15SMOI-10.3 Shipboard Meteorological Sensor Comparison: ICEALOT 2008

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1. INTRODUCTION

Meteorological measurements made from ships are always challenging not only because of the marine environment, but because there are so many different types of instrumentation to choose from. Having a reliable standard set of instruments for the basic measurements of temperature (T), relative humidity (RH), pressure (P), wind speed (Ws), wind direction (Wd), precipitation (Pr), and incoming radiation (long and short-wave: LW, SW) was the main reason for the Improved Meteorological (IMET) system (Hosom et al., 1995) currently in use on most National Oceanic and Atmospheric Administration (NOAA) and Woods Hole Oceanographic Institute (WHOI) research vessels. It is only logical as technology improves to consider changes to these instruments therefore increasing their reliability and accuracy. Another consideration is the need for higher temporal resolution to help improve model parameterization (Fairall et al., 1996 and Fairall et al., 2000). It is critical to conduct real-world inter-comparisons before making any changes. These comparisons provide a smooth transition between sensors and an understanding not only of the accuracies, but of their operating characteristics in the often harsh marine environment.

The International Chemical Experiment in the Arctic Lower Troposphere (ICEALOT 2008) provided an opportunity to inter-compare three different meteorological sets of sensors: the Improved Meteorological system, the Vaisala Weather Transmitter WXT510 (WXT), and the Earth System Research Laboratory (ESRL) Flux Standard (FLUX, Fairall et al., 1997 and Fairall and Bradley, 2006). The research cruise was broken up into two legs. The first leg started March 19, 2008 (Year Day 79) just north of Boston, MA crossing the North Atlantic to the coast of Norway ending with a short stop in Tromso, Norway April 12, 2008 (Year Day 102). The second leg continued north towards the Arctic ice pack, reaching 80^{o} N before heading south as close to the Greenland coast as ice conditions would allow arriving in Reykjavik, Iceland April 23, 2008 (Year Day 114).

2. SYSTEM DESCRIPTIONS

The standard meteorological sensor package operating on the research vessel Knorr is the IMET system measuring T, RH, P, Ws, Wd, Pr, and SW. The initial objectives in developing the IMET system were to find a set of sensors that could provide accurate and reliable measurements and design them so they could take measurements from ships and buoys. To achieve these goals WHOI conducted laboratory and field tests to document different sensors and designs and came up with a modular system. The FLUX system was developed at NOAA/ESRL and funded by NOAA's Climate Program Office as part of the Climate Observations Program. The FLUX system addresses 1) the need for a data quality assurance program, 2) the need to more efficiently utilize research vessels currently making meteorological observations, and 3) the need for observations at high time resolution. The WXT sensor package was deployed as a test to determine if this new technology would provide data of a similar quality as IMET, but with reduced cost and maintenance. By deploying the FLUX system it provided an opportunity to accomplish goals 1 & 2 described above as well as evaluate some new technology.

Figure. 1. Tower sensors located on the forward mast on the bow of the Knorr.

All three sets of sensors were mounted on the forward mast of the Knorr (Fig. 1). For the winds IMET uses a propeller-vane, the WXT uses a 2-axis sonic anemometer, and the FLUX uses a 3-axis sonic anemometer: mechanical (propeller-vane) versus acoustic sampling (sonics). For T and RH both the WXT and IMET have their sensors mounted in naturally ventilated radiation shields while the FLUX is mounted in a fan aspirated shield. For precipitation, IMET uses a self-siphoning rain gauge while the WXT uses the acoustic signal intensity from falling drops with larger drops generating a larger signal, and the FLUX has an optically based sensor. Pressure was measured by all the systems, with only FLUX using a

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quad-disk to minimize dynamic pressure port errors. Finally, only IMET and FLUX had SW measurements using the exact same brand sensor. One significant difference here was the IMET SW sensor was mounted on the forward mast (Fig. 1) and the FLUX SW sensor was mounted mid-ship. The reasoning behind this was to allow for daily cleaning of the FLUX radiometer dome. In a marine environment sea salt can coat the dome and for this cruise icing of the sensors was expected.

It should be noted that there are other measurements considered part of the FLUX and ship's sensors that are important for studying air-sea interaction, but are not discussed in this paper. These include, but are not limited to sea surface temperature, precipitation, pressure, and long-wave radiation. More details describing the sensors, including, manufacturer, make, model, resolution, and accuracy can be found in Hosom et al. (1995) and Fairall and Bradley (2006).

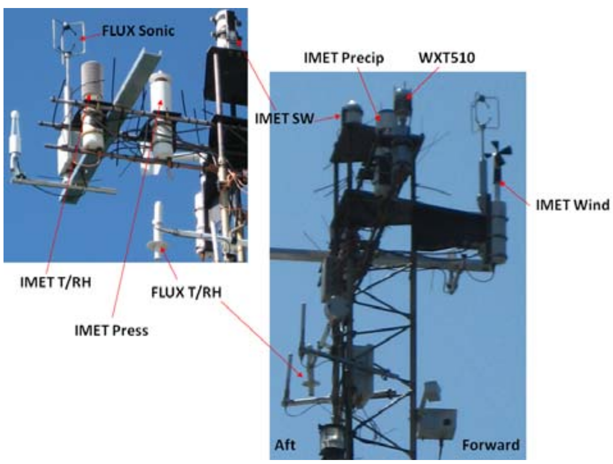

Figure 2. Expanded views of forward mast on the bow of the Knorr. The left image is the port-side sensors viewed from behind looking forward and the right image is looking from the starboard side with the bow to the right.

Figure 2 contains two expanded views of the forward mast. As with land based meteorological stations, knowledge about the location of sensors is critical in interpreting the data. An additional complication for ship-board systems is the fact the platform on which your sensors are mounted is constantly moving in 3-D. Figure 3 is a picture of each wind sensor and Fig. 4 a schematic as if you were above the mast looking down. Each wind sensor has a unique fetch for unblocked winds. Placing the wind sensor as high and as far forward as possible is optimal and creates the least contamination by flow distortion within the -90^o to 90^o sector relative to the bow. When there is more than one wind sensor, each sensor may compromise the other sensors to some degree. In this configuration the FLUX sonic is the highest and therefore should have the largest region of uncontaminated winds with the WXT sonic in what appears to be the most compromised location.

Figure 3. IMET R.M Young Propeller-Vane Vaisala WXT 520, and Gill WindMaster Pro Sonic Anemometer

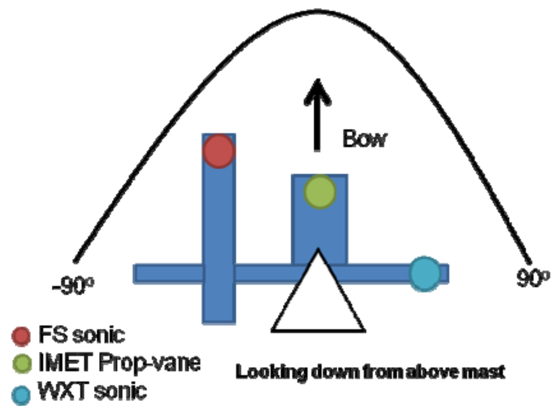

Figure 4. Relative positioning of three wind sensors looking down from above.

3. MEASUREMENT COMPARISONS

For the following comparisons, all the data have been interpolated to a common 1 min time grid. Known bad periods by a particular sensor are not included in the comparisons. Figures 5-7 are time series of the temperature, incoming short-wave solar radiation, and relative wind speed and direction for the entire cruise. These show the range of conditions experienced during 35 days at sea. Extremely cold conditions were encountered on the second leg of the cruise and a majority of the days were cloudy. Relative winds are shown in Figs. 6 and 7, because of their importance to the forward mast measurements. Wind speeds on average were greater than 7 ms^{-1} and directions were predominantly within the 270^o to 90^o optimal range depicted in Fig. 4. It should be noted that some of the comparisons were split into Leg 1 and Leg 2 and there is a period of missing data between Year Day 89 and 105 in the FLUX system due to damage caused by rough seas while crossing the Atlantic. As a result of this damage the FLUX T/RH sensor on Leg1 was replaced by a different T/RH sensor on Leg2. For this paper, only detailed results from the T and Wsd are discussed and shown.

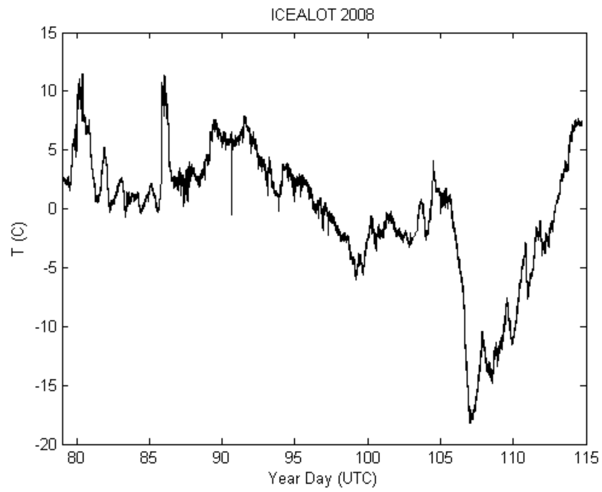

Figure 5. Time series of temperature for entire cruise.

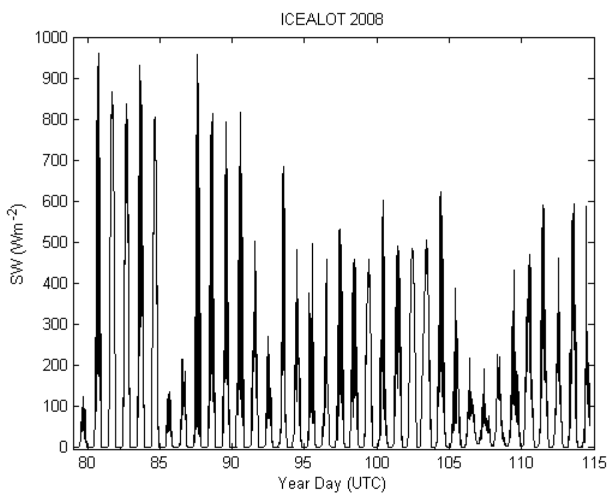

Figure 6. Time series of incoming short-wave radiation for entire cruise.

Figure 8 shows scatter-plot comparisons and Table 1 lists the statistics for the three air-temperature sensors. The comparisons were broken down into Leg 1 and Leg 2, because of the damage to the FLUX system mentioned above. All three sensors show good agreement. On Leg 1 the FLUX temperature sensor is showing more scatter compared to the IMET or WXT and is offset high 0.5-1.0^{o}C. For Leg 2 the scatter is less and the offset is about half that of Leg 1. The lower right hand scatter plot in Fig 8 is a comparison of the IMET and WXT sensors for the entire cruise, including the period when the FLUX sensor was unavailable. No significant differences are seen by including these data. These results suggest the relative winds produced by the nearly constant forward motion of the ship (Fig 8) should have provided ample natural ventilation for both the IMET and WXT T/RH sensors.

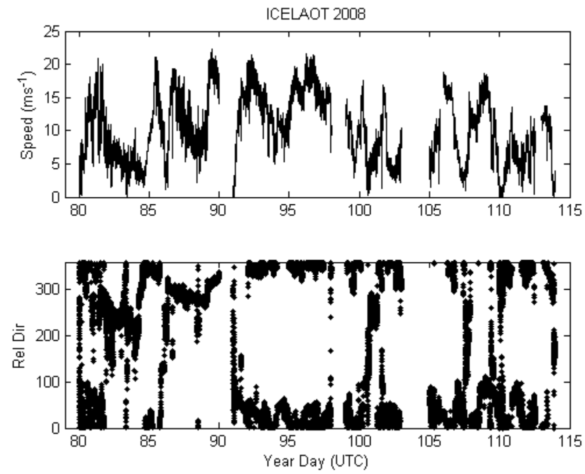

Figure 7. Time series of relative wind speed and direction for entire cruise.

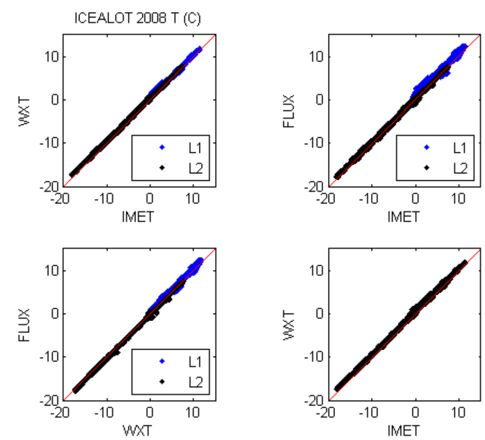

Figure 8. Air Temperature comparison of all 3 sensors. L1 = Leg 1 L2 = Leg 2.

Table 1. Air Temperature Statistics

	Mean	Min	Max	STD
Leg1				
IMET	3.42	-0.74	11.46	2.67
WXT	3.90	0.10	11.80	2.63
FLUX	4.56	0.43	12.42	2.58
Leg2				
IMET	-5.13	-18.25	7.54	6.66
WXT	-4.62	-17.50	7.80	6.58
FLUX	-4.90	-17.90	7.67	6.60

Comparisons of the three RH sensors (not shown) reveal better agreement for Leg 1 than Leg 2. Between Legs 1 & 2 the offset between the IMET and the other 2 sensors increases from 2 – 6%. This increased offset correlates to a period of very cold temperatures, but does not change when the temperatures warm. For the last 2-3 days of the cruise the offset between all three sensors visibly increases to nearly 10% after tracking within 2% most of Leg 2.

At the same time only the FLUX sensor ever reports an RH of 100%, while the IMET and WXT max out at 92% and 96% respectively.

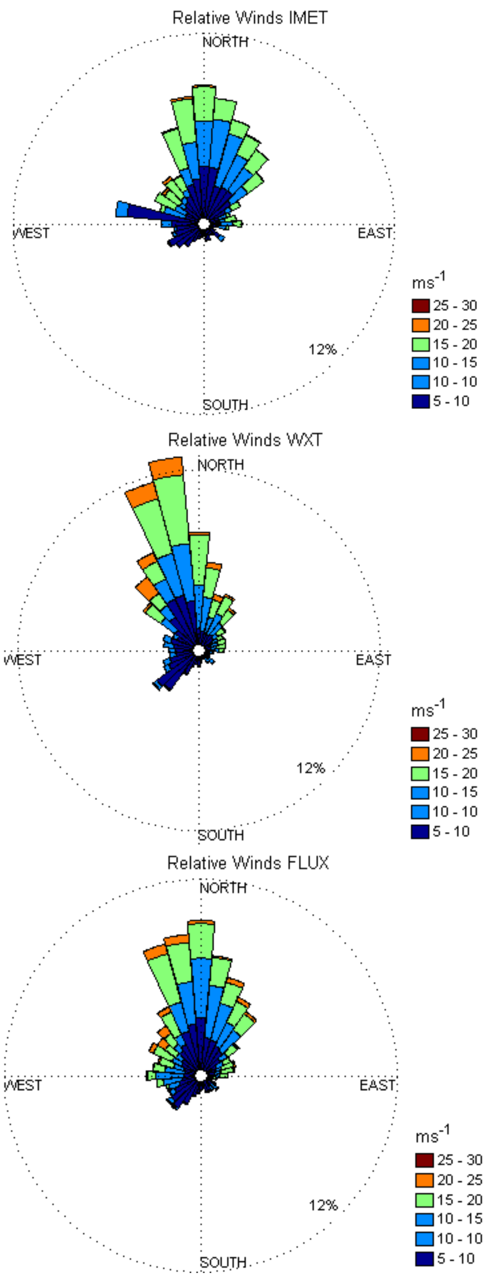

Figure 9. Wind roses for IMET, WXT, and FLUX wind sensors. Outer ring represents 12% of total points.

When the ship is traveling from place to place, there is no guarantee where the relative wind will be coming from. Once the ship is on station it can be pointed bow first into the wind. As depicted in the wind roses (Fig. 9) the relative wind was predominately coming towards the bow and the best possible angle for all mast mounted sensors. The most obvious differences between sensors are 1) the maximum wind speed for the IMET (propeller-vane) is 3-4 ms^{-1} less than the WXT and FLUX and 2) the IMET relative directions compared to the WXT and IMET is slightly skewed to the west of North. The most obvious reason for these differences is the mechanical nature of the propeller-vane. This difference may be further enhanced by the complex flows expected on the forward mast. (Fig 4) or if the initial IMET orientation is off.

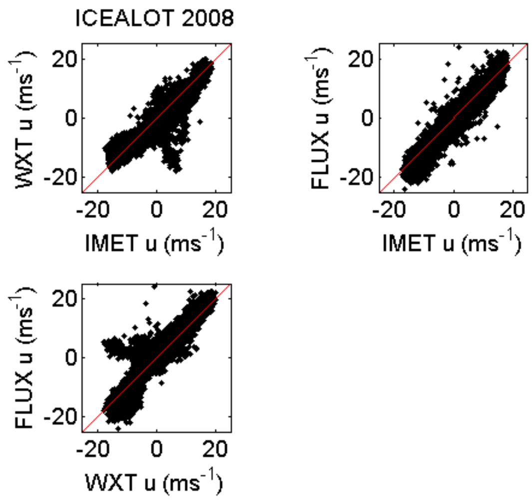

Figure 10. U-component comparisons (u is positive for winds from the bow).

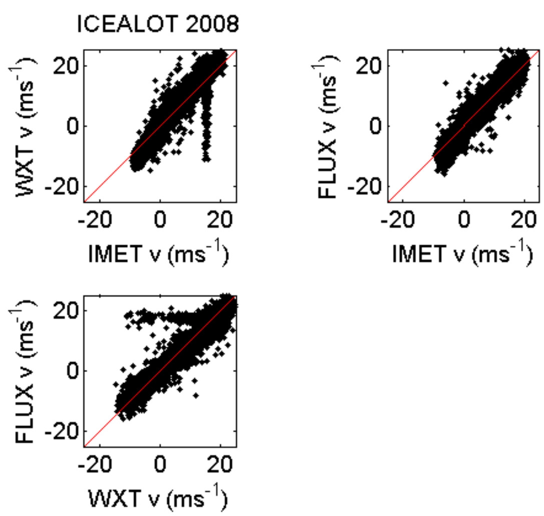

Figure 11. v-component comparisons (v is positive for winds from the starboard).

Analyzing Figs. 10 & 11, horizontal wind components, we see extremely good correlation between all three sensors. For an unknown reason the WXT produces unrealistic wind speeds at times. These show-up as horizontal and vertical scattering artifacts seen in Fig. 10 for both components. Another unsolved question is the behavior of the WXT compared to the FLUX on days when there was riming. Periods of increased variability and even some spiking in the WXT that do not show up in the FLUX sensor data suggests this is not a problem related to sonic anemometers in general. Both the FLUX and WXT had slightly larger STD than the IMET, which is expected with sonic anemometers compared to a propeller-vane. Reviewing all the data there is some indication that the WXT started to have more problems on the second leg when there were colder temperatures and periods of riming.

4. CONCLUSIONS

There were 3 sets of sensors collecting meteorological data during ICEALOT. The IMET is the system currently operating on most research vessels. The WXT system was being tested as a possible replacement to the IMET due to its reduced cost and maintenance required. The FLUX system is the portable flux standard used for comparison and calibration. Conditions during ICEALOT included very rough seas, strong wind, below freezing temperatures, snow, and riming. Except for the FLUX incoming SW radiation, the sensors were all mounted on the forward mast (Fig. 3).

- Temperature comparisons show very good agreement with small differences most likely associated with sensor accuracies.
- Wind comparisons show IMET relative wind speeds reading lower and directions skewed slightly to the west of North compared to the WXT and FLUX sensors. Detailed analysis of the WXT data found periods of increased variability and offsets in the speed and direction. Further comparisons are needed to determine if these differences are related to the mechanical vs. acoustic measurement techniques and possible initial sensor alignment errors. Based on this limited data set the WXT wind sensor is not recommended for cold Arctic like conditions.
- The three RH sensors have fairly significant differences in accuracy, especially at higher humidity's. This explains some of the larger offsets but not why the maximum reading of these sensors differed by as much as 8% at the high end with only the FLUX sensor ever reading 100%.
- Results for the IMET and FLUX incoming solar radiation are consistent with what is expected for two sensors mounted in different locations on the ship: one with daily maintenance (FLUX) and one without (IMET). Deciding how much sensor location will compromise the data or make quality control difficult is important and should be taken into serious consideration prior to the start of any field campaign.

4. REFERENCES

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