QUANTITATIVE ESTIMATION OF VARIABILITY IN THE UNDERWATER RADIANCE DISTRIBUTION (RADCAM)

Marlon R. Lewis, Principal Investigator
Ronnie Van Dommelen, Co-Investigator
Jianwei Wei, Ph.D. Candidate

Satlantic, Inc. &
Dalhousie University

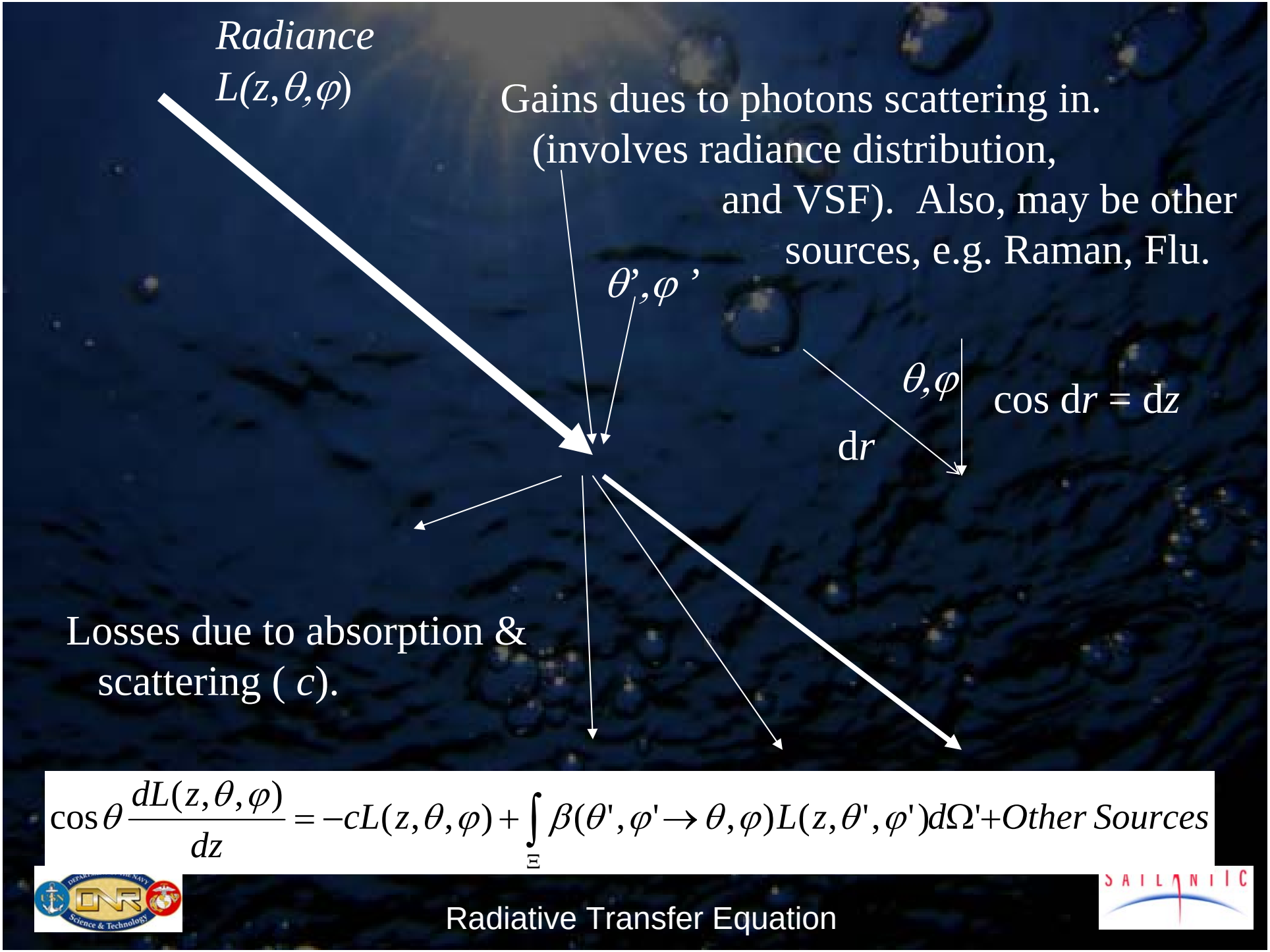
Ken Voss (U.Miami), Ping Lee (ug student, physics), May Hammad (ug student,eng) Brian Bylhouwer (ug student, physics), Ruby Quan (M.Sc. Student, maths), Scott McLean (U.Victoria),

Underwater Radiance Field

- *"Spectral radiance is the fundamental quantity of interest in hydrologic optics….all other radiometric quantities can be derived from (this)"* Mobley, 1994

- In principle, all of the apparent and inherent optical properties as well can be derived from a measurement of the radiance field and its gradient in the upper ocean.

- Modelling the dynamic radiance distribution is what made *Avatar* possible (Weta Digital)



$$\cos\theta \frac{dL(z,\theta,\varphi)}{dz} = -cL(z,\theta,\varphi) + \int_{\Xi} \beta(\theta',\varphi' \rightarrow \theta,\varphi) L(z,\theta',\varphi') d\Omega' + Other\ Sources$$

Radiative Transfer Equation

Measurement of the Radiance Distribution

- Despite this fundamental importance, few measurements of the radiance field have been made at sea.
- For RaDyO we have developed and deployed novel instrumentation for the quantitative measurement of the time and depth dependent radiance distribution fields in the upper ocean (RADCAM), and are carrying out scientific analyses of sources of variability.

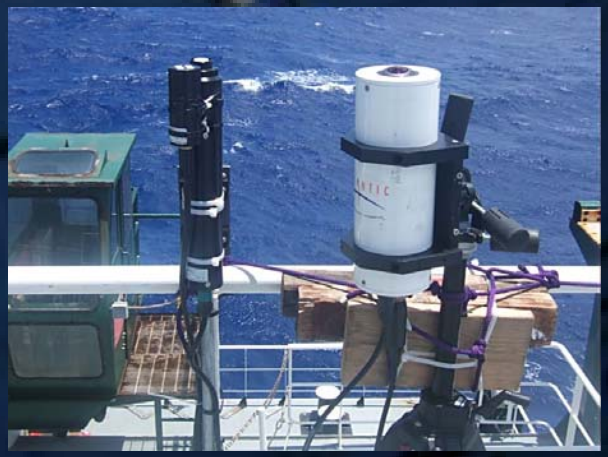
Measurement of the Radiance Distribution

- RAD-CAM uses recent advances in CMOS imaging technology to provide instrumentation for investigation of the underwater radiance field.

- High scene-dynamic range (10^5-10^6) system dynamic range (10^9)
- 550nm center wavelength, 20nm bandpass
- 1 degree resolution, ~8 Hz

Camera Systems

Profiling RadCam



Irradiance Sensors and In-Air RadCam

Logging RadCam on Bluefin

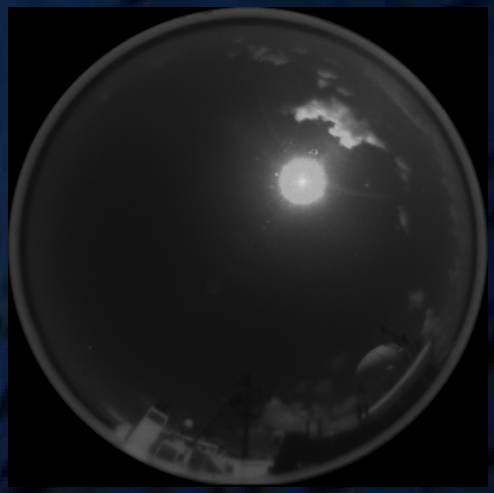
Logging RadCam on Mascot

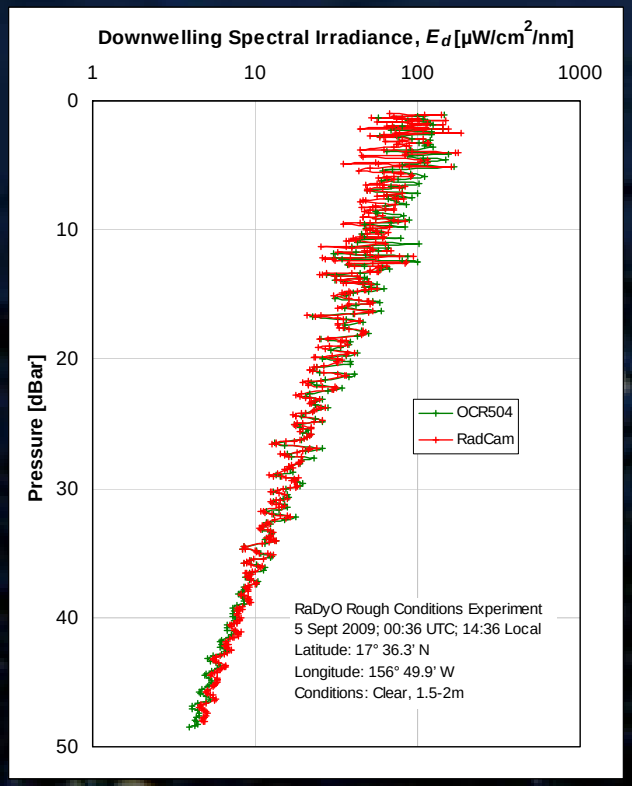
Deployments

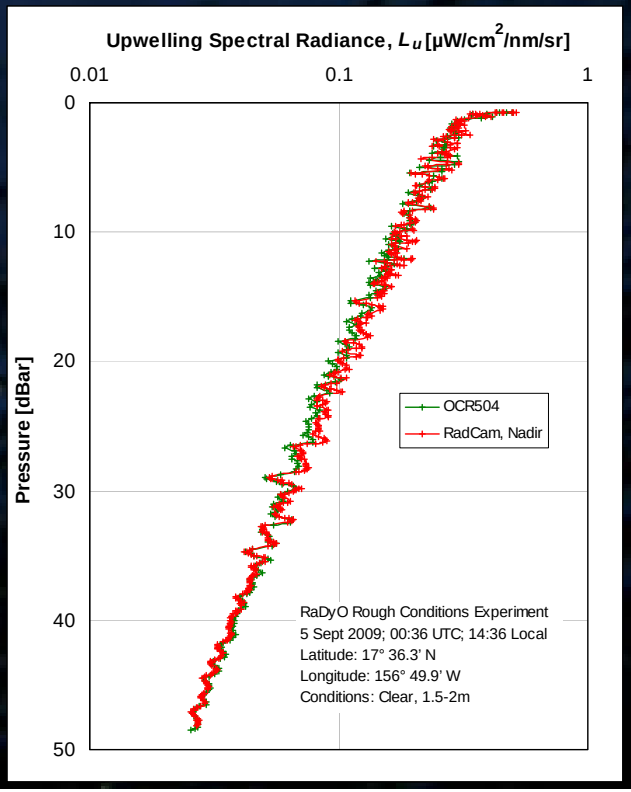
- Oligotrophic: South of Hawaii: RaDyO High Seas Conditions
- Mesotrophic: Santa Barbara Channel: RaDyO Benign Conditions
- Eutrophic: Bedford Basin, Nova Scotia: Test and Evaluation

Oligotropic Environment

Hawaii - Clear Sky

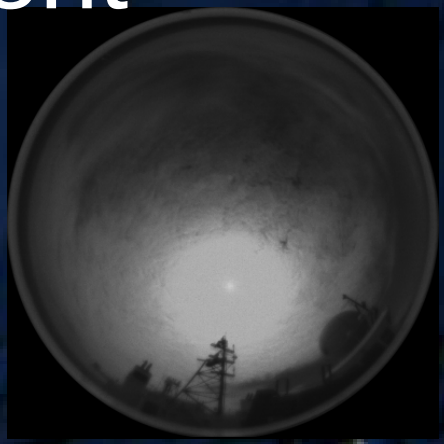


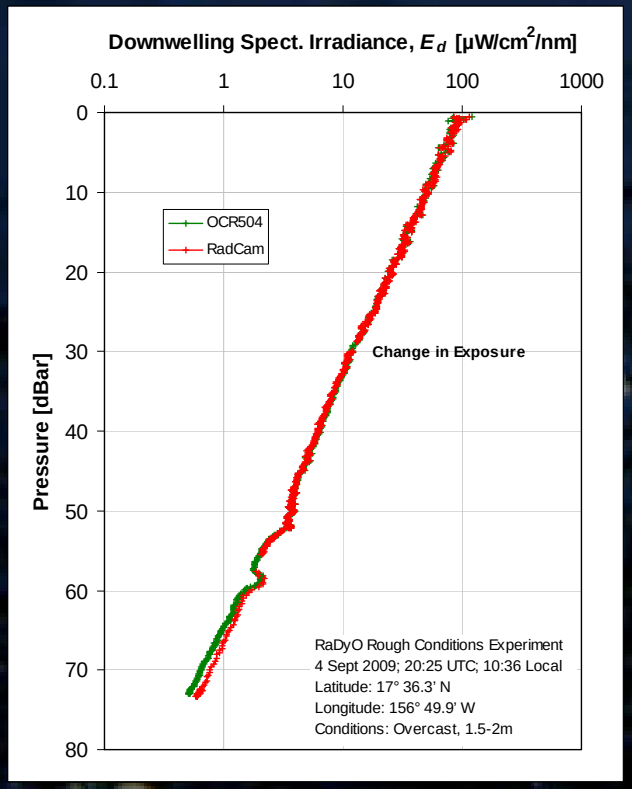


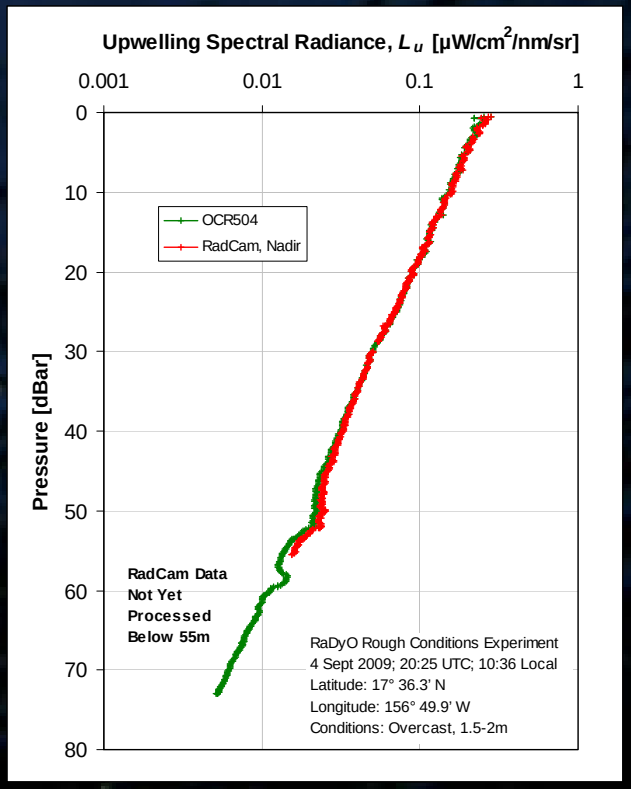


Oligotropic Environment

Hawaii - Overcast Sky

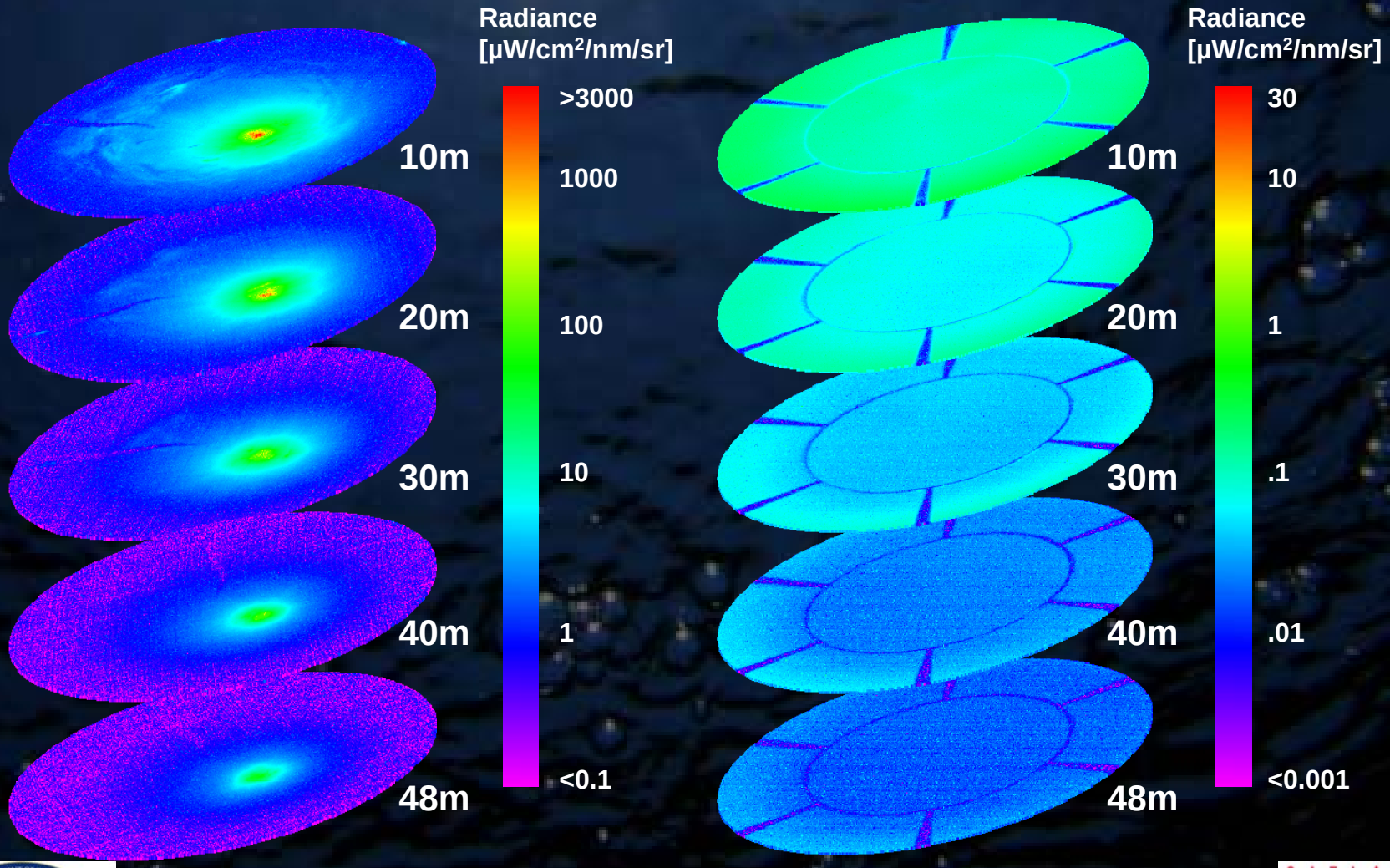






Oligotropic Environment

Hawaii - Clear Sky



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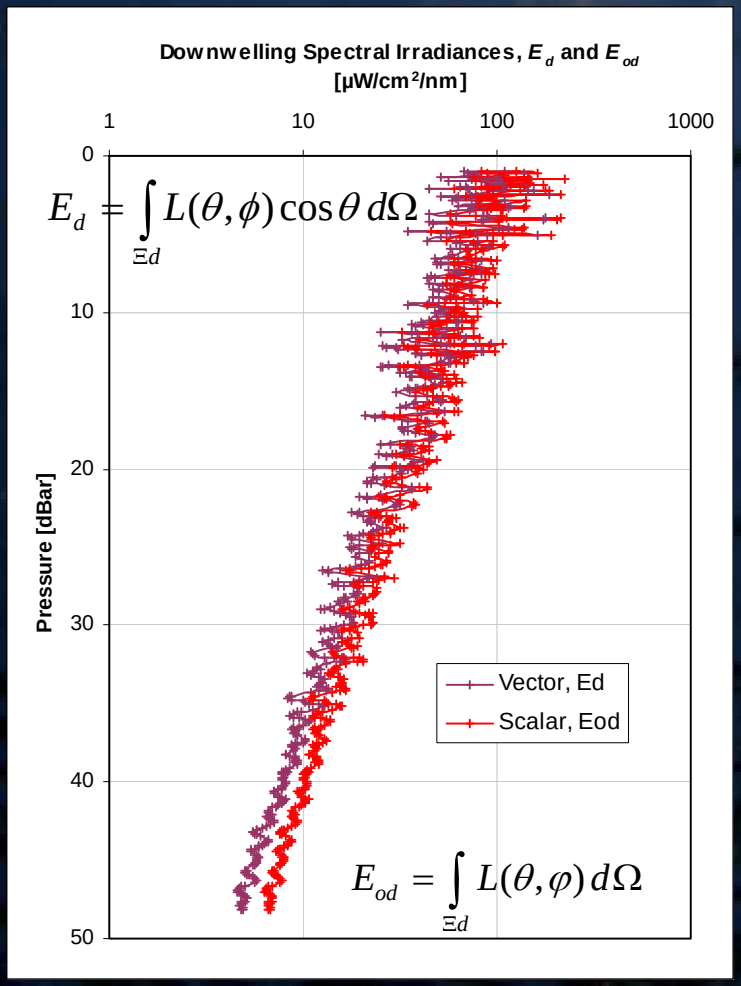
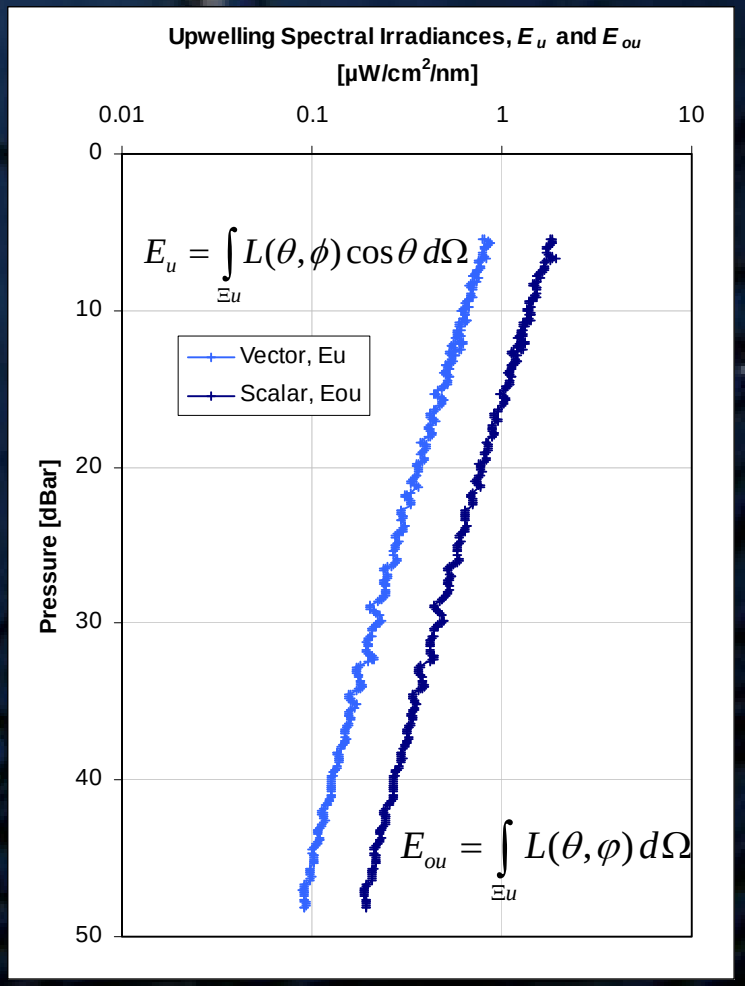
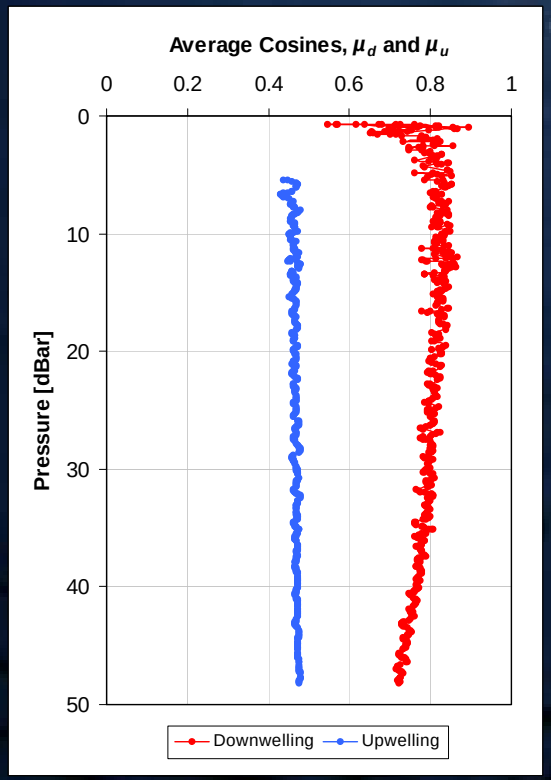
Oligotropic Environment

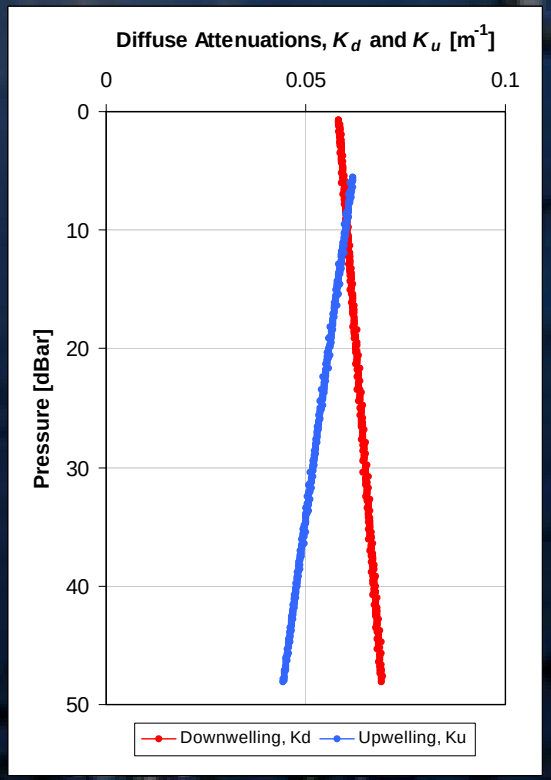


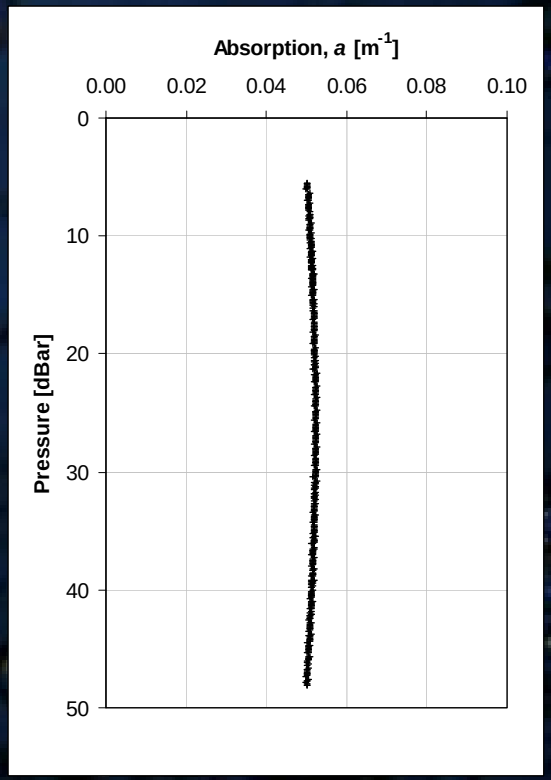


Irradiances found by integrating radiance fields

Oligotropic Environment







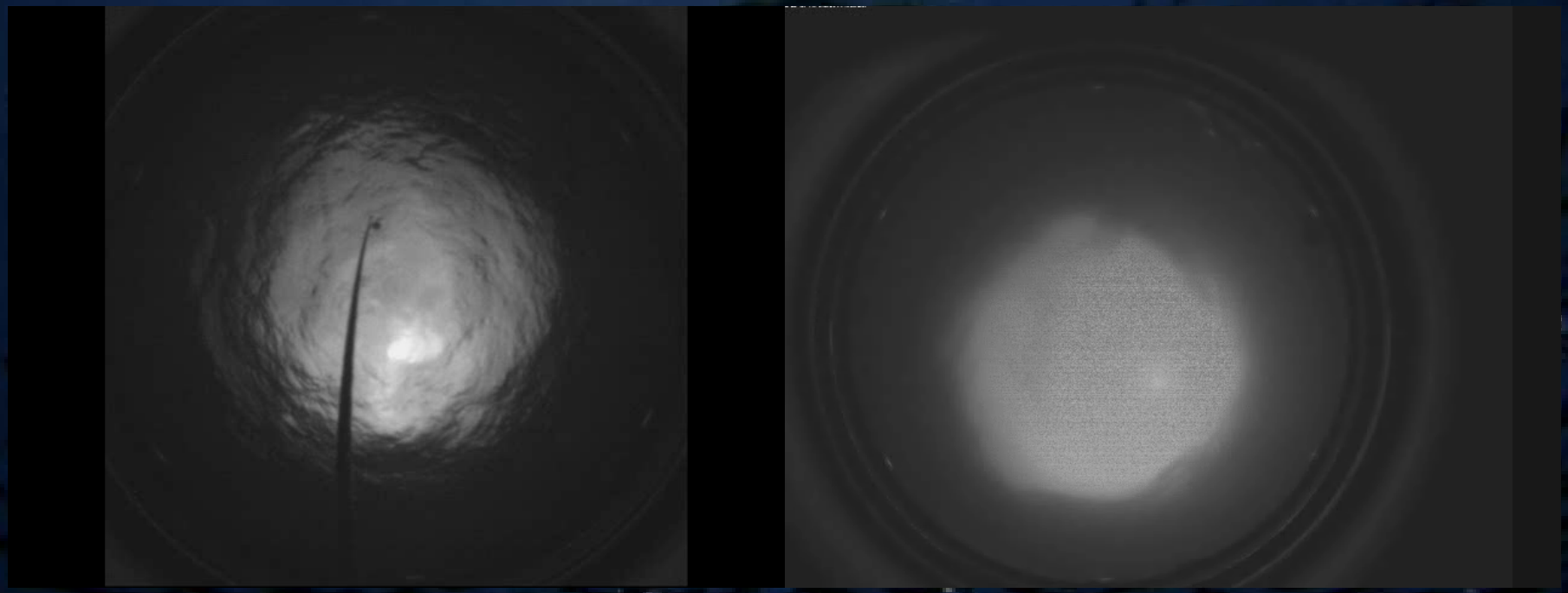
$$\overline{\mu}_d = \frac{E_d}{E_{od}} = \frac{\int_{\Xi d} L(\theta,\phi)\cos\theta d\Omega}{\int_{\Xi d} L(\theta,\phi)\, d\Omega}$$

$$\frac{1}{E_n(z)}\frac{d(E_n(z))}{dz} = -K_n(z)$$

$$\nabla \bullet \mathbf{E} = -aE_o + Sources$$

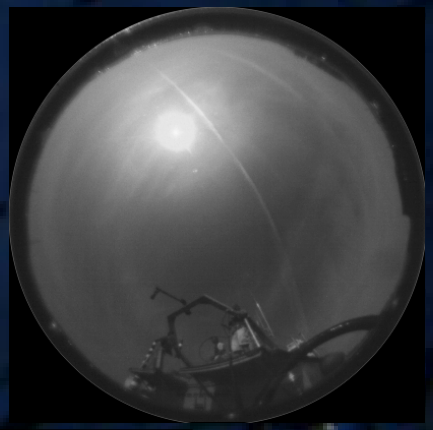
All quantities calculated from radiance fields

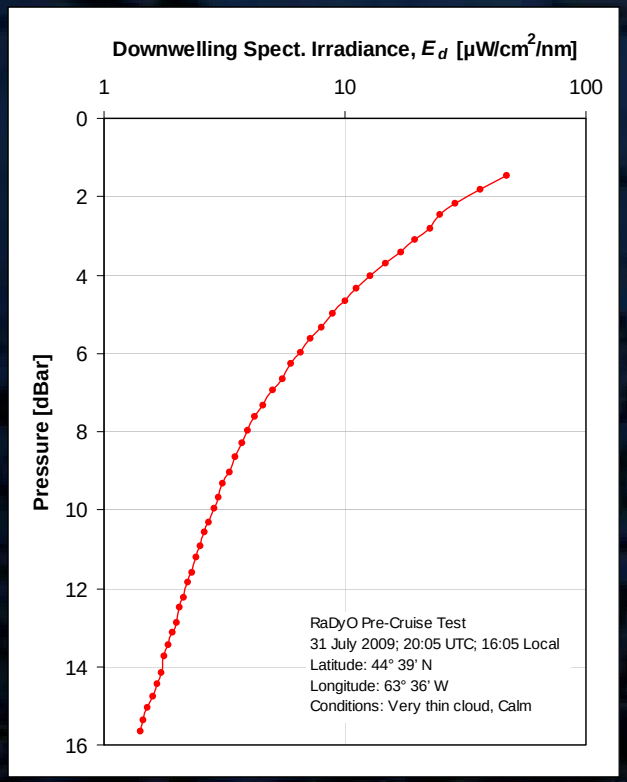
A Couple Surprises

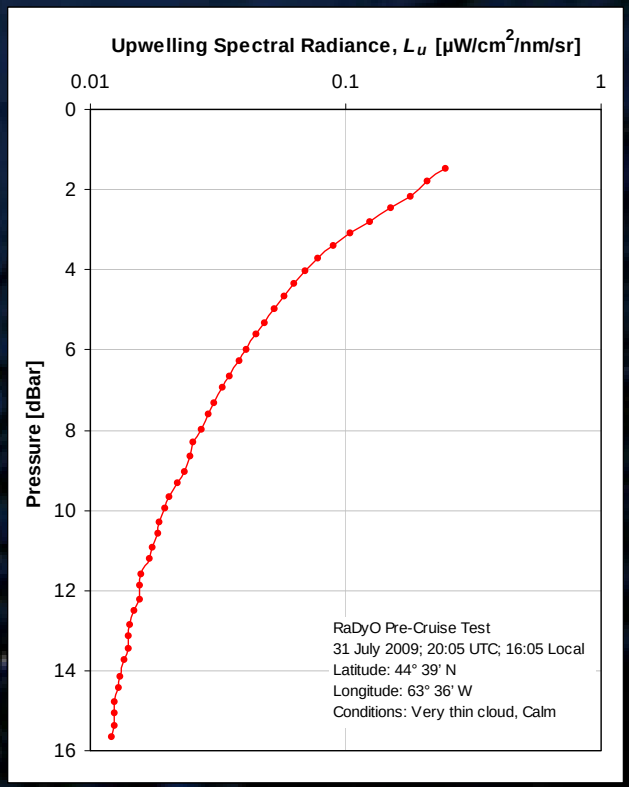


Eutrophic Environment

Bedford Basin, Nova Scotia







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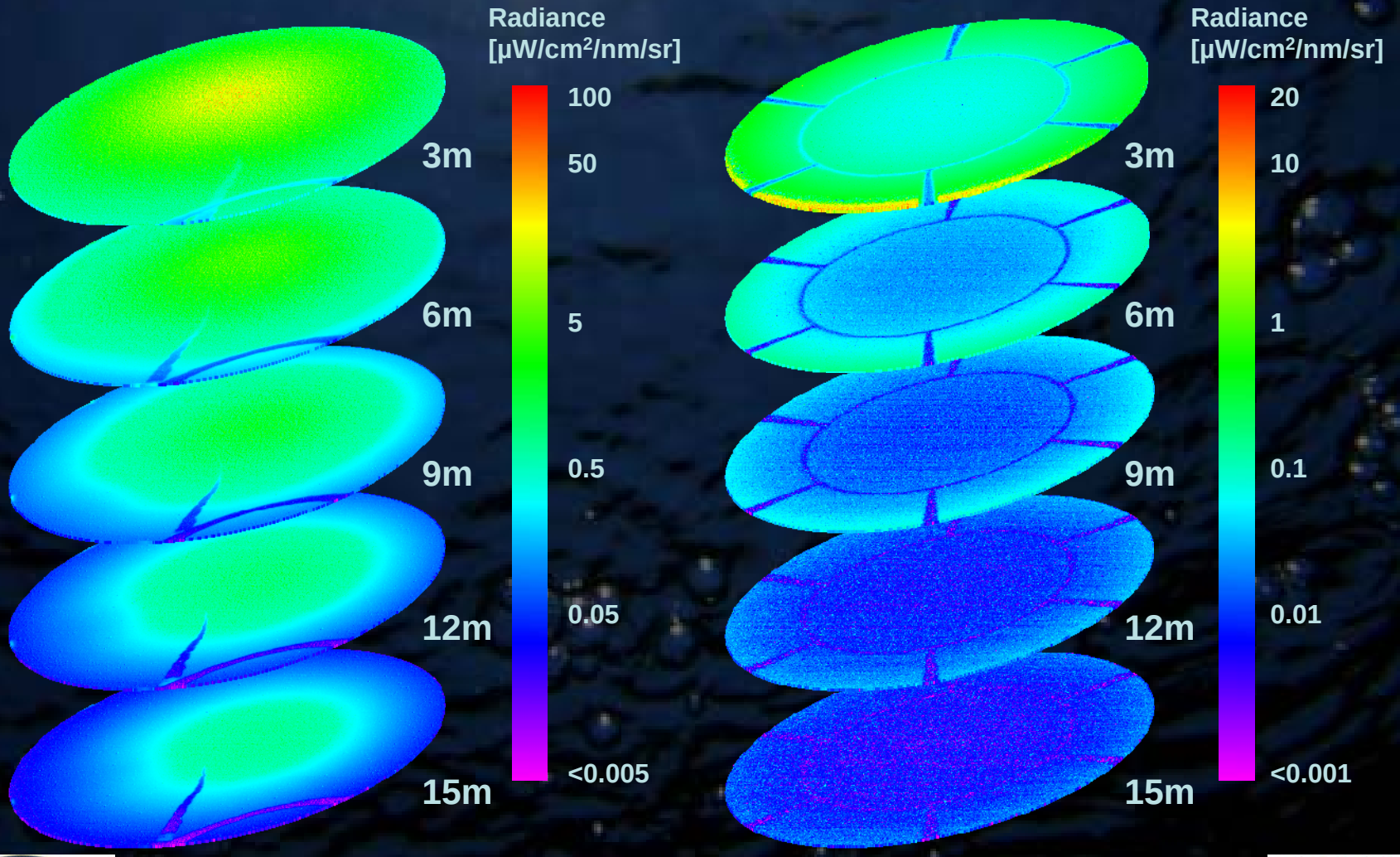

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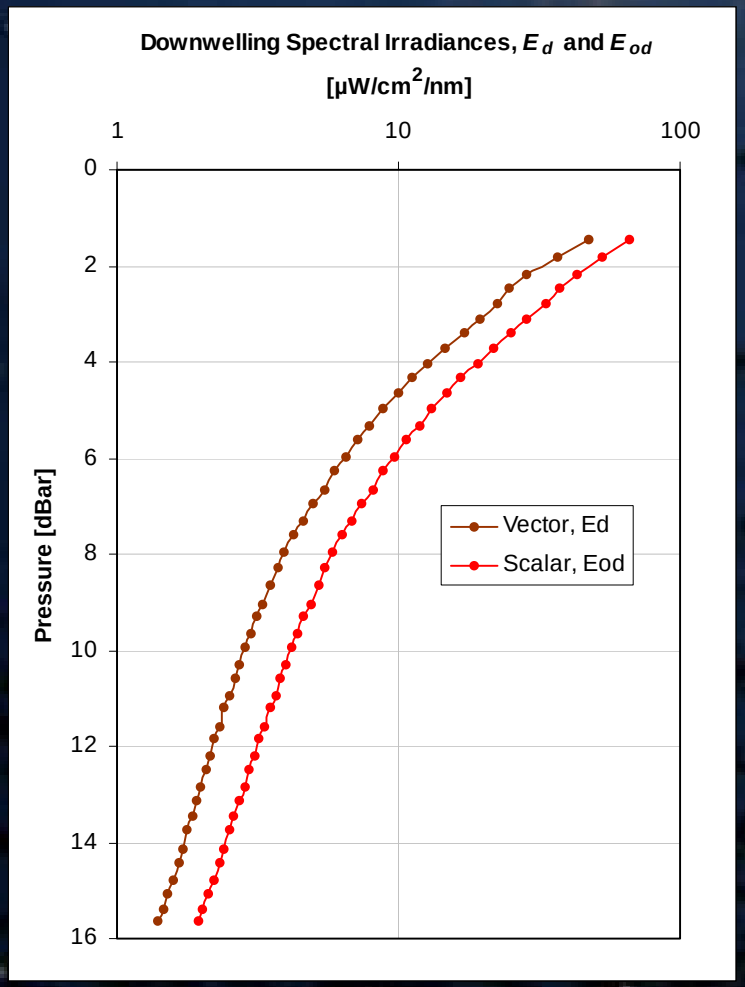
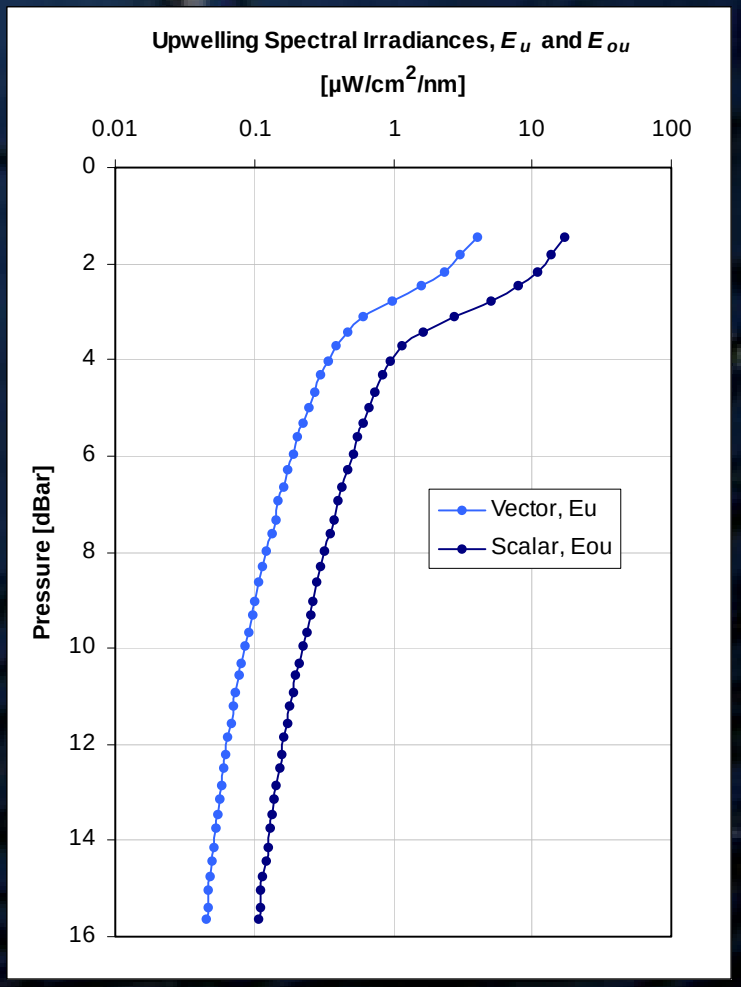
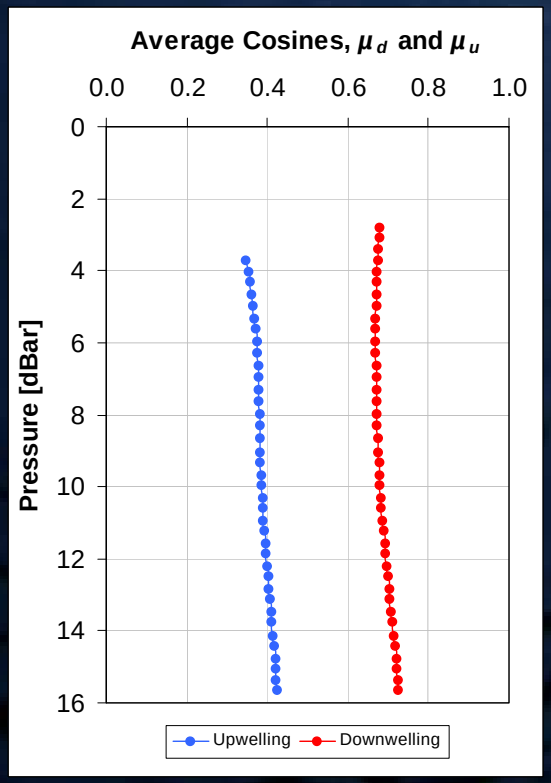
Eutrophic Environment

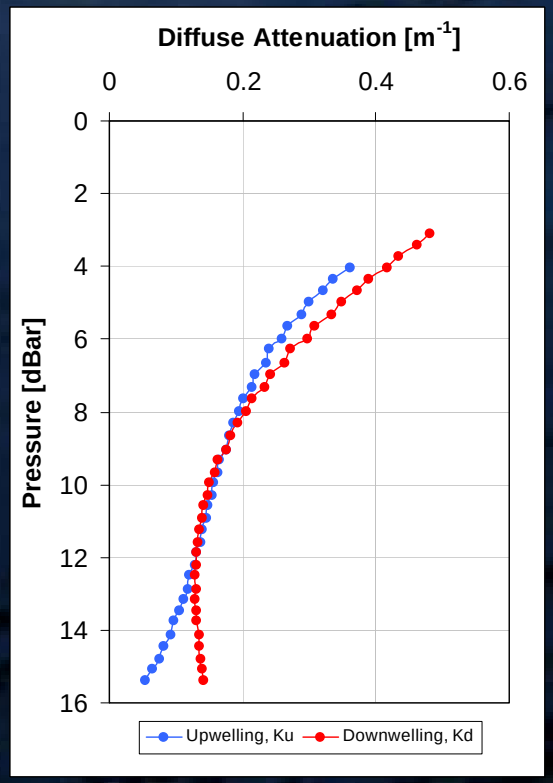


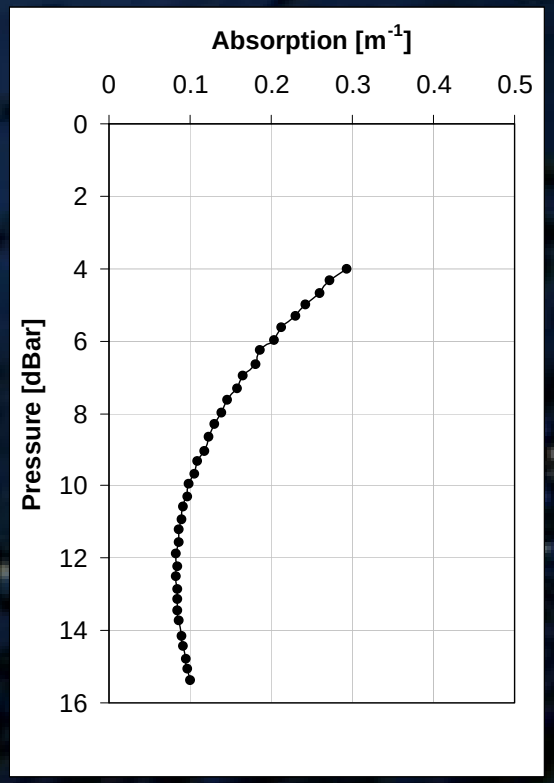


Irradiances found by integrating radiance fields

Eutrophic Environment

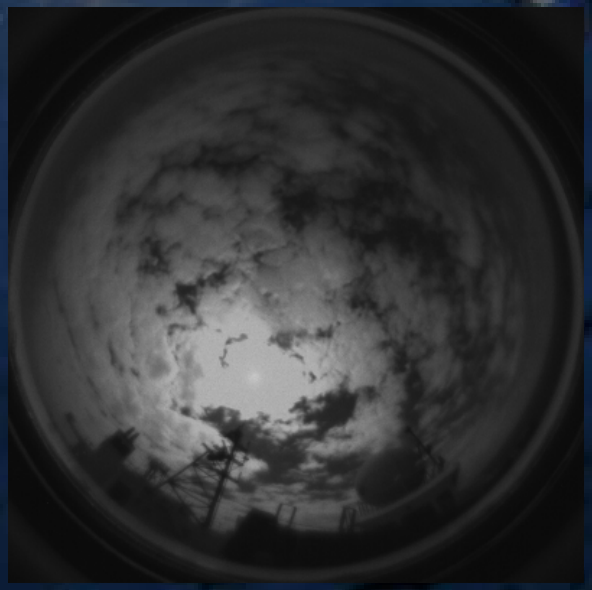






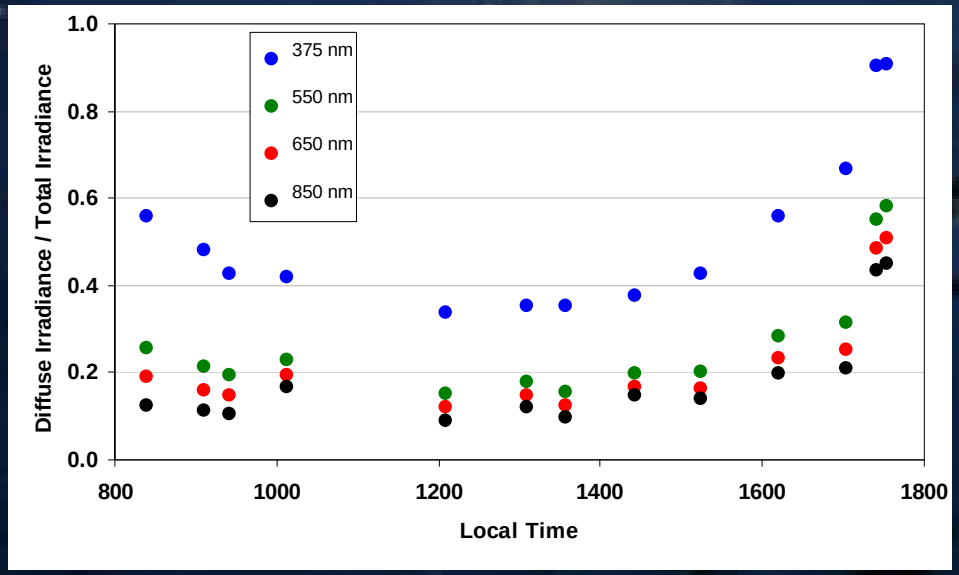
All quantities calculated from radiance fields

Sky RadCam



- **continuous sky conditions**
- **total and diffuse irradiance**
- **complete sky radiance**

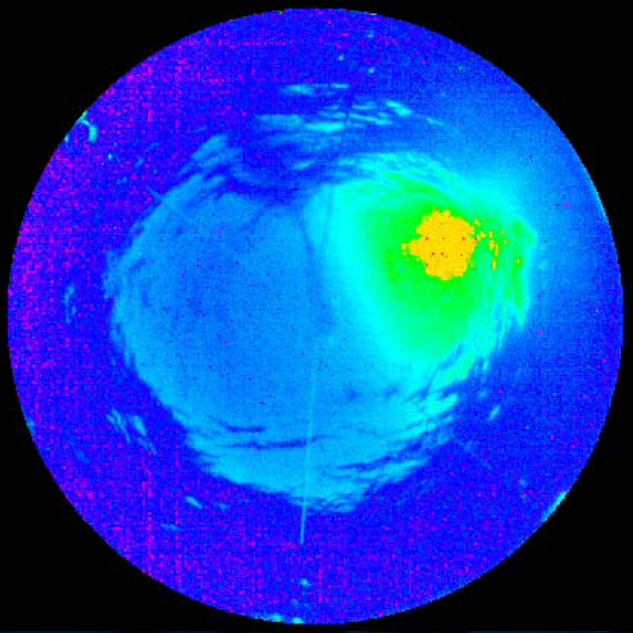
Diffuse Irradiance



Typical irradiance sensors require manual shading to measure diffuse irradiance.

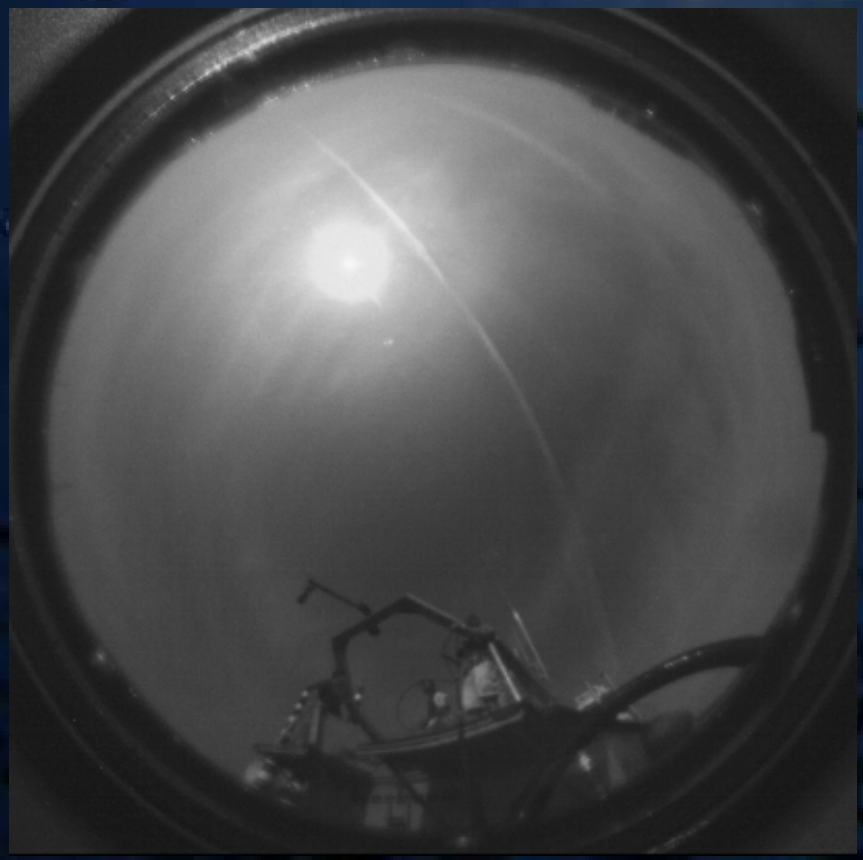
RadCam can find both total and diffuse irradiance in software, using the radiance field.

Wave Spectra and Surface Features

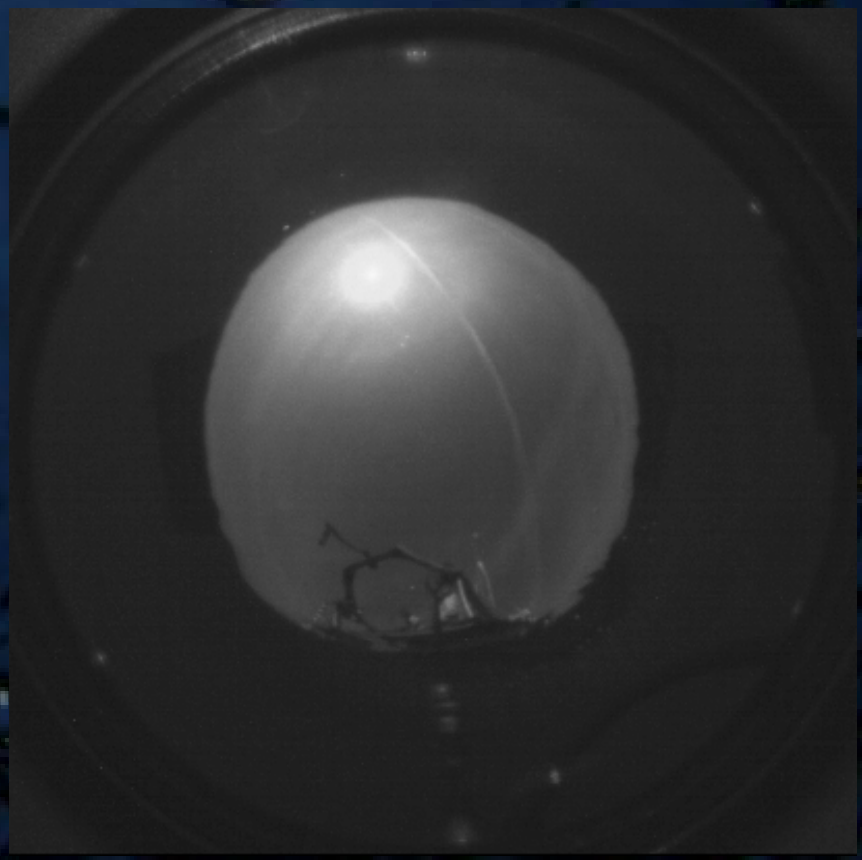


- **Radiance data and wave-slope data collected simultaneously.**

Snell Cone / Virtual Periscope

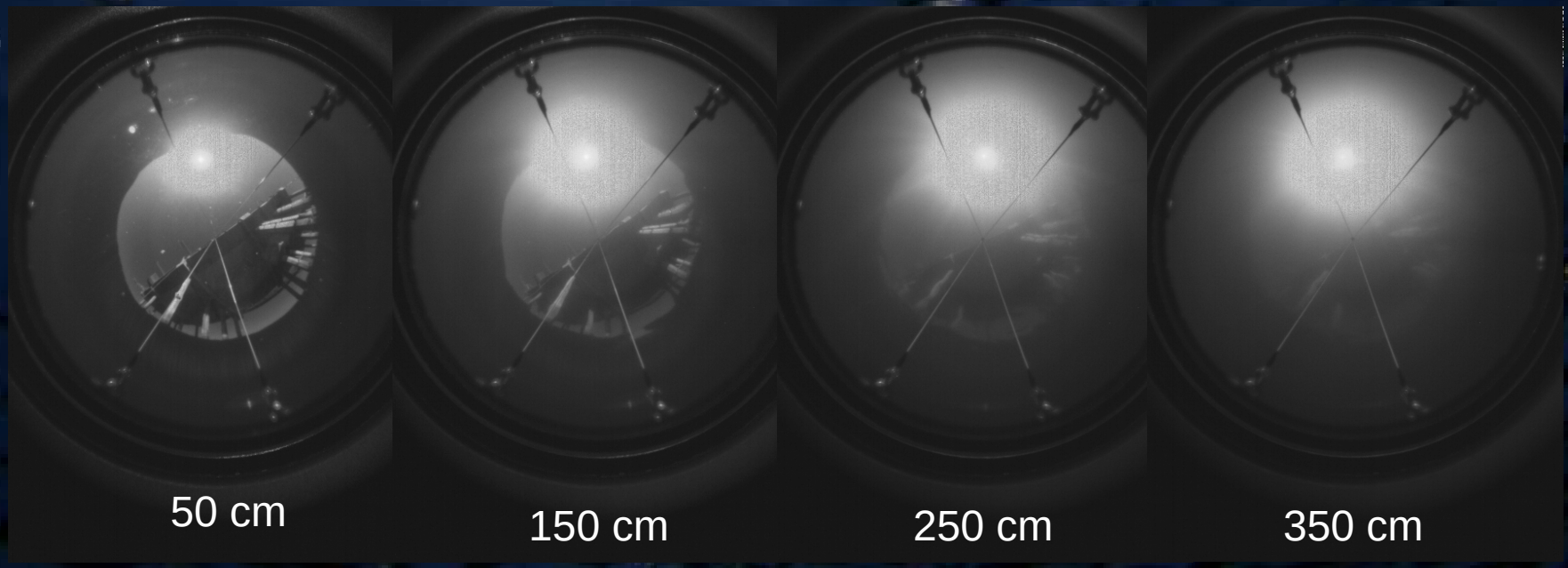


Above Water



Below Water

Imaging Through Near-Ideal Surface Boundary Layer



Further Work

- Improve calibration/processing of brightest and darkest data (Highly non-linear response)
- Attempt inversion for additional quantities (VSF, c; see Zaneveld and Pak, 1972)
- Boresight subsea and above water imaging systems to derive directional wave spectra and the influence of this on the subsea radiance distribution (w/ Zappa, Banner, Lenain, Melville).
- Provide datasets for model validation.

Thank you!