Measuring Upwelling Longwave in the Presence of an Obstruction

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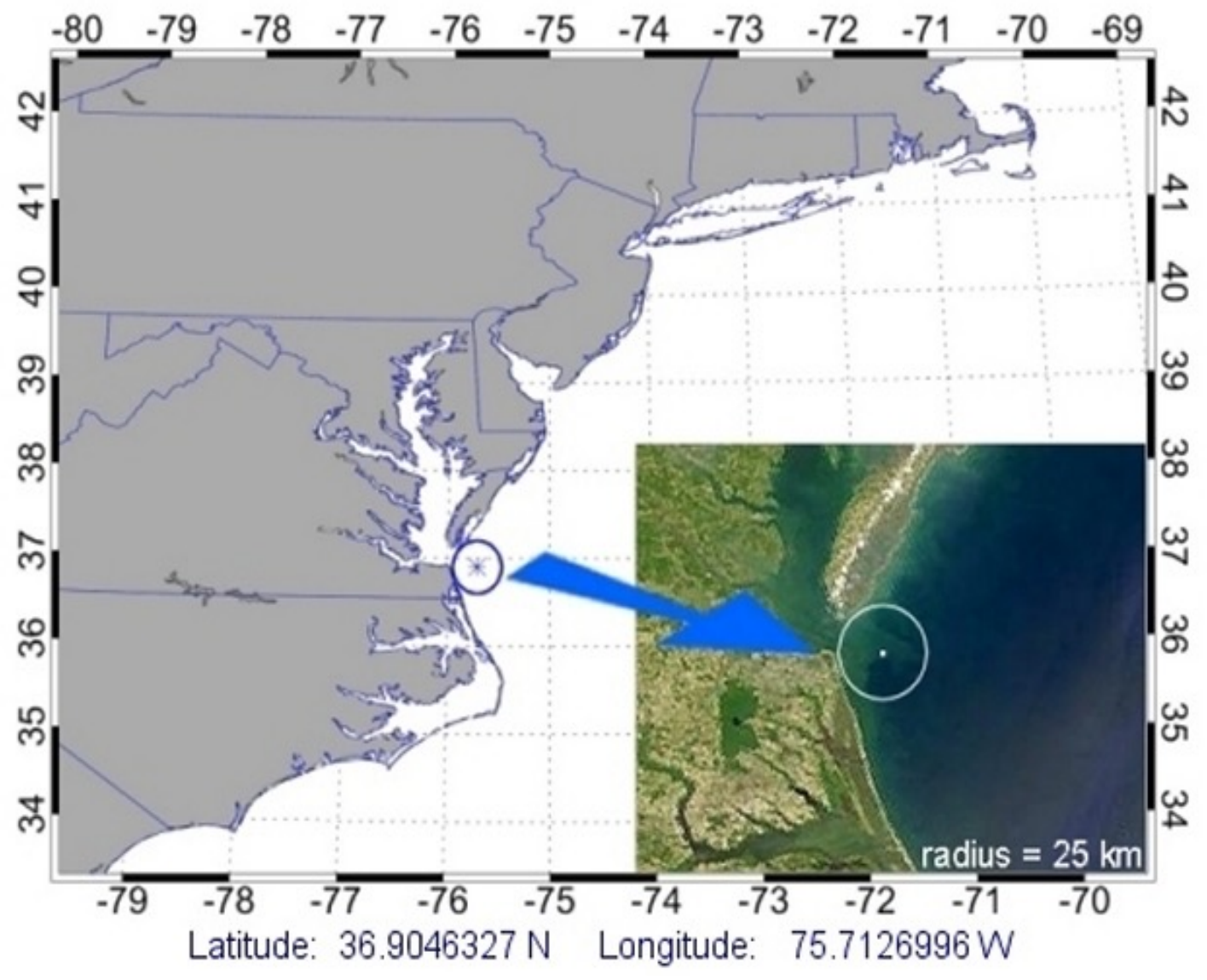
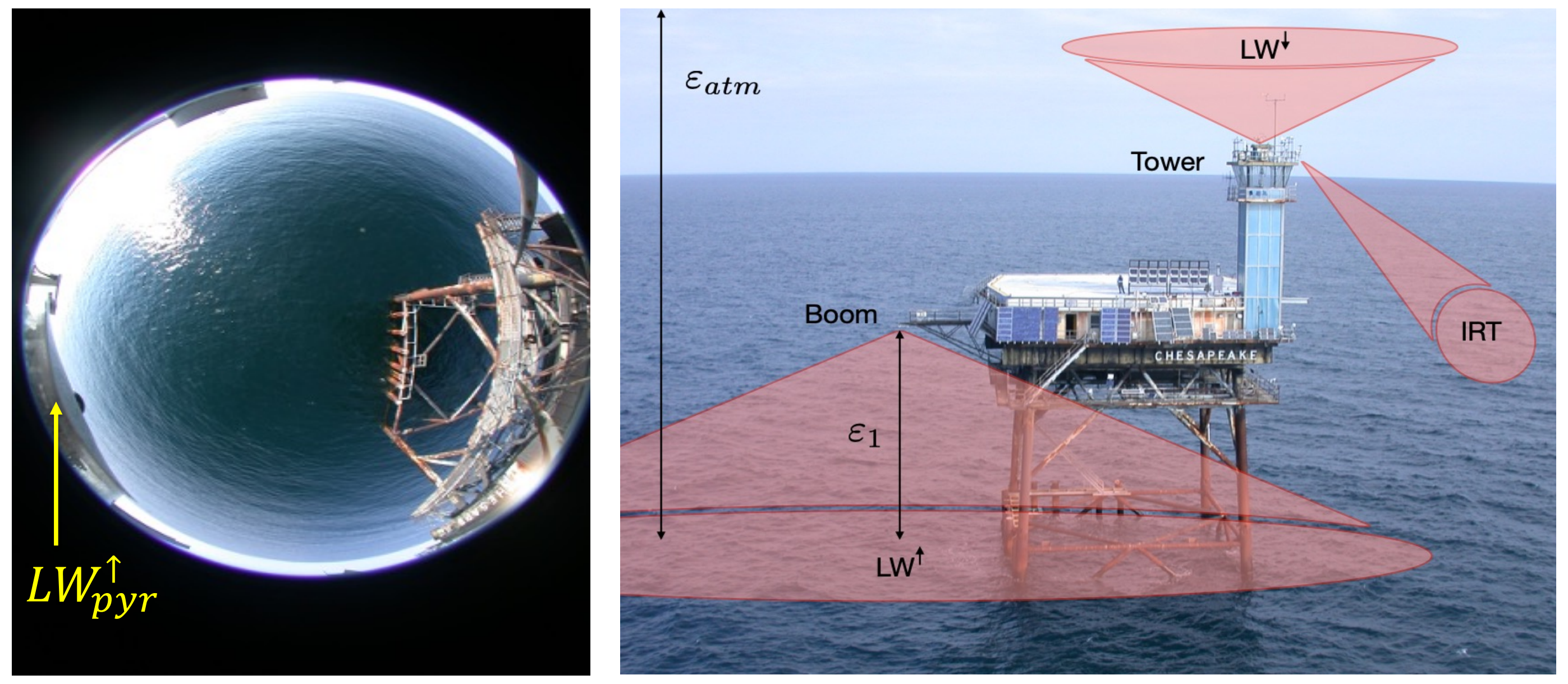
Introduction:

- One of the key measurements from the Clouds and the Earth's Radiant Energy System (CERES) satellite and the Baseline Surface Radiation Network (BSRN) is Earth emitted or longwave (LW) radiation.
- The disestablished CERES Ocean Validation Experiment (COVE), located at Chesapeake Light Station was a validation site for CERES measurements and collected upwelling LW (LW$^{\uparrow}$) with a static pyrgeometer, but the measurement was complicated due to the light station tower being in its field of view, which we estimate to be 15%.
- To resolve the tower issue, we obtain a different LW$^{\uparrow}$ value (LW$^{\uparrow}_{f=0}$) using data from other instruments located at COVE such as an Infrared Radiation Thermometer (IRT) to measure ocean skin temperature, downwelling pyrgeometer and meteorological sensors.
- Comparing the static pyrgeometer ($LW^{\uparrow}_{pyr}$) with LW$^{\uparrow}_{f=0}$ shows the unwanted consequence of the tower, evident on a clear, summer day. However, winter comparisons are biased even more with differences up to 5% (20 W/m^2). BSRN target uncertainty is 2%.

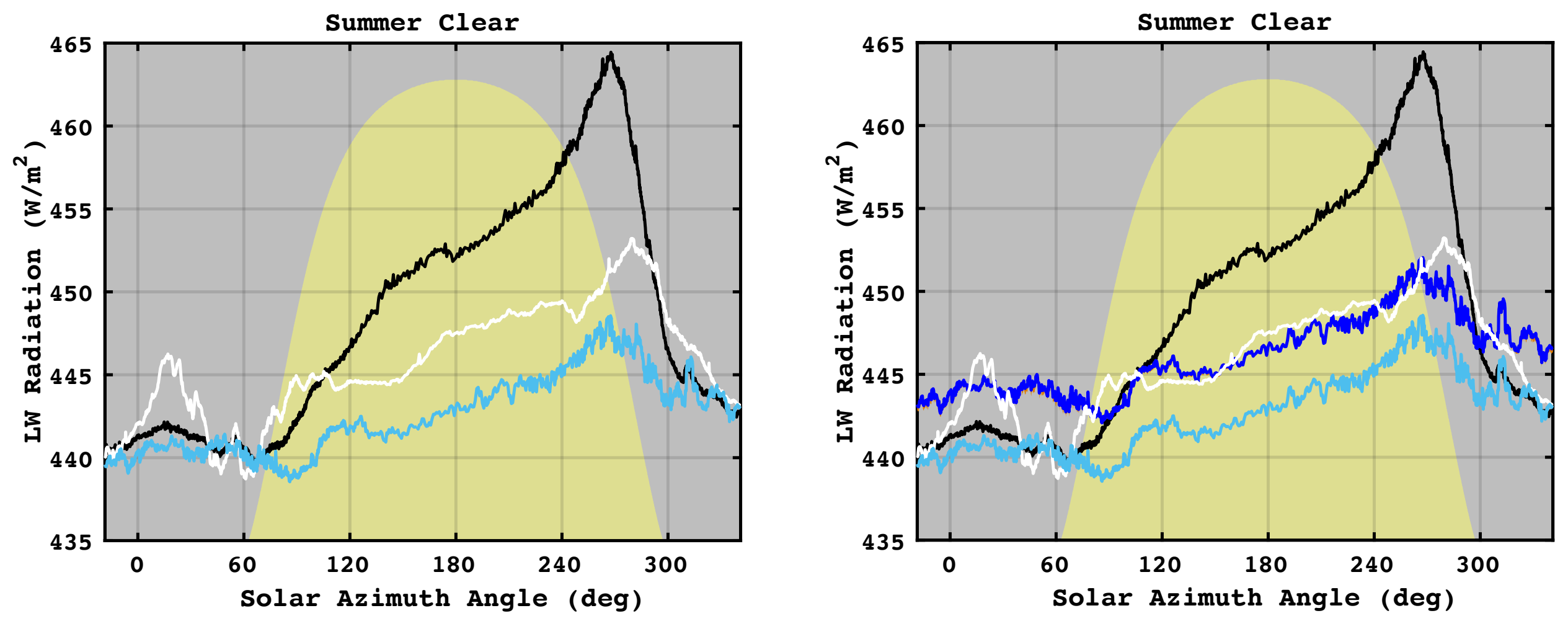


COVE at Chesapeake Light Station information:

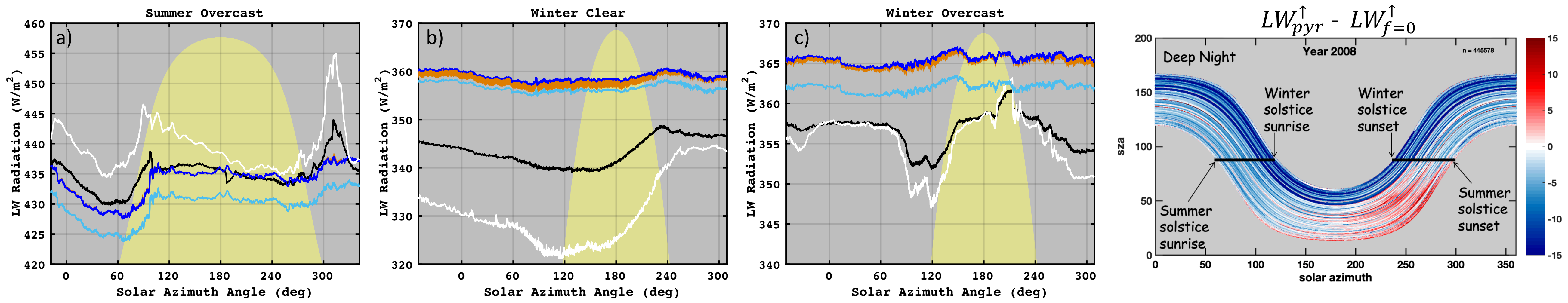
- ~25km off the coast of Southeast Virginia, USA
- Coordinates: 36.90N, 75.71W
- Water depth is ~12m
- Operational from May 1999 – December 2016



Left: Fisheye lens picture showing the approximate 15% tower obstruction in the static pyrgeometers ($LW^{\uparrow}_{pyr}$) field of view.
Right: Illustration of the instrument geometry at the Chesapeake Light Station. $LW^{\uparrow}_{pyr}$ measurements are located at the end of on an 8m boom, which is not long enough to remove the platform from the field of view. LW$^{\downarrow}$ flux measurements and narrowband IRT have an unobstructed field of view at the top of the tower. The emissivity's ε_{atm} and ε_1 are the atmospheric column and the layer of air below the boom, respectively. The height of layer ε_1 is 21m.



Left: $LW^{\uparrow}_{pyr}$ measurements (black), air temperature converted to air emission (white) and water temperature converted to water emission (light blue). The yellow shaded region denotes the solar elevation on that day (no scale). The large difference in values during this clear, summer day of the $LW^{\uparrow}_{pyr}$ measurement compared to the air and water emission suggest something other than the air and water emissions are causing a sharp increase in $LW^{\uparrow}_{pyr}$. This plot led to finding a new $LW^{\uparrow}$value.
Right: Same as the left plot with the addition of the newly derived LW$^{\uparrow}_{f=0}$values (dark blue and orange), determined by the equations on the upper right of this poster.



The line plot colors for the three single day scenarios are the same as Summer Clear. **a)** Summer Overcast. There is not a dramatic difference between $LW^{\uparrow}_{pyr}$ and LW$^{\uparrow}_{f=0}$ values, suggesting low temperature differences between the tower and water. **b)** Winter Clear. The disparity between $LW^{\uparrow}_{pyr}$ and LW$^{\uparrow}_{f=0}$ are greatest among the four scenarios, implying the tower obstruction plays an even greater role in the wintertime. **c)** Winter Overcast. Differences between $LW^{\uparrow}_{pyr}$ and LW$^{\uparrow}_{f=0}$ are less than winter clear but LW$^{\uparrow}_{f=0}$ values are still distinctly higher.
Right: A single year plot of $LW^{\uparrow}_{pyr}$ minus LW$^{\uparrow}_{f=0}$ when $\varepsilon_1 = 0$. Notice the large differences between the two values as indicated by the color bar (darker reds in late afternoon and dark blues in the winter and nighttime). Ideally, one should see all white. This plot encapsulates the need to find a better LW$^{\uparrow}$value.

$$LW^{\uparrow}_{f=0} = (1 - \varepsilon_1)[\varepsilon w \sigma T_w^4 + (1 - \varepsilon_1)(1 - \varepsilon_w)LW^{\downarrow}] + \varepsilon_1 \sigma T_1^4$$

Where,

ε_1 = Emissivity of the air below the static pyrgeometer
ε_w = Emissivity of the water (0.99)
σ = Stefan-Boltzmann constant (5.67 x 10^{-8})
T_w = Water temperature (°K)
T_1 = Air temperature (°K)
$LW^{\downarrow}$ = Downwelling LW radiation

$$(1 - \varepsilon_1) = exp(-\tau_1)$$

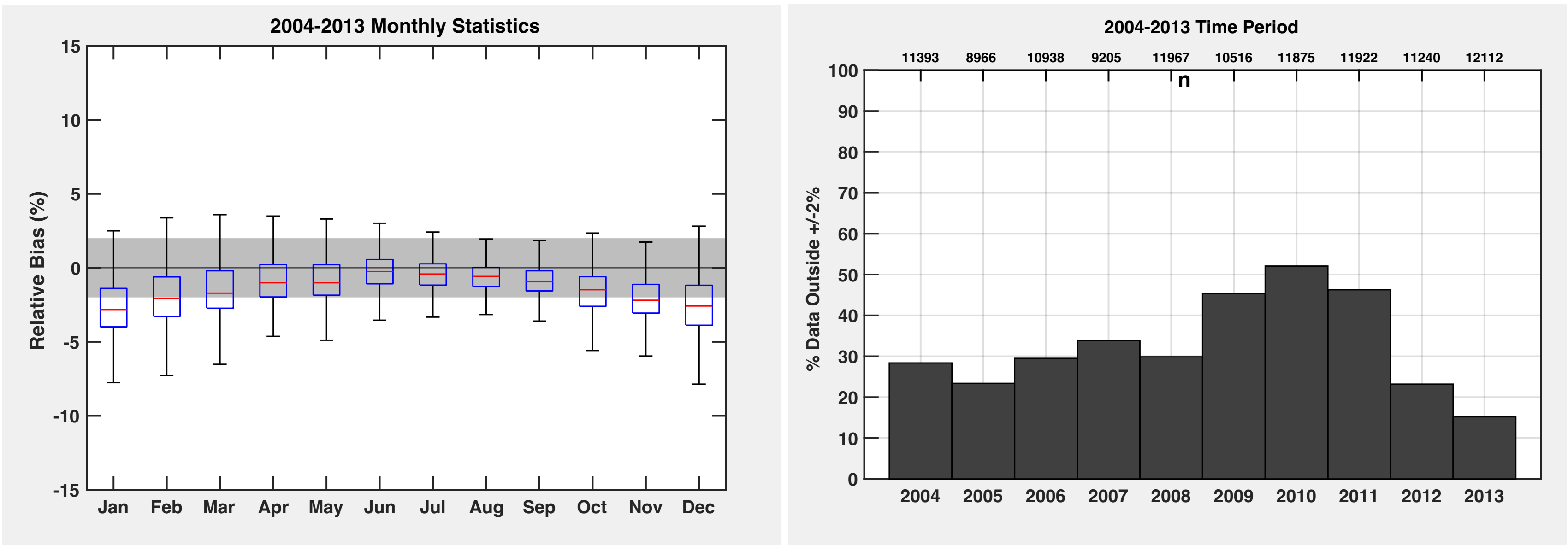
$$\tau_1 = -\left[\frac{Q_1 \rho_1 Z_1}{W}\right] \ln(1 - \varepsilon_{atm})$$

Where,

Q_1 = Water vapor mixing ratio of layer ε_1
(Obtained from meteorological data)
ρ_1 = Density of dry air of layer ε_1 (1.225 kg/m^3)
Z_1 = Height of layer ε_1 (21m)
W = Column precipitable water vapor
ε_{atm} = Emissivity of the atmosphere

Left: The new method to determine $LW^{\uparrow}$without tower interference. This equation includes water emission ($\varepsilon_w \sigma T_w^4$), water reflectance after attenuation by the air below our sensors [$(1 - \varepsilon_1)(1 - \varepsilon_w)LW^{\downarrow}$], and emission of the air below our sensors ($\varepsilon_1 \sigma T_1^4$). It also accounts for LW attenuation from the surface to the sensor.
Right: Determining ε_1. Since 1 - ε_1 is the transmissivity of the layer below the boom, we can relate this to the longwave optical depth, τ_1. Since nearly all the LW absorption is attributable to water vapor; we can scale the optical depth to the fraction of water vapor in ε_1. We have everything we need to obtain ε_1 except the emissivity of the atmosphere (ε_{atm}). Since ε_{atm} is not precisely known and varies with temperature and dewpoint, we estimate the range of ε_1 using the full range of values of ε_{atm} (0-0.99). Inserting ε_{atm} values and propagating the resulting τ_1 indicates ε_1 ranges from 0.0 to 0.049. These values are used to calculate $LW^{\uparrow}_{f=0}$, which accounts for the air and water below the boom but does not include the effects of the tower.

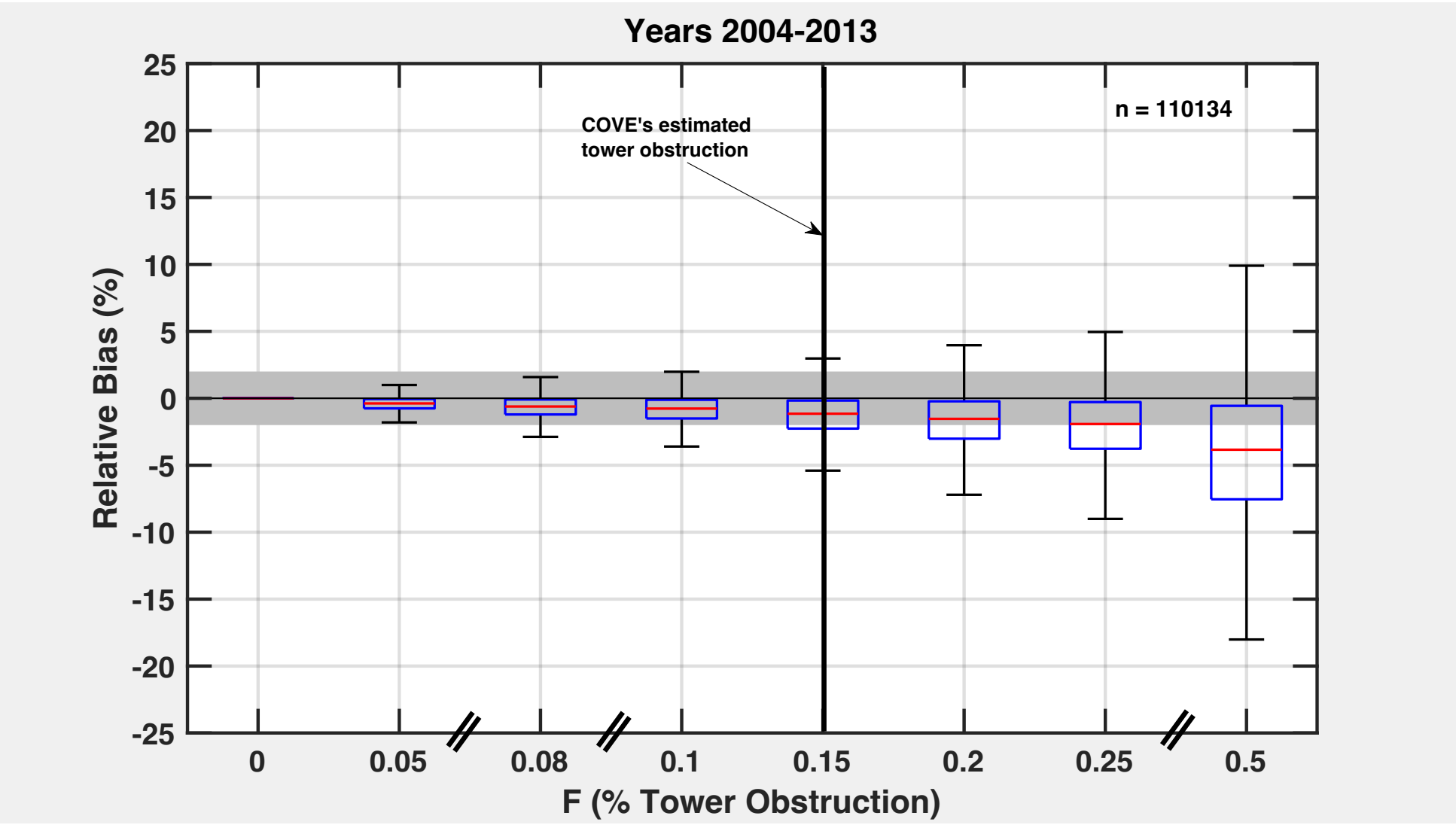
Note: The orange plot lines in the lower left of this poster are the full range of ε_1. Dark blue is $\varepsilon_1 = 0$.



Relative Bias = [(LW$^{\uparrow}_{pyr}$- LW$^{\uparrow}_{f=0}$) / LW$^{\uparrow}_{f=0}$] x 100

Left:
The shaded region is +/- 2%, the BSRN target uncertainty as of 2004. The box and whisker plots illustrate the relative bias is outside the targeted range frequently (and more so, in the colder months).

Right:
The bar plot show data falling outside the BSRN target uncertainty over 40% of the time in some years.



COVE's estimated tower obstruction is 15% (F = 0.15). Approximately one-third of the relative bias is outside the target uncertainty when F = 0.15. Therefore, the solution to the tower obstruction is to use the output determined from LW$^{\uparrow}_{f=0}$ while also meeting BSRN target uncertainty. If we were able to move the LW$^{\uparrow}_{pyr}$ instrument closer to the tower (when F gets larger), the results get worse. If we were able to move the LW$^{\uparrow}_{pyr}$ instrument further away from the tower (when F gets smaller), the numbers will eventually match LW$^{\uparrow}_{f=0}$. At COVE, the boom would need to extend to ~14m to be inside the target uncertainty at F = 0.05.

Summary:

- Many years of LW$^{\uparrow}$ data collected with a static pyrgeometer at COVE were contaminated with an estimated 15% obstruction in the pyrgeometer field of view, first noticeable on a clear, summer day.
- A new LW$^{\uparrow}$value (LW$^{\uparrow}_{f=0}$) was determined and the only unknown from the equation was air emissivity (ε_1) below the static pyrgeometer measurement. Applying the full range of ε_1 to LW$^{\uparrow}_{f=0}$ display small differences.
- Comparing LW$^{\uparrow}_{f=0}$ with LW$^{\uparrow}_{pyr}$ shows noticeable differences, more pronounced in the winter, that are outside the BSRN 2% target uncertainty and point to using LW$^{\uparrow}_{f=0}$ as an improved measurement.
- Using LW$^{\uparrow}_{f=0}$ makes the tower obstruction obsolete. This method could be used at other locations with similar field of view issues.

Acknowledgements:

- We thank the United States Coast Guard and the Department of Energy for allowing atmospheric and oceanic research at COVE.