A Solution for the Tower Effect at the CERES Ocean Validation Experiment (COVE)

Fabbri Bryan[1], Schuster Gregory[2], Denn Fred[1], Madigan Jay[1], and Arduini Robert[1]

[1]Science Systems and Applications, Inc. (SSAI)
[2]NASA Langley Research Center

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Abstract

One of the key measurements from the Clouds and the Earth's Radiant Energy System (CERES) satellite is Earth emitted or longwave (LW) radiation. The CERES Ocean Validation Experiment (COVE), located at Chesapeake Light Station, approximately 25 kilometers east of Virginia Beach, Virginia (coordinates: 36.90N, 75.71W) had provided surface validation for the CERES satellite measurements for many years. Upwelling LW radiation was one of the measurements made at COVE but was complicated due to the Light Station tower being in the upwelling LW instruments field of view. According to our estimates, the Light Station tower alters 15% of the upwelling LW radiation. An unwanted consequence of the tower being in the field of view was the tower radiating effect, particularly noticeable on clear, sunny days. During these days, the tower would radiate extra heat energy by as much as 3% (15 W/mˆ2) that was measured by the upwelling LW instrument. COVE follows the Baseline Surface Radiation Network requirements and their target uncertainty is 2%. To resolve this issue, we obtain a different upwelling longwave value using data from an infrared radiation thermometer (IRT) and a pyrgeometer that retrieves sea surface temperature (SST) and downwelling longwave respectively. Using an IRT allows conversion from SST to a water emission value and the pyrgeometer provides the reflected flux of the downward longwave radiation. By determining the extent of the undesirable obstruction in the field of view of the upwelling longwave instrument and determining its emissivity could allow others with similar issues to obtain the proper values of upwelling longwave measurements.

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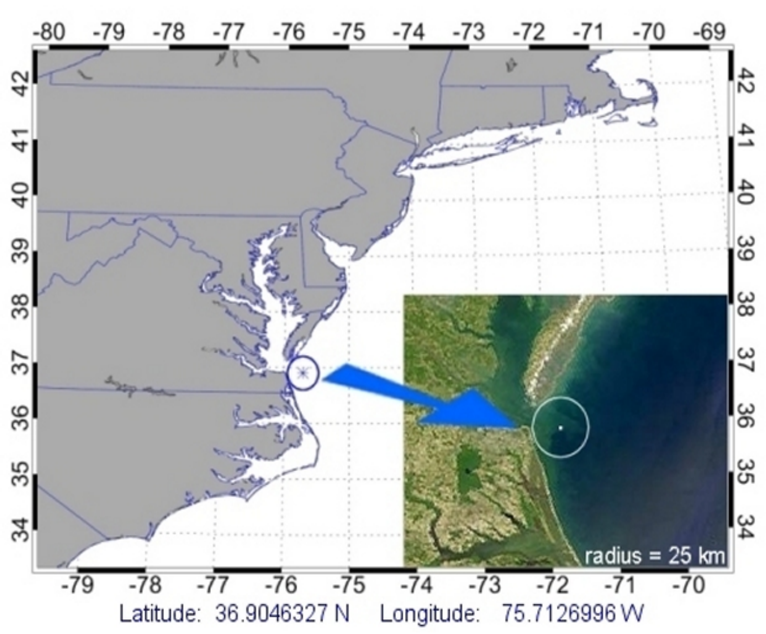
Bryan Fabbri[1], Greg Schuster[2], Fred Denn[1], Robert Arduini[1], Jay Madigan[1]

bryan.e.fabbri@nasa.gov COVE website: https://cove.larc.nasa.gov or

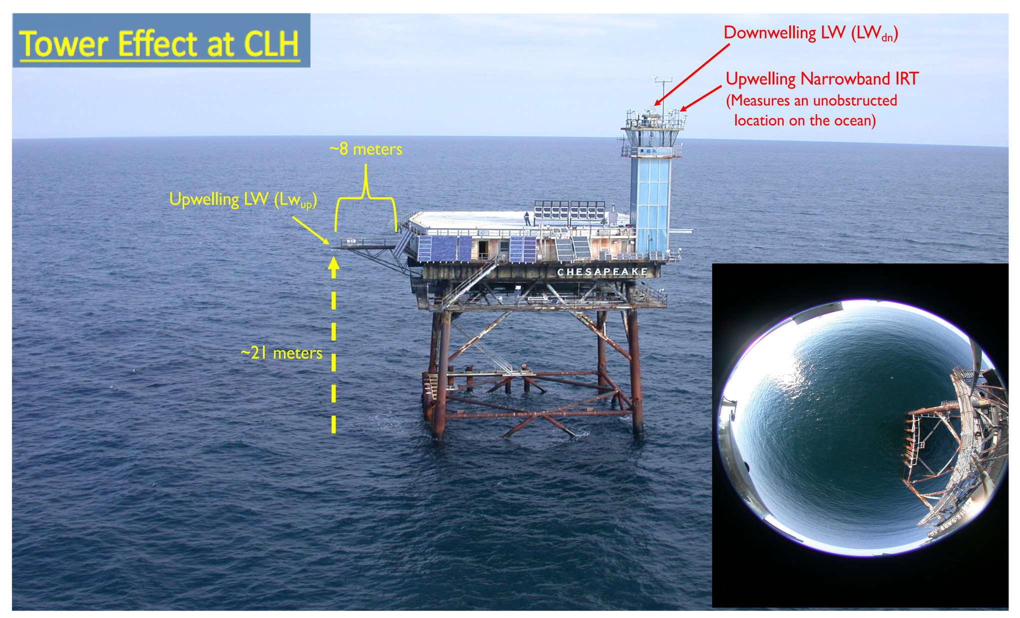
[1]Science Systems and Applications, Inc. (SSAI), Hampton, Virginia, USA, 23666 [2]Nasa Langley Research Center, Science Directorate, Hampton, Virginia, USA, 23681

Introduction:

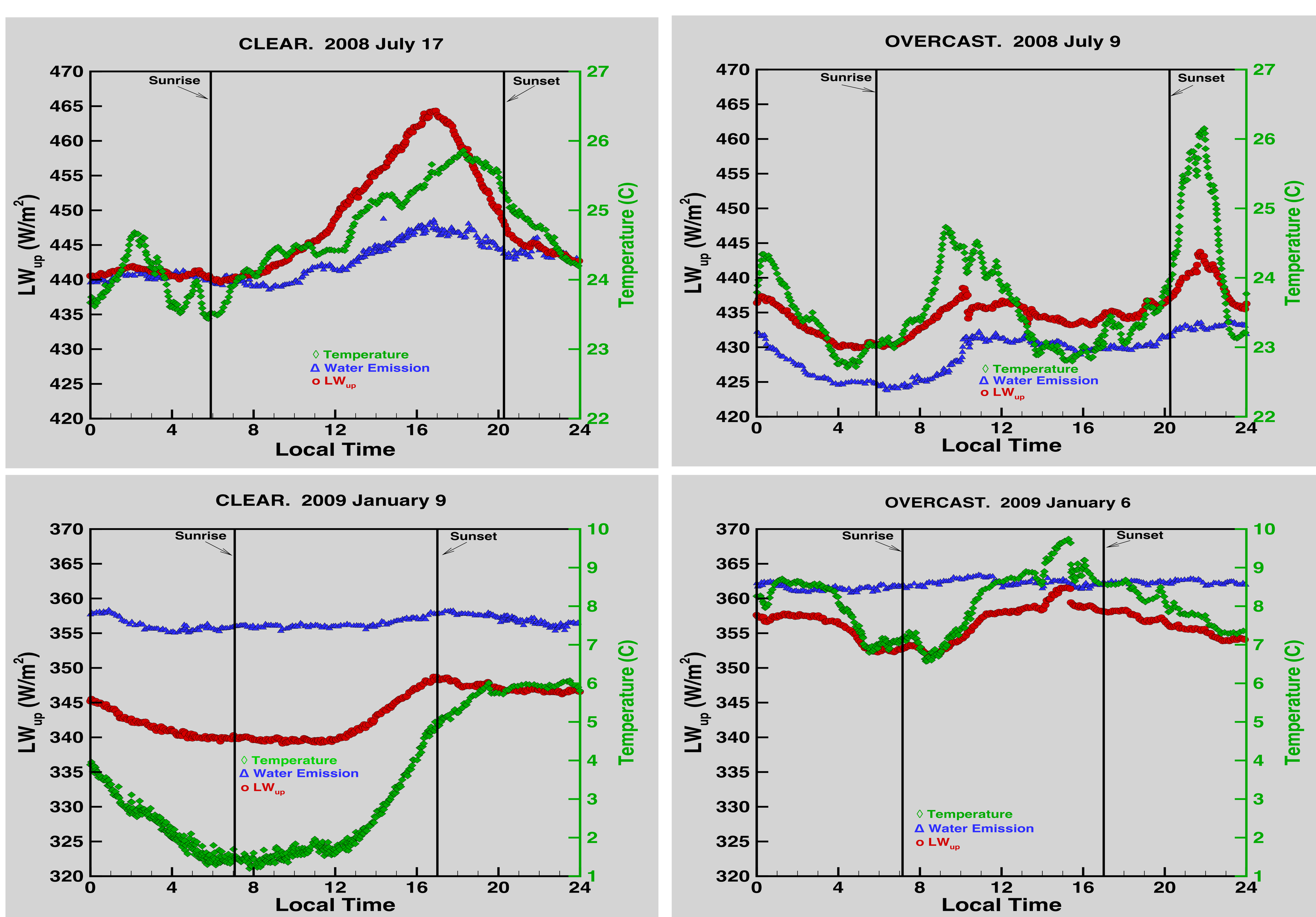
- The Clouds and the Earth's Radiant Energy System (CERES) Ocean Validation Experiment, or COVE, was established at Chesapeake Lighthouse (CLH) as a validation site for CERES and other satellites from 2000-2016.
- Minimal upwell shortwave (SW) and no upwell longwave (LW) data has been thoroughly analyzed or submitted to the Baseline Surface Radiation Network (BSRN) archives due to the CLH's tower partially obstructing (estimated at 15%) the upwelling instruments field of view.
- Here, the focus is on the upwell LW "tower radiating effect" which shows an undesired signal measured by the Precision Infrared Radiometer (PIR), particularly noticeable in the afternoon on clear, sunny days.
- This poster strives to make a case for using an Infrared Radiation Thermometer (IRT), primarily used to measure Sea Surface Temperature (SST), to derive upwelling LW. The IRT has a clear view of the ocean and provides a better upwell LW measurement than the upwell PIR.



COVE is ~25km off the coast of Southeast Virginia, USA. Water depth is ~12m.



Location of instruments used to retrieve upwelling LW (directly and derived). A fisheye lens picture shows the structure in the field of view of the direct upwelling instruments. The signal from the tower on this measurement is an undesired quantity.



Measured upwelling LW measurements (PIR, denoted with red lines and circles) are affected by the water emission (SST, denoted with blue lines and deltas), ambient air temperature (denoted with green lines and diamonds), and the tower temperature. The red line should be in between the green and blue lines and this is usually the case. When the red line is outside the green and blue lines, the tower must be playing a role. The influence of the tower signal is the most obvious on a sunny, summer day (upper left plot).

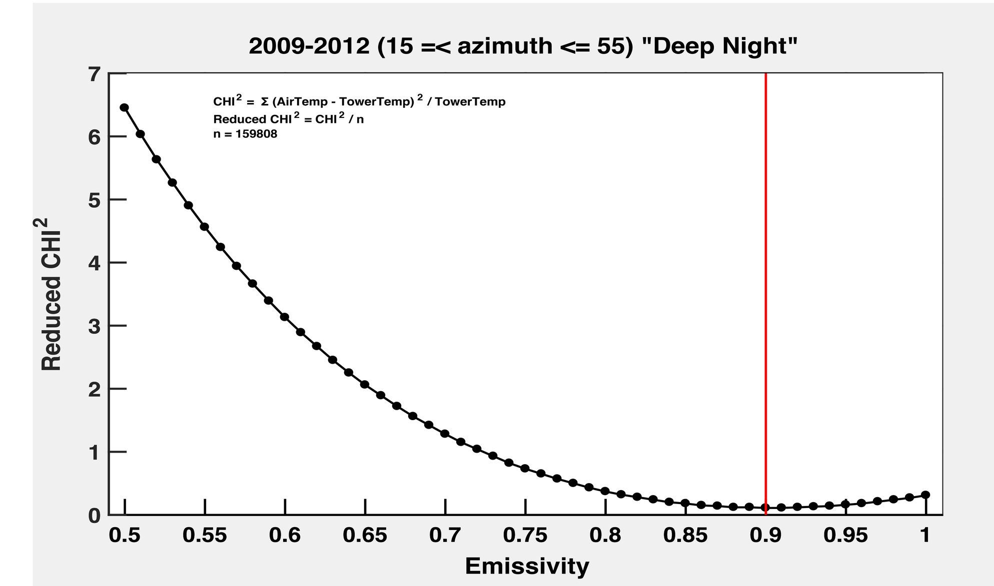
Tower Effect Equations

$$^*1)\quad LW_{up} = (1-f)[\underbrace{\epsilon_w\sigma T_w^4}_{\text{Water surface thermal emission}} + \underbrace{(1-\epsilon_w)LW_{dn}}_{\text{Reflected flux of downward atmospheric emission}}] + \underbrace{f\epsilon_t\sigma T_t^4}_{\text{Tower emission}}$$

$$2)\quad LW_{up}|_{f\neq0} - LW_{up}|_{f=0} = f[\epsilon_t\sigma T_t^4 - \epsilon_w\sigma T_w^4 - (1-\epsilon_w)LW_{dn}]$$

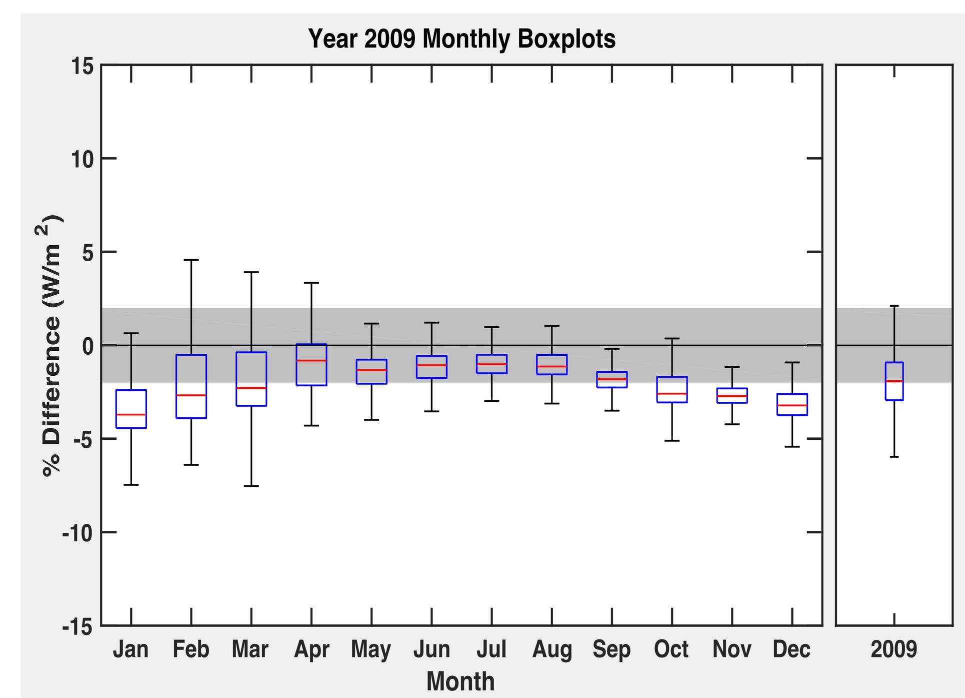
Where,

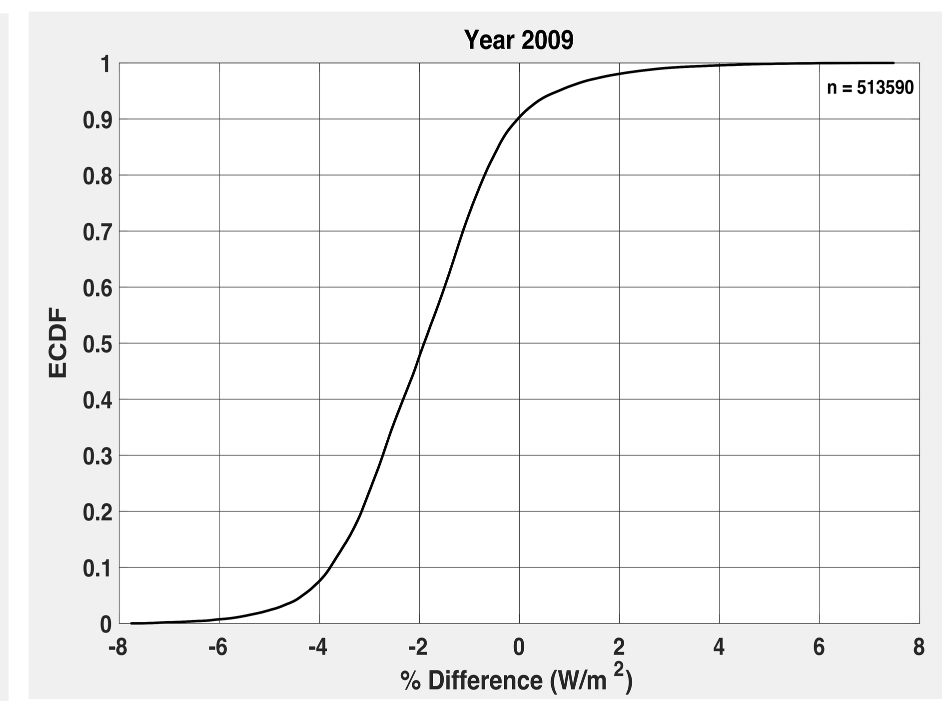
- LW_{up} = Upwelling longwave radiation
- f = The estimated fractional obstruction the tower is in the field of view of LW_{up}
- ϵ_w = Emissivity of water (ϵ_w = 0.990)
- σ = Stefan-Boltzmann constant (σ = 5.6697^{-8})
- T_w = Water temperature in degrees K. Measured with an IRT (9.6 – 11.5 µm)
- LW_{dn} = Downwelling longwave radiation. Measured with an Eppley PIR (5 – 50 µm)
- ϵ_t = Emissivity of tower (ϵ_t = 0.90). Determined by Reduced CHI^2 equation on right
- T_t = Temperature of tower in degrees K.



To minimize the effects of solar insolation during the day, we inferred tower emissivity (ϵ_t) by assuming the tower temperature is equal to ambient air temperature during the "deep night".

Upwelling measurements in the presence of an obstruction that occupies a fractional field of view "f" can be expressed as Equation 1. Ideally, we would like to report Lw_{up} when f = 0; however, the PIR at the COVE site is located at f = 0.15, and therefore measures $LW_{up}|_{f=0.15}$. Fortunately, the site also has enough instrumentation to derive Lw_{up} with the right-hand side of Equation 1 as a function of the obstruction fraction(f). Note that the values of $LW_{up}|_{f\neq0}$ and $LW_{up}|_{f=0}$ diverge when f > 0 as shown in Equation 2.

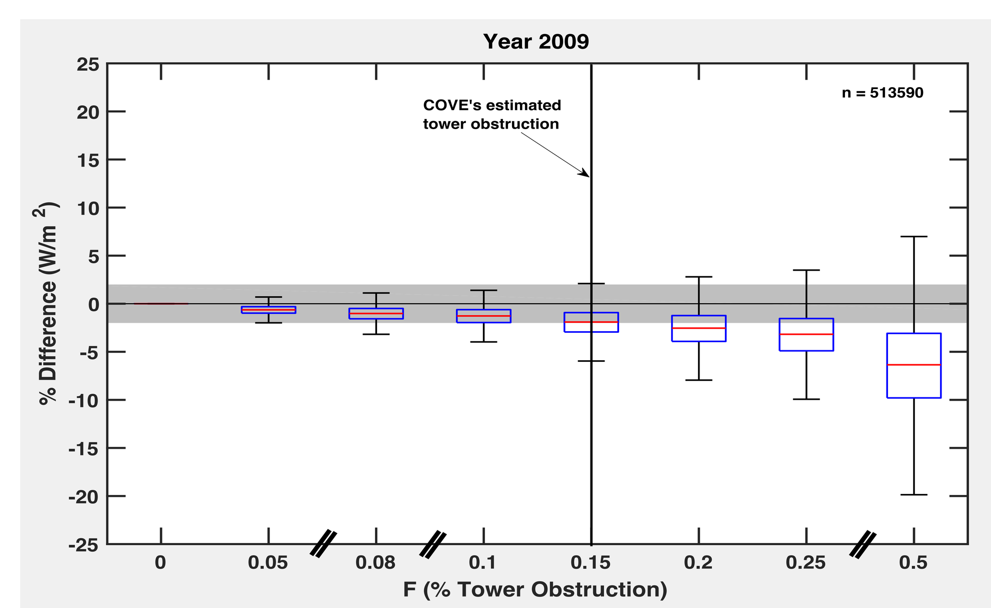




Percent Difference is determined by:

% Difference = $[(LW_{up}|_{f=0.15} - LW_{up}|_{f=0}) / LW_{up}|_{f=0}] \times 100$

The shaded region on the left plot is +/- 2% (which is the BSRN uncertainty as of 2004), but the data is outside of the targeted range frequently (and more so in the cooler months). The cumulative distribution function (right plot) shows that the data falls outside the targeted uncertainty about 50% of the time.



COVE's estimated tower obstruction is 15% (F = 0.15). Approximately half the % difference data is outside the target uncertainty when F = 0.15. If we were able to move our upwelling LW instrument closer to the tower (when F gets larger), the results get worse. If we were able to move the upwelling LW instrument further away from the tower (when F gets smaller), the numbers will eventually match $LW_{up}|_{f=0}$. Therefore, the solution to the Tower Effect is to use the output determined from $LW_{up}|_{f=0}$ due to no obstructions in the field of view while also meeting BSRN target uncertainty.

Summary:

- Many years of upwelling longwave data have been collected with a PIR at COVE, but due to an estimated 15% obstruction in the instruments field of view, was deemed contaminated and not fully analyzed or submitted to the BSRN archives.
- We suggest using an IRT and downwelling LW as a substitute for the upwelling LW measurement in order to provide a more accurate measurement.
- Comparing derived upwell LW ($LW_{up}|_{f=0}$) with measured upwell LW ($LW_{up}|_{f=0.15}$) shows noticeable differences outside BSRN 2% target uncertainty and point to using the derived upwell LW as the primary upwell LW measurement.

Acknowledgements:

- We thank the United States Coast Guard and the Department of Energy for allowing atmospheric and oceanic research at COVE.
- Inside [ ] of Equation 1 is from NOAA NESDIS Center for Satellite Applications and Research, Algorithm Theoretical Basis Document, "ABI Earth Radiation Budget, Upward Longwave Radiation: Surface (ULR)" by H.T. Lee, I. Laszlo and A. Gruber (September 2010)