 data set. Although it is comprehensive, it does not address every source of uncertainty at the same level of detail and some must be considered as approximate. Nonetheless, sufficient care was taken at all levels of the experimental process to ensure the uncertainty estimates are at least representative of what can be expected if careful metrology and practices are adhered to. Perhaps just as importantly, the consequences of discrepancies are also well estimated.

Source of Uncertainty	*Rank*	*Irradiance*	*Radiance*
NIST Lamp Standard	1	1.0%	1.0%
Secondary Lamp Standard	2	+1.0	+1.0
Excessive Lamp Age (more than 60 h)	3	+1.0	+1.0
Excessive Lamp Wear	3	+2.0	+2.0
Positioning Discrepancies	2	+1.5	+1.5
Unseasoned Lamp	3	+0.5	+0.5
Low Lamp Operating Current	3	+1.0	+1.0
Mechanical Setup	1	0.5	0.5
Sensor Rotational Discrepancies	2	+0.5	+0.5
Alignment Discrepancies	2	+0.5	+0.5
Inadequate Baffling	2	+0.5	+0.5
NIST Plaque Standard	1		1.0
Secondary Plaque Standard	2		+1.0
Excessive Plaque Age	3		+2.0
Excessive Plaque Wear	3		+4.0
Non-White (Doped) Plaque	3		+2.0
Rank 1 Only	*Minimum Quadrature Sum*	1.1%	1.5%
Ranks 1 and 2	*Typical Quadrature Sum*	2.3	2.7
Ranks 1, 2, and 3	*Maximum Quadrature Sum*	3.4	6.3

Ranks 1 and 2	*Satlantic Quadrature Sum*	1.8%	2.3%

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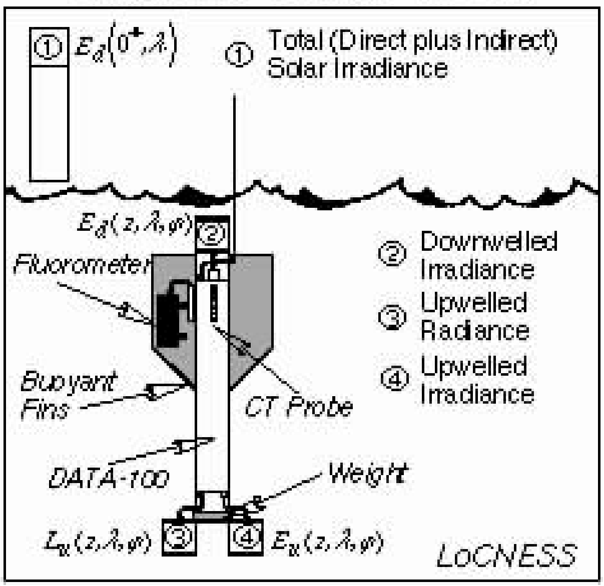
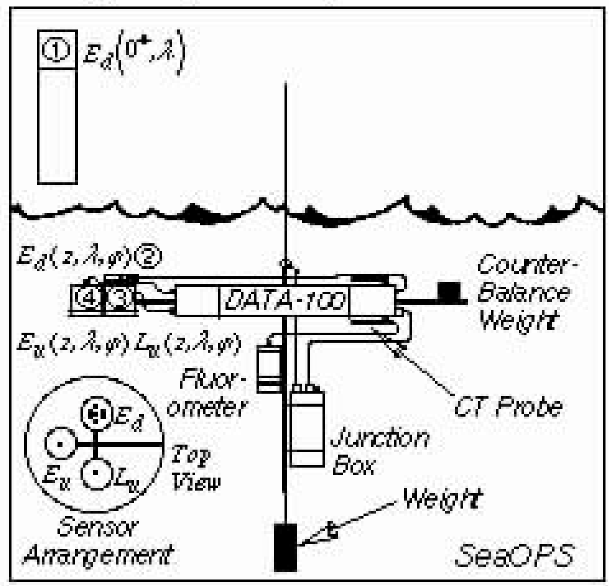
The Second SeaWiFS Data Analysis Round Robin, March 2000 (DARR-00)

- Three processors: 1) GSFC , 2) JRC, and 3) Satlantic (ProSOFT).
- Ten casts each from four different sampling systems used in two different oceanic regimes , deployed from two different platforms, plus 10 more from very clear deep ocean sites.
- The principal difference in the sampling system types is a) the vertical resolution, and b) the stability of the reference sensors.
- Nine spectral variables and a blue-green band ratio were intercompared: $L_u(0^-)$, $E_d(0^-)$, K_L, K_d, $E_d(0^+)$, R_{19} $[L_W]_N$, $E_u(0^-)$, and $Q_n(0^-)$.

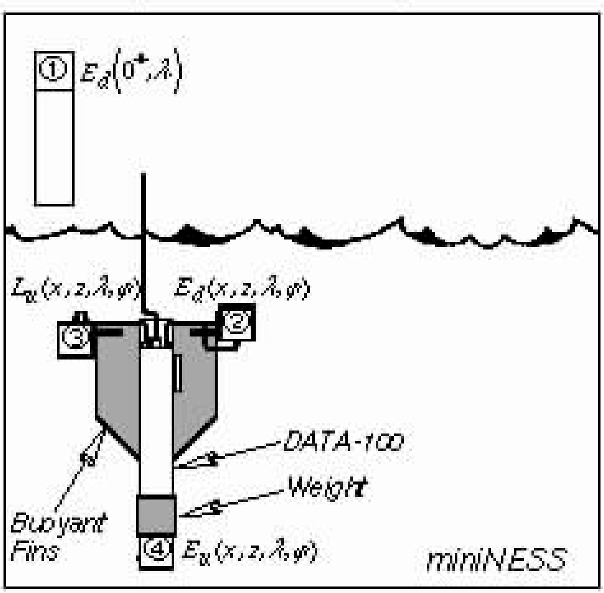
Ship, Deep Ocean, Free Fall



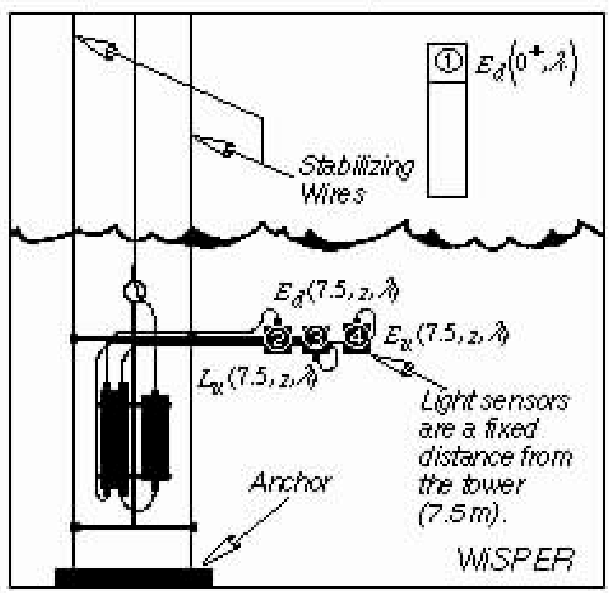
Ship, Deep Ocean, Winch & Crane



Tower, Shallow Coastal, Free Fall



Tower, Shallow Coastal, Winch & Crane



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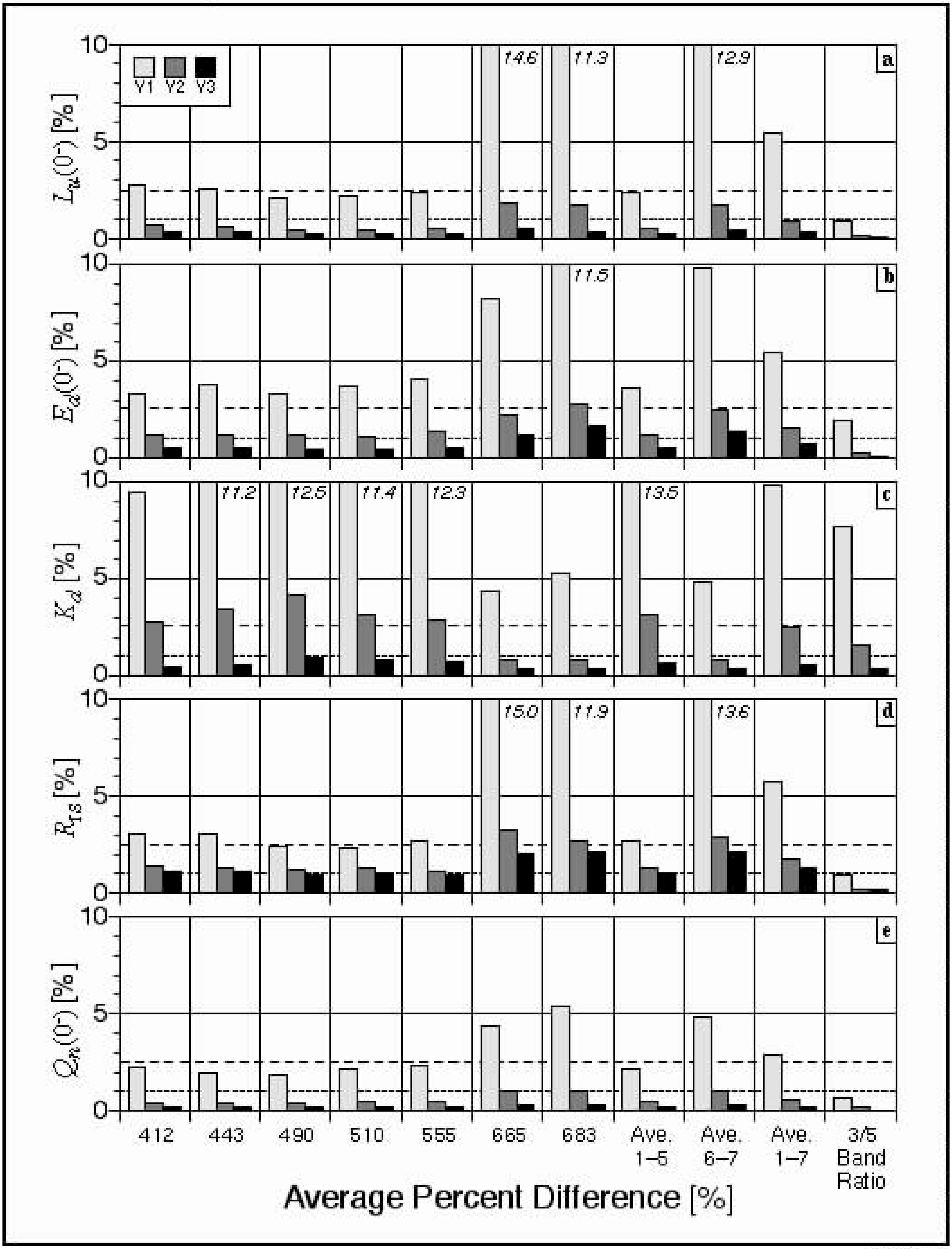
Convergence in the Percent Differences for JRC and GSFC Intercomparisons



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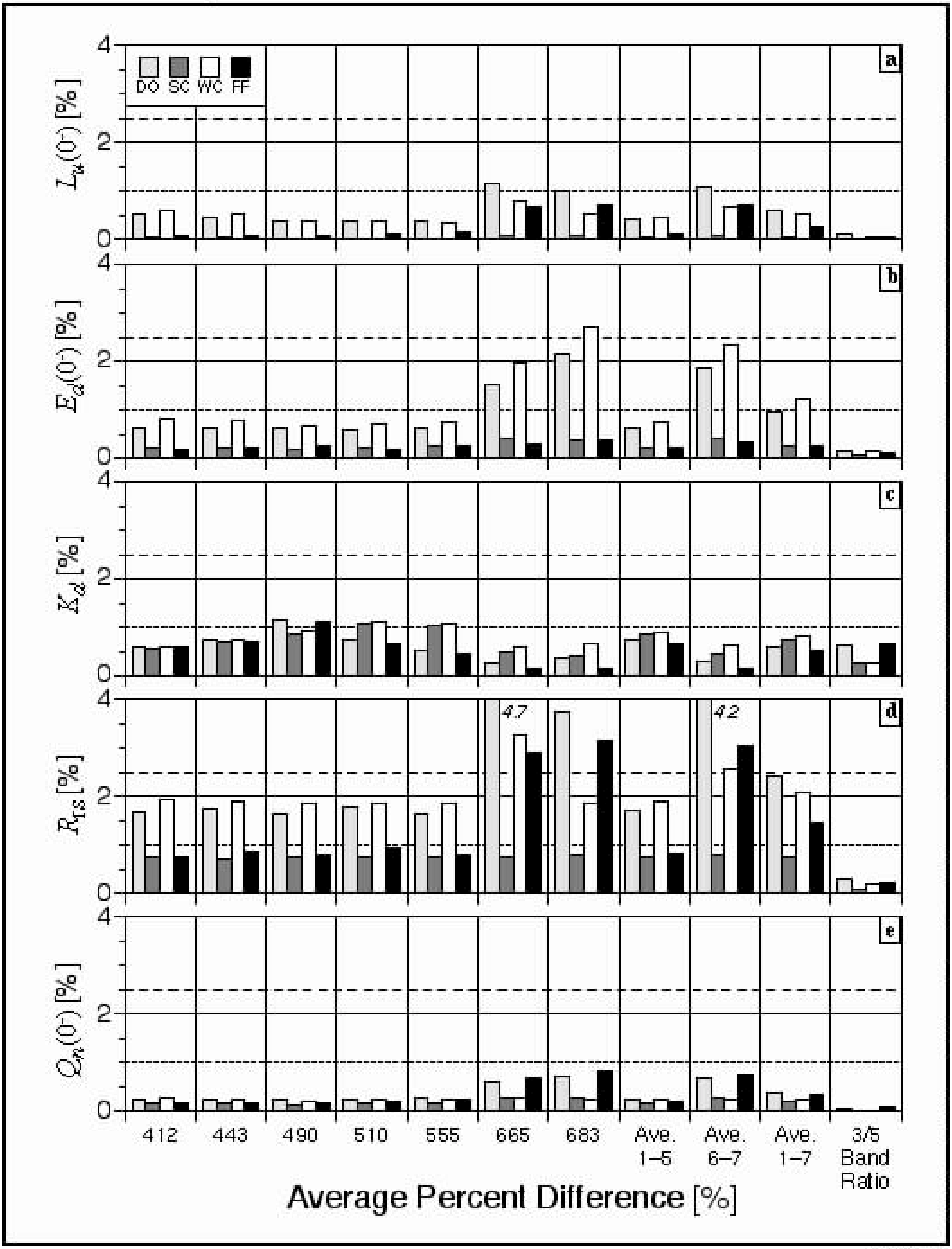
Final JRC and GSFC Percent Differences for Oceanic and Instrument Types



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Tower Perturbation Experiment at the *Acqua Alta* Oceanographic Tower

In order to measure the water-leaving radiance as a function of sampling distance from the measurement platform, the JRC designed and built an instrument support system for the GSFC micro Surface Acquisition System (microSAS) that could be extended up to 11 m from the side of the *Acqua Alta* Oceanographic Tower (AAOT).

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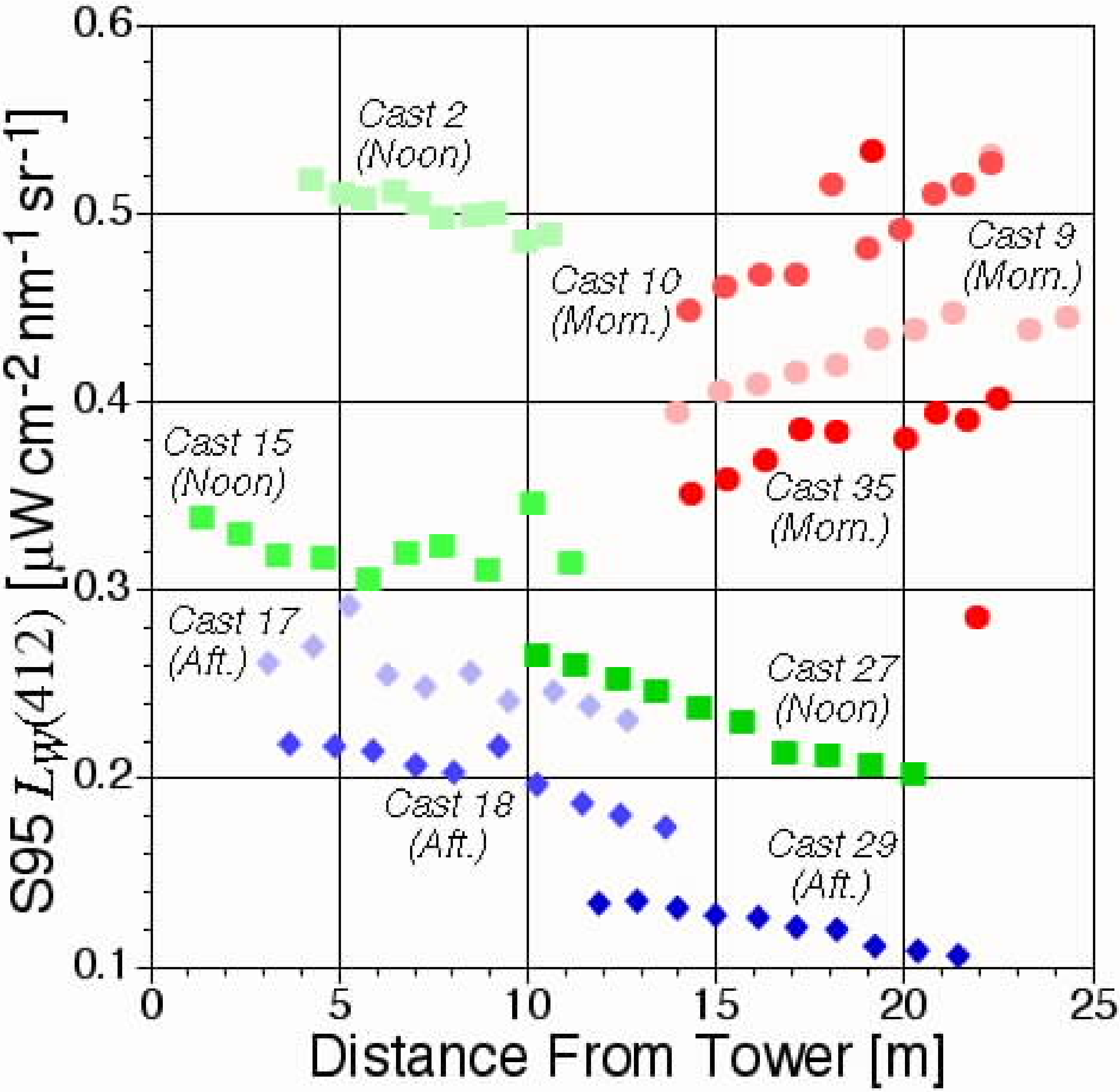
Above-Water Estimates of Water-Leaving Radiances in the Vicinity of the AAOT

The water-leaving radiance is computed using the formulation in the SeaWiFS Ocean Optics Protocols (Mueller and Austin 1995),

$$L_W(\lambda) = L_T(\lambda) - \rho L_{sky}(\lambda)$$

(assuming the pointing requirements with respect to the sun are satisfied). For the tower perturbation campaign, 42 separate above-water experiments, composed of 435 casts, were conducted during simultaneous deployments of three in-water sampling systems. A subset of the above-water measurements taken during the morning, noon, and afternoon are shown below.



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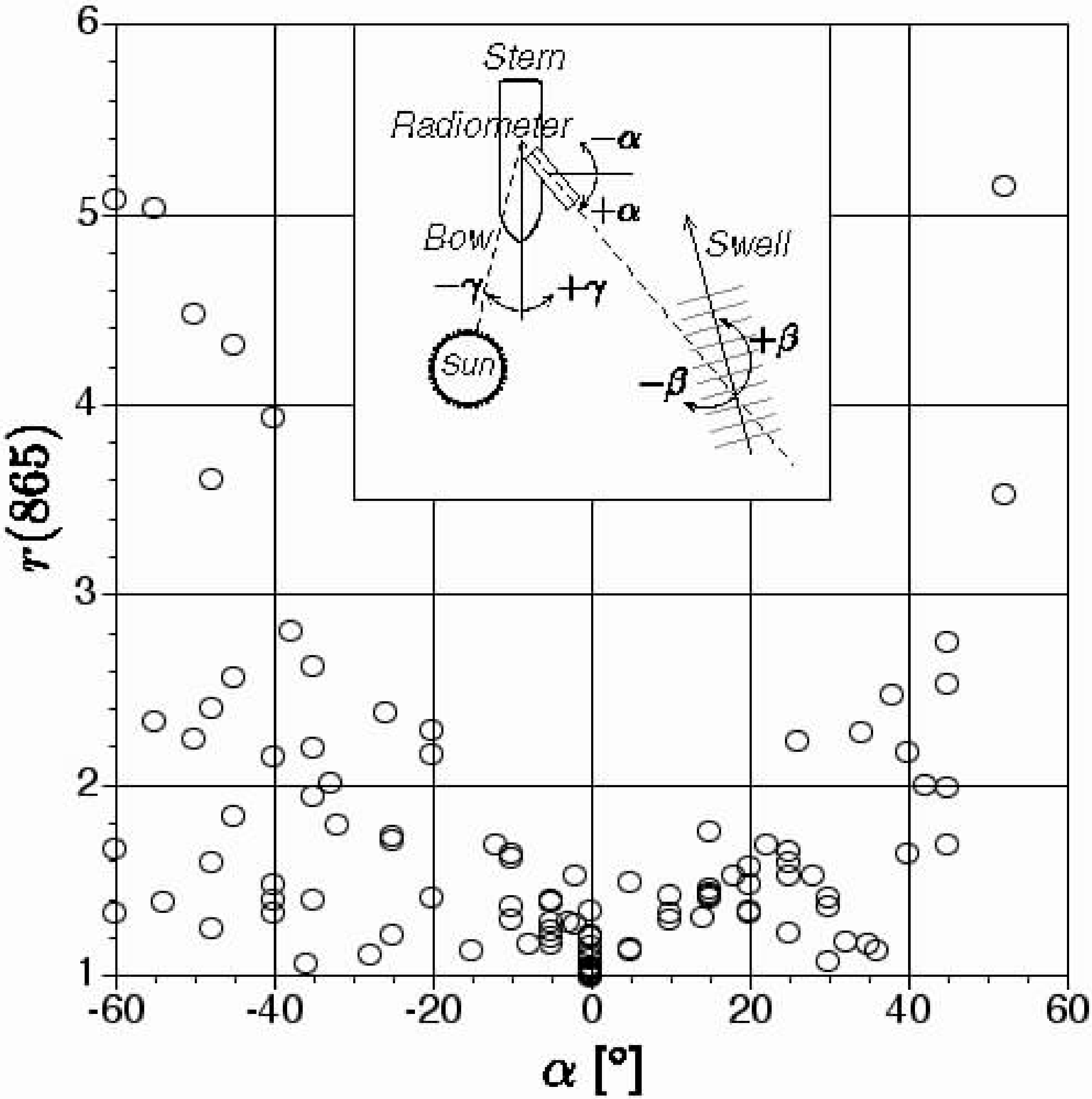
Detecting Platform Perturbations with Two Above-Water Protocols

If the Morel (1980) and Mueller and Austin (1995) methods for above-water measurements of water-leaving radiance are used together, it is possible to detect platform perturbations in Case-1 conditions. What is required is the ratio of the two surface reflectances from each protocol (Hooker and Morel 2002):

$$r(865) = \frac{L_T(865)/L_{\mathrm{sky}}(865)}{\rho}$$



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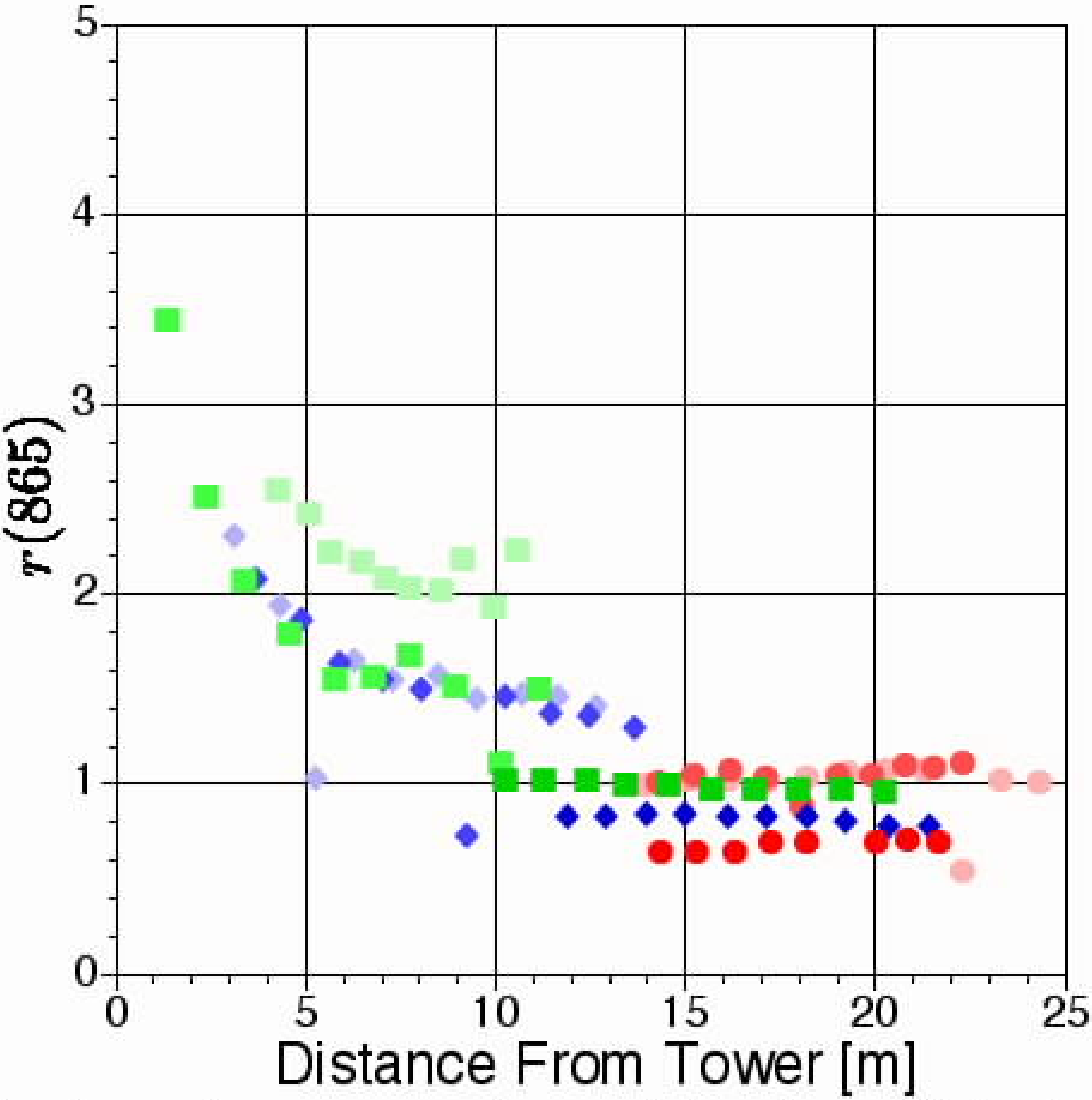
Estimation of AAOT Platform Perturbations

Although the r(865) parameter was originally designed to detect platform perturbations in Case-1 conditions, it can be used in Case-2 waters if the measurements are conducted over a short enough time interval that r(865) is not changing due to spatial heterogeneity. In this case, r(865) will not have a value of 1, but it should have a constant value, so changes in r(865) are a direct measure of platform influence on the above-water estimates of water-leaving radiance.



The above-water measurements were taken at an altitude of approximately 13 m. The platform perturbations are significant within 10 m of the tower, so as long as the surface spot is on the order of the viewing altitude, tower perturbations are minimized (this was also seen with the ship-based experiments).