A Solution for the Tower Effect on Upwelling Longwave Radiation at COVE

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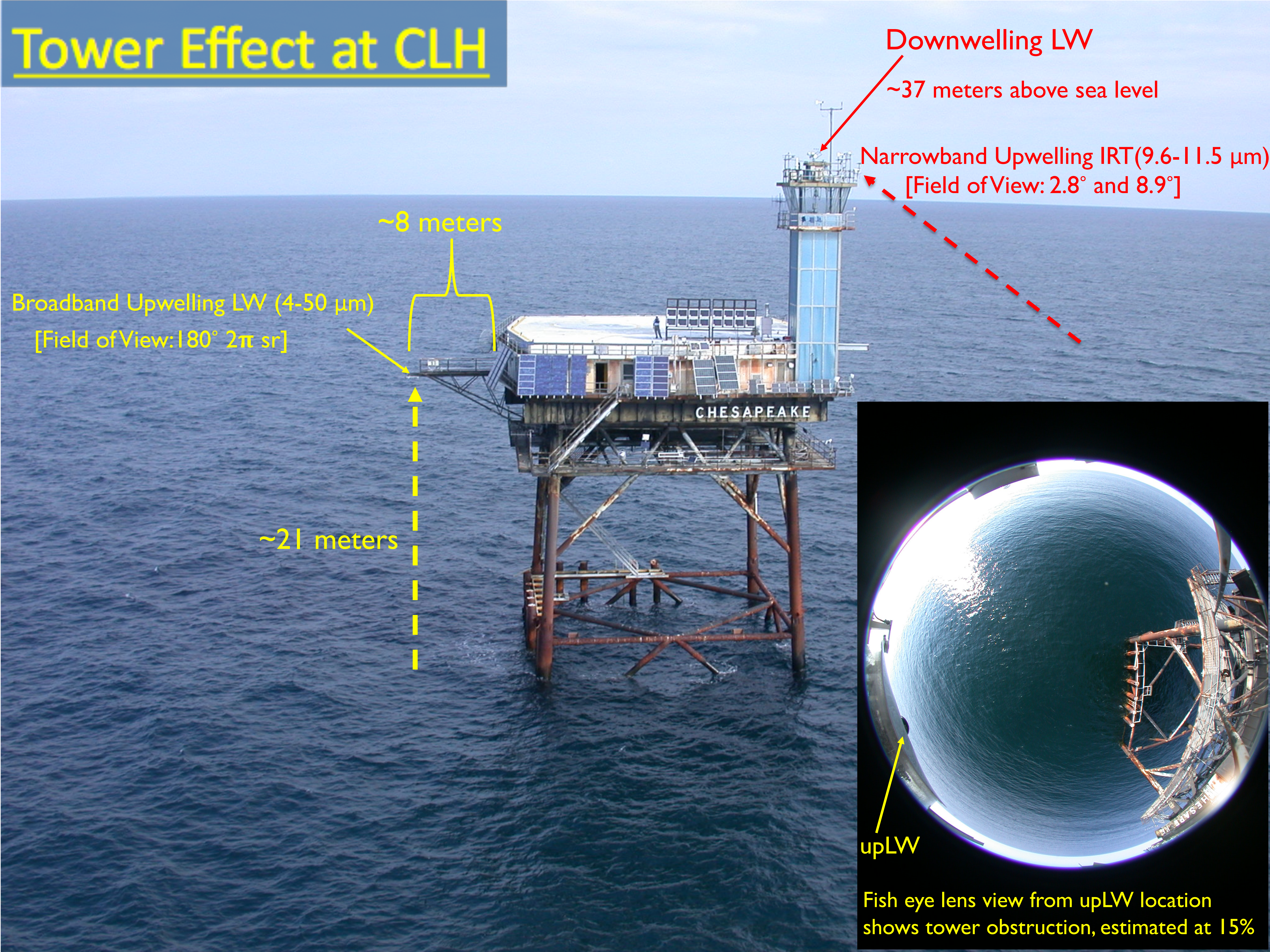
Tower Effect at CLH



Tower Effect Equations

What we had:

$$\text{Measured } LW_{up} = (1-\cancel{f})(\underbrace{\epsilon_w \sigma T_w^4}_{\text{Water surface thermal emission}} + \underbrace{(1-\epsilon_w) \cdot LW_{dn}}_{\text{Reflected flux of downward atmospheric emission}}) + \underbrace{\cancel{f}\epsilon_T \sigma T_T^4}_{\text{Tower Emission}}$$

What we want:

$$^{*}\text{ Derived } LW_{up} = \epsilon_w \sigma T_w^4 + (1-\epsilon_w) \cdot LW_{dn}$$

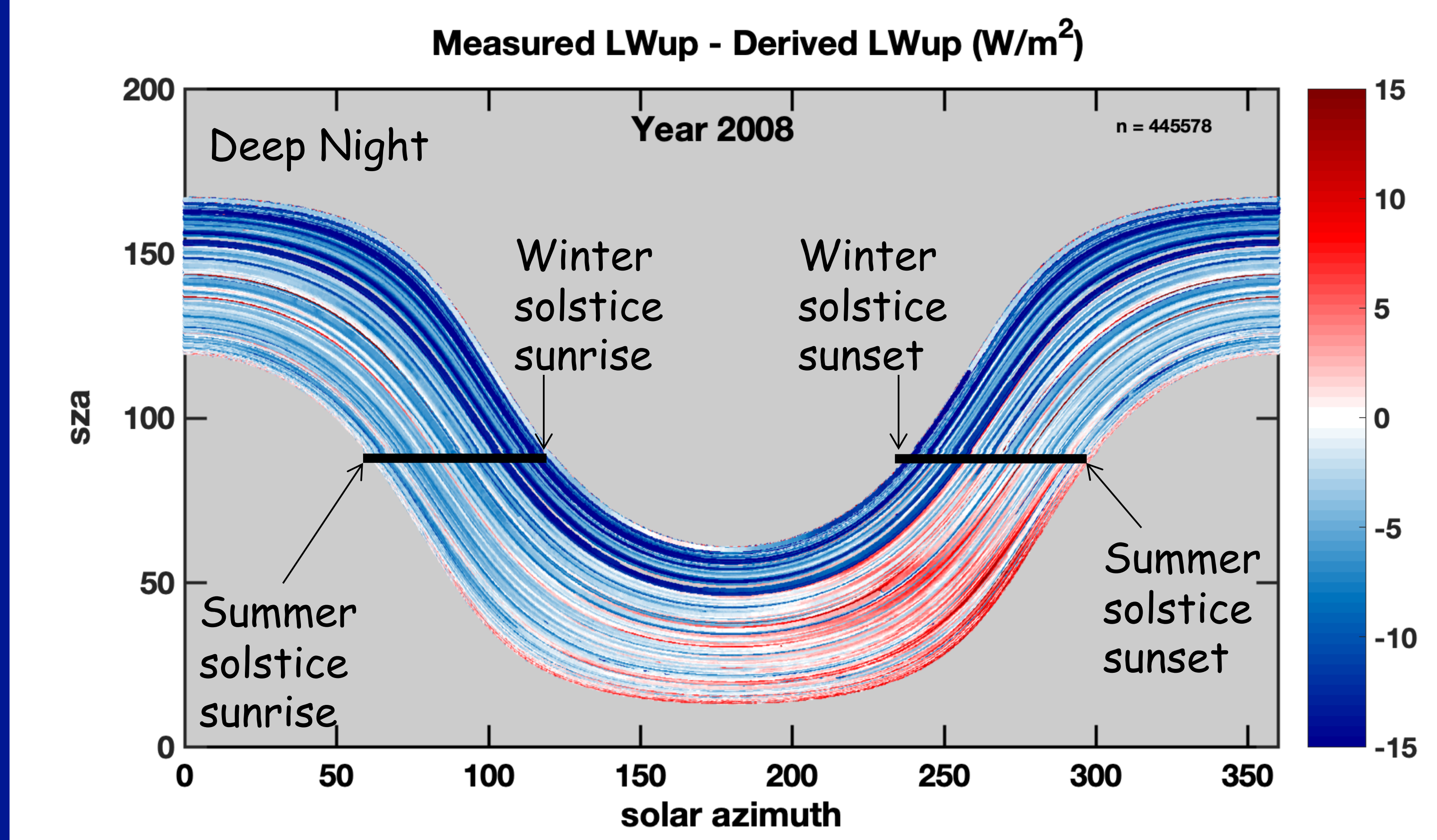
Where,

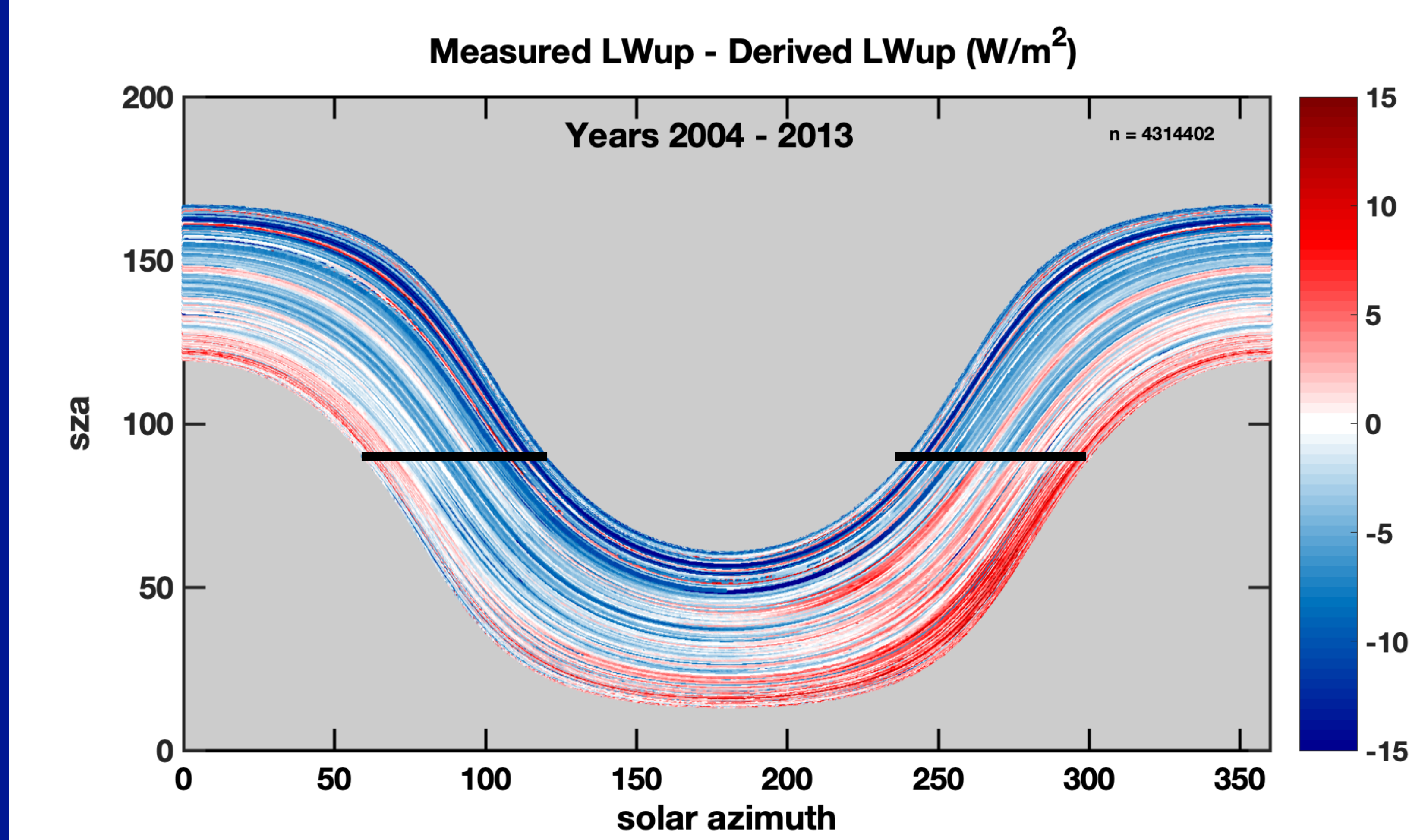
- f = The estimated fractional obstruction the tower is in the field of view of Lw_{up}. At COVE, 0.15 was the estimate.
- ϵ_w = Emissivity of water (ϵ_w = 0.990).
- σ = Stefan-Boltzmann constant (σ = 5.6697 x 10^{-8}).
- T_w = Water temperature in degrees K. Measured with an IRT (9.6 – 11.5 μm).
- LW_{dn} = Downwelling longwave radiation. Measured with an Eppley PIR (4 – 50 μm).
- ϵ_t = Emissivity of tower. Unknown, but reduced CHI^2 equation indicates ϵ_t = 0.90 (shown later).
- T_t = Temperature of tower in degrees K.

* 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)

Single Year (upper) and Total Time Period (lower) Comparisons

- Data above the solid black lines is nighttime
- The darker red lines indicate the tower heats up in the the afternoons, particularly summer, as captured by the wide field of view Measured LW_{up} measurement
- But there is a lot of blue, at night and in the morning, displaying explicit differences between the two measurements.



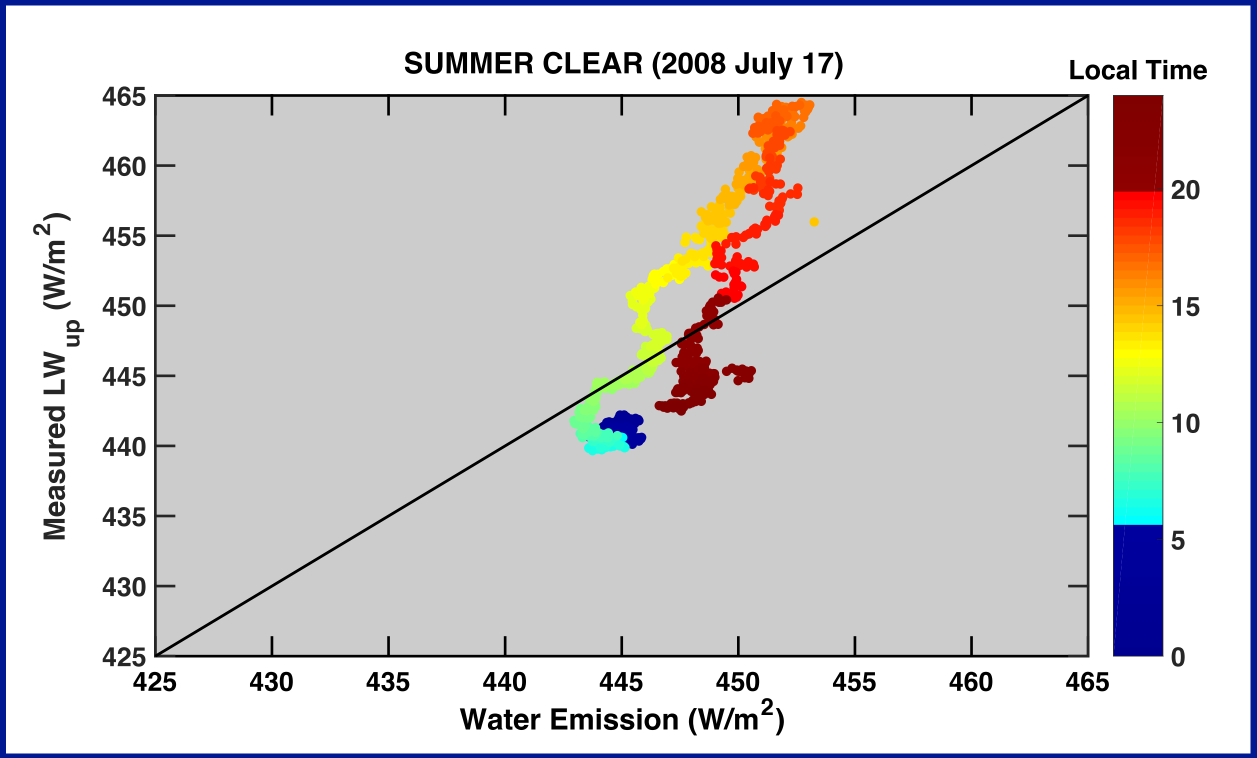


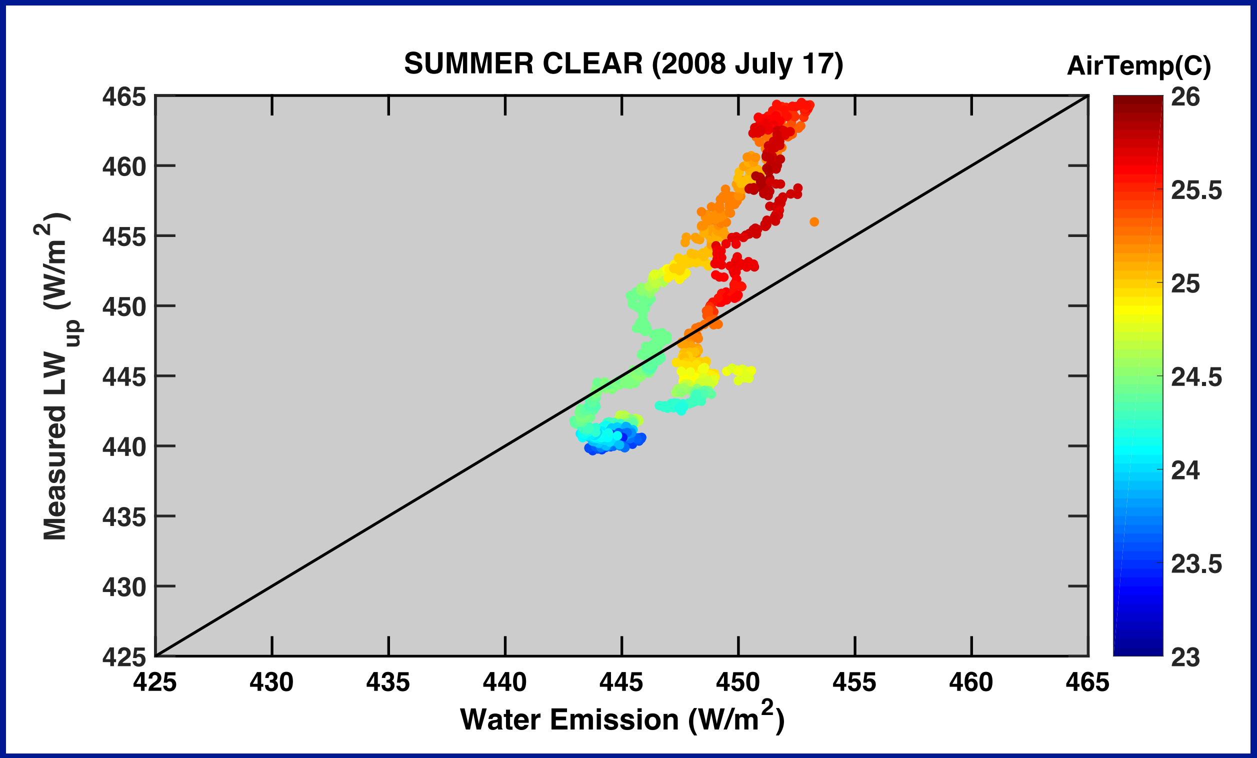
Single Day Results

Scenarios:

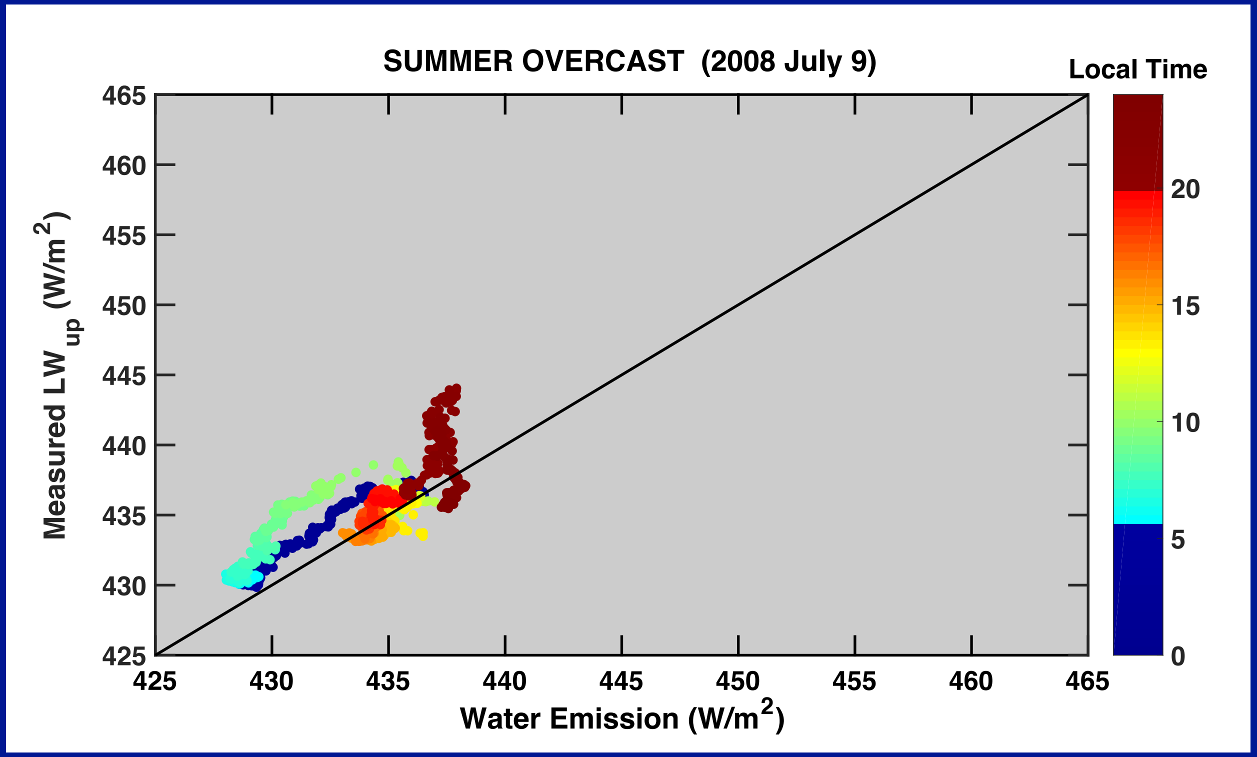
- Summer clear
- Summer overcast
- Winter clear
- Winter overcast

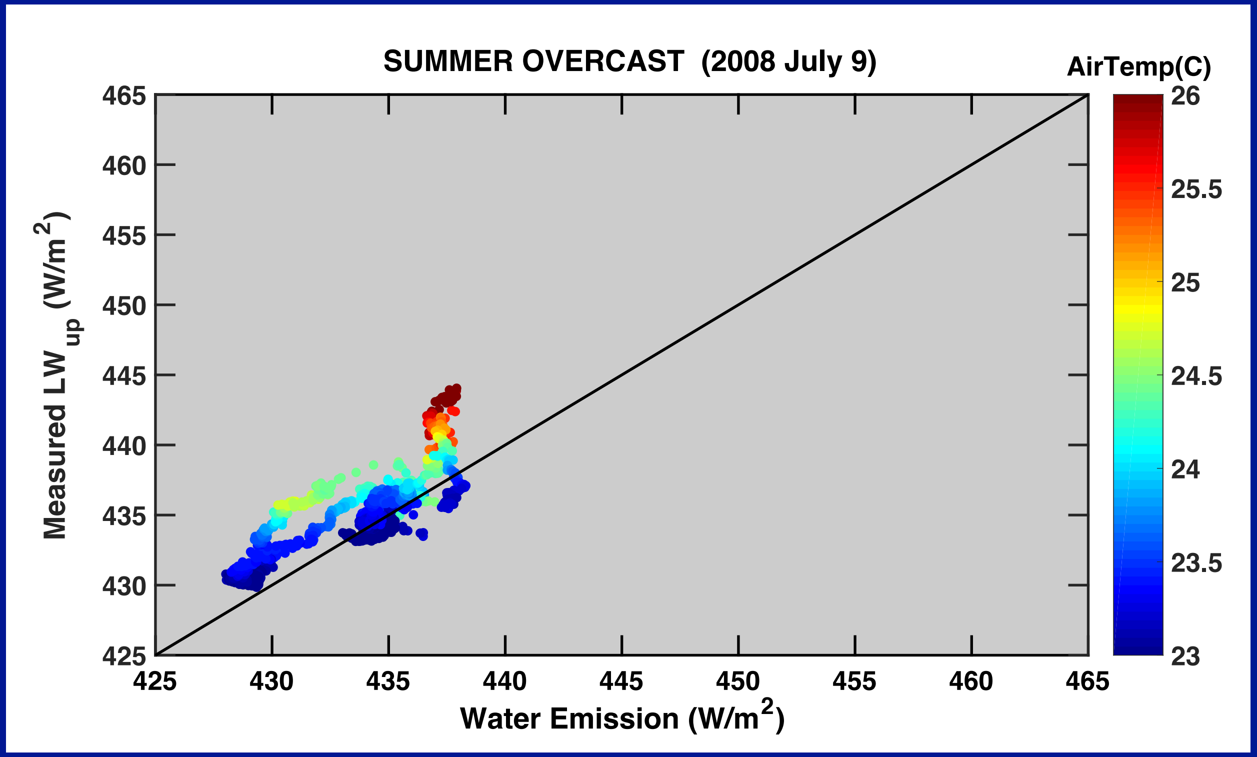
- Evidence suggests that the tower is altering the Measured LW, noticeable on this clear, summer day



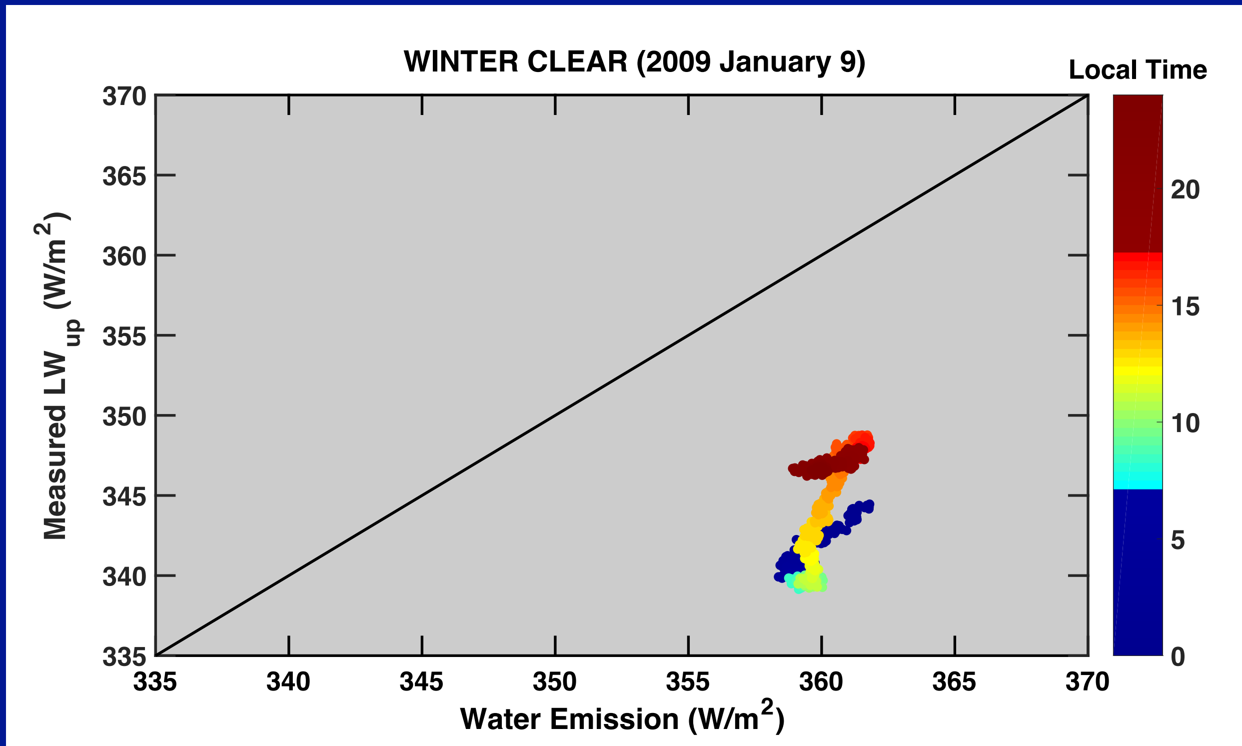


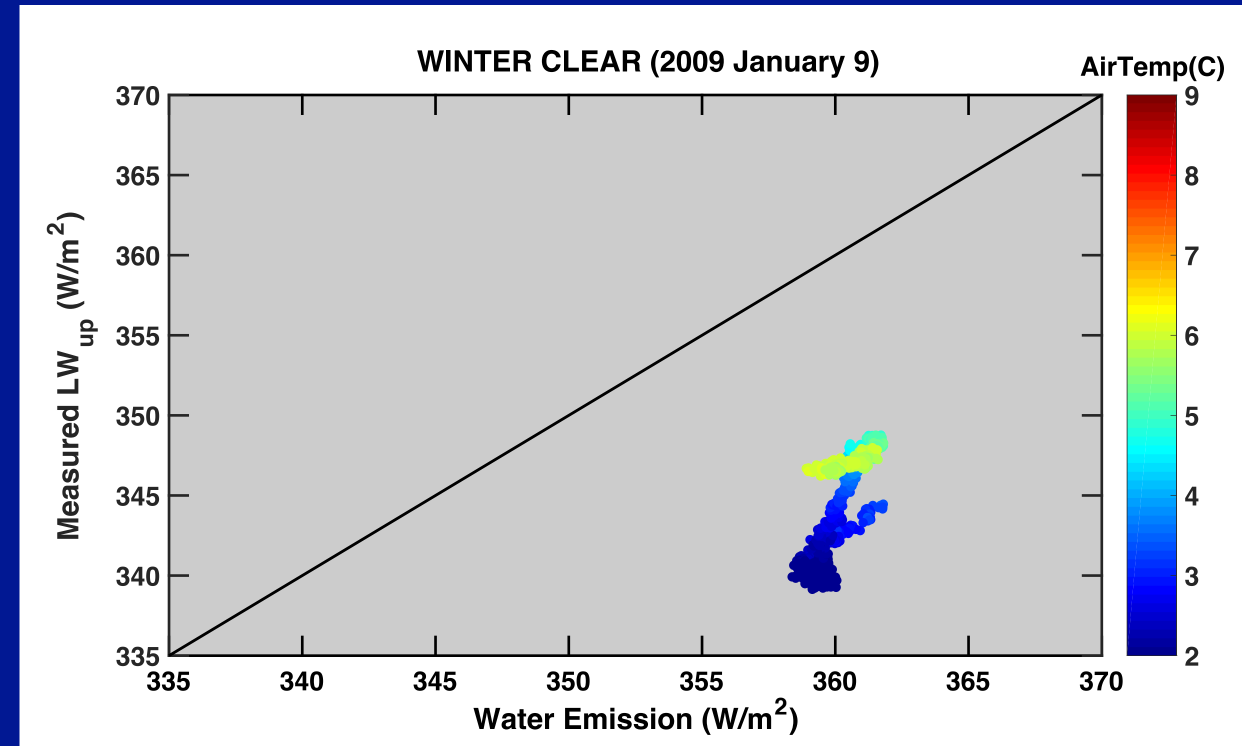
- But on overcast days, LW measurements and water emission measurements are closer to the 1:1 line.
- At night, an increase in air temperature alters the Measured LW



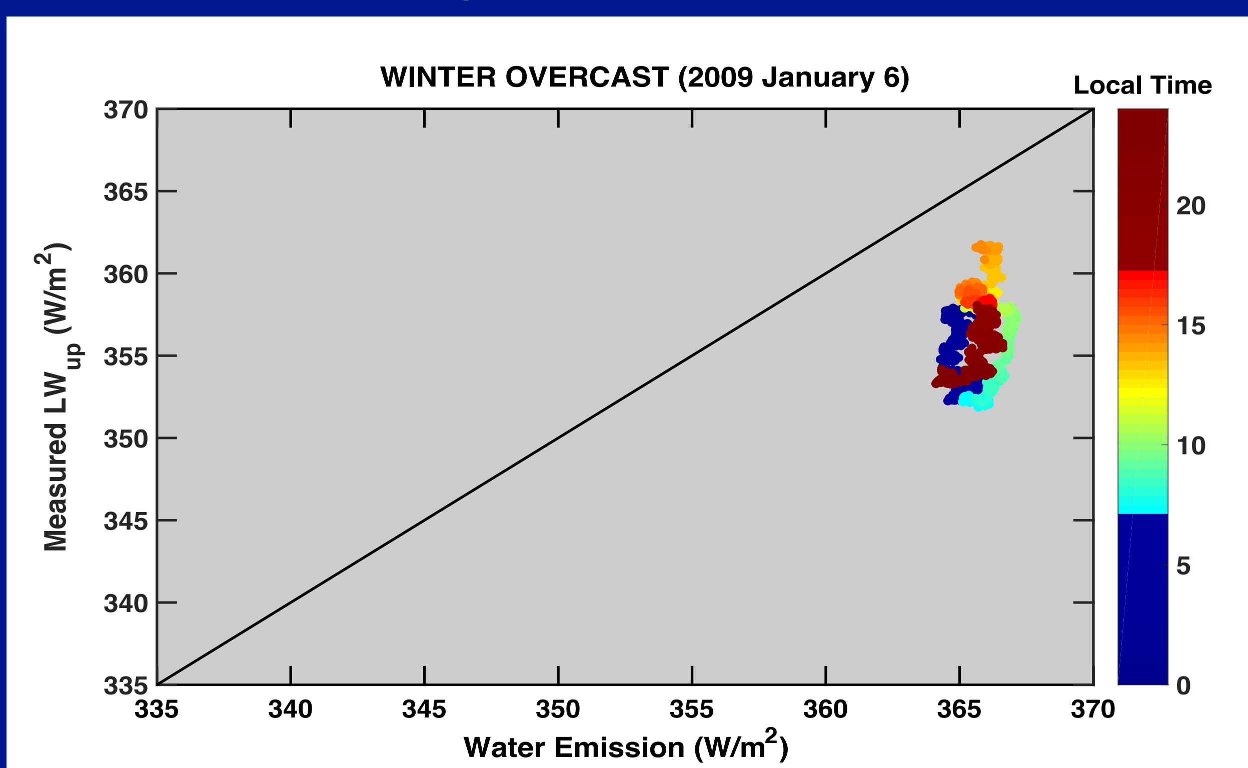


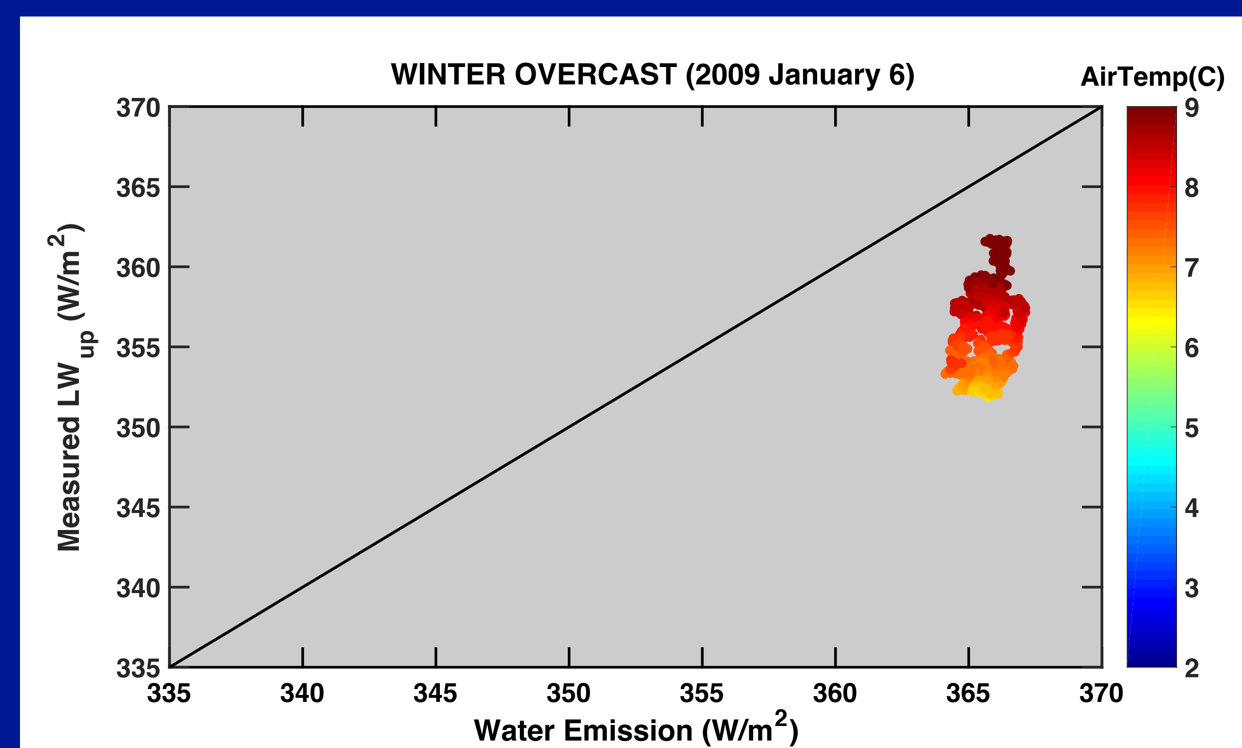
- On a clear, winter day, evidence suggests the tower is again altering the Measured LW, but not as much as the summer, clear day.
- Another significant difference is the spread from the 1:1 line. There is a large bias in the Water Emission



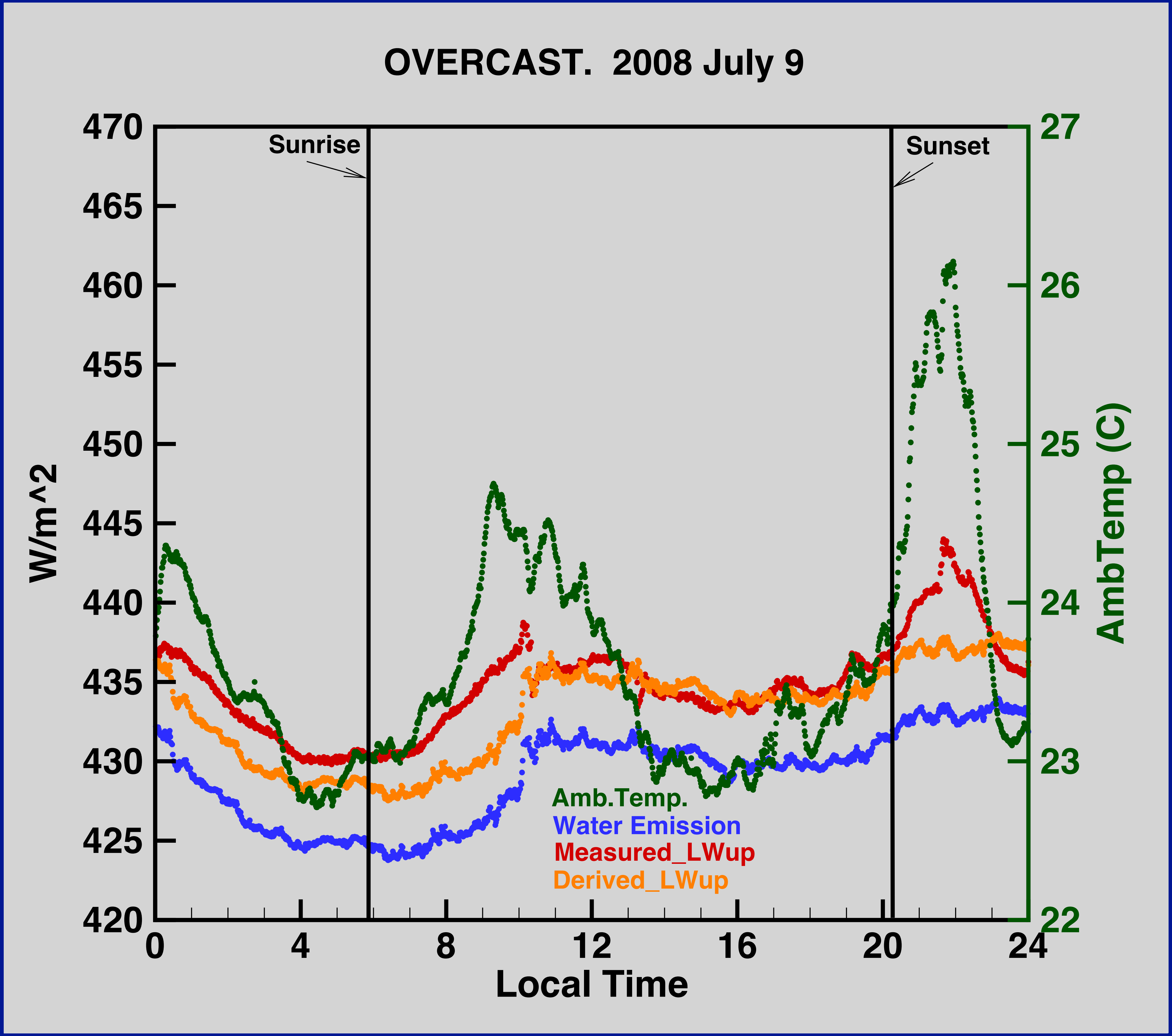


- The winter overcast day, like summer overcast, are closer to the 1:1 line, but like clear winter, there is still a bias in the Water Emission



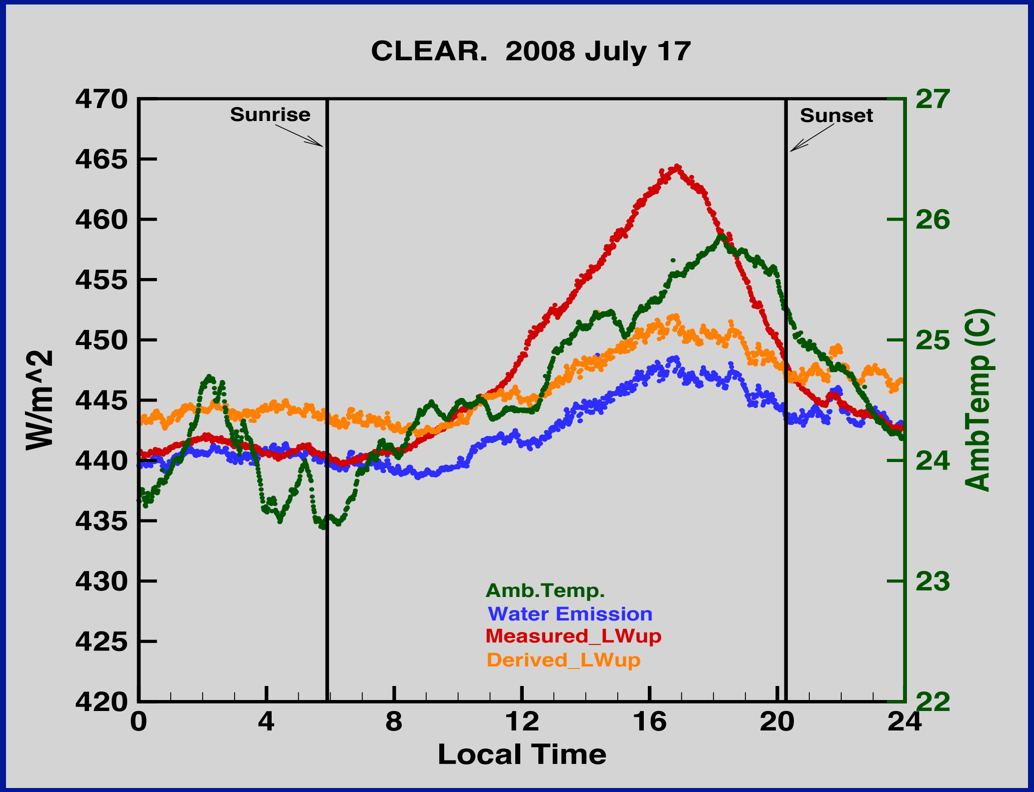


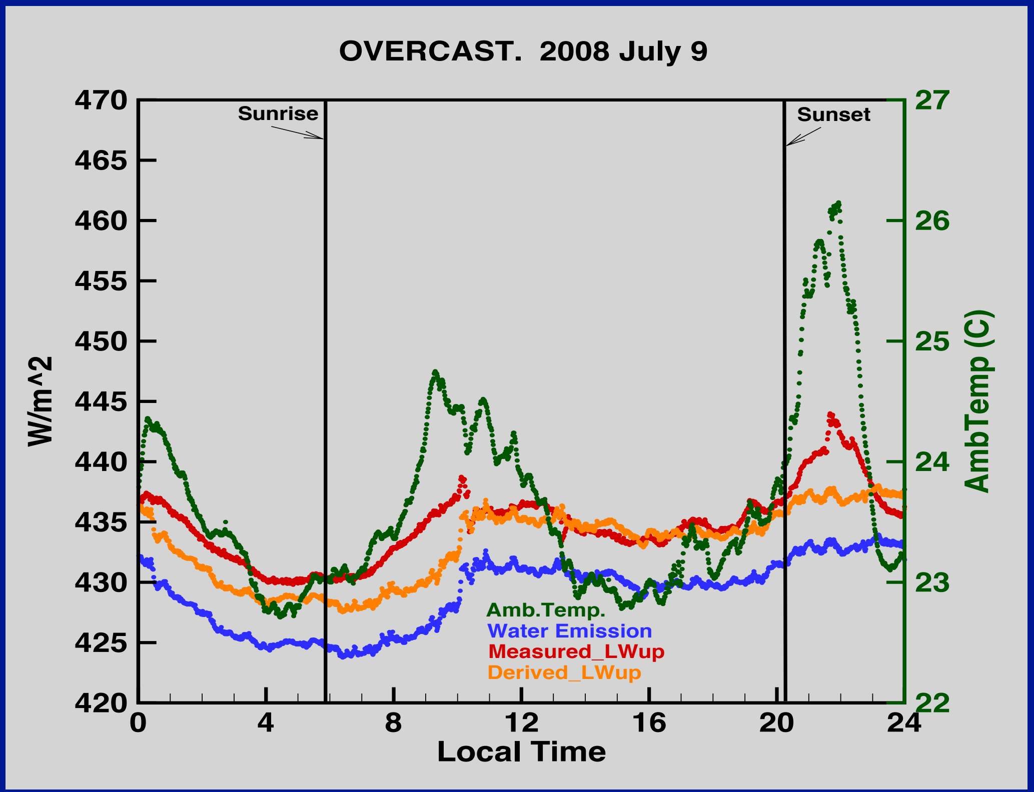
- Another way to show single day plots.
- The same variables as the previous slide are shown, but the Derived LW_{up} is added

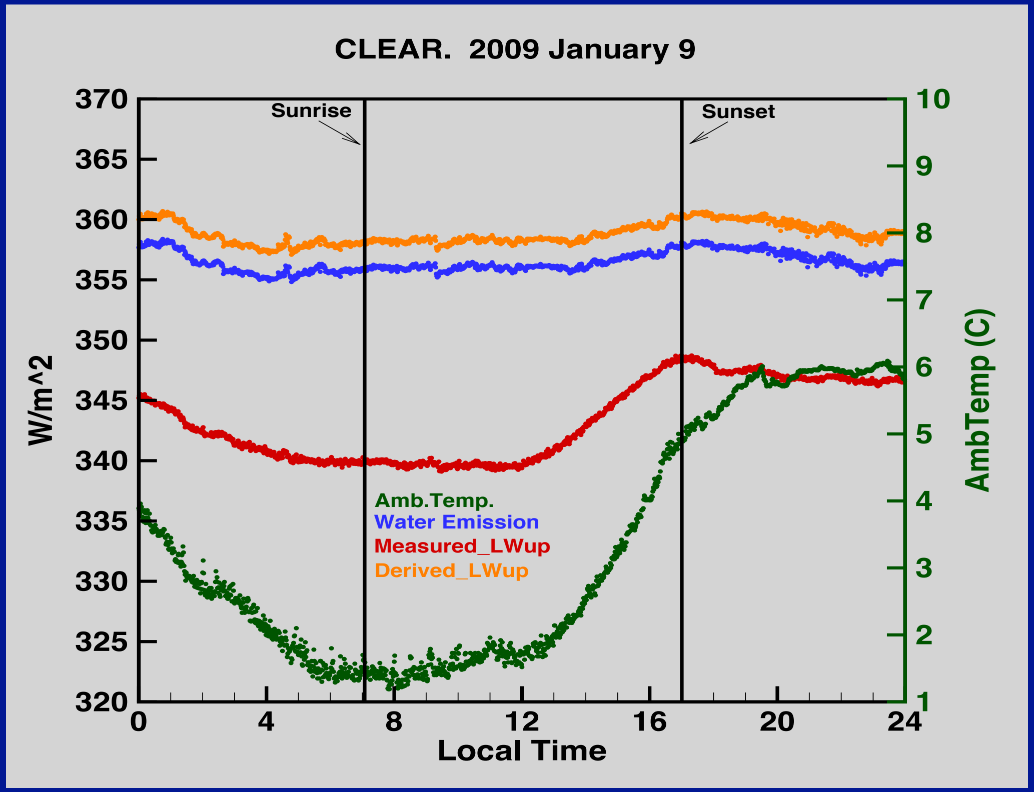


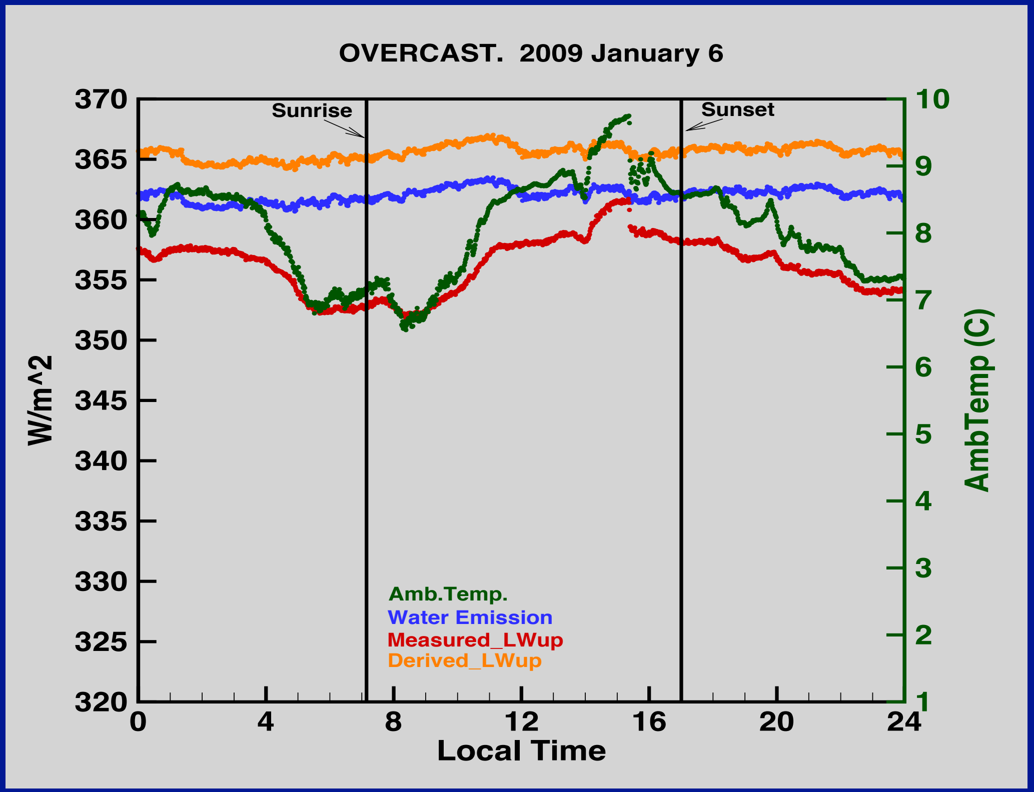
Single day plots continued…..The other single day scenarios included

- Vertical black lines represent the sunrise and sunset times for the 4 single day scenarios
- Measured LW has lower values in the winter and has more variability due to the tower obstruction
- The Derived LW is not affected by the tower emissions (e.g. the temperature and solar insolation during the day)









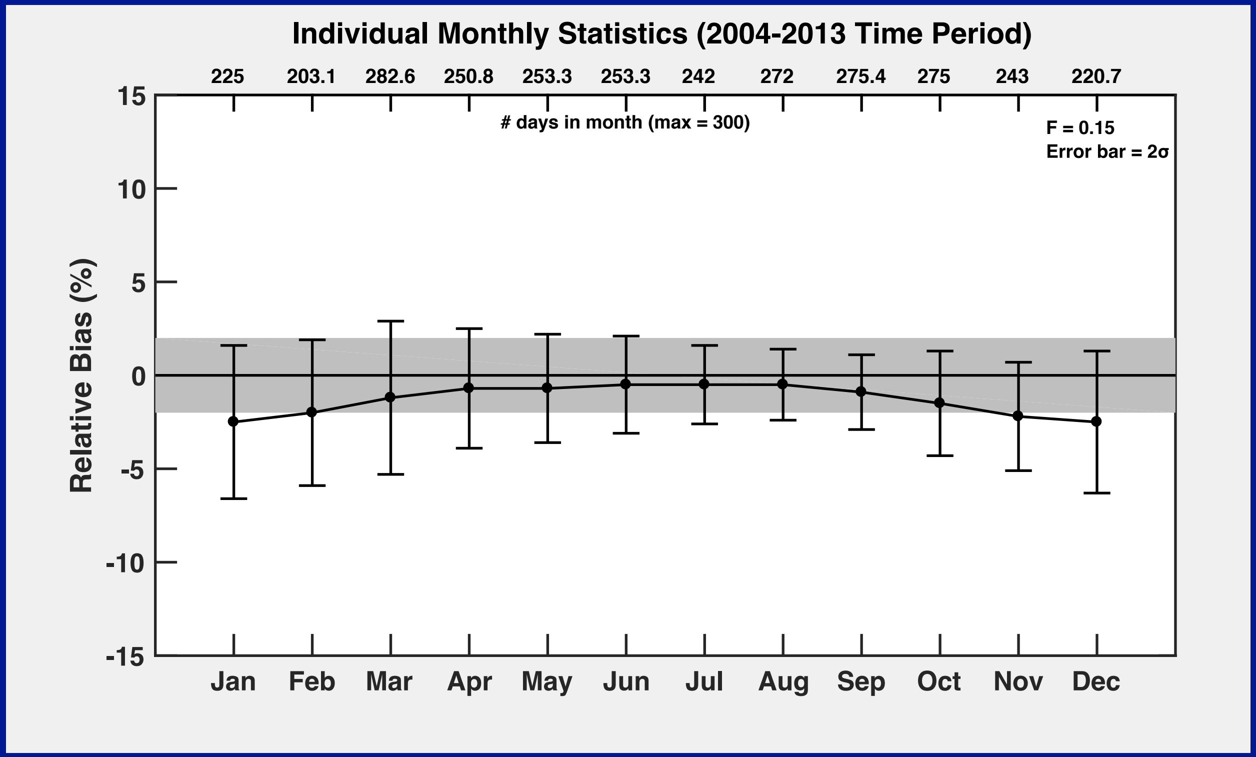
Results/Statistics Months

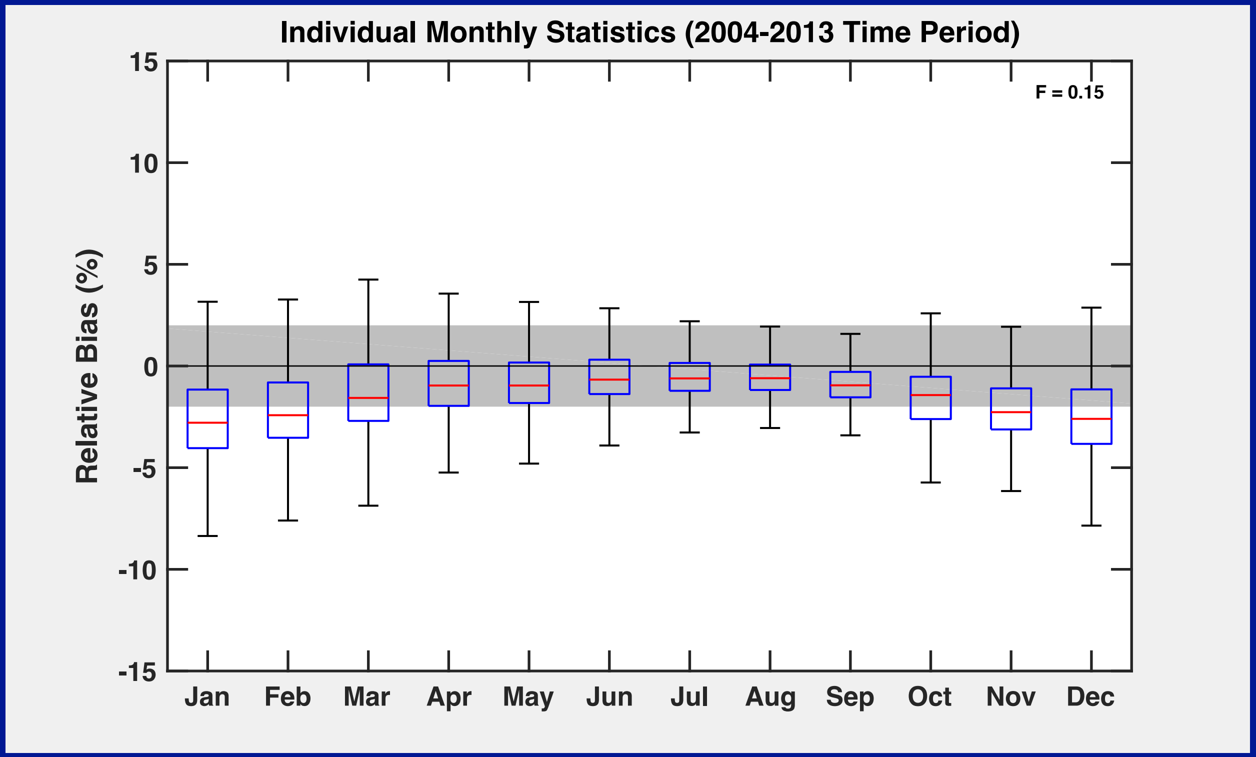
Time period for monthly data is 2004-2013

Relative Bias = ((Measured LW_{up} – Derived Lw_{up}) / Derived Lw_{up}) X 100

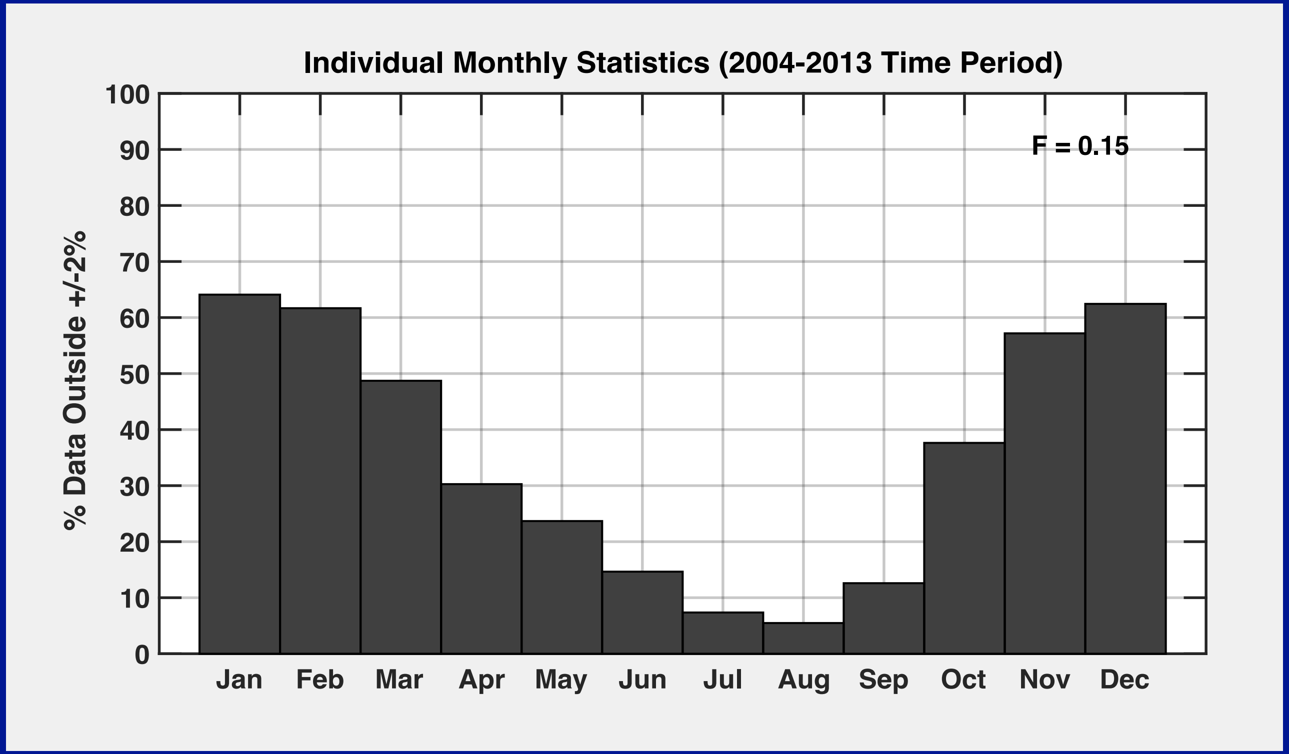
- As of 2004, BSRN target uncertainties for upwelling longwave radiation is 2% or 3 W/m^2, whichever is greatest (The shaded regions will represent the 2%).

Individual monthly plots show biases in the Derived LW_{up} with all months, mean, and medians below 0





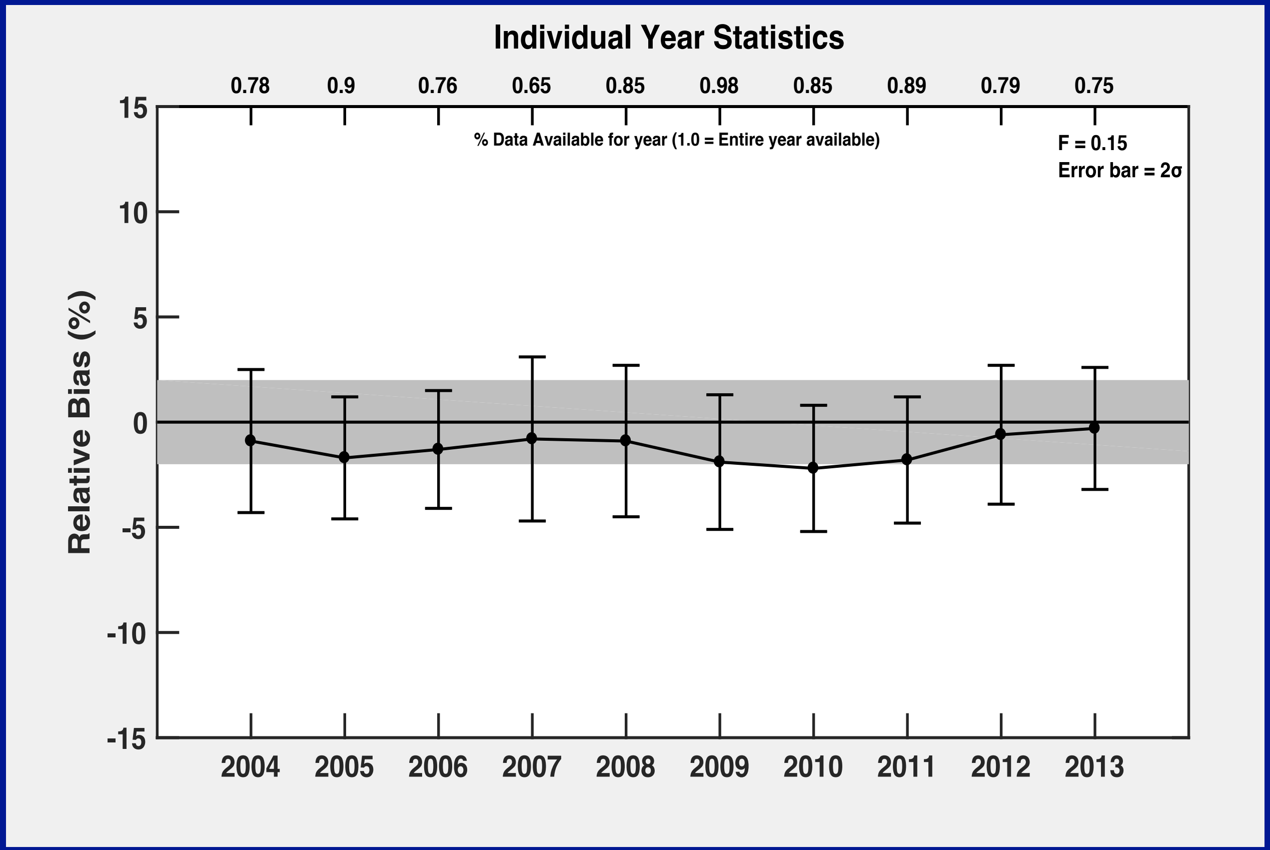
Warmer months have better agreement, less data outside the BSRN target uncertainty

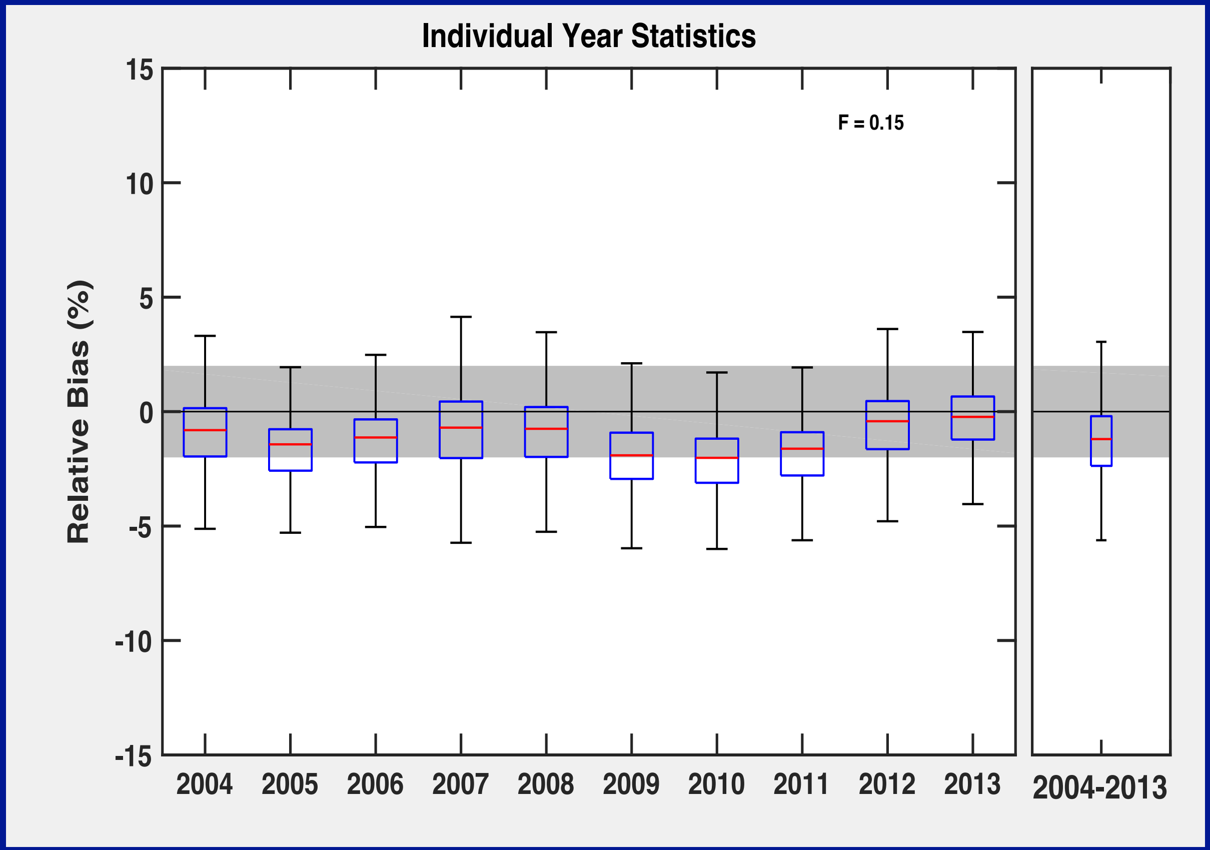


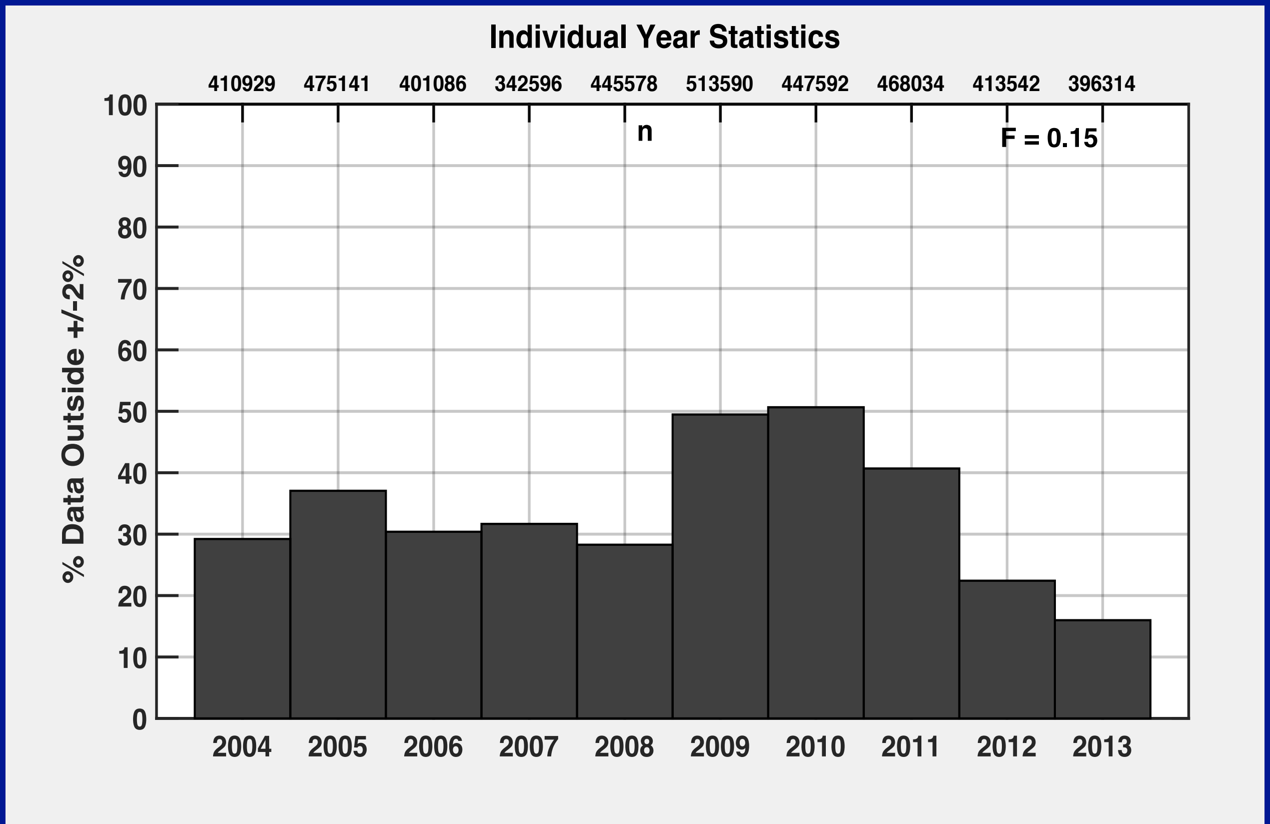
Results/Statistics for Annual

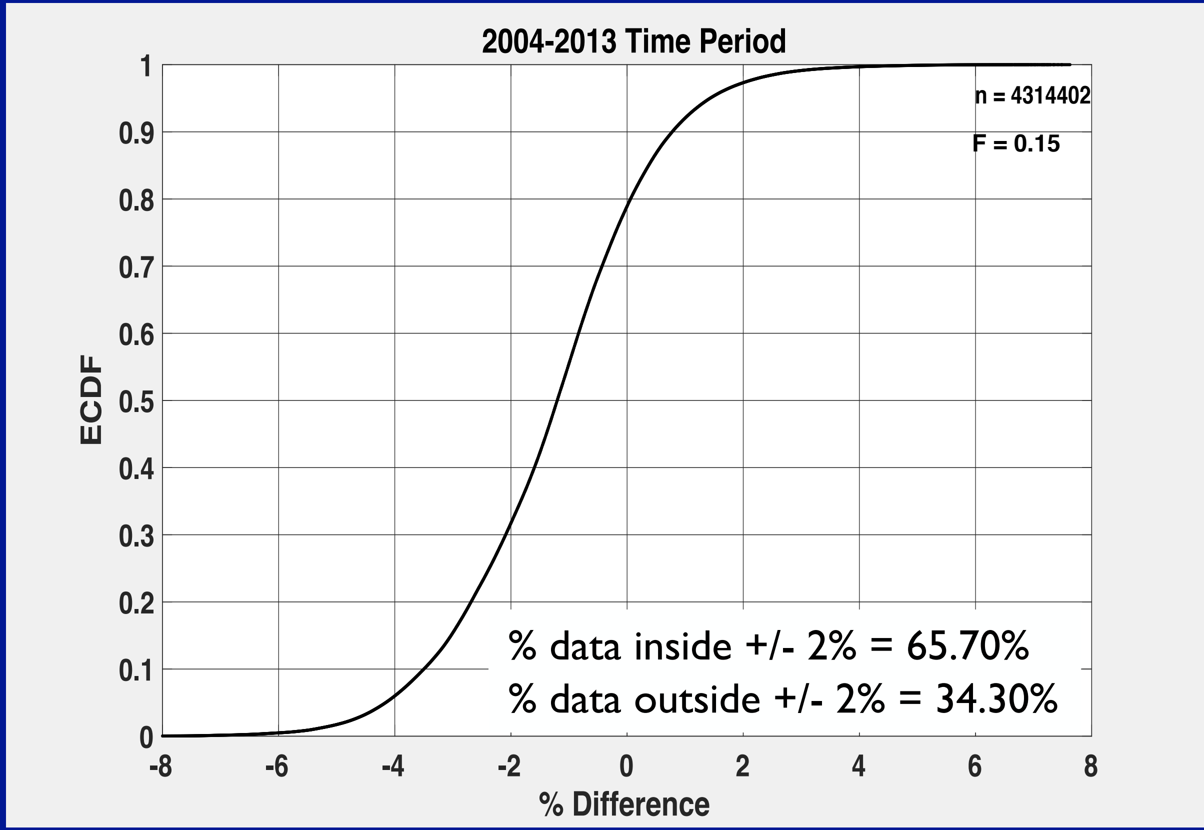
The 10 year period is from 2004-2013

- Individual year plots continue to show biases in the Derived LW_{up} with all years mean and medians below 0 (upper plots)
- All years are outside the the target uncertainty with some as high as 50% (lower left)
- The lower right plot is the entire 10 year time period displaying 1/3 of the data outside BSRN target uncertainty









Attempt to Quantify the Impact of F on obstructed Measured Lw_{up} measurements

Quantifying the Tower Emissivity

If our measurements are accurate and our approach is sound, we can compute the emissivity of the tower.
For N measurement times, our radiation balance results in N equations and N + 1 unknowns:

$$LW^{\uparrow}_{m,i} = (1-f)[\varepsilon_w \sigma T^4_{w,i} + (1-\varepsilon_w) LW^{\downarrow}_{m,i}] + f \overset{?}{\varepsilon_{twr}} \sigma \overset{?}{T^4_{twr,i}} \quad \text{for } i = 1, \ldots, N$$

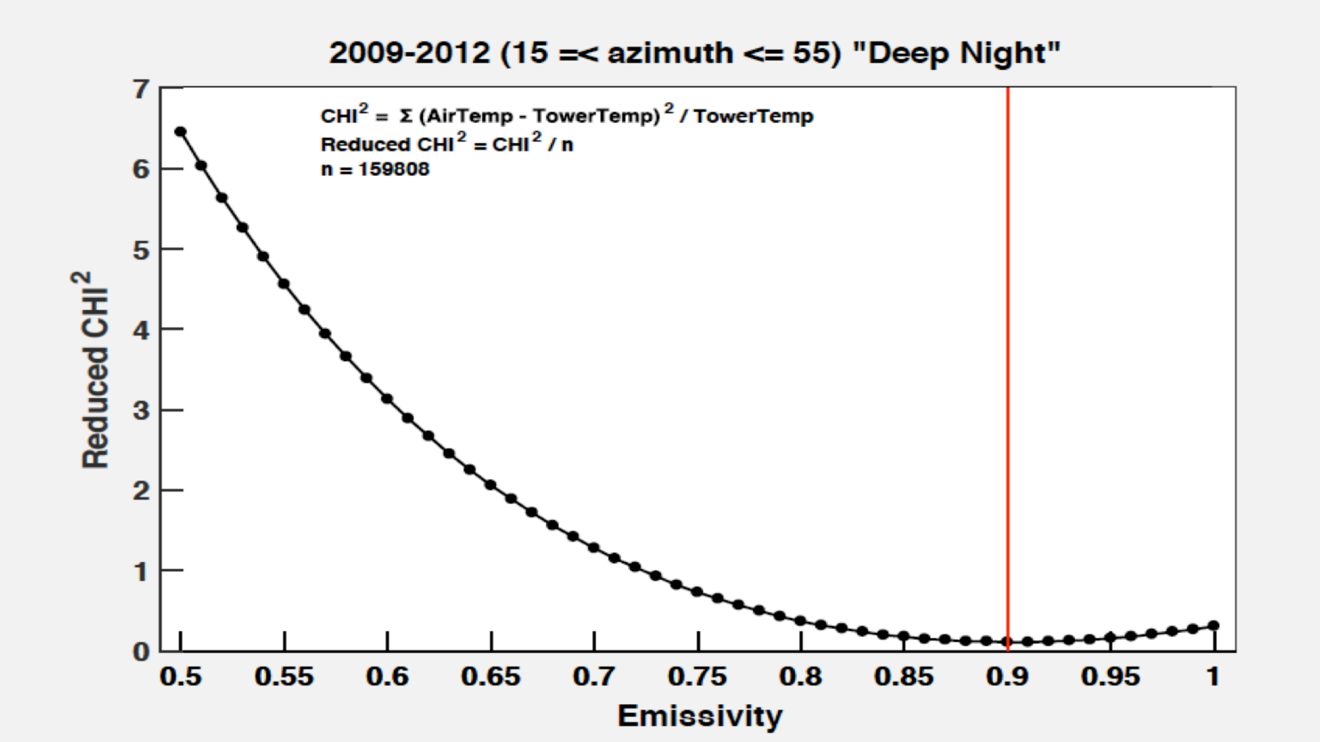
We can reduce this to N equations and 1 unknown if we solve for T_{twr} and assume that the tower is in equilibrium with the measured air temperature at night:

$$T_{twr,i}(\varepsilon_{twr}) \simeq T_{air,i}.$$

The problem is now overconstrained (N equations, 1 unknown), so we use χ^2 minimization to find optimum ε_{twr} :

$$\chi^2(\varepsilon_{twr}) = \sum_i \frac{T_{air,i} - T_{twr,i}(\varepsilon_{twr})}{T_{twr,i}(\varepsilon_{twr})} \to 0.$$

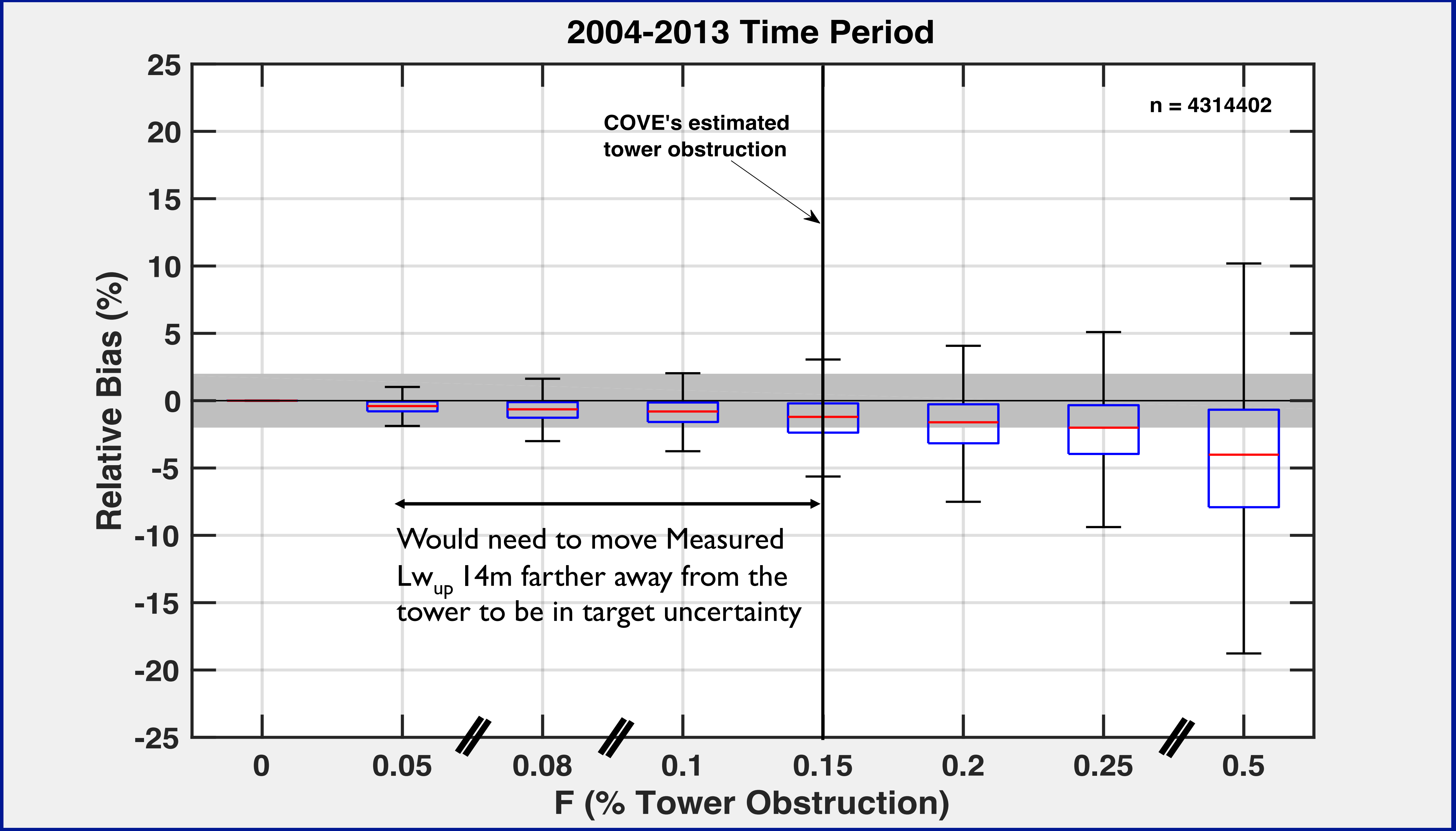
$$\Rightarrow \varepsilon_{twr} = 0.90$$



- Measured LW_{up} – Derived LW_{up} = $f(\epsilon_T \sigma T_T^4 - \epsilon_w \sigma T_w^4 + (1 - \epsilon_w) LW_{dn})$

- The values of Measured Lwup (f /= 0) and Derived Lwup (f = 0) diverge when F > 0

- COVE's obstruction is 15%. If one could move the instrument closer to the tower (as F increases), the relative bias between Measured LW_{up} and Derived LW_{up} expand. As F gets smaller and eventually to 0, the results match. One could use this method on any obstruction.



Summary

- COVE's tower obstruction, estimated at 15%, caused anomalous readings on the Measured Lw_{up} instrument.

- We used SST measurements at COVE and the reflected flux of the downward LW atmospheric emission to derive an upwelling LW emission (Derived Lw_{up}).

- The Derived LW_{up} emission is not susceptible to changes in air temperature and direct solar heating on sunny days, unlike Measured LW_{up}.

- The relative bias is largest in the colder months when the air temperature and water temperature are greatest. The relative bias is smaller in the warmest months.

- We have not submitted LW_{up} to the BSRN archives due to the tower effect. Using Derived LW_{up} will provide over 10+ years to the BSRN archive.

- Using instruments that derive Lw_{up} could be used at sites such as Granite Island where constraints limit using a wide field of view instrument.

- This solution could be used on any tower or obstruction.