P1.4 AN INTERCOMPARISON OF THREE SOUNDING TECHNIQUES EMPLOYED DURING THE EPIC2001 FIELD PROGRAM

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1. INTRODUCTION:

One of the primary challenges in any large, multi-platform field project is the task of integrating measurements made of the same basic variables from various data sources. This task becomes critical in importance when attempting to characterize a research area too large and variable to be covered by a single platform and with data streams that are unsuitable to the application of broad scale remote sensing systems. The key factors in being able to integrate multiple data sources can be defined by the precision or repeatability of each measurement system and the relative accuracy of each measurement. In the case of the Eastern Pacific Investigation of Climate Processes in the Coupled Ocean-Atmosphere System (EPIC2001) experiment, the data in question were the three dimensional temperature, humidity, and wind fields contained within a 250,000 square mile area roughly centered on the flight track presented in Figure 1.

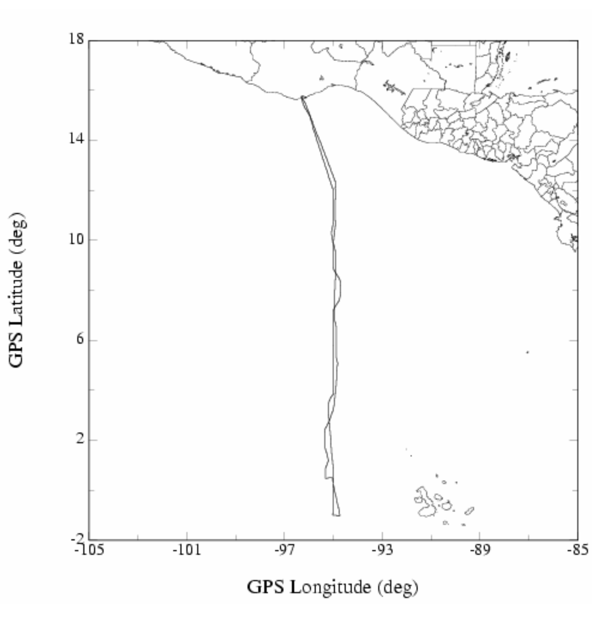

Figure 1. EPIC2001 Research Area

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This paper focuses on the "in-situ" data collected by the NSF sponsored NCAR C-130 aircraft and a series of GPS dropsondes deployed in the research area by that platform during the EPIC2001 field program. Dropsonde soundings, located in close proximity in time and space, are compared to evaluate the precision of the individual sensor packages. Similarly, localized C-130 ascents and descents are compared to test for any sign of hysteresis in the resulting data set. Selected segments from both data sets are then compared to evaluate the relative accuracy of the measurements and to provide confidence in combining the data into a realistic description of the study area.

Additional vertical profiles of the thermodynamic and wind variables have been provided by radiosonde launches from the NOAA ship, Ron Brown.

2. INSTRUMENTATION:

A complete list of the instrumentation available on the NSF/NCAR C-130 can be found on the NCAR Research Aviation Facility (RAF) web site (raf.atd.ucar.edu). The key sensors for this study, however, are limited to the following systems: Rosemount Model 102E2AL Temperature sensor; General Eastern Model 1011B Dewpoint sensor; NCAR Lyman-alpha Hygrometer; and the NCAR five hole radome wind gust probe. The performance characteristics of the primary aircraft sensors have been well documented over the years (Schanot et al, 1987; Lenschow et al, 1991; Lenschow et al, 1999). A quick overview of this information is provided in Table 1. Difficulties with using these data for sounding studies are typically tied to instrument response times and the nature of the flight track. The response time constraints inherent to the rapid vertical profiles used in making the aircraft soundings required the use of the Lyman-alpha hygrometer data in the analysis. The RAF combines the measurements from the lyman-alpha with data taken from the General Eastern dew-point sensor in the final data processing in order to improve the overall accuracy of these measurements (Friehe et al, 1986; Schanot, 1987).

The GPS dropsondes deployed from the C-130 during the experiment were the Vaisala Model RD93 units, originally developed at NCAR and manufactured under license to Vaisala. The manufacturer's performance specifications for the key components appear in Table 2. Early field testing of the units (Hock et al, 1999) have indicated that more typical field performance errors for these units should be placed at: +- 1.0 mb pressure; 5% humidity; and 0.5-2.0 m/s wind speeds with the temperature specifications holding steady. As with most expendable sounding packages, the RD93 dropsonde uses a humicap as the basis for the measurement of relative humidity. In recent studies, the RD93 has shown a tendency to under estimate relative humidity in the high humidity conditions common to a tropical boundary layer (Vance, 2001). Errors were estimated at around 8 % at mixing ratios above 11 g/kg.

Table 1. C-130 Instrumentation Performance Summary

Variable	Instrument Type	Range	Accuracy	Resolution
Temperature	Platinum Resistance	–60 to 40 C	+-0.5 C	0.006 C
Dew-point Temp. (GE 1011B)	Thermoelectric	-65 to 40 C	+-0.5 C > 0 C +-1.0 C < 0 C	0.006 C
Dew-point Temp. (Lyman-alpha)	Absorption	-65 to 40 C	+-0.5 C > 0 C +-1.0 C < 0 C	0.006 C
Wind Vectors	Gust Probe & IRS	0 to 100 m/s	+- 0.1 m/s	0.012 m/s

Table 2. Vaisala RD93 Manufacturer's Performance Summary

Variable	Instrument Type	Range	Accuracy	Resolution
Pressure	Barocap	100 to 1080 mb	+-0.4 mb	0.1 mb
Temperature	Thermocap	–90 to 60 C	+-0.1 C	0.1 C
Humidity.	H-Humicap (alt - heated)	0 to 100 %	2 %	1.0 %
Wind Vectors	GPS Position	0 to 200 m/s	+- 0.5 m/s	0.1 m/s

The radiodsondes launched by the NOAA ship Ron Brown during the experiment were all Vaisala Model RS80 units. The RS80 radiosonde has been in use for many years as one of the standard sounding packages employed by governments around the world. The technical specifications on its thermodynamic sensors are available from the manufacturer (Vaisala, 2001). Wind data are derived from GPS tracking techniques. Recent studies have shown that the Vaisala RS80 radiosonde has, in the past, exhibited a dry bias affecting humidity measurements taken in a moist, tropical environment (Wang et al, 2002). Specific causes for this bias were determined in that study and induced the manufacturer to modify the RS80 package in September 1998 and again in May of 2000. While some basic quality control techniques were used in processing the EPIC2001 rawinsonde data (Loehrer et al, 1996), no further corrections have been applied.

3. METHODOLOGY:

The C-130 flight plans employed during the EPIC2001 targeted two, very specific missions. The first was the investigation of convective cloud clusters in the Inter Tropical Convergence Zone (ITCZ). Numerous dropsonde soundings and C-130 vertical profiles were conducted in a relatively confined region near the targeted cluster.

Data from these flights were used to compare measurements from the same systems. Separations between comparable soundings were limited to roughly 50 km in distance and one hour in time. The profiles tended to be moist through their entire depth with limited thermodynamic structure and few wind shear layers. Whenever more than two soundings were included in a comparison, one would be designated as the reference measurement and all of the others would be designated as alternates. A typical example is presented in Figure 2. The secondary mission, the flight track depicted in Figure 1, called for repeated low altitude transects down the 95 W longitude line. Once the aircraft reached the Equator, course was reversed and the aircraft climbed up to roughly 6 km in height. Dropsondes were released every 1 degree of latitude on the northerly return leg. C-130 data from the initial climb out were compared against the first dropsonde dispensed from each transect to evaluate any systematic differences between the two systems. Again, maximum separations for comparison soundings were held to the 50 km and 1 hour limits. The profiles routinely showed a sharp thermal surface inversion and associated wind shear layer. Stratiform clouds frequently marked the top of the boundary layer. A typical example is presented in Figure 3.

The thermodynamic and wind field data were taken directly from the project data archive. In this case, all sounding data were stored as temperature, dew point, wind speed and direction. The following analysis was conducted on the selected fields in the same format. The data output rate from the combined RD93 / AVAPS system is basically 2 sps with a typical dropsonde fall rate of 11 m/s. Sampling rates for C-130 variables vary from 5 sps to 25 sps with processed data being averaged down to a 1 sps output. C-130 ascent and descent rates were held to roughly 5 m/s to improve the overall quality of the sounding data. The data from the RS80 radiosonde launches were recorded at one sample every two seconds. In order to reduce the data set to a more manageable level and tag the measurements at comparable altitudes, data points were selected for every 5 mb of pressure change. For the purpose of this analysis, the pressure measurements from all data sources were considered to be accurate. It should be noted that in the dropsonde data set, the dew point temperature was never allowed to exceed the ambient temperature. Whenever such an event occurred, the dew point temperature was set equal to the ambient temperature. Such was not the case with the C-130 data set.

In the comparative analysis of the selected soundings, each profile was scanned for the presence of stable layers – the primary function of thermodynamic soundings being a means of establishing the convective instability of the study area. Such layers were defined by a true temperature inversion, or a temperature decrease of less than 0.2 C between any successive 5 mb pressure levels as the overall pressure decreased. The number of stable layers was noted for each sounding. Wind speeds were compared directly by magnitude. Wind directions were compared by relative octant. That is to say that if the difference in the wind directions noted for any level exceeded +-22.5 degrees, the data point was flagged as being outside acceptable limits. Levels with comparable wind direction differences of less than that amount were considered to be in agreement. During the statistical analysis presented in the following section, the data sets were further reduced to altitude levels defined by 25 mb intervals of pressure change. Linear regressions have been calculated for each type of comparison to determine whether any systematic trends are apparent in either data set.

The nature of the field operations resulted in certain limitations on the type of comparisons that could be made with the three sets of sounding data. Specifically, no aircraft profiles were conducted in the vicinity of the NOAA ship at times that would allow a comparison between the C-130 measurements and the radiosonde soundings. Radiosonde launches were only conducted at three hourly intervals, precluding a direct comparison of individual sensor packages. Both of the expendable sounding packages experienced some intermittent problems in making wind field measurements. The resulting sample size of comparable dropsonde to radiosonde wind soundings was considered to be too small for use in this analysis.

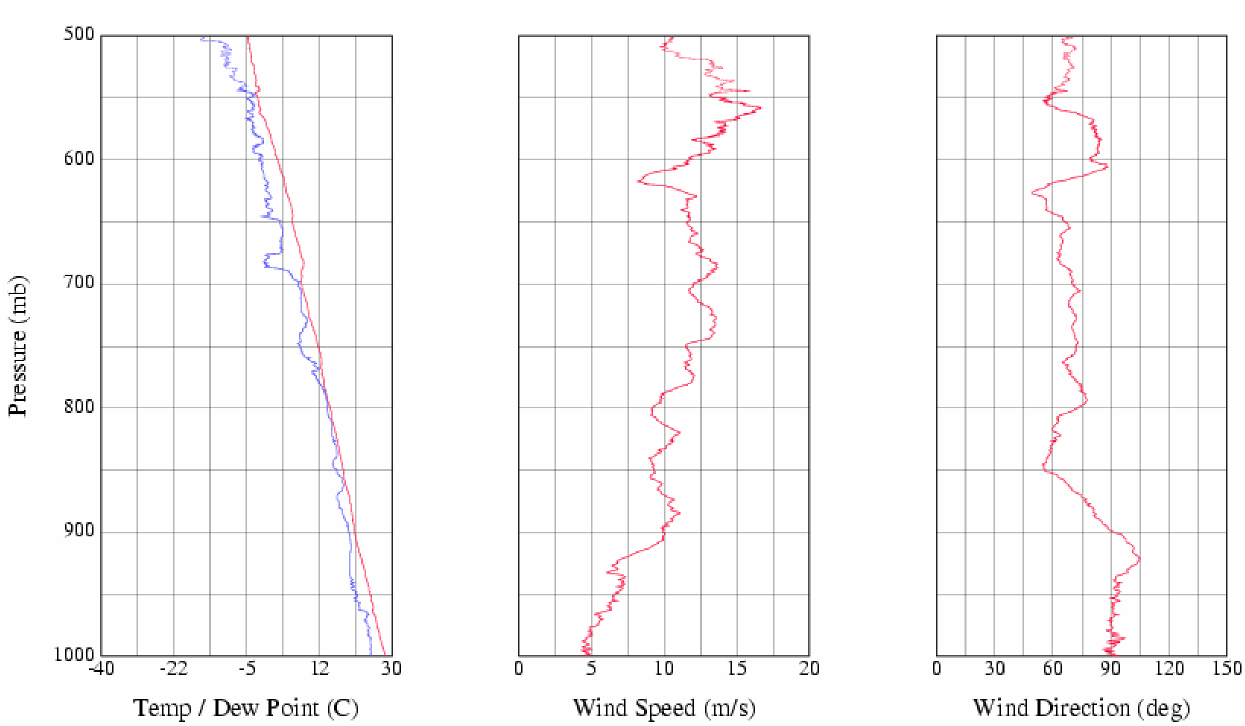

Figure 2. Component plots of typical ITCZ sounding.

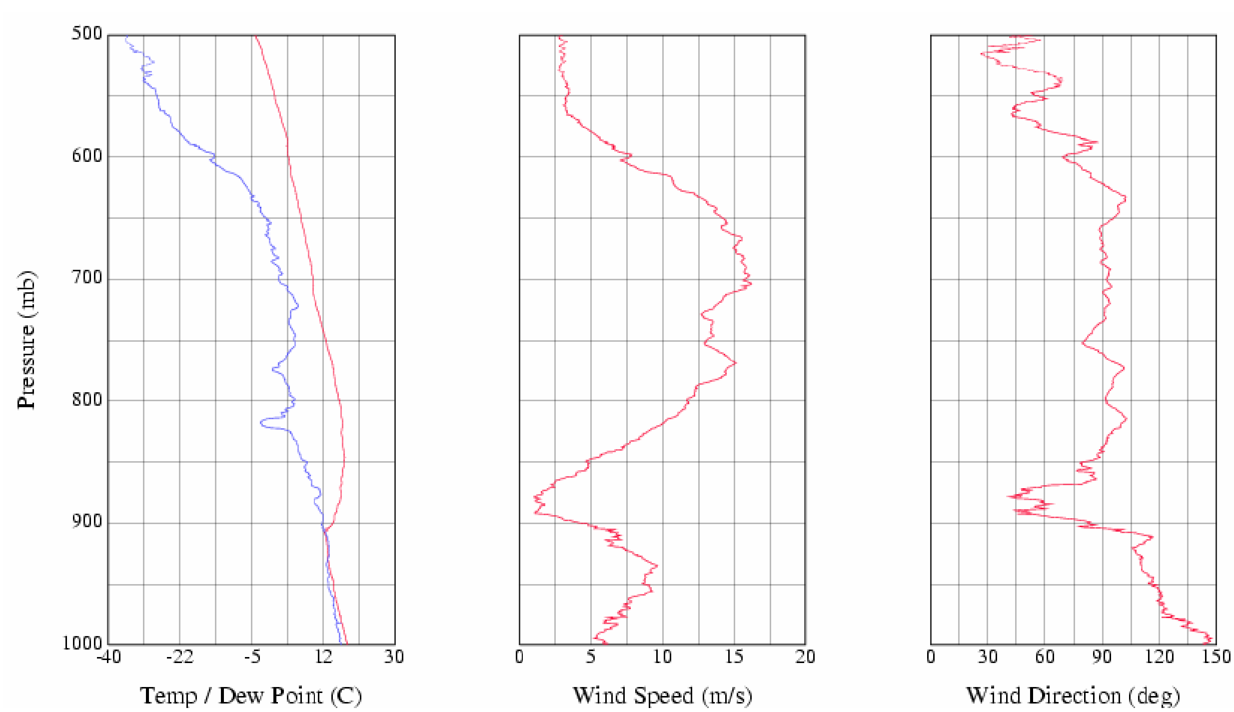

Figure 3. Component plots of typical 95W transect sounding.

4. DATA COMPARISONS:

4.1 Thermodynamic Data:

The first measure of a system's performance is the precision of the sensing components. Selected soundings from three flights were compared by measurement system. The statistical results are presented in Table 3. The reference sounding for each flight appears at the top of each flight section. The data include the number of stable layers noted in each vertical profile along with the mean and standard deviation of the difference between the reference and alternate thermodynamic sensors over the depth of the soundings. Clearly the stability of the atmosphere was well represented, and individual sensors performed well within the stated accuracy of each system. For a more detailed examination of sensor precision, a level-by-level comparison of the temperature and dew point data are provided for each system. Figures 4 & 5 provide the dropsonde data while Figures 6 & 7 cover the C-130 data. Correlations for each plot are excellent with slightly more scatter in the humidity data, as might be expected. No systematic trends are apparent in any of the plots. Using the least-square linear-regression fit plotted with the data points, one is able to project a measurement difference across the range of the data set. For the dropsonde data the projected differences remained less than 0.5 C for both temperature and dew point. For the C-130 data, the projected differences were less than 0.2 C. for both parameters.

Table 3. Summary of Thermodynamic Sounding Data by Platform

Dropsonde Precision Testing

Sounding I.D.	Stable Layers	Mean T Diff	S.D. T Diff	Mean Td Diff	S.D. Td Diff
RF07.1802	6	X	X	X	X
RF07.1811	4	-0.01	0.34	-0.05	1.05
RF07.1807	4	-0.12	0.32	-0.01	0.75
RF13.1921	8	X	X	X	X
RF13.1907	7	-0.04	0.28	0.89	0.94
RF13.1928	7	0.24	0.36	-0.14	1.37
RF13.2039	8	0.16	0.37	0.68	0.73
RF17.1704	4	X	X	X	X
RF17.1707	3	0.04	0.39	-0.58	1.35
RF17.1711	6	0.14	0.27	-0.41	0.94

C-130 In-situ Precision Testing

Sounding I.D.	Stable Layers	Mean T Diff	S.D. T Diff	Mean Td Diff	S.D. Td Diff
RF07.1758	6	X	X	X	X
RF07.1957	4	-0.01	0.45	-1.08	1.48
RF13.1921	9	X	X	X	X
RF13.1928	10	0.01	0.44	-0.04	1.02
RF17.1712	4	X	X	X	X
RF17.1730	3	-0.04	0.35	0.12	1.00

The relative accuracy of the three sounding systems was examined through a direct comparison of the separate data sets. A statistical summary of the comparisons, prepared on a flight-by-flight basis, appears in Table 4. The primary focus of this analysis is on the C-130 to dropsonde comparison data. The dropsonde to radiosonde data have been added, but it should be noted that the soundings being compared on those selected flights are not the same as the ones used in the C-130 to dropsonde comparisons. Good consistency is apparent in the assessment of vertical temperature trends, noted by the number of stable layers found in the comparable soundings. Mean differences through the depth of the soundings again, remain within stated accuracy values. There is some indication that the dropsonde humidity measurements are consistently lower than the other two systems.

Figures 8 & 9 provide the detailed information on the C-130 to dropsonde comparison. A slight trend toward lower dropsonde temperatures near the surface is apparent, as well as markedly more scatter in the data points at that altitude. Based on the regression fit, however, the maximum projected difference between the systems is less than 0.5 C. A more significant trend toward lower dropsonde humidity measurements can be found in that data comparison. Dropsonde dew points greater than 10 C are routinely lower than the comparable C-130 data. At lower dew points the trend has less of an impact. Despite the presence of this trend, maximum projected differences between the two measurements remained below 0.5 C. This corresponds to about a 3% error in relative humidity.

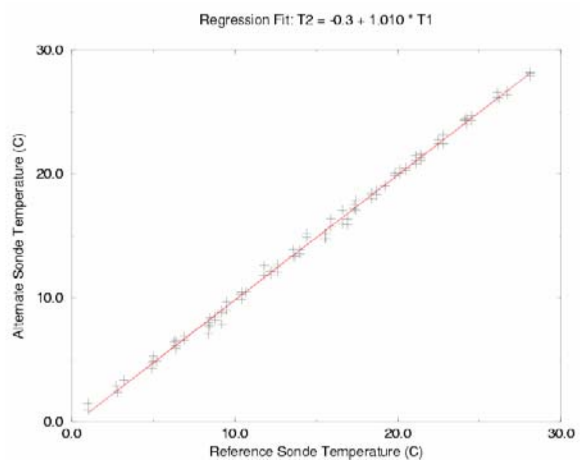

Figure 4. Dropsonde Precision Comparison - T

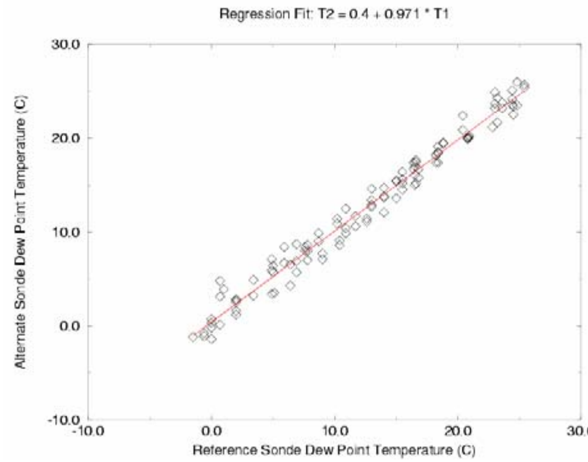

Figure 5. Dropsonde Precision Comparison - Td

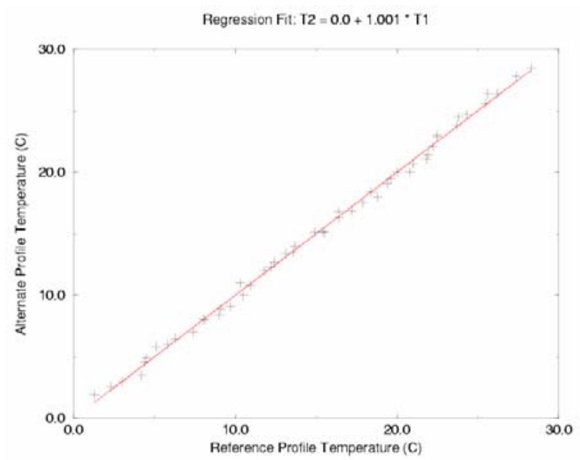

Figure 6. C-130 Precision Comparison - T

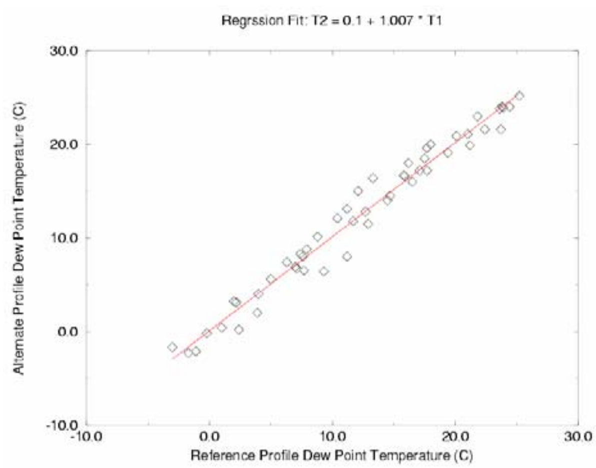

Figure 7. C-130 Precision Comparison -Td

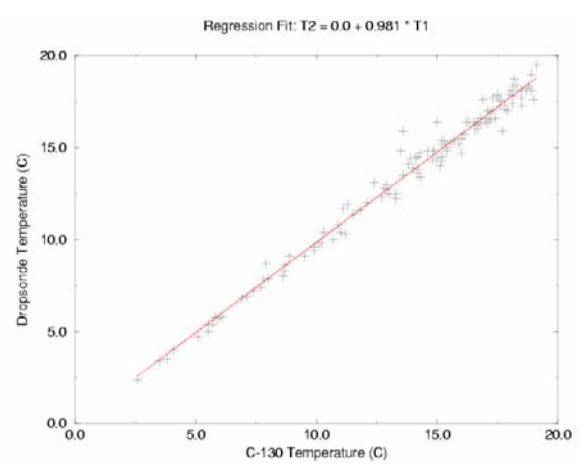

Figure 8. Dropsonde / C-130 Comparison – T

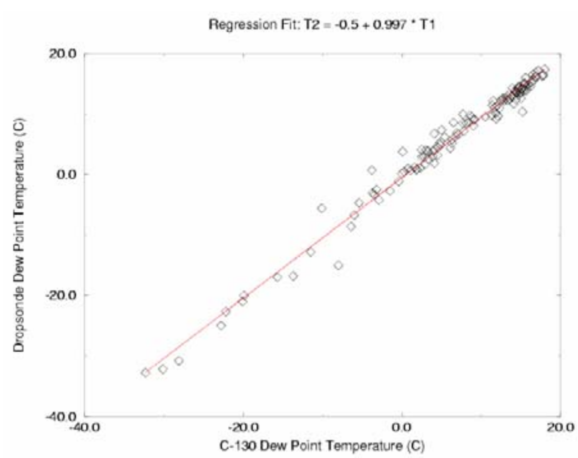

Figure 9. Dropsonde / C-130 Comparison - Td

Table 4. Comparison of Thermodynamic Sounding Data / Platform to Platform

Flight Number	Stable Layers	Mean T Diff	S.D. T Diff	Mean Td Diff	S.D. Td Diff
RF03	4==4	0.40	0.64	0.85	0.9
RF06	4==5	0.28	0.43	0.39	1.11
Ship to Drop	9==7	-0.24	0.56	0.52	2.21
RF07	8==5	0.45	0.56	0.67	1.73
RF08	4==4	0.06	0.39	-0.11	1.11
Ship to Drop	7==5	0.28	0.50	-1.21	3.28
RF10	5==3	0.20	0.75	-0.23	0.88
Ship to Drop	8==10	0.12	0.50	0.33	1.16
RF11	5==3	0.36	0.70	0.33	1.63
Ship to Drop	9==8	-0.41	0.58	0.24	1.12
RF13	9==8	0.09	0.28	0.58	0.70
RF14	6==7	0.28	0.57	0.85	1.46
Ship to Drop	14==14	0.65	0.87	3.40	2.02
RF17	2==4	-0.08	0.25	0.41	0.78
RF18	6==5	0.15	0.29	0.64	1.75
RF19	8==5	0.20	0.26	1.04	1.25

Figures 10 & 11 provide the detailed data on the dropsonde to radiosonde comparison. No systematic trends are apparent in the temperature data. There is good correlation between the two data sets with projected differences remaining around 0.1 C over the entire sampling range. Good agreement can be found at the higher end of the dew point comparison. At the lower dew point values the radiosonde values tend to be higher. The projected differences reach 1.0 C near 0 C and max out at 2.0 C at the lower extreme of –40 C.

4.2 Wind Data:

Only a limited amount of data were available to perform the precision analysis on the C-130 and dropsonde wind profiles. Multiple RD93 drops in close proximity were typically mandated by a problem with the wind measurements. These cases provided added data for the thermodynamic comparison but were useless in the wind analysis. Two of the three suitable C-130 cases were conducted near convective clusters that caused large variations in local wind flow patterns and were not deemed useful. A statistical summary of the remaining data has been combined with the C-130 to dropsonde comparison data and are presented in Table 5. Note that on research flight RF17, flight operations were specifically designed to conduct a comparison of the C-130 and dropsonde systems. The mean and standard deviation of the wind speed differences between the systems have been determined over the entire depth of the vertical profiles. There is a significant amount of scatter in the data, but the sounding averages typically remained below 1.0 m/s.

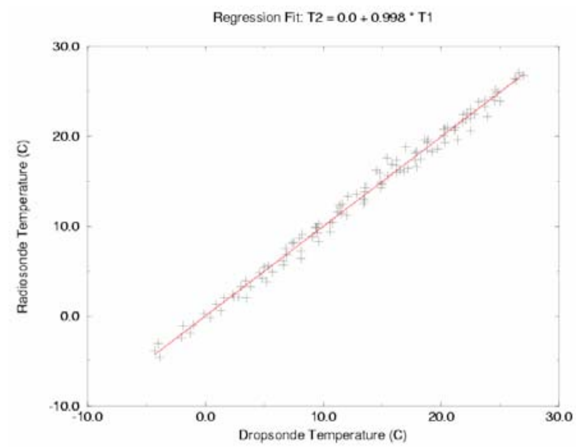

Figure 10. RD93 / RS80 Comparison - T

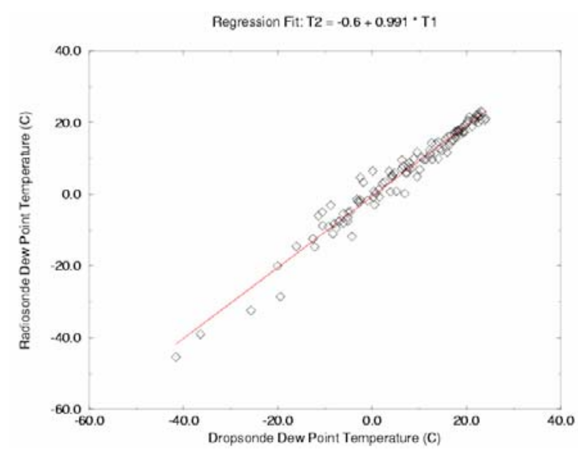

Figure 11. RD93 / RS80 Comparison - Td

The quality of the wind direction comparison has been assessed by counting the number of levels within each sounding that failed to meet the stated criteria for agreement. The first number provides the count of the failed level-by-level comparisons. The second gives the total number of levels included in each respective sounding. Agreement is generally good with only two flights having more that a quarter of the sounding levels fail the comparison test. Note the excellent agreement in both the precision and accuracy data collected during the targeted comparison flight RF17.

Table 5. Comparison of Wind Sounding Data

Flight Num.	Mean WS Diff.	Standard Dev. WS Diff.	WD Exceptions
C-130 Precision Data			
RF17	-0.55 m/s	1.06 m/s	0 / 17
Dropsonde Precision Data			
RF17A	-0.27 m/s	0.78 m/s	0 / 17
RF17B	-0.01 m/s	0.84 m/s	0 / 18
C-130 to Dropsonde Comparison Data			
RF03	1.16 m/s	2.13 m/s	3 / 17
RF06	-0.29 m/s	1.12 m/s	6 / 15
RF07	-0.29 m/s	1.12 m/s	7 / 17
RF08	-0.58 m/s	0.84 m/s	1 / 17
RF10	-0.58 m/s	1.12 m/s	3 / 17
RF11	0.53 m/s	1.26 m/s	3 / 17
RF13	1.15 m/s	2.01 m/s	0 / 15
RF14	0.12 m/s	1.10 m/s	2 / 17
RF17	0.31 m/s	1.00 m/s	0 / 17
RF18	0.32 m/s	1.08 m/s	3 / 17
RF19	0.21 m/s	0.76 m/s	4 / 16

5. CONCLUSIONS:

Data quality comparisons from large, multi-platform field experiments are always difficult. As a general rule flight operations are not designed to provide the type of data required for good platform to platform inter-comparisons. Typically, as was the case in EPIC2001, only one or two flight profiles are dedicated to this function. The bulk of the data included in this analysis were selected from the opportune coincidence of vertical soundings conducted by the three measurement systems. Despite the slight tendency for the RD93 dropsonde to produce low humidity readings at high moisture contents, both the thermodynamic and wind field data from the C-130 and dropsonde systems were deemed compatible. Any systematic differences encountered fell within the expected accuracies of the instrumentation. With over half of the sounding comparisons being obtained in an area characterized by a sharp surface temperature inversion and associated wind shear layer, the amount of scatter found in the level-by-level analysis would seem to be more a product of environmental variability than of the performance of the sensors.

The data from the ship launched radiosondes provided an added measure of validation for the performance of the airborne sensors and dropsonde packages. The divergence in RD93 dropsonde and RS80 radiosonde humidity measurements at the low humidity extremes is troubling, but the sample size in that range was very small, and the results do not detract from the overall good comparison of the bulk of the data. This analysis would indicate that all three data sets can be used, as archived, and that no corrective algorithms need to be applied.

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