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NOAA: Teachers in the Lab

Daniel E. Wolfe[1], Peter D. Blanken[2], Chris W. Fairall[1], and Diane M. Stanitski[3]

[1] NOAA Earth System Research Laboratory, Boulder, Colorado
[2] University of Colorado, Department of Geography, Boulder, Colorado
[3] NOAA Climate Program Office, Silver Spring, Maryland

1. INTRODUCTION

NOAA's Teacher in the Lab (TIL) is a new pilot program modeled after the successful NOAA Teacher at Sea program (NOAA Teacher at Sea Program, 2009: http://teacheratsea.noaa.gov/.) The mission of the TIL program is to provide teachers hands-on experience in a NOAA lab working side-by-side with NOAA scientists on a specific research project. The program's overall goals are to increase knowledge among teachers of earth system science, in-line with Ocean and Climate Literacy Principles, and to increase teachers' knowledge of careers that support earth system science. Teachers are expected to bring new and fresh ideas into the research community.

During summer 2009, Drs. Peter Blanken and Diane Stanitski participated in TIL at the Earth System Research Laboratory (ESRL) in Boulder, CO. Blanken and Stanitski have specific interests in air-sea fluxes and boundary layer climatology, which align perfectly with the expertise of their mentors, Dr. Chris Fairall and Daniel Wolfe. For three weeks they worked together to identify ways to improve education and outreach associated with these scientific fields. Blanken worked with data from the 300-meter tall tower at the Boulder Atmospheric Observatory (BAO) that monitors atmospheric profiles of temperature, moisture, wind, carbon dioxide, and other atmospheric trace gases. A small experiment was planned making use of the BAO's unique capabilities. Stanitski helped conduct an inter-comparison test between flux sensors on the University of Hawaii R/V Kilo Moana and the Woods Hole Oceanographic Institution (WHOI) Hawaii Ocean Time-series (HOT) Site (WHOTS) ocean reference mooring north of the island of Oahu. Early results from the collaborative work at the BAO and during WHOTS are shown.

The collaboration between teachers and mentors extends well beyond the initial 3-week period. Blanken and Stanitski, along with their mentors, are co-authoring papers and reports, presenting results at professional scientific meetings, and team-teaching advanced courses during the 2009-2010 academic year.

Corresponding author's address: Daniel E. Wolfe NOAA/Earth System Research Laboratory 325 Broadway St. R/PSD3 Boulder, CO 80305; e-mail: daniel.wolfe@noaa.gov.

Figure 1. Dr. Peter Blanken installing instruments (left) and collecting data (right) on the 300m tower.

2. Boulder Atmospheric Observatory

The BAO (Kaimal and Gaynor, 1983) is a research facility located approximately 15 km east of Boulder, CO. The centerpiece is a 300m tower built in 1975 for studying the Planetary Boundary Layer (PBL) and testing and calibrating atmospheric sensors. A unique capability of the tower is the ability to profile the PBL using the external instrument carriage (IC). A combination of measurements made at fixed tower levels and the IC were the focus of the work done at the BAO as part of the Teacher in the Lab program.

As an Associate Professor in the Geography Department at the University of Colorado, Peter's interests include climate and studying the surface energy budget. To *human* eyes, the view from the top of the BAO is sweeping, but Blanken and Wolfe were more interested in the view, or "sample footprint," of *sensors* at the BAO. The area "seen" by the tower's radiometric and turbulent flux measurements depends on several factors, from sensor height and design to atmospheric conditions. In a series of experiments, Blanken and Wolfe ran sensors up and down the tower on the IC, to examine changes in sampling area. The researchers expect their data will help scientists better understand and improve measurements from global tower networks.

Figures 1 and 2 show pictures of a simple experiment designed to look at how the "sample footprint" changes as sensors mounted on the IC were moved up and down the tower. In Fig. 2 the top image shows the sensors looking down from the very top of the profile (300m) with the Rocky Mountains in the background. The lower right image shows the IC with the sensor boom and data logger. The lower left image shows a ride to the top as Blanken and Wolfe get a first-hand look at what the sensors are seeing. A clear period, a cloudy period, and a somewhat unique period where the clouds were obscuring the top 100m of the tower were captured.

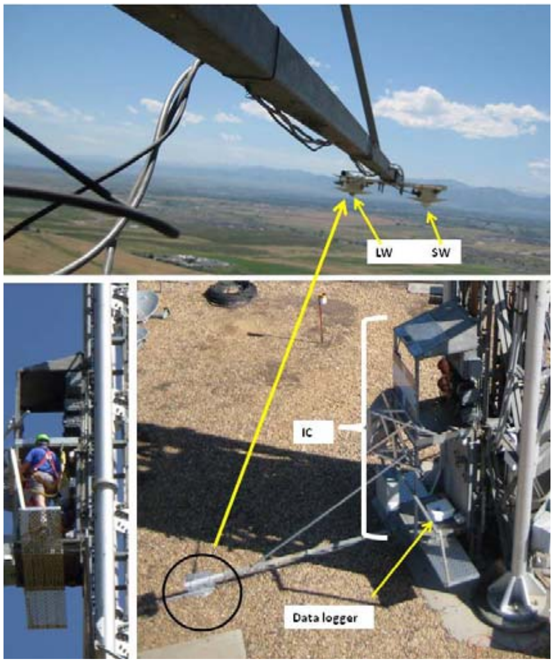

Figure 2. Downward looking radiometers at top of the tower (upper), Instrument carriage and instrument setup (lower right), riding instrument carriage to the top with instruments (lower left).

Short and long-wave radiometers (SW, LW) were mounted on the end of a boom on the IC facing downward along with a net radiometer. The SW sensor measures the reflected incoming solar radiation, the LW sensor measures the surface emitted radiation, and the net radiometer measures the incoming minus the upwelling radiation. Both upward and downward facing SW and LW radiometer measurements have been from the top of the BAO tower as part of the Baseline Surface Radiation Network (BSRN) for over 20 years (Dutton, 1990). Dutton discusses the possible affects different land surfaces could have on their measurements and presents a table listing the various surface types and their percentages. Surface conditions have changed only slightly since Dutton made his initial survey. Figure 3 shows two pictures taken from the IC looking down at 50m and 200m. The dashed circle in the lower image represents a 400m radius from the tower. Calculations show that the downward facing sensors at 300m (top of the tower) would be most affected by the area within a ~1000m radius circle. There is a significant difference between 50m and 200m as shown in Fig. 3.

Besides surface conditions and makeup, cloud radiative forcing (Stephens and Webster, 1979) plays an important role in the surface energy budget. Figures 4-6 shows time series of the SW and LW radiation for three cases when the IC was profiling. The black lines (BSRNd) in these figures refer to the Baseline Surface Radiation Network sensors mounted at the top of the tower measuring the incoming SW and LW radiation. The top plot in each figure is the SW and bottom plot the LW. Figure 7 shows the actual profiles for the three different sky conditions. Only the up profiles are shown. It takes approximately 9 minutes for the IC to go from the surface to 300m. Comparison of the up with the down profiles (not shown) suggests any change in the SW is directly related to the incoming SW (BSRNd). For the clear day this is a smooth increase or decrease as the sun rises or sets. For the other two cases the reflected SW is highly variable and dependent on the cloud cover. As seen in Figs. 5 and 6 the times when the IC was profiling are not as obvious as in Fig. 4. The profiles in Fig 7 are consistent with what is expected given the sky conditions. The sharp decrease just above the surface in the SW is due to the more highly reflective surface surrounding the tower (Fig. 3). In the two cloudy cases near the surface this gradient is less pronounced or near zero. Note the variability in the profile on the cloudy day is caused by the variability in the cloud cover that occurs even over the 9 minutes it took to complete this profile. The case when the clouds are obscuring the top 1/3 of the tower does not show this same structure, but the SW does begin to increase as a result of the increased scattering (diffuse radiation) as the IC enters the clouds near 200 m. The LW near the surface is responding to the temperature of the surface with little or no change once the IC is above about 25m. The clouds appear to have little or no effect in LW above the surface.

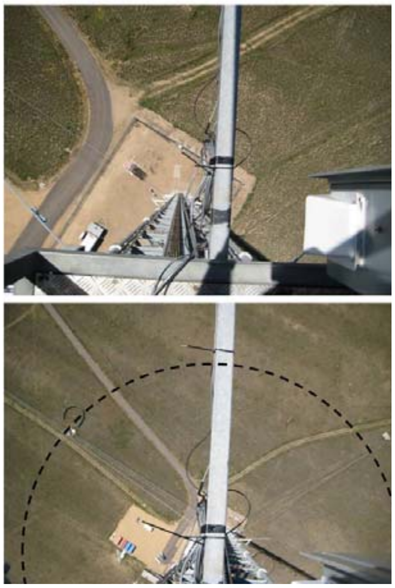

Figure 3. “Sample footprint” as seen from IC at 50m (top) and 200m (bottom). Dashed half circle represents 400m radius.

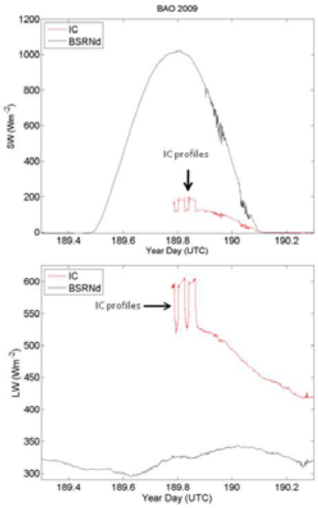

Figure 4. Time series of SW and LW radiation for clear day: July 8, 2009.

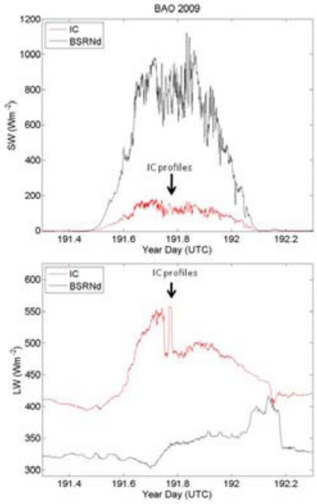

Figure 5. Time series of SW and LW radiation for cloudy day: July 10, 2009.

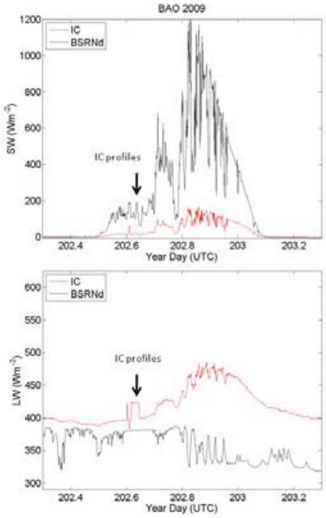

Figure 6. Time series of SW and LW radiation for a day with clouds on the top 1/3 of the tower: July 21, 2009.

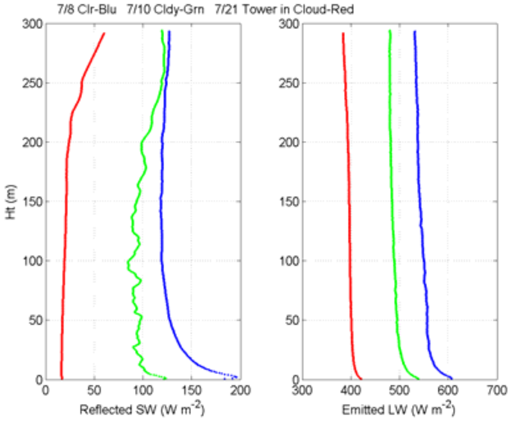

Figure 7. Up profiles of SW and LW for the IC profiles identified in Figs. 4-6.

3. Woods Hole Oceanographic Institution (WHOI) Hawaii Ocean Timeseries Site

During July 2009, mooring operations associated with the WHOI Hawaii Ocean Timeseries Station (WHOTS) project were conducted on the R/V Kilo Moana (KM). The WHOTS mooring provides long-term, high-quality air-sea fluxes and upper ocean temperature, salinity and velocity data, and provides observations of heat, fresh water and chemical fluxes at a site representative of the oligotrophic North Pacific Ocean. The first WHOTS mooring was deployed in August 2004, and the site has been continuously occupied since that time by means of annual mooring service cruises. The objectives for the cruise included recovery of the WHOTS mooring (WHOTS-5), at 22º 46.064' N, 157º 54.085' W, deployment of a replacement mooring (WHOTS-6) nearby, and comparison of meteorological and oceanographic sensors on the buoys and aboard the ship. Stanitski participated in the meteorological data comparisons.

The KM was heavily equipped with meteorological instrumentation for three separate, but interrelated purposes: 1) ship/buoy inter-comparisons, which are carried out at the time of WHOI buoy turnaround, 2) validation of the ship's suite of meteorological instruments against independent sets of instruments and, 3) continuing investigation, and hopefully resolution, of past inconsistencies in calibration and performance of short-wave radiometers.

The KM's meteorological instruments are located on a tower extending some 6-7m above the wheelhouse roof, at a height of 20.7m above the waterline (Fig. 8, yellow circle). They consist of wind vanes, temperature/relative humidity sensors, rain gauges, and a pair of long-wave and short-wave radiometers. The platform on which the radiometers are mounted has been raised by about 0.5m since the previous WHOTS cruises to reduce shadowing from other instruments. It is on the starboard side of the tower improving exposure with the ship headed east into the trade winds.

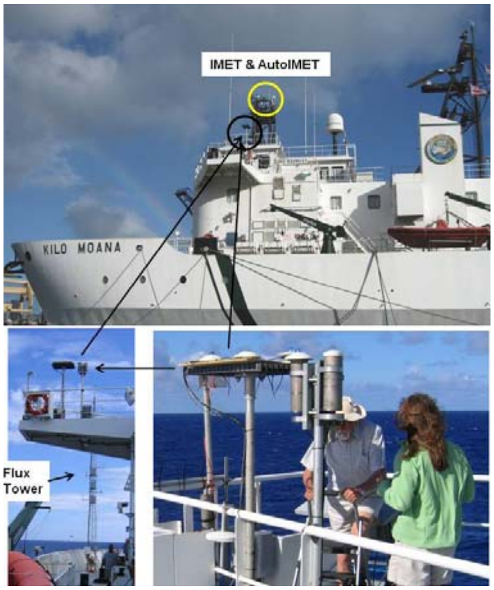

Figure 8. R/V Kilo Moana (upper), Drs. Diane Stanitski and Frank Bradley checking radiometers (lower right), Flux and WHOI radiometer locations, and Flux tower (lower left).

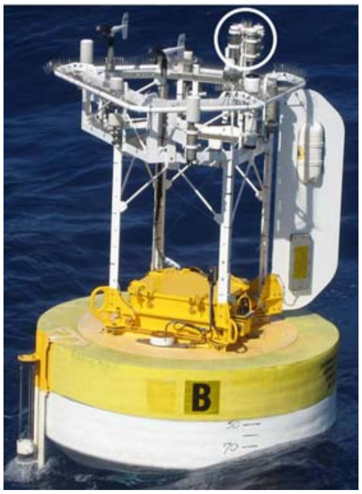

Figure 9. WHOTS-6 buoy, IMET radiometers inside white circle.

The Earth System Research Laboratory Flux Standard (Fairall et al., 1997; Fairall and Bradley, 2006) was deployed during the WHOTS 2009 cruise. All but the radiometers (Fig. 8 lower left and black circle) were mounted on a 10m tower located on the port-side bow (Figs. 8 lower left). Woods Hole also had an Improved Meteorology (IMET: Hosom et al., 1995) system located near the ship's sensors, several more IMET radiometers on the port-side bridge wing (Fig. 8), and two IMET systems with radiometers on the current mooring (WHOTS-5) and on the replacement buoy.

Figure 10. FLUX and WHOI standard radiometers setup for comparison.

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Figures 11 and 12 are preliminary radiometer comparisons. Figure 11 shows comparisons between the WHOI IMET, the ship, and the two IMET buoy radiometers. The last day of the inter-comparison beside the WHOTS-6 buoy before leaving to conduct the first day of the inter-comparison beside the WHOTS-5 buoy were both done under almost completely clear conditions. Cloud-free days allow for easier comparisons between sensors. The results appear to support the hypothesis that instruments deployed before 2009 (WHOTS-5) underestimated solar radiation by about 5%. Note the disparity in inter-comparisons between the older WHOTS-5 buoy and other sensors on Year Day 195, likely due to calibration error. Inter-comparisons are much more closely aligned at the new 2009 WHOTS-6 station on Year Day 194.

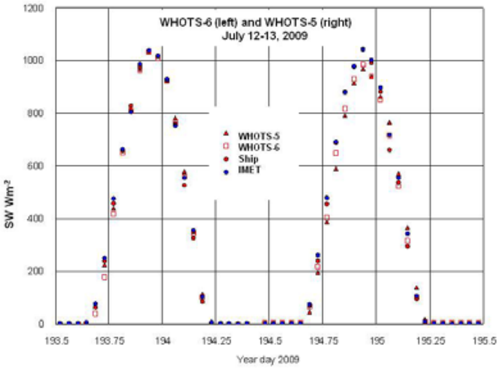

Figure 11. Hourly average values of solar radiation from ship (red circle), WHOI IMET (blue circle), and buoy pair (triangle and square). On Day 194.4 the ship moved from beside WHOTS-6 to beside WHOTS-5.

Figure 12 is an expanded view around solar noon of the clearest day during the cruise. The Ship and IMET instruments are Eppley radiometers that were recently calibrated at Eppley and WHOI, respectively. The FLUX trace is the average of two instruments (Fig. 10, wooden platform), an Eppley and a Kipp and Zonen; the calibration history of these two instruments involves a third calibration facility at ESRL in Boulder.

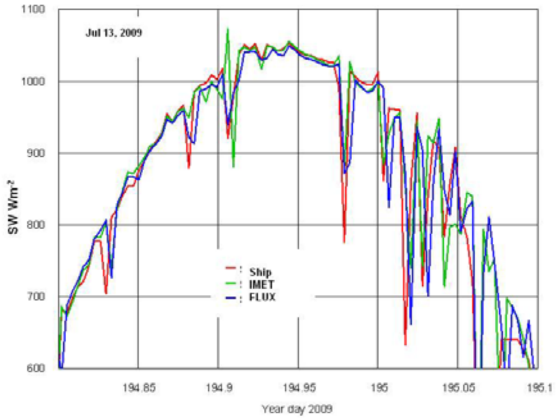

Figure 12. Comparison of all shipboard SW sensors for clear period around solar noon, July 13, 2009.

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At the time of TOGA-COARE (1992) even the principle of operation of the LW radiometer was not well understood. Differences of 12 Wm^{-2} and 50 Wm^{-2} during the day and night, respectively, were not uncommon. Initial results from WHOTS (not shown) indicate differences in the LW measurements are now on the order of 5 Wm^{-2}. Continued calibration and inter-comparison exercises will improve accuracy and precision of radiation fluxes, which will improve measurements from ocean reference stations where critical long-term ocean time series are monitored.

4. CONCLUSIONS

After less than a year, implementation of the Teacher in the Lab program at ESRL has been extremely successful. Three weeks were spent in the labs talking about the mentors' areas of expertise, orienting the teachers to ESRL, and exchanging ideas between the mentors and teachers. Two experiments were planned in the lab, data were collected over the summer, and preliminary results were analyzed to be presented at the annual AMS meeting in Atlanta. Collaborative work has also begun between students at the University of Colorado (CU Boulder), the United States Naval Academy (USNA), and ESRL on how they too can benefit from this program. CU Boulder graduate students were given a tour of the facility, and a PhD. research project collecting data from sensors mounted on the tower is scheduled to start in early 2010. Dr Blanken incorporated data collected at the BAO into his daily classroom lectures. Dr. Stanitski included WHOTS data in her labs taught at the USNA. Drs. Fairall and Stanitski will co-teach a seminar for gifted middle and high school students during spring 2010.

The NOAA Teacher in the Lab (TIL) Program is not a one-way experience. Scientists in NOAA research labs benefit from new and exciting ideas and the talent of up and coming scientists. The TIL participants look forward to many productive years of collaboration even beyond the original scope of this project.

For further information on the Teacher in the Lab program contact:

Jennifer Hammond
Director, NOAA's Teacher at Sea Program
Email: jennifer.hammond@noaa.gov
Phone: 301-713-0353 x225

Applications are competitive and accepted from October 1 - December 31 each year.
http://teacheratsea.noaa.gov/contact.html

5. REFERENCES

Dutton, E.G., 1990: Annual Forcing of the Surface Radiation Balance Diurnal Cycle Measured from a High Tower near Boulder, Colorado. *Journal of Climate,* Vol. 3, pp. 1400–1408.

Fairall, C.W., A.B. White, J.B. Edson, and J.E. Hare, 1997: Integrated Shipboard Measurements of the Marine Boundary Layer. *Journal of Atmospheric and Oceanic Technology*, Vol. 14, Issue 3 pp. 338–359.

Fairall, C.W. and E.F. Bradley, 2006: *A Guide to Making Climate Quality Meteorological and Flux Measurements at Sea*. NOAA Technical Memorandum, OAR PSD-311.

Hosom, D.S., R.A. Weller, R.E. Payne, and K.E. Prada, 1995: The IMET (Improved Meteorology) Ship and Buoy Systems. *Journal of Atmospheric and Oceanic Technology,* Vol. 12, Issue 3 pp. 527–540.

Kaimal, J.C. and J.E. Gaynor, 1983: The Boulder Atmospheric Observatory. *Journal of Applied Meteor.,* Vol. 22, pp. 863-880.

NOAA Teacher at Sea Program, 2009: http://teacheratsea.noaa.gov/.

Stephens, G.l. and P.J. Webster, 1979: Sensitivity of Radiative Forcing to Variable Cloud and Moisture**,** *Journal of Atmospheric Sciences,* Vol. 36, pp. 1542-1556.